Recommendation

ITU-T G.9711 (2021) Cor. 2 (06/2023)

SERIES G: Transmission systems and media, digital systems and networks

Access networks – Metallic access networks

Multi-gigabit fast access to subscriber terminals (MGfast) – Physical layer specification

Corrigendum 2

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Recommendation ITU-T G.9711

Multi-gigabit fast access to subscriber terminals (MGfast) – Physical layer specification

Corrigendum 2

Summary

Recommendation ITU-T G.9711 specifies a multi-gigabit broadband access technology that exploits the existing infrastructure of wire-pairs and coaxial cable that were originally deployed for plain old telephone service (POTS) or television (TV) services. Equipment implementing this Recommendation can be deployed from fibre-fed distribution points (fibre to the distribution point, FTTdp) located in close proximity to customer premises, or within buildings, including MDUs and business facilities (fibre to the building). This Recommendation supports asymmetric and symmetric transmission at an aggregate net data rate up to 8 Gbit/s on metallic wires using spectrum up to 424 MHz, and provides functionalities for far-end crosstalk (FEXT) and near-end crosstalk (NEXT) cancellation between multiple wire-pairs.

Amendment 1 (2022) specifies or corrects:

– DBR-PT and bidirectional DBR for facilating the acceleration of DBR,
– diagnostics and monitoring of DTA,
– downstream PSD objects common to all links in the P2MP group,
– upstream frame configuration request, and
– support of DTFO in P2MP TDMA/FDMA.

Corrigendum 1 (2022) corrects:

– OLR type 1 and type 2
– PCS-LCM fields in DBR-PR
– O-SIGNATURE and O-PMD message in clause 12
– O-SIGNATURE and O-MSG message in Annex X
– LCM-PCS aspects related to RPA, RTS and low number of bits per symbol

Corrigendum 2 (2023) corrects:

– the actual retransmission overhead to be used for the calculation of ANDEFTR.

History [*]

Edition	Recommendation	Approval	Study Group	Unique ID
1.0	ITU-T G.9711	2021-04-23	15	11.1002/1000/14513
1.1	ITU-T G.9711 (2021) Amd. 1	2022-04-22	15	11.1002/1000/14890
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1.3	ITU-T G.9711 (2021) Cor. 2	2023-06-13	15	11.1002/1000/15568

[*] To access the Recommendation, type the URL https://handle.itu.int/ in the address field of your web browser, followed by the Recommendation's unique ID.

FOREWORD

The International Telecommunication Union (ITU) is the United Nations specialized agency in the field of telecommunications, information and communication technologies (ICTs). The ITU Telecommunication Standardization Sector (ITU-T) is a permanent organ of ITU. ITU-T is responsible for studying technical, operating and tariff questions and issuing Recommendations on them with a view to standardizing telecommunications on a worldwide basis.

The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

NOTE

In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

Compliance with this Recommendation is voluntary. However, the Recommendation may contain certain mandatory provisions (to ensure, e.g., interoperability or applicability) and compliance with the Recommendation is achieved when all of these mandatory provisions are met. The words "shall" or some other obligatory language such as "must" and the negative equivalents are used to express requirements. The use of such words does not suggest that compliance with the Recommendation is required of any party.

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As of the date of approval of this Recommendation, ITU had received notice of intellectual property, protected by patents/software copyrights, which may be required to implement this Recommendation. However, implementers are cautioned that this may not represent the latest information and are therefore strongly urged to consult the appropriate ITU-T databases available via the ITU-T website at http://www.itu.int/ITU-T/ipr/.

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Corrigendum 2

Editorial note: This is a complete-text publication. Modifications introduced by this corrigendum are shown in revision marks relative to Recommendation ITU-T G.9711 (2021) plus its Amendment 1 (2022) and Corrigendum 1 (2022).

1 Scope

This Recommendation supports transmission at an aggregate net data rate (the sum of upstream and downstream rates) up to approximately 8 Gbit/s (for full duplex (FDX) mode) and 4 Gbit/s (for time division duplexing (TDD) mode) on metallic wires, to provide capabilities supporting internet access with low transmission latency (such as cloud computing, advanced video service, cloud-based 360-degree virtual reality and 8K video services). This Recommendation specifies the operation of a broadband access technology that exploits the existing infrastructure of both wire-pairs that were originally deployed for plain old telephone service (POTS) and coaxial cables that were originally deployed for television (TV) services.

Whilst asymmetric digital subscriber line transceivers 2 (ADSL2) – extended bandwidth (ADSL2plus) uses approximately 2 MHz of the spectrum, very high speed digital subscriber line transceivers 2 (VDSL2) uses up to 35 MHz of the spectrum, and fast access to subscriber terminals (G.fast) uses up to 212 MHz of the spectrum, this Recommendation defines profiles using spectrum up to 424 MHz and 848 MHz. The 424 MHz profiles are fully specified, while the 848 MHz profiles are for further study. For any profile using spectrum up to 424 MHz, it specifies all necessary functionality to support the use of far-end crosstalk (FEXT) and near-end crosstalk (NEXT) cancellation between ITU-T G.9711 transceivers deployed on multiple wire-pairs. The availability of spectrum up to 424 MHz allows ITU-T G.9711 transceivers to provide reliable high data rate operation on short loops. This Recommendation can be deployed from fibre-fed distribution points located very near the customer premises, or within the buildings. This Recommendation is optimized to operate over twisted pairs between 30 m and 100 m. However, it is capable of operation over twisted pairs and coaxial cable up to at least 400 m, subject to some performance limitations.

This Recommendation defines a wide range of settings for various parameters that may be supported by a transceiver. Therefore, this Recommendation specifies profiles to allow transceivers to support a subset of the allowed settings and still be compliant with the Recommendation. The specification of multiple profiles allows vendors to limit the implementation complexity and develop implementations that target specific service requirements. This Recommendation specifies the profile for in-band spectral usage of up to 424 MHz at +4 dBm and + 2 dBm maximum transmit power for operation over twisted pairs and coaxial cable respectively, with the aggregate bit rate upto 8 Gbit/s (for FDX mode) and 4 Gbit/s (for TDD mode). Devices compliant with this Recommendation operate in compliance with the power spectral density (PSD) specification in [ITU-T G.9710].

As do ITU-T Recommendations in the ITU-T G.99x series, this Recommendation uses [ITU-T G.994.1] to initiate the transceiver training sequence. Through negotiation during the handshake phase of the initialization, the capability of equipment to support this Recommendation and/or ITU-T G.99x series and G.97xx series Recommendations (e.g., [b-ITU-T G.993.2] applicable to VDSL2 and [b-ITU-T G.9701] applicable to G.fast) is identified. For reasons of interoperability, equipment may support multiple Recommendations such that it is able to operate using a mode supported by the far-end equipment.

It is the intention of this Recommendation to provide, by negotiation during the initialization, compatibility and interoperability at the U interface between transceivers complying with this Recommendation, including transceivers that support different combinations of options.

The technology specified in this Recommendation provides the following key application features:

- Best aspects of fibre to the home (FTTH): up to multi-gigabit per second aggregate net data rate;
- Best aspects of ADSL2: customer self-install and operation in the presence of bridged taps, avoiding operator truck-rolls to the customer premises for installation and activation of the broadband access service;
- Coexistence with ADSL2 and VDSL2 on adjacent wire-pairs by crosstalk mitigation;
- Coexistence with G.fast on adjacent wire-pairs (connected to the same distribution point unit (DPU)) by crosstalk cancellation;
- Management capabilities allowing transceivers to operate in a zero touch deployment, avoiding truck-rolls to the network equipment for installation and activation of new or upgraded broadband access service;
- Control of the upstream vs downstream transmission scheme to adapt net data rates (especially in the TDD mode) to the needs of the business and the residential customers;
- Vectoring (self-crosstalk cancellation) for increased net data rates on wire-pairs that experience FEXT from other wire-pairs where ITU-T G.9711/G.9701 transceivers operate in the same vectored group, in the same cable or originated from the same network equipment;
- Echo-cancellation and near-end crosstalk cancellation/mitigation for increased net data rates on wire-pairs which are operated in FDX mode using the same frequency spectrum in both directions concurrently;
- Support of ultra-low latency services by improved retransmission and by use of FDX transmission;
- Network timing reference (NTR) and time-of-day (ToD) transport for network frequency and time synchronization between network and customer premises equipment;
- Configuration of spectrum use, including configuration of the transmit power spectral density (PSD) limitations and notches to meet electromagnetic compatibility (EMC) requirements;
- Point-to-multipoint (P2MP) operation, when multiple units of customer premises equipment can be connected to the same physical wire and port of network equipment;
- Quality of service (QoS) support by means of support of up to four QoS channels in upstream and downstream direction by the transceivers;
- Showtime reconfiguration (SREC) to reconfigure a line with a specified set of configuration parameters, applied during showtime without requiring a fast retrain or full re-initialization;
- Power saving by dynamic control of the time and frequency band available for data transmission depending on user traffic (using discontinuous time frequency operation (DTFO) functionality).

The technology specified in this Recommendation uses the following key functionalities and capabilities:

- Transparent transport of data packets (e.g., Ethernet packets) at an aggregate (sum of upstream and downstream) data rate of up to 8 Gbit/s;
- This edition of the Recommendation specifies profiles up to 424 MHz with +4 dBm and +2 dBm maximum transmit power;
- Configurable start and stop frequencies, PSD shaping and notching;
- Discrete multitone (DMT) modulation (using an inverse discrete fourier transform (IDFT) with 8192 subcarriers with 51.75 kHz subcarrier spacing for 424 MHz profiles;
- TDD (sharing time between upstream and downstream transmission);
- FDX (transmission in both directions at the same time at the same frequency);
- Improved retransmission techniques and use of proactive retransmissions for support of ultra-low latency services;
- Low latency retransmission, facilitating impulse noise protection (INP) between the V and T reference points at all data rates to deal at least with isolated erasure events at the U reference point of 10 ms, without loss of user data;
- Forward error correction (FEC) based on the combination of an inner trellis coded modulation (TCM) and an outer Reed-Solomon coding, or low-density parity-check (LDPC) coded modulation with probabilistic constellation shaping (PCS-LCM) and an outer Reed-Solomon coding;
- Discontinuous time-frequency operation (DTFO) in which the time and frequency band available for data transmission may change dynamically;
- Online reconfiguration (OLR) for adaptation to changes of the channel and noise characteristics.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T G.117] Recommendation ITU-T G.117 (1996), *Transmission aspects of unbalance about earth*.

[ITU-T G.994.1] Recommendation ITU-T G.994.1 (2021), *Handshake procedures for digital subscriber line transceivers*.

[ITU-T G.997.3] Recommendation ITU-T G.997.3 (2021), *Physical layer management for MGfast transceivers.*

[ITU-T G.9710] Recommendation ITU-T G.9710 (2020), *Multi-gigabit fast access to subscriber terminals (MGfast) – Power spectral density specification*.

[ITU-T O.9] Recommendation ITU-T O.9 (1999), *Measuring arrangements to assess the degree of unbalance about earth.*

[ITU-T T.35] Recommendation ITU-T T.35 (2000), *Procedure for the allocation of ITU-T defined codes for non-standard facilities*.

[IEEE 802.1X] IEEE 802.1X-2020, *IEEE Standard for Local and Metropolitan Area Networks: Port-Based Network Access Control*.
(http://standards.ieee.org/)

[IETF RFC 5216] IETF RFC 5216 (2008), *The EAP-TLS Authentication Protocol*.

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 ceiling(*x*): The smallest integer which is not less than *x*.

3.1.2 floor(*x*): The largest integer which is not greater than *x*.

3.1.3 MOD: The modulo function is defined as $x \text{ MOD } y = x - y \times \text{floor}\left(\frac{x}{y}\right)$.

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 active link: A link where both of the connected transceiver paths (at MTU-O and MTU-R) are in showtime.

3.2.2 aggregate net data rate (ANDR): The sum of the net data rate **(**NDR) in downstream and upstream.

3.2.3 bearer channel: A transparent data channel between the γ reference points of peer transceivers (i.e., from the γ_O at the MTU-O to the γ_R at the MTU-R, or vice versa).

3.2.4 bit-loading table/bit-allocation table: A table that for TCM contains the raw bit-loading values (b_i) and that for PCS-LCM contains the modulation index values (m_i). The terms bit-loading table and bit-allocation table are used interchangeably in this Recommendation.

3.2.5 BLACKOUT set: A subset of the SUPPORTEDCARRIERS set determined by the receiver during the initialization to be allocated no power by the transmitter.

3.2.6 data frame: An object originated by the physical media specific – transmission convergence (PMS-TC) sub-layer that contains a set of data transfer unit **(**DTU) bytes and possibly a set of robust management channel (RMC) bytes and retransmission return channel (RRC) to be encoded and modulated by the physical media dependent (PMD) sub-layer onto a single symbol.

NOTE – The number of bits in a data frame depends on the number of bits that could be modulated on a single symbol and whether or not it includes RMC or RRC bytes. If no DTU bytes and no RMC or RRC bytes are available for transmission at the PMS-TC sub-layer, no data frame is sent.

3.2.7 data packet: A set of bits of the bearer channel (e.g., an Ethernet packet) exchanged over the γ reference point between the L2+ functional block and transport protocol specific – transmission convergence (TPS-TC) sub-layer.

NOTE – Data packets are retrieved by the TPS-TC from the L2+ functional block, transmitted transparently over the line and recovered by the peer TPS-TC, which passes them to the peer L2+ functional block.

3.2.8 data symbol (general): A symbol that carries a data frame consisting of DTU bytes and RRC bytes (normal data frame) using subcarriers of at least Band 0. The data symbol is a generic term related to one of the following symbol types:

3.2.8.1 data_data symbol: A data symbol that carries a normal data frame loaded on subcarriers of both Band 0 and Band 1. This symbol type is applicable to both normal operation interval (NOI) and discontinuous operation interval (DOI).

3.2.8.2 data_dcm symbol: A data symbol that carries a normal data frame loaded on subcarriers of Band 0 only, while subcarriers of Band 1 are loaded with a DCM signal This symbol type is applicable only to NOI.

3.2.8.3 data_idle symbol: A data symbol that carries a normal data frame loaded on subcarriers of Band 0 only, while setting all the precoder inputs (Z_i) equal to 0 for all subcarriers of Band 1 (see PMD functional reference model, Figure 10-1). This symbol type is applicable only to NOI.

3.2.8.4 data_preamble symbol: A data symbol that carries a normal data frame loaded on subcarriers of Band 0 only, while subcarriers of Band 1 are loaded with a preamble signal. This symbol type is applicable only to NOI.

3.2.8.5 data_quiet symbol: A data symbol that carries a normal data frame loaded on subcarriers of Band 0 only, while there is no transmission (Z_i=0, Z_i'=0) on subcarriers of Band 1. This symbol type is applicable only to NOI.

3.2.9 data transfer unit (DTU): A frame used to transfer data bits transparently between α reference points of peer transceivers.

NOTE – Data is passed between peer transceivers by sets, each encapsulated into a single DTU. DTUs are exchanged over the α reference point between the TPS-TC and PMS-TC sub-layers.

3.2.10 discontinuous operation: A functionality facilitating power savings by discontinuing transmission on frequencies of Band 1 or on frequencies of both Band 0 and Band 1 during certain symbol periods when no user data is available or when transmission is not allowed. The method facilitating discontinuous transmission in both time and frequency is called discontinuous time-frequency operation (DTFO).

3.2.11 DTU payload rate (DPR): The data rate corresponding to the data transfer unit **(**DTU) payload in any one direction of transmission, assuming:

- no discontinuous operation,
- only data transmission on all subcarriers (including RMC and RRC) of all valid symbol positions, and
- no retransmissions.

3.2.12 dummy DTU: A DTU marked as "dummy DTU" in the DTU header. The payload of a DTU marked as "dummy DTU" in the DTU header contains no data packet or embedded operation channel (eoc) packet or fraction thereof.

3.2.13 dynamic resource allocation (DRA): A functionality that determines the downstream and upstream transmission opportunity for each PHY duplexing (PDX) frame based on the occupancy of higher layer downstream and upstream quality of service (QoS) queues and within the bounds configured by the operator through the DPU-MIB.

NOTE – As the QoS requirements (SLA, including best effort, as a QoS class) are served, the next target of the DRA functionality is to minimize power consumption. DRA is performed during the showtime, seamlessly (causing no loss of data or violation in the order of data).

3.2.14 idle symbol (general): A symbol that may be sent if no data frame is available for transmission. An idle symbol is constructed by setting the precoder inputs (Z_i) equal to 0 for at least the subcarriers in Band 0. The idle symbol is a generic term related to one of the following symbol types:

3.2.14.1 idle_idle symbol: An idle_idle symbol is constructed by setting the precoder inputs (Z_i) equal to 0 for all subcarriers in both Band 0 and Band 1. This symbol type is applicable to both NOI and DOI.

3.2.14.2 idle_preamble symbol: An idle_preamble symbol is constructed by setting the precoder inputs (Z_i) equal to 0 for subcarriers in Band 0, while a preamble signal is transmitted in Band 1. This symbol type is applicable only to NOI.

3.2.14.3 idle_quiet symbol: An idle_quiet symbol is constructed by setting the precoder inputs (Z_i) equal to 0 for all subcarriers, while there is no transmission (Z_i=0, Z_i'=0) on subcarriers of Band 1. This symbol type is applicable only to NOI.

NOTE – If transmission of an idle_quiet symbol coincides with a data symbol being transmitted on another line in the vectored group, the idle symbol consists of crosstalk pre-compensation signals only on subcarriers of Band 0.

3.2.15 impulse noise protection against SHINE: The number of consecutive DMT symbol periods that are corrupted by SHINE as seen at the δ-reference point, for which errored DTUs can be successfully recovered by the retransmission function resulting in no errors at higher layers, regardless of the number of errors within the DMT symbol periods, for those QoS channels with a *delay_max* value equal to the largest value of *delay_max* over all QoS channels.

3.2.16 impulse noise protection against REIN: The number of consecutive DMT symbol periods that are corrupted by REIN, as seen at the δ-reference point, for which errored DTUs can be successfully recovered by the retransmission function resulting in no errors at higher layers, regardless of the number of errors within the DMT symbol periods, for those QoS channels with a *delay_max* value equal to the largest value of *delay_max* over all QoS channels.

3.2.17 joining line: A line that is in the process of joining the precoded group (in case of downstream vectoring), the post-coded group (in case of upstream vectoring), or both.

3.2.18 line: A physical medium connected to the MTU at the U reference point, that may be used by a link to convey user data and management data between its MTU-O path and its MTU-R path.

3.2.19 link: A combination of a path in the MTU-O and its corresponding path in the MTU-R connected to the MTU-O.

3.2.20 logical frame: A set of symbol positions assigned to the same transmission direction, starting with (and including) an RMC symbol position and ending on the last symbol position just before the next RMC symbol position in the same direction.

3.2.21 management data packet: A set of bits generated by the MTU management entity to be transmitted to the management entity of the peer MTU.

NOTE – Management data packets are retrieved by the TPS-TC from the MTU management entity via the TPS-TC_MGMT interface, transmitted transparently over the line and retrieved by the peer TPS-TC, which passes them to the peer MTU management entity.

3.2.22 MEDLEYG set: A subset of the SUPPORTEDCARRIERSG set determined during the initialization to contain the subcarriers that may be used for transmission. A single MEDLEYG set is defined per link per direction of transmission, denoted the MEDLEYGds and MEDLEYGus, respectively, for the downstream and upstream directions. BLACKOUT subcarriers are not part of the MEDLEYG set.

3.2.22.1 MEDLEY set: For P2P operation, MEDLEY set is the same as the MEDLEYG set. For P2MP operation, the MEDLEY set is a subset of the MEDLEYG set and SUPPORTEDCARRIERS set of a particular link; it contains only those subcarriers from the MEDLEYG set that belong to the P2MPOB allocated to that link and that other MTU-Rs do not use as pilot tone groups plus the pilot tone groups outside of the P2MPOB associated with that link. The subcarriers of the MEDLEY set are used for transmission over the link they are allocated to, exclusively. For each subcarrier in the MEDLEY set, a b_i or m_i and a g_i value is assigned and exchanged during the initialization. The MEDLEY set is denoted MEDLEYds and MEDLEYus, respectively, for the downstream and upstream directions.

3.2.23 monitoring symbol (general): Symbols used to support DTFO. Monitoring symbol is a generic term related to one of the following symbol types:

3.2.23.1 DCM symbol (general): A monitoring symbol that can be implemented as an RMC_DCM or a data_DCM symbol; used for DTFO concurrent monitoring and applicable for NOI only.

3.2.23.2 DSQM symbol (general): A monitoring symbol that can be implemented as an RMC_data or a data_data symbol; used for DTFO sequential monitoring and applicable to both NOI and DOI.

3.2.23.3 preamble symbol (general): A monitoring symbol that can be implemented as an RMC_preamble, a data_preamble, an idle_preamble or preamble_preamble symbol; used for supporting DTFO. RMC_preamble, data_preamble, idle_preamble or preamble_preamble symbols are applicable to NOI only. Preamble_preamble symbols are applicable to DOI only.

3.2.23.3.1 preamble_preamble symbol: A preamble symbol in DOI, in which all subcarriers of Band 0 and Band 1 are used for preamble signals.

3.2.24 net data rate (NDR): The data transfer unit (DTU) payload rate (DPR) minus the embedded operation channel (eoc) data rate.

3.2.25 P2MP-group: A group of all links that have their MTU-O path within the same MTU-O.

3.2.26 P2MP operation band (P2MPOB): The P2MP operation band (P2MPOB) is a control parameter used to determine the SUPPORTEDCARRIERS set. In initialization, the P2MPOB is sent to the MTU-R during ITU-T G.994.1 handshake (for downstream) and in O-SIGNATURE (for upstream). In showtime, the P2MPOB may be updated by a DBR procedure. In that case, the P2MPOB is the set of active DBR sub-bands as indicated in the DBR sub-band assignment descriptor.

3.2.27 path: A combination of a single TPS-TC, a single PMS-TC and a single PMD function (including both transmit and receive directions) in the MTU-O or in the MTU-R, which conveys user data between the γ reference point and the U reference point and conveys management data for this TPS-TC, PMS-TC and PMD between the MTU management entity and the U reference point.

3.2.28 PDX frame: An ordered group of symbol positions consisting of M_{ds} symbol periods dedicated for full duplex compatible downstream sub-frame (FDS) and M_{us} symbol periods dedicated for full duplex compatible upstream sub-frame (FUS), separated by time gaps that sum up to either one symbol period in TDD, TDDZ and FDXC framing mode or zero symbol period in FDXZ framing mode (see clause 10.5).

3.2.29 pilot tone set: A subset of the SUPPORTEDCARRIERS set determined by the MTU-R receiver during the initialization to be allocated for transmission of pilot tones in the downstream direction. Selected pilot tone subcarriers are transmitted using special modulation (see clause 10.2.1.4.4). Pilot tone subcarriers are part of the MEDLEY set. In case of P2MP operation, pilot tones may be outside of the MTU-R's downstream P2MPOB (see clause 10.4.5).

3.2.30 post-coded group: The set of lines over which reception at the DPU is being coordinated by post-cancellation (upstream vectoring).

3.2.31 precoded group: The set of lines over which transmission from the DPU is being coordinated by precoding (downstream vectoring).

3.2.32 quiet symbol: A symbol that is constructed by setting the modulator input (Z_i' at the MTU-O and Z_i at the MTU-R) equal to zero for all subcarriers of both Band 0 and Band 1 (see PMD functional reference model, Figure 10-1). Transmission of a quiet symbol results in zero transmit power at the U reference point. This symbol type is applicable only to DOI.

3.2.33 reference point: A set of interfaces between any two related functional blocks through which information flows from one block to the other. A reference point comprises one or more logical (non-physical) information-transfer interfaces, and one or more physical signal-transfer interfaces.

3.2.34 repetitive electrical impulse noise (REIN): A type of electrical noise encountered on subscriber lines. It is evident as a continuous and periodic stream of short impulse noise events. Individual REIN impulses commonly have a duration of less than 1 millisecond. REIN is generally coupled from electrical power cable when appliances draw power from the AC electrical power network.

3.2.35 RMC frame: An object originated by the physical media specific – transmission coverage sub-layer that contains management and control information to be communicated through the RMC, protected by a Reed-Solomon forward error correction (FEC) code. An RMC frame is multiplexed with DTU(s) and mapped into a data frame by the PMS-TC sub-layer.

3.2.36 RMC message: A group of RMC commands encoded over a single RMC frame (see Figure 9-4).

3.2.37 RMC symbol (general): A symbol that carries an RMC data frame, consisting of both RMC bytes and data transfer unit **(**DTU) bytes using subcarriers of at least Band 0. An RMC symbol can only be transmitted at RMC symbol position. The RMC symbol is a generic term related to one of the following symbol types:

3.2.37.1 RMC_data symbol: An RMC symbol that carries an RMC data frame using subcarriers of both Band 0 and Band 1.

3.2.37.2 RMC_DCM symbol: An RMC symbol that carries an RMC data frame using subcarriers of Band 0 only, while subcarriers of Band 1 are carrying a DCM signal.

3.2.37.3 RMC_idle symbol: An RMC symbol that carries an RMC data frame using subcarriers of Band 0 only, while setting all the precoder inputs (Z_i) equal to 0 for all subcarriers of Band 1.

3.2.37.4 RMC_preamble symbol: An RMC symbol that carries an RMC data frame using subcarriers of Band 0 only, while subcarriers of Band 1 are carrying a preamble signal.

3.2.37.5 RMC_quiet symbol: An RMC symbol that carries an RMC data frame using subcarriers of Band 0 only, while there is no transmission (Z_i=0, Z_i'=0) on subcarriers of Band 1.

3.2.38 RMC symbol position: The single symbol position within each PHY duplexing (PDX) frame reserved for the transmission of the RMC symbol.

3.2.39 RRC symbol: In RRC symbol all subcarriers are loaded as monitored tones (see clause 10.2.1.4.4), except 16 subcarriers in Band 0 used for transmission of RRC, while there is no transmission (Z_i=0, Z_i'=0) on subcarriers of Band 1. On these 16 subcarriers (RRC subcarriers), the RRC bytes are modulated. This symbol type is applicable only to NPSF (NOI) in FDX mode.

3.2.40 showtime: The state that a path reaches after the initialization procedure has been completed in which bearer channel data are transmitted.

3.2.41 single high impulse noise event (SHINE): A type of electrical noise encountered on subscriber lines. It is evident as a single high-power impulse noise event with a duration ranging from milliseconds to seconds. SHINE is generally coupled from electrical power cable when appliances draw power from the AC electrical power network, and from lightning.

3.2.42 subcarrier: A fundamental element of a DMT modulator. The modulator partitions the channel bandwidth into a set of parallel subchannels. The centre frequency of each subchannel is a subcarrier onto which bits may be modulated for transmission over a channel.

3.2.43 subcarrier group: A group of *G* adjacent subcarriers.

NOTE – Subcarrier groups are used to reduce the number of test parameter data points that need to be stored by and communicated between the MTU-O and MTU-R. Each subcarrier in a subcarrier group is characterized by the same value of a test parameter (see clause 11.4.1).

3.2.44 subcarrier spacing (f_{SC}): A parameter representing the difference between frequencies of two adjacent subcarriers (between the center frequencies of two adjacent subchannels), expressed in Hz.

3.2.45 superframe: An ordered group of M_{SF} contiguous PHY duplexing (PDX) frames, starting with a PDX sync frame (see clause 10.6). The duration of a superframe is approximately six ms.

3.2.46 SUPPORTEDCARRIERSG set: The global supported subcarriers set. For both P2P and P2MP operation, this is the set of subcarriers allocated for transmission in one direction, as determined by the frequency band of the selected profile and any restrictions imposed by the operator via the DPU-MIB, denoted SUPPORTEDCARRIERSGds and SUPPORTEDCARRIERSGus, respectively, for the downstream and upstream directions.

3.2.46.1 SUPPORTEDCARRIERS set: For P2P operation, SUPPORTEDCARRIERS set is same as the SUPPORTEDCARRIERSG set. For P2MP operation, the SUPPORTEDCARRIERS set corresponds to those subcarriers from the SUPPORTEDCARRIERSG set that belong to the P2MPOB allocated to the link and that are not used by other MTU-Rs as pilot tone groups, plus the pilot tone groups outside the P2MPOB associated with that link. The SUPPORTEDCARRIERSds and SUPPORTEDCARRIERSus denote the SUPPORTEDCARRIERS sets for the downstream and upstream directions, respectively.

3.2.47 symbol: The time-domain samples emerging from the discrete multitone (DMT) modulator during one symbol period, following insertion of the cyclic extension and completion of the windowing and overlap-and-add operations.

3.2.48 symbol position: A numbered symbol period (with valid range defined in clause 10.5) within a logical frame in which a symbol is transmitted.

3.2.49 sync symbol: A symbol modulated by probe sequences that is used for synchronization and channel estimation. No data frame is encoded and modulated onto a sync symbol.

3.2.50 sync symbol position: A symbol position within each superframe reserved for transmission of a sync symbol. In TDD mode there is a single symbol position within each superframe reserved for transmission of sync symbol, while in FDX mode there are two symbol positions within each superframe reserved for transmission of sync symbols.

3.2.51 target maximum delay: The time of data packet propagation, in milliseconds, from the γ reference point of the transmitter to the γ reference point of the receiver.

3.2.52 timing advance (TAD): A timing offset between transmit and receive DMT symbols defined in samples; the MTU starts transmission of a symbol TA samples earlier than it receives a symbol. A time reference point for TA measurement is floor($\beta/2$) after the first sample of the cyclic prefix. MTU vendors make their best effort to estimate the time position of the first sample accurately.

3.2.53 transmission opportunity (TXOP): The set of symbol positions in a logical frame (excluding sync symbol position) at which data transmission is allowed. Outside the transmission opportunity, the MTU only transmits quiet symbols.

NOTE 1 – The downstream and upstream transmission opportunities are determined by the DRA function and received by the MTU-O over the γ_O reference point (through the TXOPds and TXOPus primitives). The parameters received with the TXOPus primitive are communicated to the MTU-R through the RMC. For the PSF, the transmission opportunity contains symbol positions allocated to the NOI, and may contain symbol positions allocated to the DTFO block of the DOI and allocated for the DTFO block of the NOI (in Band 1). For the NPSF, the transmission opportunity contains only symbol positions allocated to NOI. Transmission opportunities are set for each logical frame of each line of the vectored group and may be changed as often as once per logical frame.

NOTE 2 – The DRA function controls the number of symbol positions in the transmission opportunity, thereby having the ability to control energy efficiency.

3.2.54 vectored group: The set of lines over which transmission from the DPU is eligible to be coordinated by pre-coding (downstream vectoring), or over which reception at the distribution point (DPU) is eligible to be coordinated by post-cancellation (upstream vectoring), or both. Depending on the configuration of the vectored group, downstream vectoring, upstream vectoring, both or none may be enabled.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

ACK	Acknowledgement
ADSL2	Asymmetric Digital Subscriber Line transceivers 2
ADSL2plus	ADSL2 – extended bandwidth
AFE	Analogue Front-End
ANDR	Aggregate Net Data Rate
AR	Automatic Repeat
CE	Cyclic Extension
CID	Channel Identifier
CL	Capabilities List
CLR	Capabilities List Request
CP	Cyclic Prefix
CRC	Cyclic Redundancy Check
CS	Cyclic Suffix
DC	Direct Current
DCM	DTFO Concurrent Monitoring
DMT	Discrete Multitone
DBR	Dynamic Bandwidth Redistribution
DOI	Discontinuous Operation Interval
DP	Distribution Point
DPU	Distribution Point Unit
DRA	Dynamic Resource Allocation
DRR	Dynamic Resource Report
DRRDSF	DRR Downstream Function
DRRUSF	DRR Upstream Function
DSL	Digital Subscriber Line
DSQM	DTFO Sequential Monitoring
DTA	Dynamic Time Assignment
DTFO	Discontinuous Time Frequency Operation
DTU	Data Transfer Unit
EC	Echo Canceler

ECS	Error Check Sequence
EMC	Electromagnetic Compatibility
eoc	embedded operation channel
FEC	Forward Error Correction
FEQ	Frequency domain Equalizer
FEXT	Far-End crosstalk
FCS	Frame Check Sequence
FDS	Full duplex compatible Downstream Sub-frame
FDX	Full Duplex
FDXC	FDX in Compatibility
FDXZ	FDX with Zero-gap
FRA	Fast Rate Adaptation
FTTB	Fibre To The Building
FTTdp	Fibre To The Distribution Point
FTTH	Fibre To The Home
FUS	Full duplex compatible Upstream Sub-frame
FXO	Foreign Exchange Office
FXS	Foreign Exchange Subscriber
HDLC	High-level Data Link Control
HON	Higher Order Node
IAR	International Amateur Radio
IDFT	Inverse Discrete Fourier Transform
INP	Impulse Noise Protection
ISDN	Integrated Services Digital Network
LDPC	Low-Density Parity-Check
LESM	Low-frequency Edge Stop-band Mask
LPM	Limit PSD Mask
LSB	Least Significant Bit
MDU	Multi-Dwelling Unit
ME	Management Entity
MGfast	Multi-gigabit Fast Access to Subscriber Terminals
MME	MTU Management Entity
MSB	Most Significant Bit
MTU	MGfast Transceiver Unit
MTU-O	MTU at the Optical Network Unit
MTU-R	MTU at the Remote Site (i.e., subscriber end of the loop)
MUX	Multiplexer

NMS	Network Management System
NOI	Normal Operation Interval
NPSF	Non-priority Sub-frame
NR	Non-Repeat
NSF	Non Standard Facility
NT	Network Termination
NTR	Network Timing Reference
ODN	Optical Distribution Network
OLR	Online Reconfiguration
P2MP	Point-to-multipoint
P2P	Point-to-Point
PCE	Power Control Entity
PCS-LCM	Probabilistic Constellation Shaping
PDX	PHY duplexing
PHY	Physical layer
PMS	Physical Media Specific
POTS	Plain Old Telephone Service
PSF	Priority Sub-frame
PRBS	Pseudo Random Binary Sequence
PSD	Power Spectral Density
PSM	PSD Shaping Mask
QA	Queue Arrival
QF	Queue Fill
QID	Queue Identifier
QoS	Quality of Service
REIN	Repetitive Electrical Impulse Noise
RFI	Radio Frequency Interference
RMC	Robust Management Channel
RMCR	RMC Recovery
RPA	RMC Parameter Adjustment
RQ	Repeat Request
RRC	Retransmission Return Channel
RTS	RMC Tone Set
RTX	Retransmission
SA	Sub-band Assignment
SDI	Sub-band Description Index
SHINE	Single High Impulse Noise Event

SID	Sequence Identifier
SM	Shell Mapping
SOC	Special Operations Channel
SRA	Seamless Rate Adaptation
SREC	Showtime Reconfiguration
TAD	Timing Advance
TC	Transmission Convergence
TCE	Timing Control Entity
TDD	Time Division Duplexing
TIGA	Transmitter Initiated Gain Adjustment
ToD	Time-of-Day
TS	Time Stamp
TPS	Transport Protocol Specific
UTC	Unable To Comply
VBB	Vectored Band Blocks
VCE	Vectoring Control Entity
VDSL2	Very high speed Digital Subscriber Line transceivers 2
VF	Vectoring Feedback
VFRB	Vectoring Feedback Report Block

5 Reference models

5.1 System reference model

This Recommendation covers the interface specification between an MTU-O and the MTU-R, as applied at the U reference point. The MTU-O is located inside the DPU at the network side (U-O reference point). The MTU-Rs are located inside the network termination (NT) at the customer premises side (U-R reference point). Implementations complying with this Recommendation are typically deployed in a fibre-to-the-distribution-point (FTTdp) scenario and fibre-to-the-building (FTTB) scenario. The MTU-O and MTU-R are connected via either a dedicated or a shared transmission line, which can be a wire pair (a twisted pair or a quad) or a coaxial cable.

Figure 5-1 presents a functional reference model of FTTdp and FTTB deployment. In this model, the upstream traffic from the shown DPU is aggregated with the upstream traffic from other DPUs by the optical distribution network (ODN) and higher order node (HON) up to the V reference point. The downstream traffic at the V reference point is distributed towards the shown DPU and other DPUs by the HON and ODN. The aggregation and distribution functions of the ODN and HON are out of the scope of this Recommendation. Different aggregation examples are united under the HON, ODN and DPU.

Each DPU contains one or more MTU-Os, with each MTU-O connected to one or more MTU-Rs, which are peers of the MTU-O of the corresponding DPU. Each NT contains one MTU-R, thus one or more NTs may be connected to the given MTU-O at the DPU. The generic reference model containing multiple peer MTU-Rs per MTU-O, further referred as P2MP deployment, is shown in Figure 5-1a, the model containing only one peer MTU-R per MTU-O, further referred as point-to-point (P2P) deployment, is shown in Figure 5-1b.

The management of a DPU is performed by the network management system (NMS), passing management information to each DPU's management entity (ME) over the Q reference point. The NMS may also monitor each MTU-R via the related NT's ME via the G reference point. The connection between the ME functions at the DPU and at the NT is established over the management channels provided by the MTU-Os and MTU-Rs via the transmission line.

The PHY blocks represent the physical layer of the DPU towards the ODN and the physical layer of the NT towards the customer premises equipment (CPE), at T/S interface, respectively. The L2+ blocks represent the Layer 2 and above functionalities contained in the DPU and the NTs. These blocks are shown for completeness of the data flow but are out of scope of this Recommendation.

An MTU-O represents the physical interface of the DPU towards the transmission line and functions as a transceiver. The DPU includes a number of transceivers (MTU-O-1 for transmission line 1 in Figure 5-1a/b). For each MTU-O, the peer transceivers are multiple MTU-Rs in general (P2MP deployment) or only one MTU-R (P2P deployment). With P2MP, the transmission line consists of one or more physical lines per MTU-O, each shared by one or more MTU-Rs. With P2P, the transmission line consists of one physical line per MTU-O, dedicated to one MTU-R. Functionalities related to maintaining plain old telephone service (POTS) and power (local power feeding, reversed power feeding, or remote power feeding of the DPU) are not illustrated in either Figure 5-1a/b or Figure 5-2.

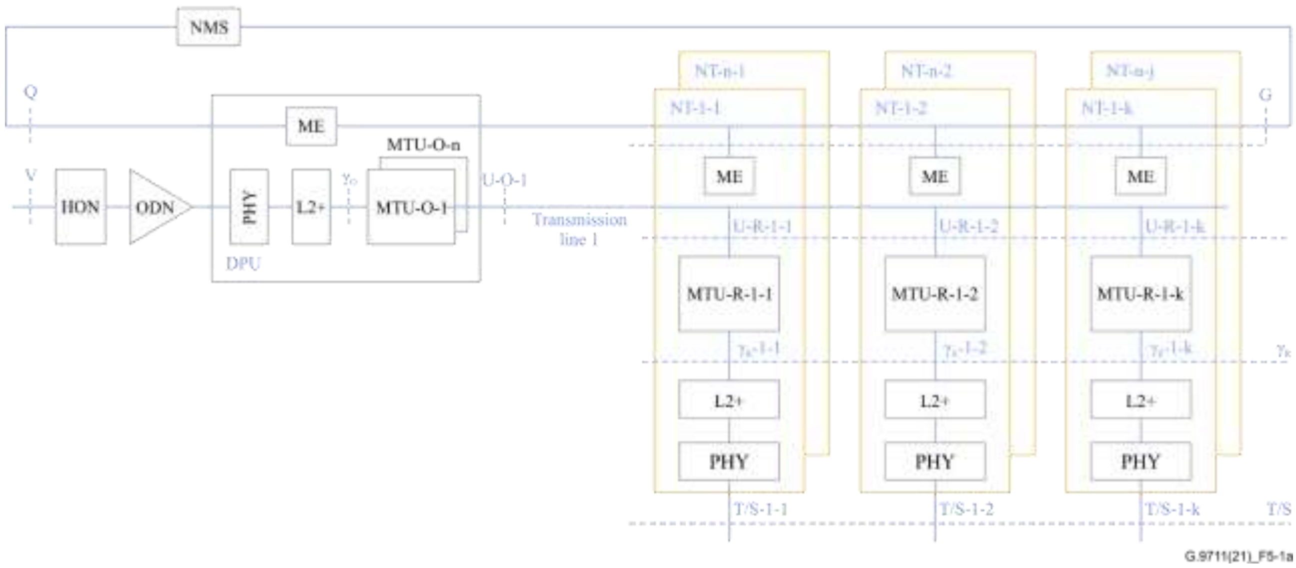


Figure 5-1a – Generic system reference model for FTTx P2MP deployment (shown 1 of N MTU-O in the DPU with multiple peer MTU-Rs)

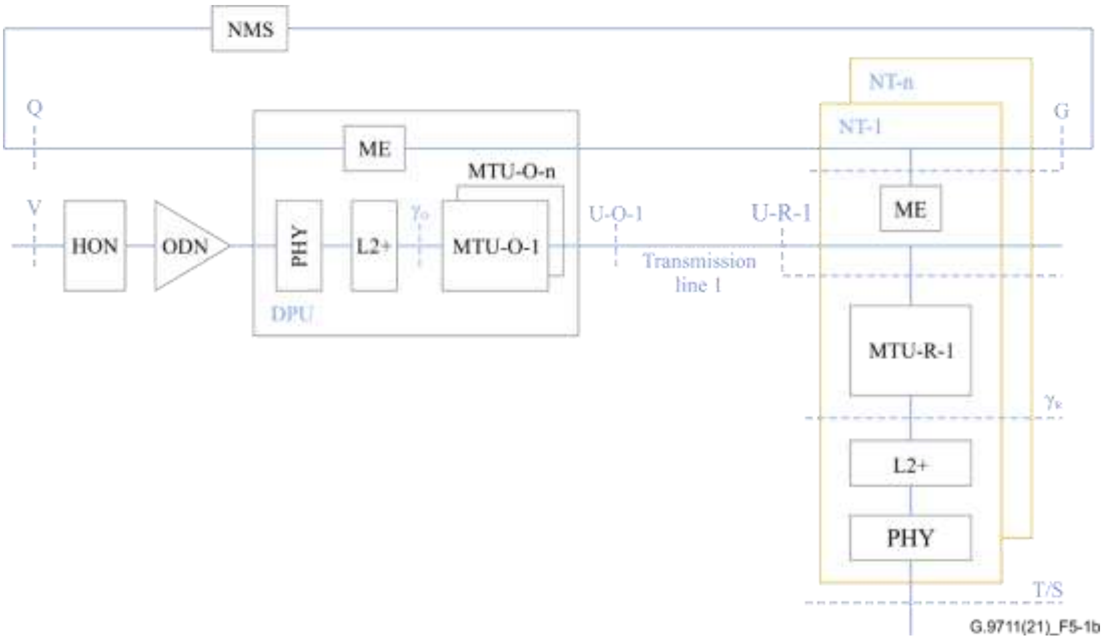


Figure 5-1b – System reference model for FTTx P2P deployment (shown 1 of N MTU-O in the DPU with a single peer MTU-R)

Figure 5-2 shows the reference model of the information flows within a DPU containing *N* MTU-Os. These information flows include components of multiple services and multiple MTU-Os and are shown as thick lines in Figure 5-2. The fundamental principle of the system is its capability of synchronous and coordinated transmission and reception of signals from all *N* transmission lines connected to the DPU. These signals may be represented as a vector where each component is the signal on one of the multiple transmission lines, and these signals may be exchanged for coordination among the MTU-Os, from each MTU-O to all other MTU-Os of the DPU. Transmission lines connected to coordinated MTU-Os form a vectored group.

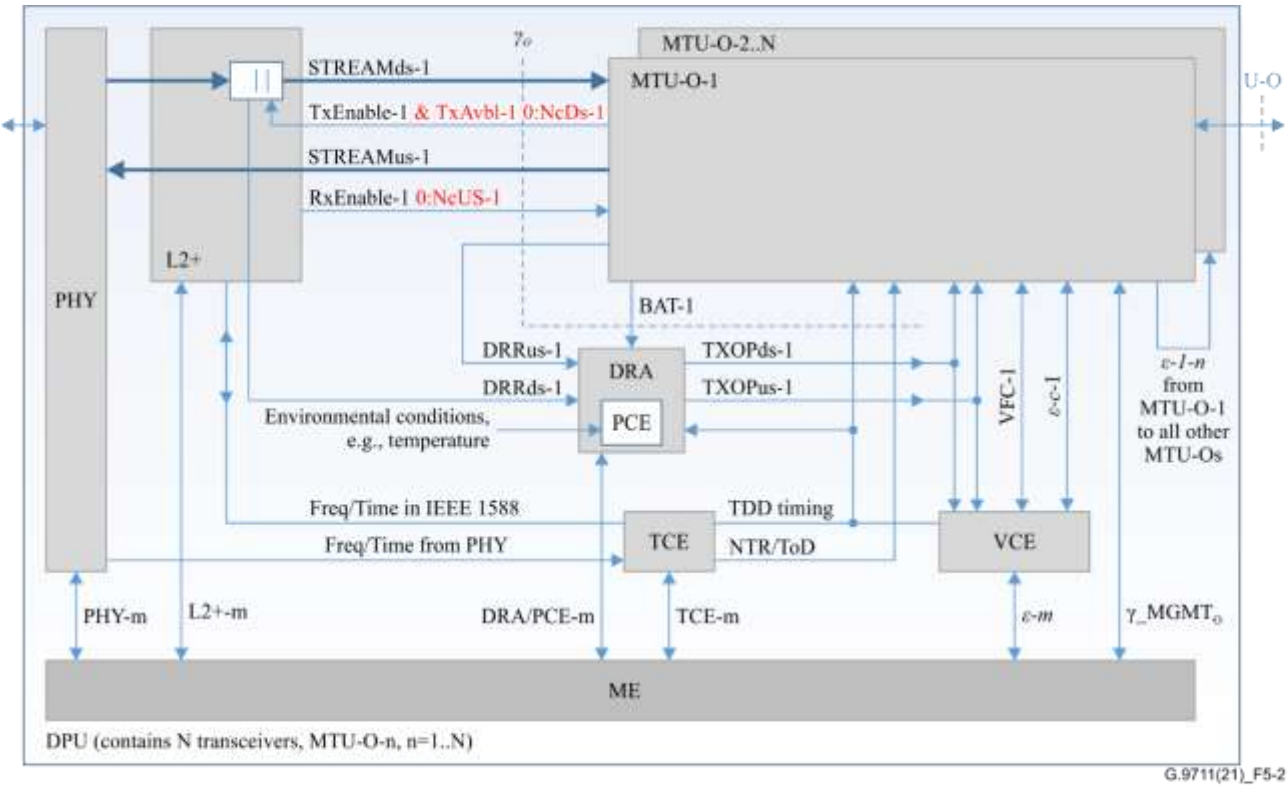


Figure 5-2 – System reference model of the DPU
(shown MTU-O-1 for transmission line 1 of *N* transmission lines connected to the DPU)

For each MTU-O, the data plane information flow over the γ_O reference point is represented by downstream data streams (STREAMds-n-k, for k=1..K, shown as STREAMds-n) and upstream data streams (STREAMus-n-k, k=1..K, shown as STREAMus-n), where 'n' is an identifier for a specific MTU-O (MTU-O-n) and associated transmission line, and 'k' is an identifier for a specific MTU-R (MTU-R-n-k) out of the K MTU-Rs connected to MTU-O-n. The MTU-O may use flow control (TX Enable-n-k and TX Avbl-n-k) on the downstream data stream STREAMds-n-k. The L2+ entity may use flow control (RX Enable-n-k) on the upstream data stream STREAMds-n-k. Both TX Enable-n-k/Avbl-n-k and RX Enable-n-k are per QoS channel in case multiple QoS channels are supported in a particular data stream, for downstream and upstream respectively, see clause 5.5.1 and clause 5.5.2. Inside the DPU, the ME conveys the management information (over the γ_{MGMT} interface) to each of the MTU-Os.

The functionalities of the DPU also include:

- Timing control entity (TCE);
- Vectoring control entity (VCE);
- Dynamic resource allocation (DRA) that also includes power control entity (PCE).

The TCE coordinates the transmission and reception with TDD or FDX over the vectored group. At the U-O reference point, downstream symbols transmitted by all MTU-Os, upstream symbols transmitted by all MTU-Rs, downstream sync symbols transmitted by all MTU-Os, and upstream sync symbols transmitted by all MTU-Rs are aligned over all transmission lines in the vectored group respectively. The coordination is shown in Figure 5-2 as the same TDD timing being passed from the TCE to all N MTU-Os.

The TCE also manages the NTR and ToD. The network frequency/timing is received over the V reference point (e.g., [b-ITU-T G.8264], [b-IEEE 1588]) and conveyed through the OLT, ODN, and PHY and/or L2+ block to the TCE. The TCE passes the NTR and ToD signals to MTU-O(s). The TCE may synchronize the TDD timing (including the transceiver sample clock f_s) to the NTR or

ToD reference frequency. Inside the DPU, the ME conveys the management information (over the TCE-m interface, see Figure 5-2) to the TCE.

The VCE coordinates the crosstalk cancellation over the vectored group. This coordination is made possible through communication from each MTU-O to all other MTU-Os; for example, ε-1-n identifies the interface between an MTU-O on transmission line 1 (here called MTU-O-1) and all other MTU-Os on transmission lines *n* (here called MTU-O-*n*, *n*=2…*N*). Coordination data (e.g., precoder data for vectoring) are exchanged between MTU-O-*n*1 and MTU-O-*n*2 over an interface here called ε-*n*1-*n*2. Each VCE controls a single DPU, and controls MTU-O-*n* (connected to transmission line *n*) over an interface here called ε-c-*n* (e.g., to set precoder coefficients for vectoring). The information contained in the vectoring feedback channel (VFC-n) enables the VCE to determine the precoder coefficients. The vectoring feedback information is conveyed from the MTU-Rs over the U interface to the MTU-O and then over the VFC to the VCE. Inside the DPU, the ME conveys the management information (over an interface here called ε-m) to the VCE.

The DRA coordinates the downstream and upstream transmission opportunities within each transmission line and over the vectored group to facilitate TDD or FDX transmission or both. The allocation of downstream and upstream transmission opportunities may be static (i.e., constant over time as set by the ME) or may be dynamic (i.e., variable over time, depending on the traffic needs and within the bounds set by the ME and the PCE). The DRA and L2+ functionality together coordinate the downstream and upstream transmission opportunities over each transmission line of the vectored group. The DRA receives dynamic resource reports (DRRs) from the L2+ functionality for each NT operating over each of the transmission lines in the vectored group (shown as DRRds-n-k and DRRus-n-k). The DRRus is passed from the NT to the DRA over the γ_R, U-R, U-O, and γ_O reference points. Inside the DPU, the ME conveys the management information (over an interface called DRA-m here) to the DRA. In case multiple MTU-Rs are connected to an MTU-O, the DRA can use this information to coordinate the transmission opportunities both among the multiple MTU-Rs connected to one MTU-O and among multiple MTU-Rs over the vectored group served by the DPU. Battery operation at the NT is indicated to the DRA via BAT primitive.

The management information conveyed over the DRA-m interface imposes bounds on the allocation of upstream and downstream transmission opportunities per transmission line within the vectored group.

The PCE may further impose bounds on the allocation of downstream and upstream transmission opportunities using information about traffic needs per transmission line, about environmental information within the DPU related to power dissipation, e.g., temperatures inside the DPU and available power supplies, and about NT being on battery powering, indicated through the BAT-n primitives. The necessary management information (e.g., temperature limits and power dissipation targets) is conveyed over the PCE-m interface. Based on this information, the PCE tracks the power consumption of the DPU and limits the allocation of transmission opportunities per transmission line, in both upstream and downstream directions, accounting for various criteria including the traffic need, environmental information and NT powering.

Figure 5-3 shows the reference model of the information flows within NT-n-k (where 'n' identifies the MTU-O and associated transmission line, and 'k' identifies the MTU-R connected to MTU-O-n). The NT reference model represents a single MTU-R. All functionality of an NT related to the transmission and reception with both the TDD or FDX over the vectored group is contained inside the MTU-R and coordinated by the TCE under control from the DPU.

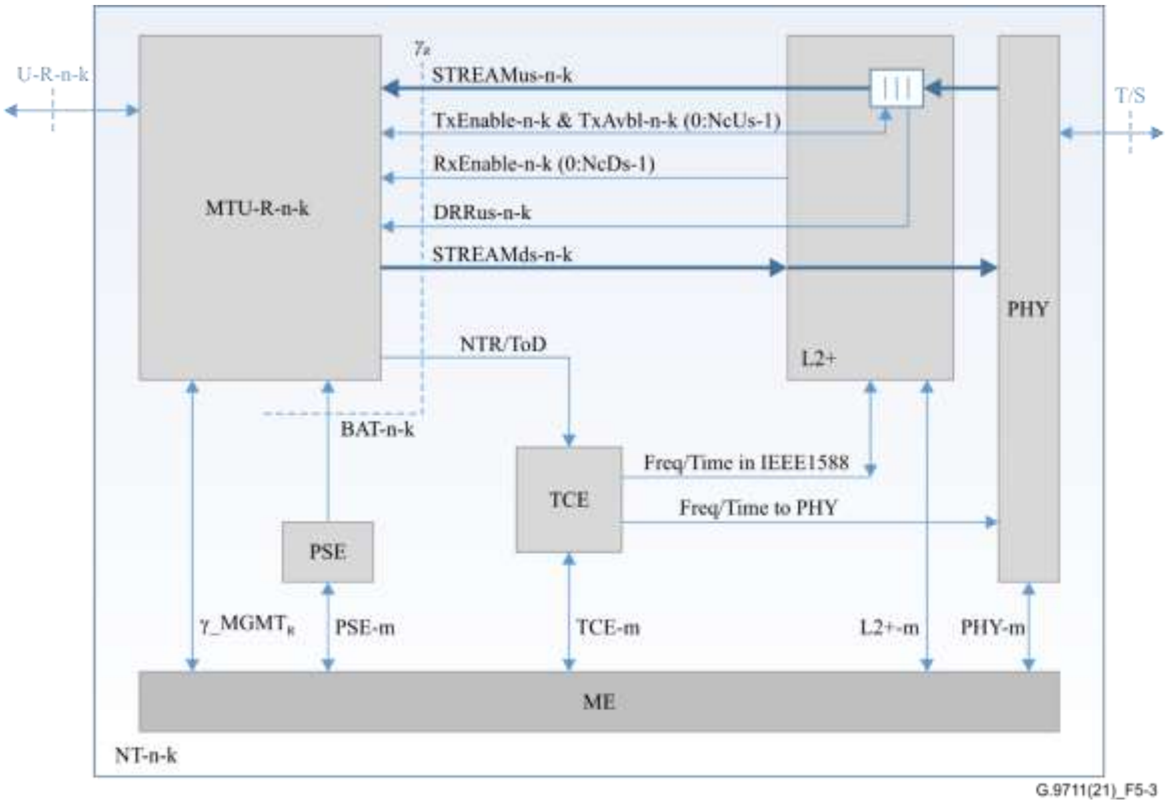


Figure 5-3 – Reference model of NT-n-k

The data plane information flow over the γ_R reference point is represented by a single downstream data stream (STREAMds-n-k) and a single upstream data stream (STREAMus-n-k). The MTU-Rs may use flow control (TX Enable-n-k and TX Avbl-n-k) on the upstream data steam. The L2+ entity may use flow control (RX Enable-n-k) on the downstream data stream. Both TX Enable-n-k/Avbl-n-k and RX Enable-n-k are per QoS channel in case multiple QoS channels are supported in a data stream, for downstream and upstream respectively, see clause 5.5.1 and clause 5.5.2. The ME conveys the management information (over an interface here called γ_MGMT) to the MTU-Rs.

The TCE receives NTR and ToD over the network frequency/timing from the MTU-R over the γ_R reference point, and passes the network frequency/timing to the PHY and the L2+ block so as to provide network frequency/timing at the T reference point (e.g., 1PPS, IEEE1588). The TCE, under control of the DPU, also facilitates the transmission and reception timing of the MTU-R in the vectored group. Inside the NT-n-k, the ME conveys the management information (over the TCE-m interface) to the TCE.

The DRA related primitives associated with the MTU-R are represented by DRRus-n-k, and battery operation (BAT-n-k) crossing the γ_R reference point. The DRRus primitive is for the MTU-R to receive the DRR from the L2+ and to send/receive DRR configuration to/from the L2+. The battery-operation (BAT) primitive is for the power source equipment (PSE), shown as internal to the NT, to indicate the battery operation to the MTU-R. The PSE also indicates the battery operation to the ME of the MTU-R over the PSE-m interface.

5.2 Application reference models

Implementations complying with this Recommendation are typically deployed in an FTTdp scenario. An FTTdp or FTTB deployment may be a further evolution of an FTTx (e.g., FTTCabinet and FTTcurb) deployment, taking the fibre deeper into the network. They may also be a FTTH deployment with a copper extension where installation of the fibre inside the customer premises is not possible. The ODN that feeds the DPUs may be based on P2MP (e.g., PON) or P2P (e.g., GbE) technologies.

A key aspect of FTTdp deployment is the requirement that the customer should be able to self-install the equipment.

5.2.1 In-premises telephone wiring

Figure 5-4 provides an overview of the basic application reference model for a P2P customer self-install over a copper pair with POTS as the underlying narrowband service. Alternatively, the integrated services digital network (ISDN) may be used as the underlying narrowband service. This application model is very similar to the ITU-T G.993.2 generic application reference model for splitterless remote deployment (see Figure 5-5 of [b-ITU-T G.993.2]). The DPU may contain one or multiple instantiations of the MTU-O and service splitter functionalities.

Table 5-1 specifies the signal flows applicable at the reference points shown in Figure 5-4.

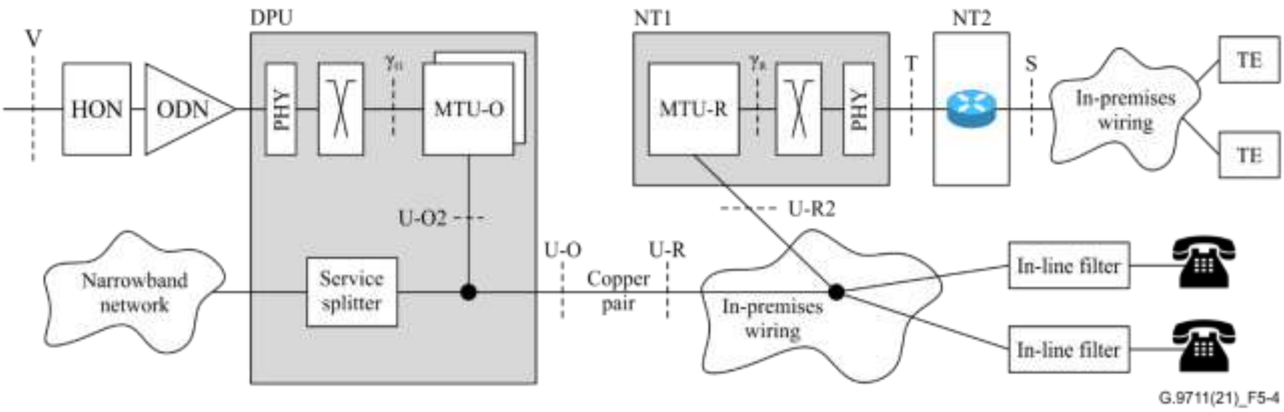


Figure 5-4 – Application reference model for FTTdp with POTS

Table 5-1 – Signal flows applicable at the reference points shown in Figure 5-4

Reference point	ITU-T G.9711 signals	Reverse power feeding	Conventional analogue POTS
U-O2	Yes	No	No
U-O /U-R	Yes	No	Yes
U-R2	Yes	No	No

The ITU-T G.9711 equipment is connected using existing telephone wires, where the NT1 can be plugged into any telephone wall socket. This deployment model implies that the wiring topology of the existing network may include bridged taps. This Recommendation thus defines the functionality necessary to facilitate deployment of ITU-T G.9711 equipment in the presence of bridged taps, and related radio frequency interference (RFI), and impulse noise.

As the DPU is deployed closer to the customer premises, the number of ports on a DPU gets smaller and more DPUs are deployed throughout the network. Distribution points (DPs) are at locations where local powering may not be available. In this case, reverse power feeding (RPF) is applied. The DPU is powered from the customer premises, sharing the same wire-pair with the data service. The application of reverse powering is included in the application reference model for FTTdp with reverse powering and POTS in Figure 5-4a.

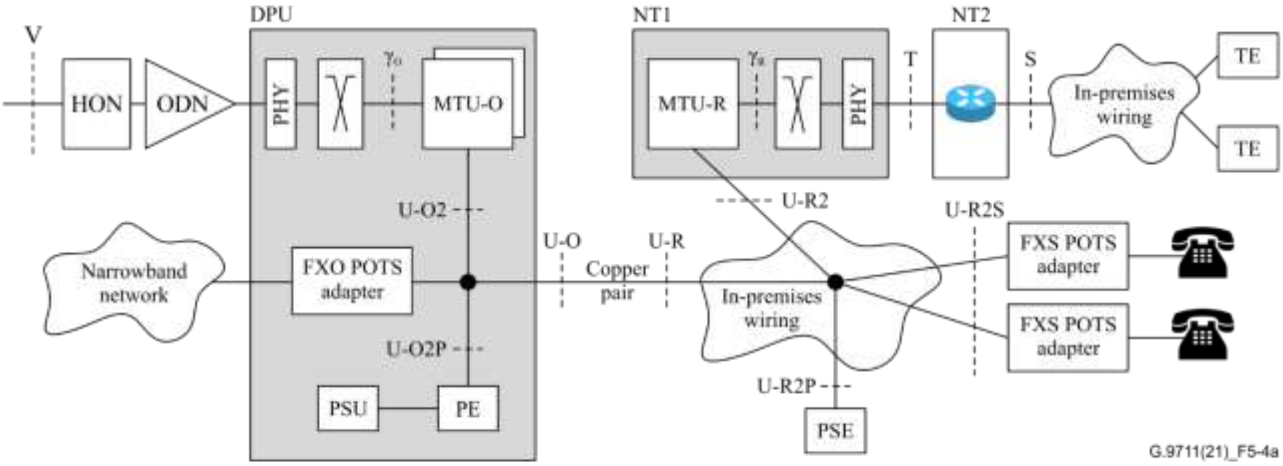


Figure 5-4a – Application reference model for FTTdp with RPF and POTS

The power is inserted on the wire-pair by the power source equipment (PSE) located in the customer premises and extracted from the wire-pair by the power extractor (PE) located in the DPU. Power is extracted from each active port and combined in the power supply unit (PSU). The PSE and the NT may be integrated into the same physical box. Table 5-2 shows signal flows associated with RPF at reference points shown in Figure 5-4a.

Table 5-2 – Signal flows applicable at the reference points associated with RPF as shown in Figure 5-4a

Reference point	ITU-T G.9711 signals	RPF	Conventional analogue POTS
U-O2P	No	Yes	No
U-O/U-R	Yes	Yes	Yes
U-R2P	No	Yes	No
U-R2S	No	Yes (Note)	Yes
NOTE – RPF provides power for FXS POTS adapters implementing signalling conversion.			

Since RPF uses direct current (DC) from the customer premises, the underlying POTS service use adapters to share the same wire-pair with the RPF and data service. POTS adapters provide alternative signalling means on the U reference point, equivalent to POTS signalling. At the network side, a FXO-type POTS adapter converts the foreign exchange office (FXO) interface POTS DC signalling from the narrowband network into the alternative signalling on the U reference point. At the customer premises side, an FXS-type POTS adapter converts the alternative signalling on the U reference point into foreign exchange subscriber (FXS) interface POTS DC signalling towards the telephones.

For the telephone wire scenario, Figure 5-4b provides an overview of the basic application reference model for P2MP customer self-install. The ITU-T G.9711 equipment is connected using existing telephone wires, where each of NTs can be plugged into any telephone wall socket.

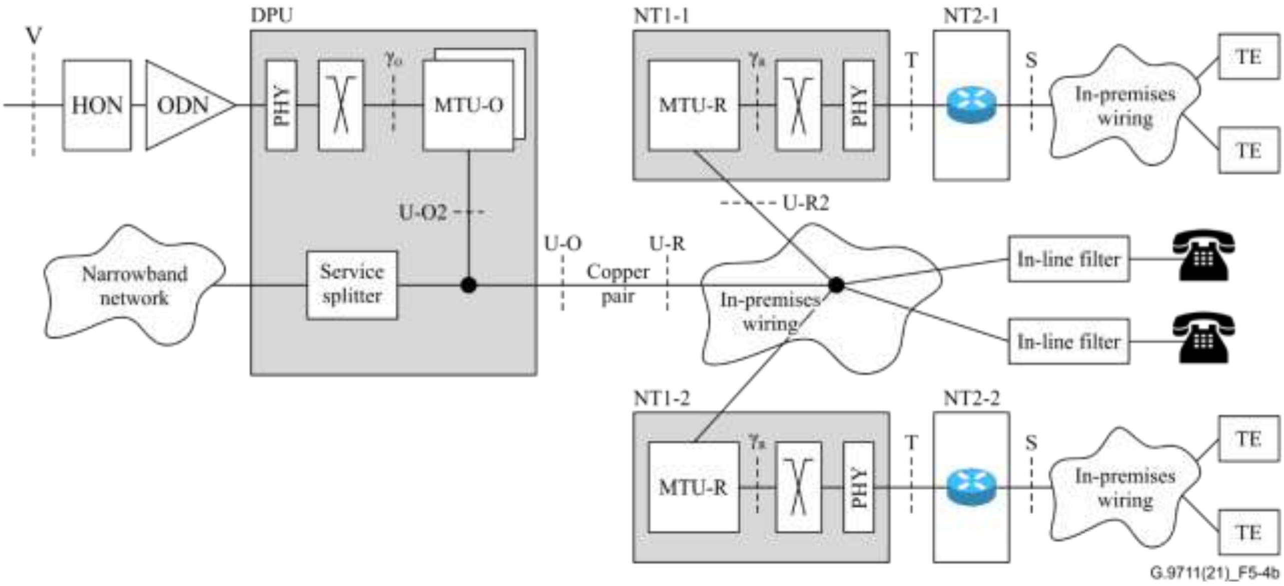


Figure 5-4b – Application reference model for in-premises telephone wire (P2MP, two NT1)

5.2.2 In-premises coaxial wiring

For the coaxial cable scenario, Figure 5-4c provides an overview of the basic application reference model for P2P customer self-install. The ITU-T G.9711 equipment is connected over the existing coaxial cable, which is shared (using diplexers at both sides) with the underlying TV service.

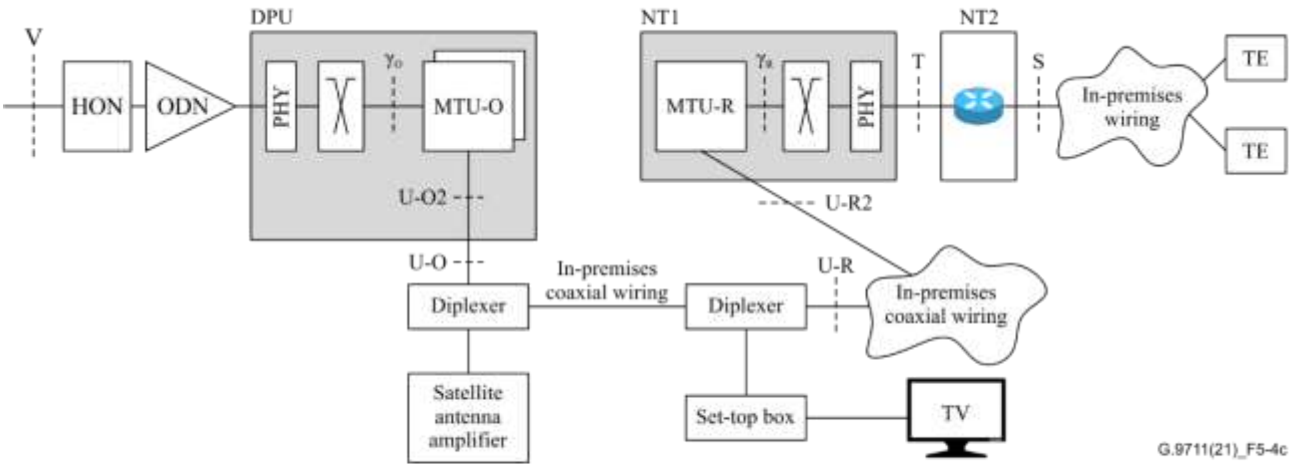


Figure 5-4c – Application reference model for in-premises coaxial cable medium

An extension of the application reference model shown in Figure 5-4a for P2MP scenario is shown in Figure 5-4b for the case of two NT1 connected to the same MTU-O at customer premises. Each NT1 feeds a particular premises network, for instance a local WiFi network.

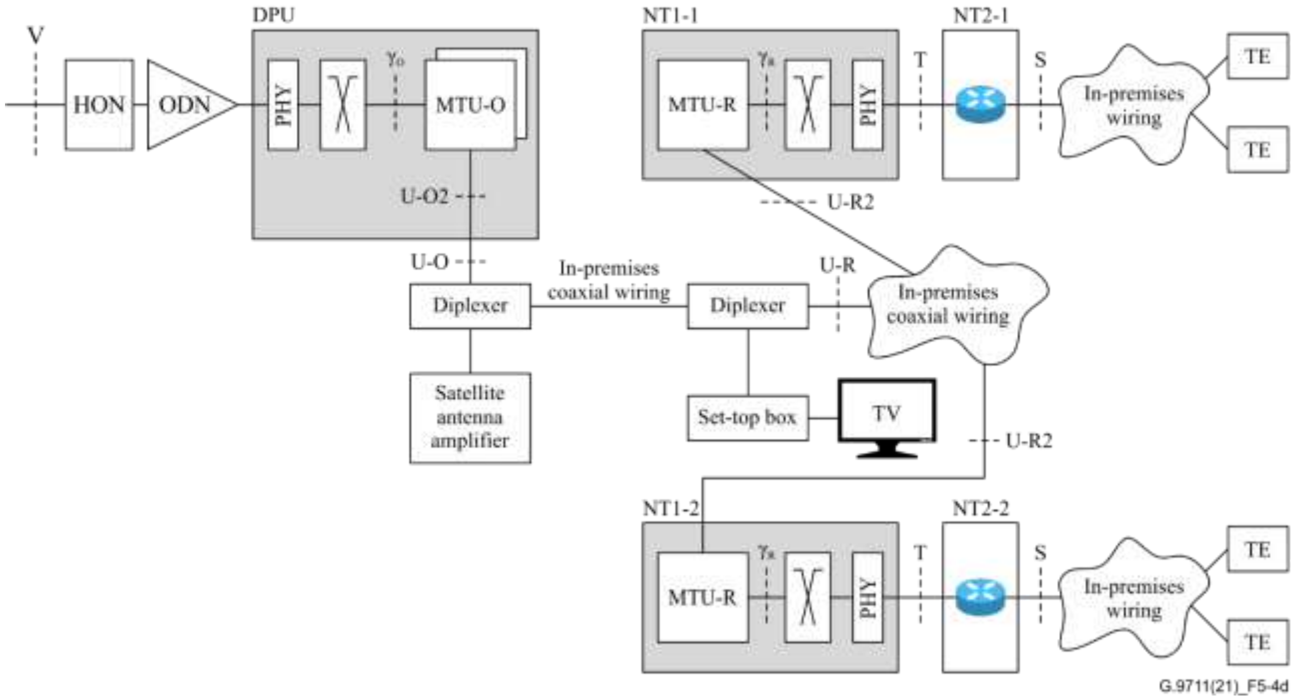


Figure 5-4d – Application reference model for in-premises coaxial cable medium (P2MP, two NT1)

Similar to the case of the twisted pair shown in Figure 5-4a, in case the DPU is deployed closer to the customer premises at locations where local powering may not be available, RPF is applied. The DPU is powered from the customer premises, sharing the same wire-pair with the data service. The application of reverse powering is included in the application reference model for FTTdp with reverse powering in Figure 5-4e.

The electrical characteristics of the PSE and PE (shown in Figure 5-4e) and the communication protocol(s) between them are beyond the scope this Recommendation. They are specified elsewhere (e.g., in [b-ETSI, TS 101 548-2]).

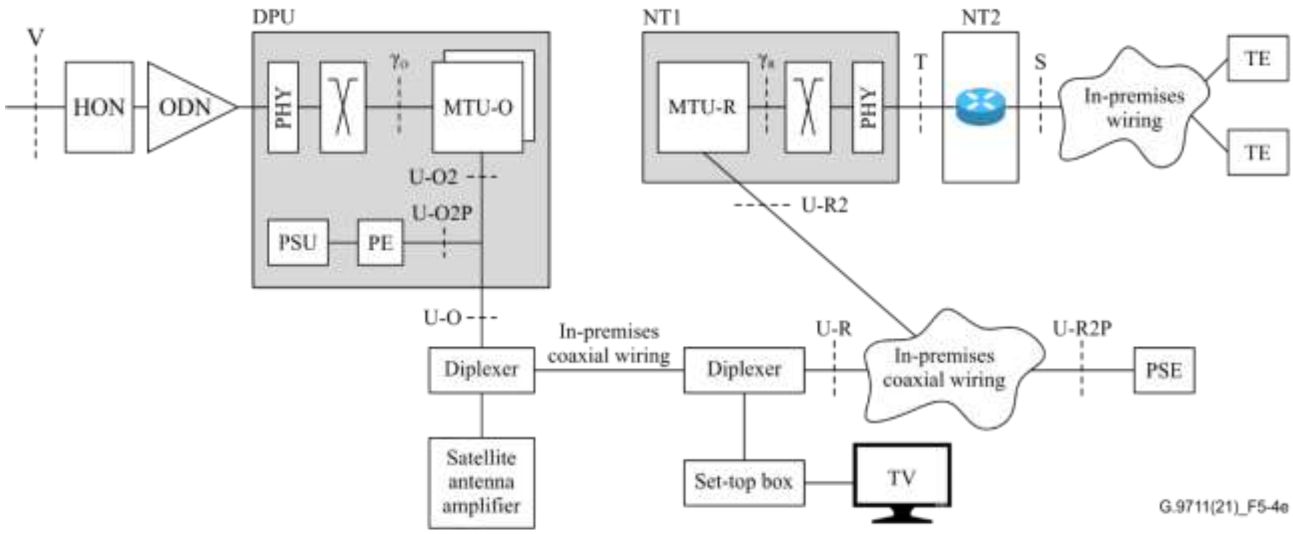


Figure 5-4e – Application reference model for in-premises coaxial cable medium with RPF

5.3 MTU protocol reference model

The MTU protocol reference model defined in this clause describes both the MTU-O and the MTU-R, and concerns the MTU protocol sub-layers that are all below the γ reference point. The reference model includes data and management planes addressing the TPS-TC, PMS-TC and PMD sub-layers.

The MTU protocol reference model is shown in Figure 5-5. The sub-layers and reference points shown in black are defined in this Recommendation, whilst those shown in grey are beyond the scope of this Recommendation.

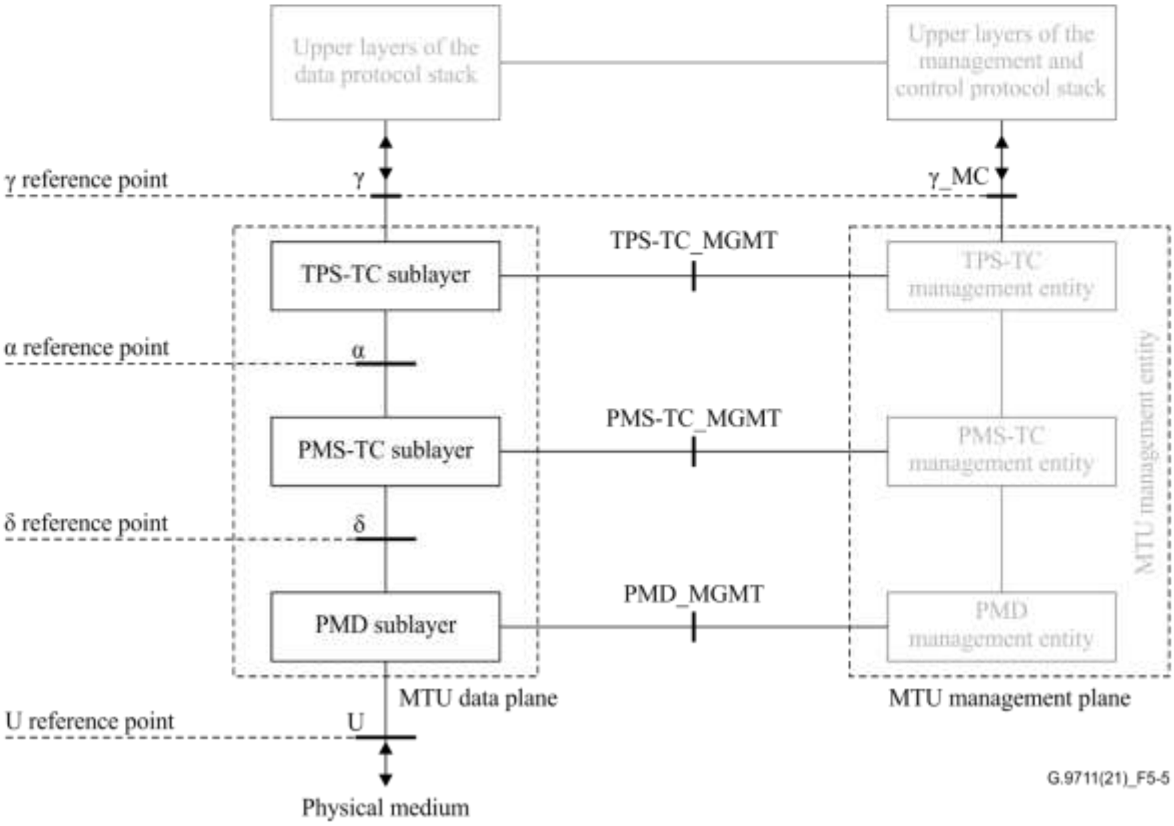


Figure 5-5 – MTU protocol reference model

The functionality of the TPS-TC, PMS-TC and PMD sub-layers is defined, respectively, in clauses 8, 9 and 10 of this Recommendation.

The reference points presented in Figure 5-5 are defined by sets of corresponding data or management primitives. A brief summary of these reference points is presented in Table 5-3. Detailed descriptions can be found in the clauses referenced in this table.

Table 5-3 – Summary of the MTU reference points defined in this Recommendation

Reference point	Category	Brief description of information flow	Reference
γ	Data, bidirectional, logical	Units of user data of the applied transmission protocols, data flow-control signalling, data start/stop markers, etc.	Clause 8.1.1
α	Data, bidirectional, logical	Primitives of the data stream incoming to the PMS-TC from the TPS-TC and of the data stream forwarded by the PMS-TC to the	Clause 8.1.2

Table 5-3 – Summary of the MTU reference points defined in this Recommendation

Reference point	Category	Brief description of information flow	Reference
		TPS-TC	
δ	Data, bidirectional, logical	Primitives of the data stream incoming to the PMD from the PMS-TC and of the data stream forwarded by the PMD to the PMS-TC	Clause 9.1.1
U	Data, bidirectional, physical	Primitives of the physical signal on the line	Clauses 7.3, 10.1.1, and 14
γ_MC	Management/control, bidirectional, logical/functional	Management and control primitives exchanged between the MME and the upper-layer functions DRA, TCE, ME and VCE.	Clauses 8.1.1, 10.3 and 11.1.1
TPS-TC_MGMT	Management/control, bidirectional, logical/functional	Management and control primitives exchanged between the TPS-TC and MME. These include parameters of TPS-TC and DTU size.	Clause 8.1.3
PMS-TC_MGMT	Management/control, bidirectional, logical/functional	Management and control primitives exchanged between the PMS-TC and MME. These include parameters of FEC, framing and PMS-TC framing overhead data.	Clause 9.1.2
PMD_ MGMT	Management/control, bidirectional, logical/functional	Management and control primitives exchanged between the PMD and MME. These include parameters that determine bit loading, gain adjustment, PSD shaping, TDD timing (TCE) and vectoring (VCE).	Clause 10.1.2

The data plane protocol reference model of the ITU-T G.9711 link is shown in Figure 5-6 and corresponds to the MTU protocol reference model shown in Figure 5-5.

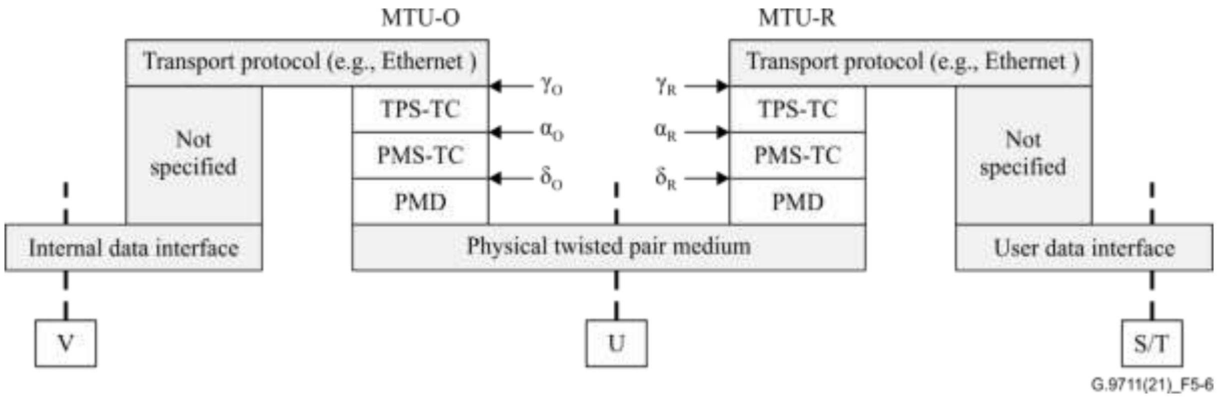


Figure 5-6 – Data plane protocol reference model

5.4 MTU functional model

Figure 5-7a shows the generic functional model of an MTU-O connected to multiple peer MTU-Rs, which is further referred as a P2MP connection. The generic functional model includes multiple paths, each of which conveys user data between the MTU-O and the corresponding distinct MTU-R.

The functional model of an MTU-O connecting only one peer MTU-R, which is further referenced as a P2P connection, is shown in Figure 5-7b. It includes a single path.

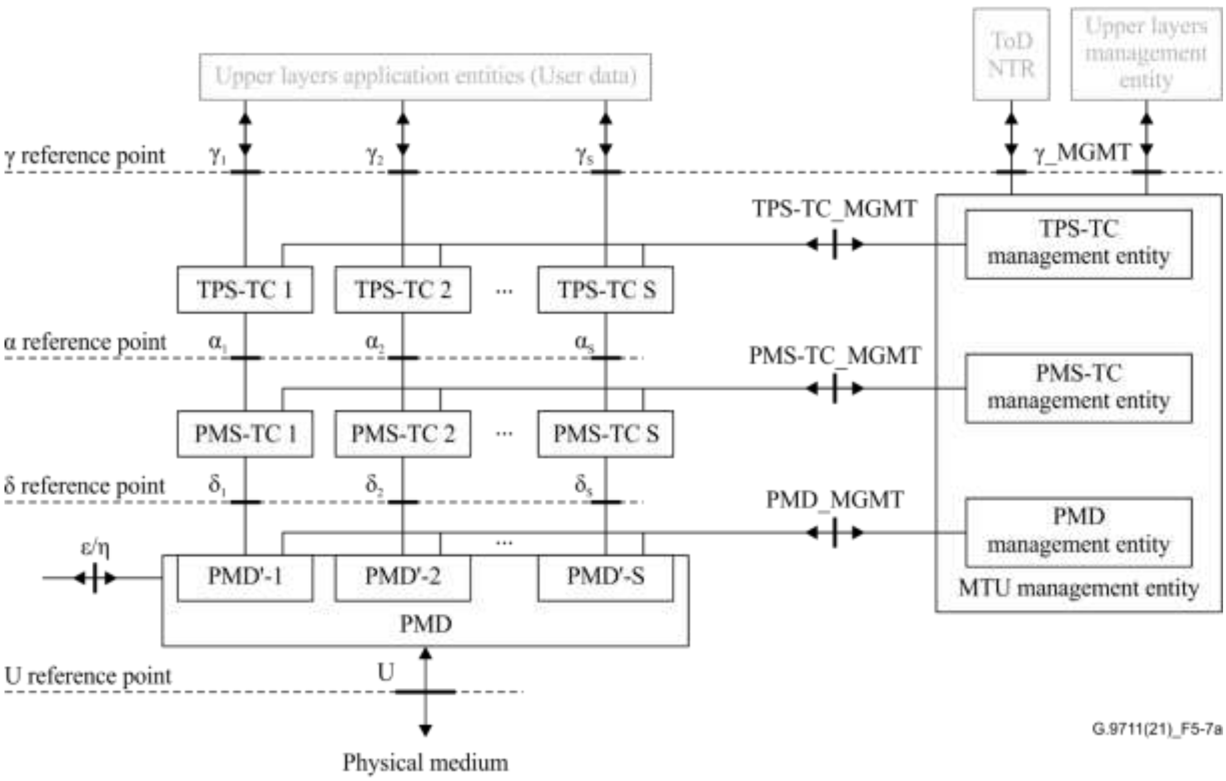


Figure 5-7a – Generic MTU-O functional model (P2MP connection, S paths)

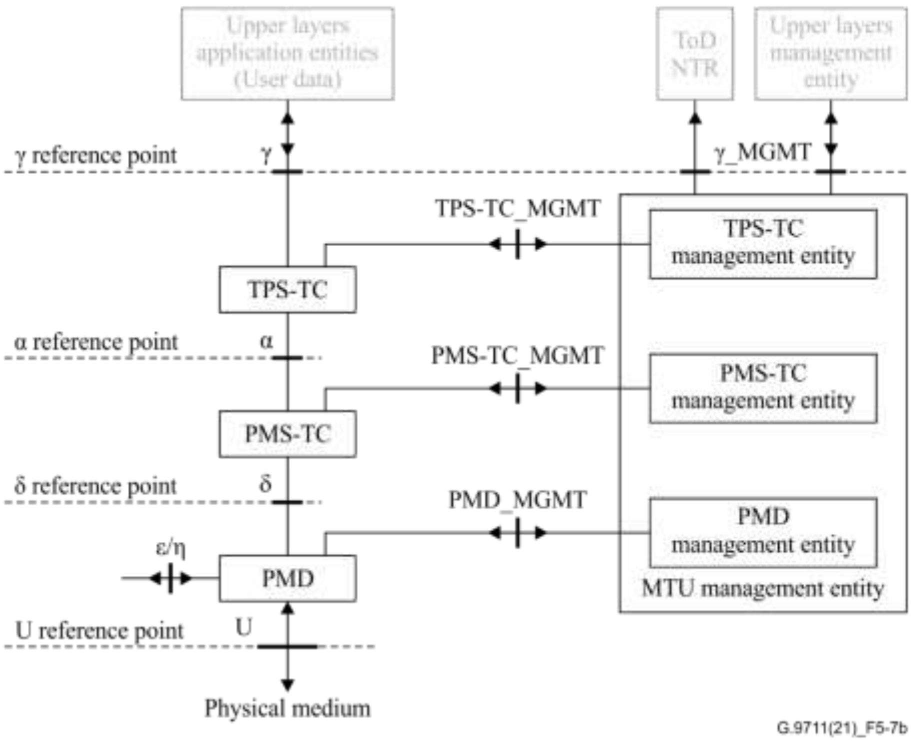


Figure 5-7b – MTU-O functional model (P2P connection, single path)

The functional model of the MTU-R is shown in Figure 5-8 and is similar to that of the P2P MTU-O, see Figure 5-7b, but without precoding capabilities. It includes a single path.

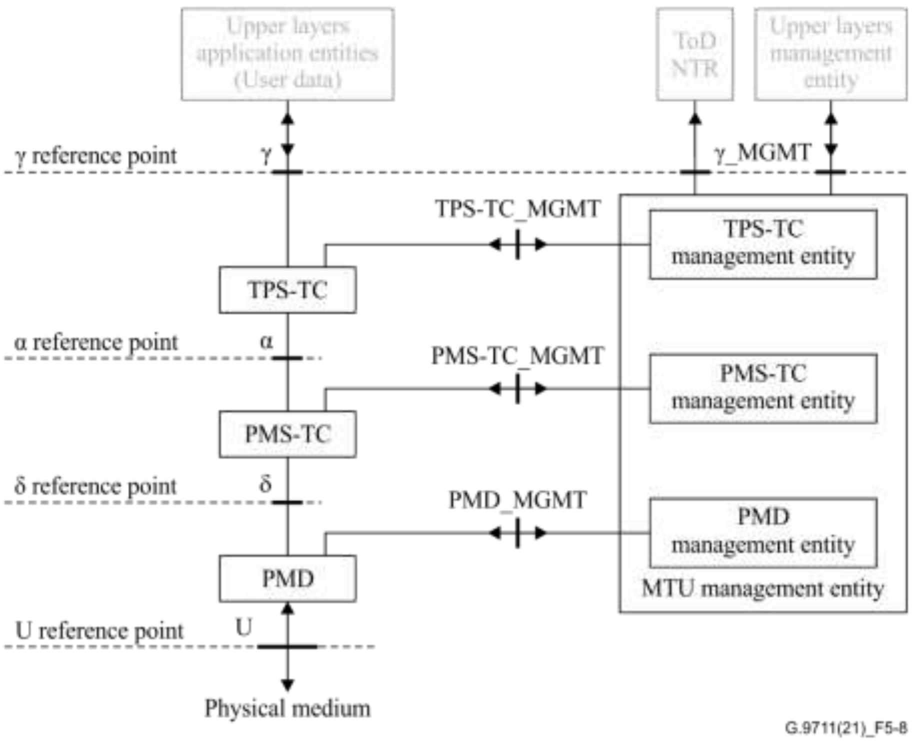


Figure 5-8 – MTU-R functional model

The MTU functional models presented in Figure 5-7a, Figure 5-7b and Figure 5-8 include functional blocks and interfaces of the MTU-O and MTU-R specified in this Recommendation. These models illustrate the most basic functionality of an MTU and comprises an application-invariant part and an application-specific part associated with each path. The application-invariant part consists of the physical media specific transmission convergence (PMS-TC) sub-layer and the physical media dependent (PMD) sub-layer, which reside between α and U reference points and are defined in clauses 9 and 10, respectively.

The application-specific part of each path is confined to the transport protocol specific transmission convergence (TPS-TC) sub-layer that resides between γ and α reference points; the γ reference point is the MTU application interface. The TPS-TC sub-layer is described in clause 8 and includes a TPS-TC function intended to present data packets of the corresponding application protocols to the unified application-independent α reference point. These data packets carry application data that are intended to be transmitted transparently to the corresponding application entity above the γ-reference point of the peer MTU.

The MME contains all relevant MTU management functions of each path, including those related to TPS-TC, PMS-TC and PMD associated with this path. The management primitives between the MME and upper-layer ME are exchanged via the γ_MGMT interface, which is a part of γ_MC (see Table 5-3). The γ_MC interface also communicates primitives between the MME and TCE, DRA and VCEs function at the MTU-O, and PSE, TCE and DRRus functions at the MTU-R.

NOTE – The upper layer application entities in Figure 5-7, Figure 5-8 correspond to L2+ function in Figure 5-2 (for MTU-O) and Figure 5-3 (for MTU-R), respectively. Similarly, the upper layer management and control entity in Figure 5-5 corresponds to the ME-O, DRA, TCE and VCE functions in Figure 5-2 for the MTU-O, and ME-R, PSE, TCE, and DRR functions in Figure 5-3 for the MTU-R.

Functions above the γ reference point are beyond the scope of this Recommendation, except the NTR and ToD functions of the TCE, which are specified in clauses 8.4 and 8.5, respectively.

The main functions of the PMD are symbol generation and recovery, constellation mapping and decoding, modulation and demodulation, and FEXT/NEXT cancellation (at the MTU-O). The PMD may also include line equalization. The symbol timing of the MTU-R is synchronized to the central clock of the DPU. All the aforementioned PMD functions are supported by the corresponding management/control primitives exchanged via the PMD_MGMT reference point (see clause 10.1.2). The PMD function of the MTU-O also provides the precoding necessary to support vectoring. The ε and η reference points (at the MTU-O) define, respectively, transmit and receive interfaces with PMD functions of other MTU-Os related to the same vectored group (see clause 10.3).

The main functions of the PMS-TC sub-layer are FEC encoding and decoding, framing and frame synchronization, retransmission, error detection, interleaving and de-interleaving, and scrambling and descrambling. The PMS-TC is connected to the PMD via the δ reference point, and is connected to the TPS-TC via the α-reference point. PMS-TC functions are supported by the corresponding management/control primitives exchanged via the PMS-TC_MGMT reference point (see clause 9.1.2). The PMS-TC also establishes the RMC.

The TPS-TC is application-specific and is intended to convert the corresponding application data transport protocol (e.g., Ethernet) into the unified format required at the α-reference point, hereafter referred to as a data transfer unit (DTU). The TPS-TC also provides data rate adaptation between the application data and the data link established by the peer MTUs (flow control) and QoS queues prioritization (QoS control) in upstream and downstream directions. Operation of the TPS-TC is supported by the corresponding management/control primitives exchanged via the TPS-TC_MGMT reference point (see clause 8.1.3).

The TPS-TC of each particular path communicates with the associated application entity at the MTU-R and MTU-O via the corresponding γ-DATA interface (γ_R and γ_O, respectively).

The γ_R and γ_O, α_R and α_O, and δ_R and δ_O reference points are only intended as logical separations and are defined as a set of functional primitives; they are not expected to be physically accessible. The U_R and U_O reference point are physically accessible and defined in terms of physical signal primitives.

The MME facilitates operation of the MTU sub-layers described above associated with each path. The TPS-TC_MGMT, PMS-TC_MGMT and PMD_MGMT management interfaces represent the control and management parameters exchanged between the MME and the corresponding path sub-layer functions. The MME primitives exchanged via the γ_MC interface (which includes the γ_MGMT interface) to the upper-layer ME include those of the NMS controlling the DPU-MIB (see Figure 5-1). All management/control interfaces are logicaland are defined in Table 5-3 and in clauses 8.1.1, 11.1, and 10.3.

Management data is exchanged between the peer MME reference points of the MTU-O and MTU-R sub-layers through the management communications channels provided by the TPS-TC, PMS-TC and PMD (see clause 11.1).

The DPU ME associates each MTU-O path with an instance of the set of management objects. In case of P2P connection, a single set of management objects is associated with a link. In case of P2MP connection, when an NT attempts to connect to the DPU, the DPU ME associates the MTU-R path of this NT to an already existing or newly created instance of the set of management objects, based on NT identification during ITU-T G.994.1 handshake (see clause 12.4). Once the MTU-O path and the corresponding MTU-R path are both in showtime, the NT identity is verified through NT authentication at Layer 2.

5.5 L2+ queues and QoS channels reference model

The QoS is managed in both upstream and downstream directions by setting separate QoS channels, each associated with a particular QoS class. Each QoS class is characterized in terms of its priority, a target maximum delay of packet transfer, and proactive retransmission type, that are all configured via the DPU MIB.

The priority is represented by an integer in the range from 0 to 3, where 0 represents the lowest and 3 represents the highest priority; each QoS class shall have different priority. The target maximum delay shall be in the range from 0ms to 16ms. Three proactive retransmission types are defined. Different QoS classes may have the same or different target maximum delays and the same or different proactive retransmission types.

QoS channels are established at the γ reference point by the L2+ function using associated queues, each having a different queue identifier (QID) and serving the corresponding QoS channel. Each QoS channel is assigned a different channel identifier (CID) number. More than one queue can be mapped to a particular QoS channel. This QID-to-CID mapping and the association of a particular QoS class to each CID are defined in the DPU-MIB, separately for downstream and upstream. The QID-to-CID mapping occurs at L2+ and is beyond the scope of this Recommendation.

The CID values for each of the upstream and each of the downstream QoS channels are defined in the DPU-MIB; these CID values and their associated QoS classes are communicated to the ME-R during initialization. The ME-R assigns the obtained CID values to the established QoS channels at the NT.

The same number of QoS channels is established in the upstream and the downstream direction.

5.5.1 Downstream L2+ queues and QoS channels

Figure 5-9 shows the reference model for the downstream QoS channels, including the DRRds and corresponding L2+ queues.

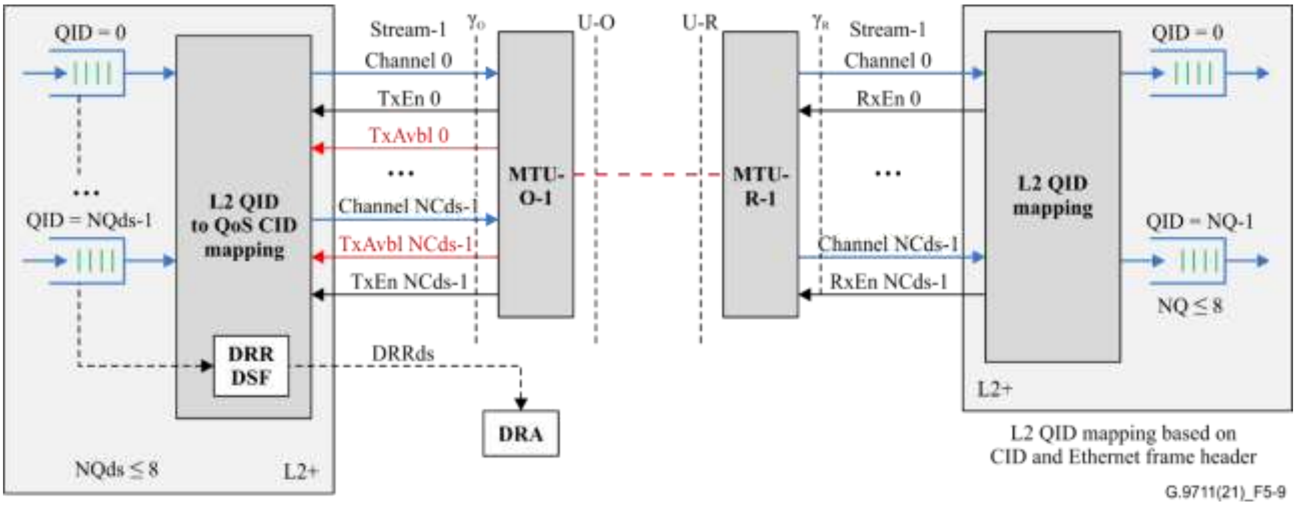


Figure 5-9 – L2+ downstream queues and QoS channels

In the downstream direction, the ITU-T G.9711 transceiver shall support 2 and may support 4 QoS channels, forming the data stream between the L2+ function and MTU-O (γ_O reference point). Each downstream channel has its CID. Each data packet in the stream is associated with a QIDds (see e.g., [b-BBF TR-383]) by the DPU L2+ function. Each QIDds is mapped to a CIDds defined in the DPU-MIB, see clause 11.4.7.1. The downstream data packets sent over each QoS channel (the γ_O reference point) are delivered transparently to the NT L2+ function via the corresponding channel (at the γ_R reference point), still associated with the same CIDds.

Multiple downstream QoS channels may have the same target maximum delay value; all downstream channels may have a different target maximum delay value. The configuration of all downstream channels (i.e., the CIDds and associated QoS class) is sent to the MTU-R during initialization, see clause 12.3.4.

NOTE – The particular CID assigned to a QoS channel neither imply nor represent any of its characteristics. For instance, higher PRIORITY value is not necessarily assigned to a channel with a higher CID value.

The DRR downstream function aggregates the queue arrival (QA) and queue fill (QF) information from the physical downstream queues into a single QA metric and a single QF metric per downstream channel, in accordance with the QID-to-CID mapping. The DPU L2+ function delivers DRRds reports containing a QA metric and a QF metric for each downstream channel to the DRA.

5.5.2 Upstream L2+ queues and QoS channels

Figure 5-10 shows the reference model for the upstream QoS channels, including the DRRus and corresponding L2+ queues.

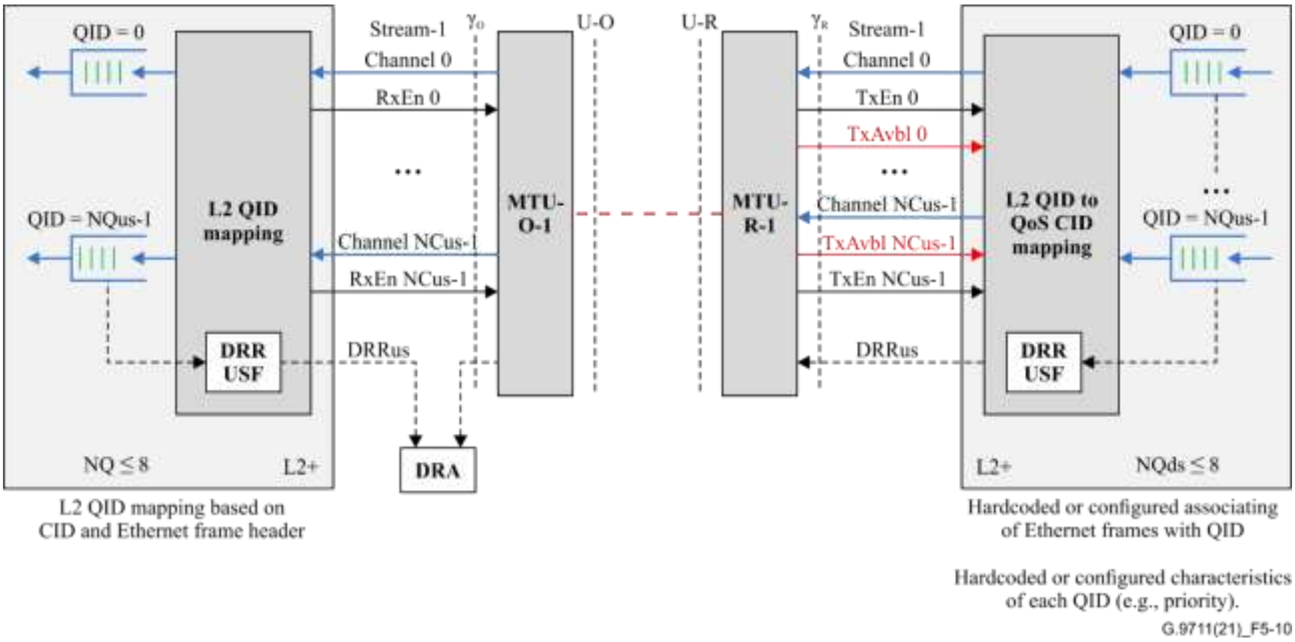


Figure 5-10 – L2+ upstream queues and QoS channels

In the upstream direction, the ITU-T G.9711 transceiver shall support 2 and may support 4 QoS channels, forming the data stream between the L2+ and MTU-R (γ_R reference point). Each upstream channel has its CID. Each data packet in the stream is associated with QIDus (see e.g., [b-BBF TR-383]) by the NT L2+ function. Each QIDus is mapped to a CIDus defined in the DPU-MIB, see clause 11.4.7.1. The upstream data packets sent over each QoS channel (the γ_R reference point) are delivered transparently and within the target maximum delay to the DPU L2+ function via the corresponding channel (the γ_O reference point), still associated with the same CIDus.

Multiple upstream QoS channels may have the same target maximum delay value; all upstream channels may have a different target maximum delay value. The configuration of all upstream channels (i.e., the CIDus and associated QoS class) is sent to the MTU-R during initialization, see clause 12.3.4.

NOTE – The particular CID assigned to a QoS channel neither imply nor represent any of its characteristics. For instance, higher PRIORITY value is not necessarily assigned to a channel with a higher CID value.

The DRR upstream function at the DPU L2+ shall aggregate the QA information from the physical upstream queues into a single QA metric per upstream channel, in accordance with the QID-to-CID mapping. The DRRus (local at the DPU) sends the QA metric for each of the upstream channels to the DRA.

The DRR function at the NT L2+ shall aggregate the QF information from the physical upstream queues into a single QF metric per upstream channel, in accordance with the QID-to-CID mapping.

The DPU L2+ function delivers DRRus reports containing a QA metric for each upstream channel to the DRA. The NT L2+ function delivers a DRRus report containing a QF value for each upstream channel to the MTU-R and further, via the U-reference point, to the MTU-O and the DRA.

5.5.3 QoS channels in P2MP scenario

In the case of P2MP connection, the DPU uses multiple streams at γ_O reference point, each corresponding to a particular NT, and corresponding γ_R reference point. In the downstream direction, when M NTs are connected, there are M downstream STREAMs (STREAM-1, STREAM-2 … STREAM-M), each including the same primitives as defined for STREAM-1 described in Figure 5-9. Each STREAM corresponds to a particular NT.

Each STREAM contains a number of QoS channels per NT, which is NC_1, NC_2 … NC_M for STREAM-1, STREAM-2, and STREAM-M, respectively. This same number of QoS channels are established in the receive direction of the corresponding NT. Same rules are applied in the upstream direction.

Figure 5-11 shows downstream channels for the case of two NTs connected to one MTU-O having two paths (S=2).

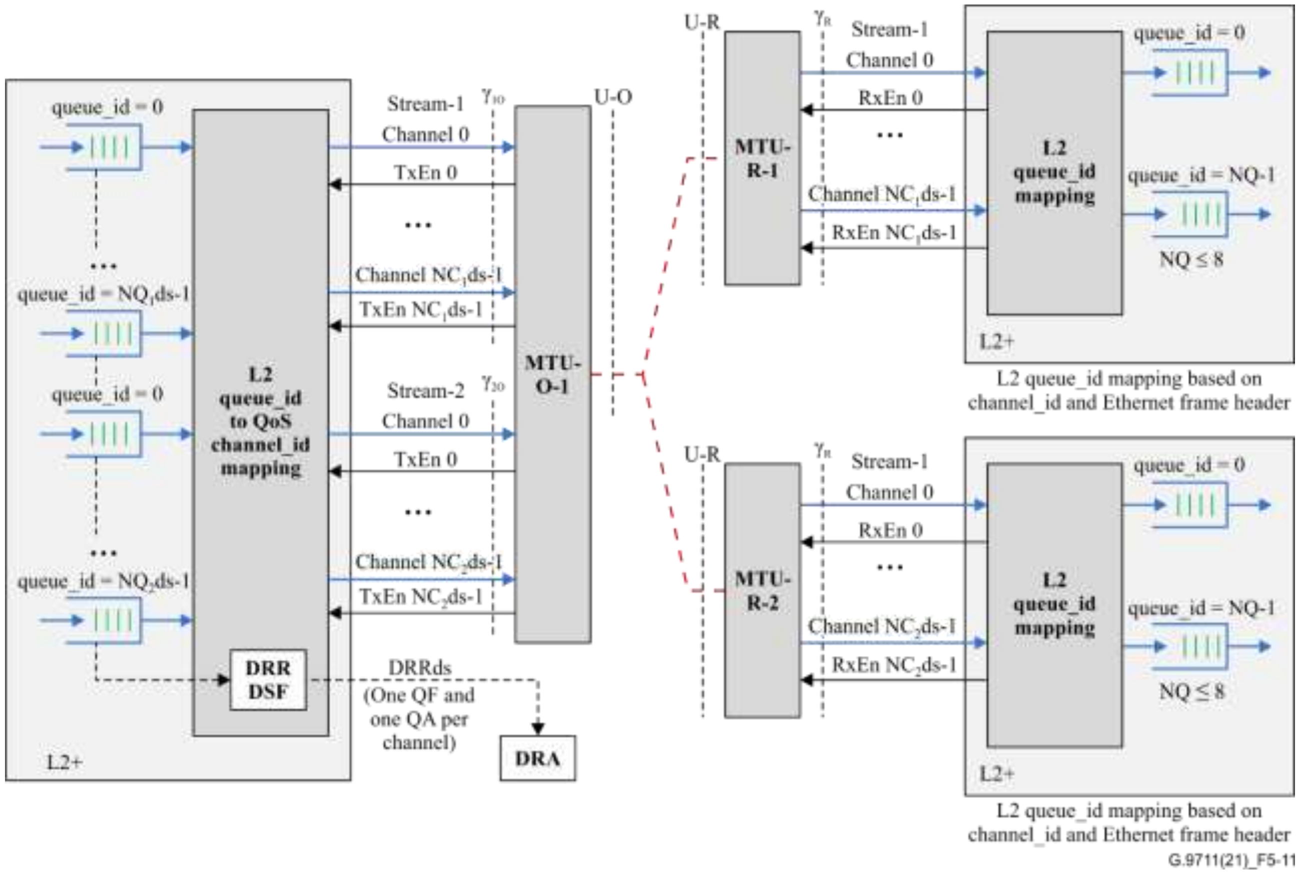


Figure 5-11 – L2+ downstream queues and QoS channels for P2MP case of 2 NTs

5.6 INP system requirements

The equipment between the V and T reference points (i.e., the access section including the HON, DPU and NT1, see Figure 5-4) shall have the capability to support INP (see clause 9.8.3.3) against SHINE impulses of up to 10 ms at all supported data rates without loss of user data.

In order to support this system requirement, the transceiver shall be compliant with the INP requirements defined in clause 9.8.

6 Profiles

6.1 Definition

This Recommendation defines a wide range of settings for various parameters that could potentially be supported by an ITU-T G.9711 transceiver. Profiles are specified to allow transceivers to support a subset of the allowed settings and still be compliant with this Recommendation. The specification of multiple profiles allows vendors to limit implementation complexity and develop implementations that target specific service requirements.

Transceivers compliant with this Recommendation shall comply with at least one profile (specified in Tables P.1 and Q.1). Compliance with more than one profile is allowed.

To be compliant with a specific profile, the transceiver shall comply with all parameter values associated with the specific profile.

6.2 Profile compliance

The following paragraphs gives further clarifications on the requirements for profile compliance specified in clause 6.1.

To be compliant with a selected profile, an MTU-O shall:

- Be capable of transmitting data on all subcarriers, with indices within the range from the index of the lowest supported downstream data-bearing subcarrier and the index of the highest supported downstream data-bearing subcarrier;
- Support the specified type of precoding;
- Support its aggregate net data-rate (ANDR) capability assuming a perfect analogue front-end (AFE). The ANDR capability may be lower with a realistic non-perfect AFE.

To be compliant with a selected profile, an MTU-R shall:

- Be capable of transmitting data on all subcarriers, with indices within the range from the index of the lowest supported upstream data-bearing subcarrier and the index of the highest supported upstream data-bearing subcarrier;
- Support its ANDR capability assuming a perfect AFE. The ANDR capability may be lower with a realistic non-perfect AFE.

Furthermore, an MTU complying with a selected profile shall:

- Use only the subcarrier spacing value specified in the profile;
- Transmit in a passband that includes only subcarriers specified for the profile, with indices within the range from the index of the lowest supported downstream (upstream) data-bearing subcarrier and the index of the highest supported downstream (upstream) data-bearing subcarrier;
- Operate using the specified duplexing method;
- Operate using the specified type of precoding, if precoding is enabled;
- Operate in P2MP mode with at least up to the number of MTU-Rs as defined in the profile, if P2MP mode is supported in the profile.

7 Transmission medium interface characteristics

7.1 Duplexing method

The ITU-T G.9711 transceivers shall operate either in TDD mode or in FDX mode. Both modes shall use the same PDX frame structure that consists of a FDX compatible downstream sub-frame (FDS) and a FDX compatible upstream sub-frame (FUS), defined in clause 10.5.

- In the TDD mode, the ITU-T G.9711 transceivers are allowed to transmit in the DS direction only during the FDS part of the PDX frame and in the US direction only during the FUS part of the PDX frame. These transmissions can be on all subcarriers allowed by the selected profile or on some of these subcarriers.
- In the FDX mode, the ITU-T G.9711 transceivers are allowed to transmit simultaneously in both the US direction and the DS direction in both the FDS and the FUS parts of the PDX frame, on all subcarriers allowed by the selected profile or on some of these subcarriers. In FDX mode, on subcarriers not used for simultaneous transmission, the ITU-T G.9711 transceivers may transmit in the DS direction only during the FDS part of the PDX frame, and in the US direction only during the FUS part of the PDX frame.

7.2 Frequency band

The ITU-T G.9711 transceivers can use frequencies within the range from 2.2 MHz to 848 MHz. The use of this frequency range depends on the profile. Two profile sets (see clause 6.1) are defined based on frequency range:

- The P424a, P424amp, P424d, P424dmp, Q424c, Q424cmp, Q424d, and Q424dmp profiles are allowed to operate in the frequency range between 2.2 MHz and 424 MHz;
- The P848a and Q848c profiles are intended for operation in the frequency range between 2.2 MHz and 848 MHz, although they are for further study.

With each profile, the same frequencies can be used for both upstream and downstream transmissions. Other parameters of the twisted pair profiles (P424x and P848x) are defined in clause P.5 and of the coaxial cable profiles (Q424x, Q848x) are defined in clause Q.5. This edition of the Recommendation specifies transceivers operating in the P424x and Q424x profiles, while operation with P848x and Q848x profiles is for further study.

The in-band and out of band PSD limits, total wideband transmit power limit and termination impedance for both profile sets are defined in [ITU-T G.9710]. The in-band PSD shaping, and further details of the transmission medium interface are defined in clause 7.3.

7.3 Power spectral density

7.3.1 Transmit PSD mask

The following PSD masking functions to construct the transmit PSD mask (TxPSDM) are specified in [ITU-T G.9710]:

- Limit PSD mask (LPM),
- PSD shaping mask (PSM),
- Low-frequency edge stop-band mask (LESM),
- Notching of specific frequency bands, and
- Subcarrier masking.

These [ITU-T G.9710] PSD masking functions are implemented by the ITU-T G.9711 transceivers using a number of control parameters. The relation between the [ITU-T G.9710] PSD masking functions, DPU-MIB configuration parameters, ITU-T G.9711 transceiver control parameters and the final transmit PSD mask is shown in Figure 7-1.

NOTE 1 – Vendor discretionary transmit PSD controls are not included in Figure 7-1.

An MTU shall always confine the PSD of its transmit signal to be within the final transmit PSD masks (U reference point transmit PSD masks) shown in Figure 7-1. By construction, all U reference point transmit PSD masks are below the TxPSDM, which is determined by [ITU-T G.9710] parameters listed above.

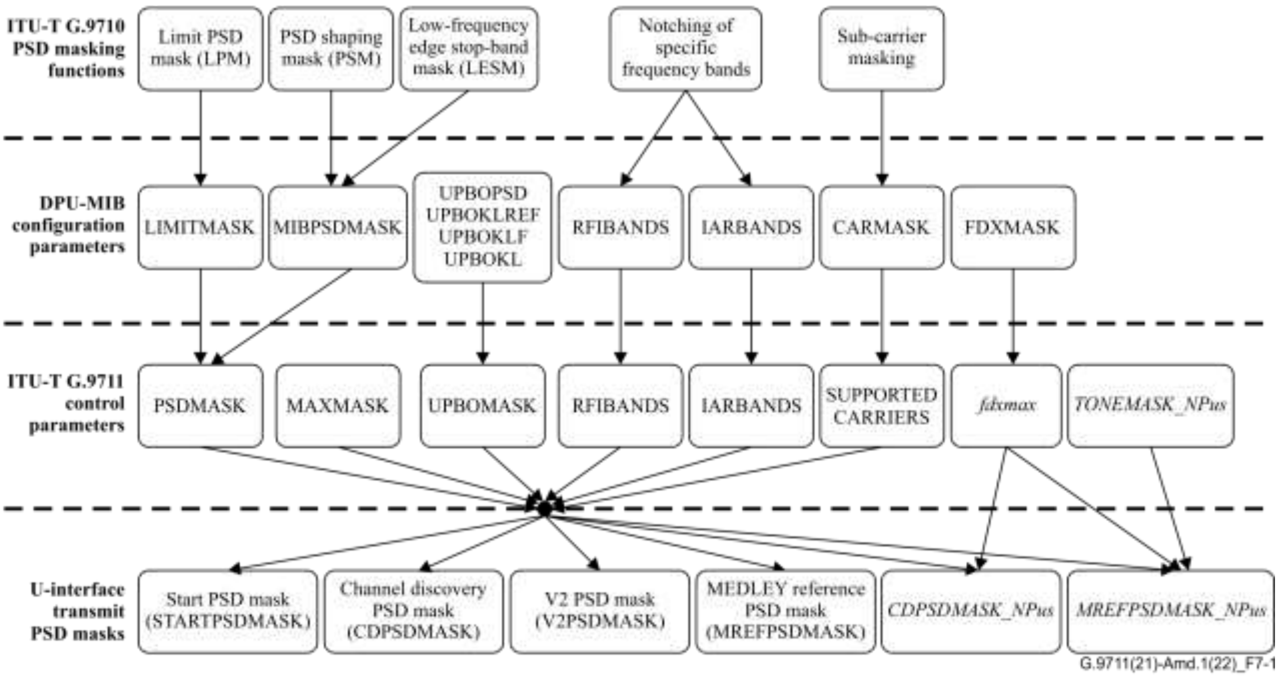


Figure 7-1 – Relation between ITU-T G.9710 PSD masking functions, DPU-MIB configuration parameters, ITU-T G.9711 transceiver control parameters and final transmit PSD mask (at U reference point)

The LPM specified in [ITU-T G.9710] is referred to in the DPU-MIB and in this Recommendation as LIMITMASK.

A PSM may be specified by the service provider and is provided to the MTU-O via the DPU-MIB parameter MIBPSDMASK.

If a LESM is configured such that $f_{tr3} > f_{tr1}$ (see Figures 6-1 and 7-1 of [ITU-T G.9710]), the DPU-MIB parameter MIBPSDMASK shall also be used to specify the part of the LESM above f_{tr1}, consistent with [ITU-T G.9710]. The part of the LESM below f_{tr1} is specified in [ITU-T G.9710].

Both the LIMITMASK and the MIBPSDMASK are translated into an ITU-T G.9711 control parameter PSDMASK (PSDMASKds and PSDMASKus for downstream and upstream, respectively).

In the upstream direction, upstream power back off (UPBO) provides further PSD reduction to improve spectral compatibility between ITU-T G.9711 transceivers operating on loops of different lengths deployed in the same binder. It is an autonomous PSD reduction implemented within constraints configured via the DPU-MIB parameters UPBOPSD, UPBOKLREF, UPBOKLF and UPBOKL which results in an additional upstream mask defined by the ITU-T G.9711 control parameter UPBOMASK.

The notching of specific frequency bands is configured via the DPU-MIB parameters RFIBANDS and IARBANDS, and is controlled in an ITU-T G.9711 transceiver via the parameters RFIBANDS and IARBANDS, respectively (same for both transmission directions).

The subcarrier masking function is configured via the DPU-MIB parameter CARMASK, and is controlled in an ITU-T G.9711 MTU via the parameters SUPPORTEDCARRIERSGus and SUPPORTEDCARRIERSGds for upstream and downstream, respectively.

The FDX masking is configured via the DPU-MIB parameter FDXMASK and is controlled in an MTU via the parameters *fdxmaskds* for the downstream and *fdxmaskus* for the upstream. Additional FDX masking for the upstream is defined by the control parameter *TONEMASK_NPus* during initialization (see clause 12.3.3.2.15).

The ITU-T G.9711 control parameter MAXMASK (as specified in clause 12.3.3) allows the ITU-T G.9711 transceivers to autonomously reduce further the transmit PSD mask.

The PSD mask to be applied to the signals at the U reference point after all masking control methods are applied depends on the state of the link and is different during different phases of initialization and showtime: STARTPSDMASK, CDPSDMASK, CDPSDMASK_NPus, MREFPSDMASK, MREFPSDMASK_NPus and V2PSDMASK.

NOTE 2 – Attention should be drawn to the distinction between the [ITU-T G.9710] term "transmit PSD mask (TxPSDM)" and the ITU-T G.9711 control parameter "PSDMASK".

- TxPSDM is the final mask at the U reference point after all masking methods are applied and therefore includes the notching of specific frequency bands and subcarrier masking.
- PSDMASK is an intermediate control parameter that does not include the notching of RFI bands and the international amateur radio (IAR) bands and the subcarrier masking.

In the case of FDX operation, all the relevant PSD masks defined in this clause apply to both the priority sub-frame (PSF) as the non-priority sub-frame (NPSF) (no separate instantiations related to PSD masks for PSF and NPSF are defined).

NOTE 3 – In Figure 7-1, the box CDPSDMASK_NPus represents three PSD mask parameters, i.e. CDPSDMASK_NPus, CDPSDMASK_NP1us and CDPSDMASK_NP2us.

In the case of P2MP operation, the DPU-MIB parameters will be instantiated per link (consisting of an MTU-O path and the peer MTU-R path). However, the following DPU-MIB parameters shall be configured with identical values for all links of the P2MP group: PROFILES, MAXATPds, CLASSMASKds, MIBPSDMASKds, FDXMASKds, CARMASKds, IARBANDS and RFIBANDS. Other MIB parameters related to the PSD may take different values for each link of the same P2MP group. In the case of P2MP operation, all the relevant downstream PSD masks defined in this clause apply to the U-O reference point, and all the relevant upstream PSD masks apply to U-R reference points of each particular MTU-R of the P2MP group.

7.3.1.1 MIBPSDMASK construction

This clause provides requirements and constraints for construction of the MIBPSDMASK, which can be used to constrain the transmit PSD mask to levels lower than those specified by the LPM.

In this clause, the term "the band" corresponds to frequencies from f_{tr1} to f_{tr2} as defined for the in-band LPM (see Figure 7-1 of [ITU-T G.9710] for the 424 MHz profile). The term "frequency range" is used to indicate a part of the band.

7.3.1.1.1 Overview

The MIBPSDMASK shall lie at or below the LPM. Its definition shall be under the network management control (a DPU-MIB-controlled mechanism).

The MIBPSDMASK is specified in the DPU-MIB by a set of breakpoints. Up to 32 breakpoints may be specified to construct the MIBPSDMASK for upstream, and up to 32 breakpoints may be specified to construct the MIBPSDMASK for downstream. Breakpoints shall be specified for the full band (i.e., from f_{tr1} to f_{tr2}) defined in [ITU-T G.9710].

Each breakpoint used to specify the MIBPSDMASK shall consist of an index t_n and a PSD mask value PSD_n at frequency f_n expressed in dBm/Hz, where $f_n = t_n \times 51.75$ kHz.

Breakpoints shall be represented by the set {(t_1, PSD_1), ..., (t_n, PSD_n), ..., (t_{NBP}, PSD_{NBP})}, where $NBP \leq 32$. The first breakpoint shall have the index t_1 = ceiling (f_{tr1}/51.75 kHz), where f_{tr1} is the frequency of the lower band edge of the in-band LPM (see Figure 7-1 of [ITU-T G.9710]). The index t_1 corresponds to the lowest-frequency subcarrier in the band. The last breakpoint in the band shall have the index t_{NBP} = floor(f_{tr2}/51.75 kHz), where f_{tr2} is the frequency of the upper band edge of the in-band LPM (see Figure 7-1 of [ITU-T G.9710] for the 424 MHz profile). Additional breakpoints within the band, if needed, shall be specified such that $t_n < t_{n+1}$ for n = 2 to NBP – 1, where NBP is the total number of breakpoints ($NBP \leq 32$).

All t_i values shall be coded in the DPU-MIB as unsigned integers.

The value of the PSD at a breakpoint with index t_n, PSD_n, shall be coded in the DPU-MIB as an unsigned integer. The PSD values shall be coded from 0 dBm/Hz (coded as 0) to −127.5 dBm/Hz (coded as 255), with a step size of 0.5 dBm/Hz. The valid range of PSD values is specified in clause 7.3.1.1.2.1 (for the case when no LESM is specified) and clause 7.3.1.1.2.2 (for the case when a LESM is specified).

7.3.1.1.2 Definition of breakpoints

Breakpoints specified in the DPU-MIB shall comply with the restrictions specified in this clause.

The LESM, if applicable, shall also be specified by breakpoints of the MIBPSDMASK. The breakpoints for the LESM shall be specified according to the rules in clause 7.3.1.1.2.2. The breakpoints for PSD shaping other than LESM shall be specified according to the rules in clause 7.3.1.1.2.1.

7.3.1.1.2.1 Definition of breakpoints for PSD shaping other than LESM

The valid range of PSD values is from 0 dBm/Hz to −90 dBm/Hz, although the values entered via the DPU-MIB shall be no higher than allowed by the LPM.

For all breakpoints, the values of PSD_n shall be defined with the following restrictions, except for the LESM defined in clause 7.3.1.1.2.2.

- For $t_n < t_{n+1}$, the slope of the MIBPSDMASK levels shall comply with:

$$\left|\frac{\mathrm{PSD}_{n+1}-\mathrm{PSD}_n}{t_{n+1}-t_n}\right| \leq 0.75\mathrm{dB}/51.75\ \mathrm{kHz}$$

- min(PSD_n) ≥ −90 dBm/Hz and max(PSD_n) − min(PSD_n) ≤ 40 dB, where max(PSD_n) denotes the maximum and min(PSD_n) denotes the minimum of all breakpoint PSD values at or above −90 dBm/Hz.

The MIBPSDMASK at an arbitrary frequency f shall be obtained by interpolation in dB on a linear frequency scale as follows:

$$MIBPSDMASK\,(f) = PSD_n + (PSD_{n+1} - PSD_n) \times \frac{(f/51.75kHz) - t_n}{t_{n+1} - t_n},\ t_n < (f/51.75kHz) \leq t_{n+1}$$

Figure 7-2 illustrates the MIBPSDMASK in the case no LESM is specified (with min(PSD_n) = PSD_5 and max(PSD_n) = PSD_3).

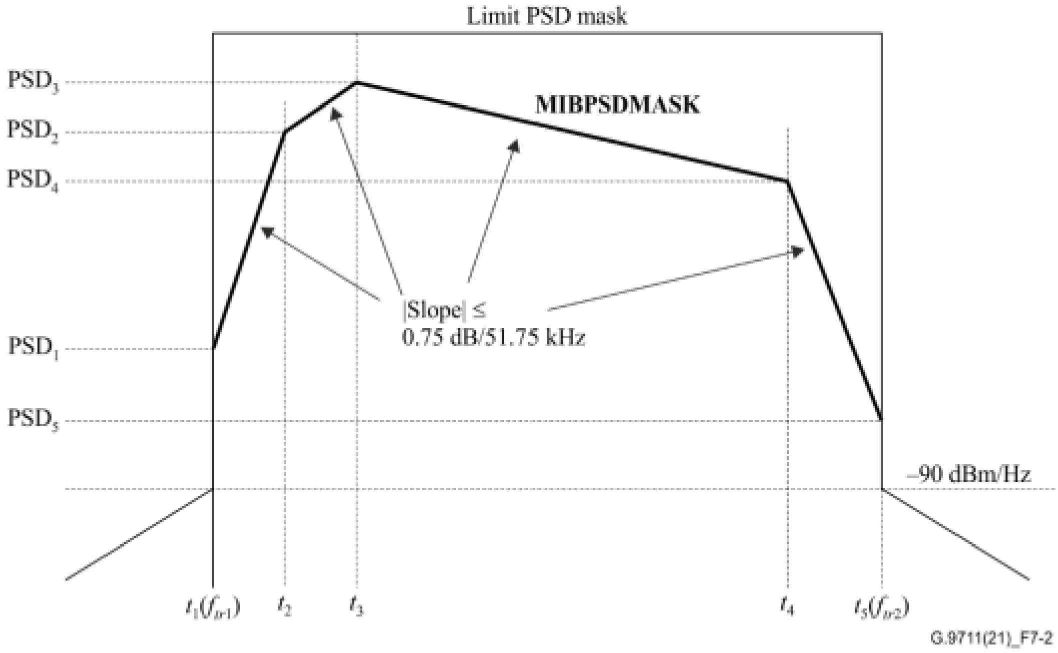


Figure 7-2 – Illustration of a MIBPSDMASK when no LESM is specified

7.3.1.1.2.2 Definition of the breakpoints for the LESM

The breakpoints of the LESM shall be:

- (t_1, PSD_1): t_1 = ceiling(f_{tr1} / 51.75 kHz), $PSD_1 = -100$ *dBm/Hz*
- (t_2, PSD_2): t_2 = ceiling(($f_{tr3}-175$ *kHz)*/51.75 kHz), $PSD_2 = -100$ *dBm/Hz*
- (t_3, PSD_3): t_3 = ceiling(f_{tr3}/51.75 kHz), $PSD_3 = -80$ *dBm/Hz*
  - the valid values for f_{tr3} are $f_{tr3} \geq f_{tr1}$+175 kHz
- further breakpoints (t_4, PSD_4), ..., (t_n, PSD_n), ..., (t_{NBP}, PSD_{NBP})
  - shall be according to the requirements for the breakpoints for the regular PSD shaping as defined in clause 7.3.1.1.2.1, or
  - shall be according to the requirements for the one-slope steep upward shape as defined in clause 7.3.1.1.2.2.1.

NOTE – The values PSD_1 and PSD_2 of the LESM are the only allowed breakpoints in the MIBPSDMASK outside of the [0, −90] dBm/Hz range.

7.3.1.1.2.2.1 One-slope steep upward shape

The one-slope steep upward shape is defined as:

- $PSD_3 = -80$ dBm/Hz;
- $PSD_4 \leq -65$ dBm/Hz;
- $\left|\frac{PSD_4 - PSD_3}{t_4 - t_3}\right| \leq 2.86\text{dB}/51.75\text{ kHz}$
- $PSD_j \leq PSD_4$ for all $j > 4$;
- breakpoints (t_5, PSD_5), ..., (t_n, PSD_n), ..., (t_{NBP}, PSD_{NBP}) shall also be according to the requirements for the breakpoints for the regular PSD shaping as defined in clause 7.3.1.1.2.1.

NOTE – These slopes correspond approximately to a maximum of 15 dB increase in the PSD mask level over six subcarriers.

The one-slope steep upward shape is illustrated in Figure 7-3.

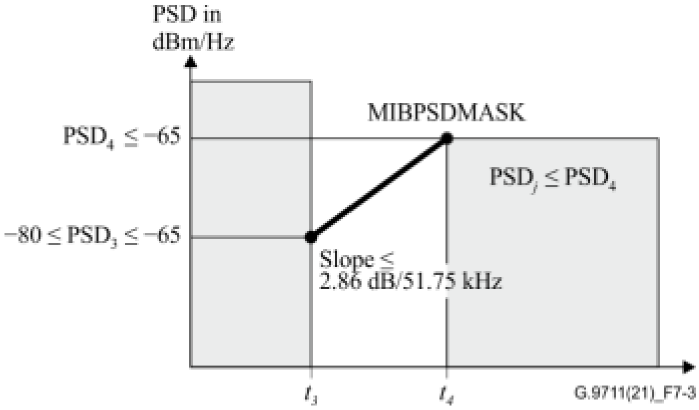


Figure 7-3 – Illustration of the one-slope steep upward shape

7.3.1.1.2.3 Definition of breakpoints at the edge of a band

Except for the specification of the LESM, no additional restrictions on the MIBPSDMASK are imposed at the band edges. The values PSD_1 and PSD_{NBP} can be any value between the value of the LPM at that frequency and −90 dBm/Hz, provided that the MIBPSDMASK construction rules are not violated as a result.

7.3.1.2 Notching of specific frequency bands

The ITU-T G.9711 transmitters shall be able to notch one or more specific frequency bands in order to protect radio services, for example, IAR bands (see Appendix I of [ITU-T G.9710]) or broadcast radio bands. In this Recommendation, the IAR bands to be notched are referred to as IAR bands, whilst the rest of the bands to be notched are referred to as RFI bands (parameters IARBANDS and RFIBANDS, respectively, in Table 7-5).

The required PSD level in the notched frequency bands (TXPSDM_N and TXPSDM_W) shall be as specified in clause 6.5 of [ITU-T G.9710]. Within notched frequency bands, all subcarriers shall be turned off (see clause 6.5 of [ITU-T G.9710]), i.e., Zi' = 0 (see Figure 10-27).

The value of TXPSDM_N shall be accounted for in the determination of all U reference point transmit PSD masks (see Figure 7-1 and Table 7-3 through Table 7-5).

An MTU shall support notching of 32 RFI bands and notching of 15 IAR bands simultaneously.

The specific frequency bands to be notched are configured in the DPU-MIB by the operator and set during the ITU-T G.994.1 handshake phase of initialization (see clause 12.3.2).

The configuration parameter RFIBANDS specified in the DPU-MIB specifies the start and stop frequencies of each notched RFI band. The configuration parameter IARBANDS specified in the DPU-MIB specifies whether or not a given IAR band is notched. The PSD slopes forming the notch outside of the start and stop frequencies are vendor discretionary.

7.3.1.3 Carrier masking

The ITU-T G.9711 transmitters shall be able to mask one or more subcarriers. Subcarrier masking is defined in the DPU-MIB by a configuration parameter (CARMASK).

All masked subcarriers shall be turned off (see clause 6.5 of [ITU-T G.9710]), i.e., $Z_i' = 0$ (see Figure 10-27). The subcarrier masking shall override all other instructions related to the transmit power of the subcarrier.

7.3.1.4 FDX masking

With FDX masking, the transceivers shall force one or more subcarriers such that these subcarriers are allowed to transmit in the DS direction only during the FDS part of the PDX frame and in the US direction only during the FUS part of the PDX frame. If the transceivers are in the FDX mode and FDX masking is not applied to a particular subcarrier, then this subcarrier may be used for simultaneous upstream and downstream transmission in either the FDS part or FUS part of the PDX frame or in both parts.

In the downstream direction, FDX masking is applied before the precoder, such that $Z_i = 0$ (see Figure 10-27) for FDX-masked subcarriers while in the upstream direction that subcarrier can be used for transmission.

NOTE 1 – If for a particular subcarrier *i* all links are configured for $Z_i = 0$ (i.e., the FDX masking is applied), then $Z_i' = 0$ for that subcarrier on all lines in the vectored group.

NOTE 2 – In the downstream direction, if the FDXMASKds masks all supported subcarriers of all links on all transmission lines in the vectored group, there is no NEXT at the MTU-O side in the vectored group.

NOTE 3 – In the upstream direction, if the FDXMASKus masks all supported subcarriers of a particular link on a transmission line, there is no NEXT caused by the corresponding MTU-R connected to that transmission line into other transmission lines in the same vectored group.

FDX masking applies in the FDX mode defined in clause 7.1, however it is applied differently with operation in Annex X (see clause X.9.2).

NOTE 4 – FDX masking is applied differently with operation in Annex X due to the requirement for identical *gi* tables in PSF and NPSF (clause X.9.1).

DPU MIB parameter FDXMASKds applies to the downstream direction in the FUS part of the PDX frame. DPU MIB parameter FDXMASKus applies to the upstream direction in the FDS part of the PDX frame. The corresponding control parameters are *fdxmaskus* and *fdxmaskds*. Additional FDX masking for upstream subcarriers in FDS is determine by the parameter TONEMASK_NPus, obtained by the MTU-O during initialization (see clause 12.3.3.2.15).

The control parameter *fdxmask* specifies the start and stop frequencies of each FDX masking band. Each FDX masking band is specified by a start subcarrier index (x_L) and a stop subcarrier index (x_H), as $\{x_L, x_H\}$. An FDXMASK parameter defining *S* FDX masked bands can be represented in the following format:

$$\text{FDXMASK(S)} = [\{x_{L1}, x_{H1}\}, \{x_{L2}, x_{H2}\}, \ldots \{x_{LS}, x_{HS}\}].$$

7.3.1.5 Upstream power back-off (UPBO)

Upstream power back-off (UPBO) shall be performed by the MTU-R to improve spectral compatibility between the ITU-T G.9711 systems operating on loops of different lengths deployed in the same binder. This UPBO mechanism does not apply during the ITU-T G.994.1 handshake phase.

7.3.1.5.1 UPBO mechanism

The transmit PSD of the MTU-R shall be established using the following procedure:

- The MTU-O shall communicate to the MTU-R during the channel discovery phase of the initialization (in the O-SIGNATURE message, see clause 12.3.3.2) the PSDMASKus (see clause 7.3.1.1) defined in the DPU-MIB.
- The MTU-O shall communicate to the MTU-R during the channel discovery phase of the initialization the UPBO parameters defined by the operator via the DPU-MIB (in the O-SIGNATURE message).
- The MTU-R shall perform UPBO as described in clause 7.3.1.5.2, using the obtained UPBO parameters. The UPBO shall be performed autonomously, i.e., without sending any

significant information to the MTU-O until the UPBO is applied. No upstream transmission after the handshake phase is allowed prior to UPBO being applied.

- After UPBO has been applied, the MTU-O shall be capable of further adjusting the transmit PSD selected by the MTU-R; the adjusted transmit PSD shall be subject to the limitations above and those given in clause 7.3.1.5.2.

7.3.1.5.2 UPBO PSD mask

The MTU-R shall explicitly estimate the electrical length of its loop, kl_0, and use this value to calculate the UPBO PSD mask (UPBOMASK) at the beginning of the channel discovery phase of the initialization, prior to the first upstream transmission. The MTU-R shall then adapt its transmit signal PSD to conform to the UPBOMASK during the initialization and showtime. Other restrictions to the transmit signal PSD are detailed in clause 7.3.2.

7.3.1.5.2.1 Electrical length estimation

The MTU-R shall, and the MTU-O may, estimate the value of kl_0 autonomously, using the following equation:

$$kl_0 = AVERAGE\left(\frac{loss(f_i)_{dB}}{\sqrt{f_i}}\right) \qquad [\mathrm{dB}/\sqrt{\mathrm{MHz}}]$$

where the average is taken over the usable part of the ITU-T G.9711 frequency band. The function $loss(f_i)$ is the insertion loss in dB of the loop at the subcarrier frequency f_i expressed in MHz and corresponding to a subcarrier with index i. Only subcarriers within the SUPPORTEDCARRIERSGds set shall be accounted. The AVERAGE function refers to mean average, computed as a sum of terms divided by the number of terms.

NOTE – The estimate of the electrical length at each frequency should be sufficiently accurate to avoid spectrum management problems while minimizing performance loss. Specification of the accuracy of the kl_0 estimate by the MTU-R is for further study.

The MTU-O may override the kl_0 value estimated by the MTU-R with its own value of kl_0. If in the DPU-MIB a forced kl_0 is configured (UPBOKLF = 1), the MTU-O shall override the kl_0 with the DPU-MIB value of UPBOKL.

7.3.1.5.2.2 Computation of UPBOMASK

If the reference electrical length kl_{0_REF}=0, the UPBOMASK at any frequency f of the ITU-T G.9711 frequency band shall be calculated as:

$$UPBOMASK(kl_0, f) = UPBOPSD(f) + LOSS(kl_0, f) \qquad [\mathrm{dBm/Hz}]$$

where:

$$LOSS(kl_0, f) = kl_0\sqrt{f} \qquad [\mathrm{dB}], \text{ and}$$

$$UPBOPSD(f) = -a - b\sqrt{f} \qquad [\mathrm{dBm/Hz}],$$

with f expressed in MHz.

The values of *a, b* are determined by the DPU-MIB configuration parameters UPBOPSD.

The *UPBOPSD*(*f*) is a function of frequency but it is independent of the length and type of the loop.

If the reference electrical length $kl_{0\_REF} \neq 0$, the UPBOMASK at any frequency f of the ITU-T G.9711 frequency band shall be calculated as:

- for ($1.8 \leq kl_0 < kl_{0\_REF}$):

$$UPBOMASK(f) = UPBOPSD(f) + 10\log_{10}\left(\frac{kl_{0\_REF}}{kl_0}\right) + LOSS(kl_0, f) \quad \text{[dBm/Hz]}$$

- for ($kl_0 < 1.8$):

$$UPBOMASK(f) = UPBOPSD(f) + 10\log_{10}\left(\frac{kl_{0\_REF}}{1.8}\right) + LOSS(1.8, f) \quad \text{[dBm/Hz]}$$

- for ($kl_0 \geq kl_{0\_REF}$):

$$UPBOMASK(f) = UPBOPSD(f) + LOSS(kl_0, f) \quad \text{[dBm/Hz]}$$

with *f* expressed in MHz.

The value of kl_{0_REF} is determined by the DPU-MIB configuration parameter UPBOKLREF.

These values shall be provided to the MTU-R during the initialization (in the O-SIGNATURE message, see clause 12.3.3.2). Further, the updated value of kl_0 is provided to the MTU-R in the O-UPDATE message (see clause 12.3.3.2).

UPBOMASK shall be equal to the LIMITMASKus when UPBO is turned off.

NOTE 1 – For sufficiently short loops, by the nature of FEXT coupling, FEXT is rapidly decreasing as the loop length decreases. Accordingly, as the electrical length kl_0 of the loop is below 1.8, no further increase in power back-off is needed. Therefore, for lines with $kl_0 < 1.8$, the MTU-R performs UPBO using $kl_0 = 1.8$. An electrical length of 1.8 corresponds to, for example, a 0.4 mm loop about 70 m long.

NOTE 2 – In case of upstream vectoring, the operator may provision or allow for values of a and b corresponding to higher upstream PSDs up to the limit established by PSDMASKus, because upstream FEXT is reduced through crosstalk cancellation. After UPBO has been applied (during the initialization), the MTU-R may further adjust its transmit PSD (while it remains below the UPBOMASK) during the showtime by request from the MTU-O (under control of the VCE), via OLR procedure Type 1, to improve upstream performance. The operator may also adjust the values of *a* and *b* in the DPU-MIB and apply them via a new initialization.

In case of P2MP operation, each of the joining NTs applies the UPBO mask using the mechanism described in this clause. The UPBO mask shall be computed over the SUPPORTEDCARRIERSGus set.

7.3.1.6 LPM classes

The goal of the LPM class concept is to limit the number of configuration possibilities with respect to the in-band LPM as specified in [ITU-T G.9710].

Only one classmask is defined, comprising only one LPM:

- *classmask_1* comprises LPM_424

NOTE 1 – Although, there is no strict need for LPM classes in current ITU-T G.9711, the LPM class concept is defined to avoid interoperability issues in case of future extension and use of the LPM class concept.

NOTE 2 – If more LPM classes will be defined in the future, each LPM class should still be designed such that any pair of in-band LPMs belonging to the particular class has identical PSD limits in the overlapping parts of their passbands.

An LPM class is associated with a particulardirection of transmission and can be configured in the DPU-MIB through the optional configuration parameters CLASSMASKds and CLASSMASKus. The valid value for CLASSMASKds is *classmask_1*. The valid value for CLASSMASKus is *classmask_1*.

If a particular *classmask* value is supported, then all related in-band LPMs (see Table 7-1) shall be supported as applicable to the supported profiles. Support of *classmask_1* is a mandatory capability.

Each LPM class specifies the in-band LPM that shall be used for each profile as indicated in Table 7-1 for the downstream direction and Table 7-2 for the upstream direction.

Table 7-1 – Restrictions on the selection of downstream in-band LPMs for a profile as a function of CLASSMASKds

Profile	CLASSMASKds
	classmask_1
P424a	LPM_424
P424amp	LPM_424
P424d	LPM_424
P424dmp	LPM_424
Q424c	LPM_424
Q424cmp	LPM_424
Q424d	LPM_424
Q424dmp	LPM_424

Table 7-2 – Restrictions on the selection of the upstream in-band LPM for a profile as a function of CLASSMASKus

Profile	CLASSMASKus
	classmask_1
P424a	LPM_424
P424amp	LPM_424
P424d	LPM_424
P424dmp	LPM_424
Q424c	LPM_424
Q424cmp	LPM_424
Q424d	LPM_424
Q424dmp	LPM_424

7.3.2 PSD and PSD mask summary

A summary of the various PSDs and PSD masks used during the initialization and the showtime is presented in Table 7-3.

Table 7-3 – Transmit PSD masks and PSDs used in this Recommendation

Parameter	Description	Notation
Limit PSD mask	A PSD mask specified in [ITU-T G.9710]	LIMITMASKds, LIMITMASKus
DPU-MIB PSD mask	A PSD mask specified by the operator intended to restrict the transmit PSD to levels below those allowed by the applicable limit PSD mask.	MIBPSDMASKds, MIBPSDMASKus

Table 7-3 – Transmit PSD masks and PSDs used in this Recommendation

Parameter	Description	Notation
Transmit PSD mask	A PSD mask that is the minimum of: 1) the applicable LIMITMASK, 2) the MIBPSDMASK, and 3) vendor-discretionary mask restrictions imposed by the MTU-O and VCE.	PSDMASKds, PSDMASKus
UPBO PSD mask	A PSD mask applicable for the upstream direction only that is calculated by the MTU-R as a function of the electrical length of the loop (see clause 7.3.1.5).	UPBOMASK
STARTPSD mask	A PSD mask limited to PSDMASK and further limited to TXPSDM_N inside the notched frequency bands (RFI and IAR bands). In the upstream direction, also limited in accordance with the UPBO requirements.	STARTPSDMASKds, STARTPSDMASKus
STARTPSD	The PSD of the first signals transmitted by an MTU during the first stage of the channel discovery phase of the initialization	STARTPSDds, STARTPSDus, STARTPSD_NPus (Note)
Channel discovery PSD mask	A PSD mask limited to PSDMASK and further limited to TXPSDM_N inside the notched frequency bands (RFI and IAR bands). In the upstream direction, also limited in accordance with the UPBO requirements and by the PSD ceiling (MAXMASKus).	CDPSDMASKds, CDPSDMASKus, CDPSDMASK_NPus (Note)
Channel discovery PSD	The PSD of signals transmitted by an MTU during the later stages of the channel discovery phase of the initialization.	CDPSDds, CDPSDus, CDPSD_NPus, CDPSD_NP1us, CDPSD_NP2us (Note)
MAXMASK	A PSD level, independent of frequency, used as PSD ceiling in determination of CDPSDMASKus and V2PSDMASKds.	MAXMASKds, MAXMASKus
V2PSD mask	A PSD mask limited to PSDMASK and further limited to TXPSDM_N inside the notched frequency bands (RFI and IAR bands) and by the MAXMASK (MAXMASKds).	V2PSDMASKds
V2PSDds	The PSD of signals transmitted by an MTU-O during the VECTOR 2 stage of the Channel Discovery phase of the initialization.	V2PSDds
PRMPSDds	The PSD of signals transmitted by an MTU-O during the PARAMETER UPDATE stage of the channel discovery phase of the initialization.	PRMPSDds
MEDLEY reference PSD mask	A PSD mask limited to PSDMASK and further limited to TXPSDM_N inside the notched frequency bands (RFI and IAR bands) and by the MAXMASK. In the upstream direction, also limited in accordance with the UPBO requirements.	MREFPSDMASKds, MREFPSDMASKus, MREFPSDMASK_NPus (Note)

Table 7-3 – Transmit PSD masks and PSDs used in this Recommendation

Parameter	Description	Notation
MEDLEY reference PSD	The PSD of signals transmitted by an MTU during the Channel Analysis and Exchange phase of the initialization.	MREFPSDds, MREFPSDus, MREFPSD_NPus (Note)
Showtime PSD	The PSD of signals transmitted by an MTU during the showtime.	STPSDds STPSDus, STPSD_NPus (Note)
NOTE – In the upstream direction, the NPSF PSD parameters only apply to the NPSF in the case of FDX operation, while the PSD parameters without explicit reference to NPSF are either applicable to the PSF in the case of FDX operation and to FUS in case of TDD mode. In the downstream direction, all PSD parameters are applicable to FDS in case of TDD mode and to both the PSF and the NPSF in the case of FDX operation and therefore do not have explicit reference to NPSF.		

The details of computation rules for the PSD masks and setting rules for the PSDs are presented in Table 7-4.

Table 7-4 – Formulae for transmit PSD and PSD mask calculations

Parameter	Calculation
Transmit PSD mask (PSDMASK)	Calculated by the MTU-O for all frequencies as (Note 1): PSDMASKds(f) = min(LIMITMASKds(f), MIBPSDMASKds(f), ds_mask_restrictions_by_MTU-O_and_VCE) PSDMASKus(f) = min(LIMITMASKus(f), MIBPSDMASKus(f), us_mask_restrictions_by_MTU-O_and_VCE)
Downstream start PSD mask (START PSDMASKds)	STARTPSDMASKds(f) $= \begin{cases} \text{PSDMASKds}(f), f \notin (\text{RFIBANDS} \cup \text{IARBANDS}) \\ \min[\text{PSDMASKds}(f), \text{TXPSDM\_N}], f \in (\text{RFIBANDS} \cup \text{IARBANDS}) \end{cases}$
Downstream start PSD (STARTPSDds) (Note 2)	STARTPSDds, expressed in dBm/Hz, is determined by the MTU-O and applies to both the PSF and NPSF for the downstream direction. STARTPSDds(f) ≤ STARTPSDMASKds(f) (Note 4)
Upstream start PSD mask (START PSDMASKus)	STARTPSDMASKus(f) $= \begin{cases} \min[\text{PSDMASKus}(f), \text{UPBOMASK}(kl_0\_initial, f)], f \notin (\text{RFIBANDS} \cup \text{IARBANDS}) \\ \min[\text{PSDMASKus}(f), \text{UPBOMASK}(kl_0\_initial, f), \text{TXPSDM\_N}], f \in (\text{RFIBANDS} \cup \text{IARBANDS}) \end{cases}$ with $kl_0\_initial$ denoting the initial estimate of the electrical length.
Upstream start PSD (STARTPSDus STARTPSD_NPus) (Note 2)	STARTPSDus, expressed in dBm/Hz, is determined by the MTU-R for the upstream direction. STARTPSDus(f) ≤ STARTPSDMASKus(f) for PSF STARTPSD_NPus(f) = STARTPSDus(f) -STARTCB_NPus for NPSF (Note 5)

Table 7-4 – Formulae for transmit PSD and PSD mask calculations

Parameter	Calculation
Channel discovery PSD mask (CDPSDMASK)	CDPSDMASKds (f) = { min[PSDMASKds(f), ds_mask_restrictions_by_VCE], $f \notin$ (RFIBANDS ∪ IARBANDS) min[PSDMASKds(f)), TXPSDM_N], $f \in$ (RFIBANDS ∪ IARBANDS) CDPSDMASKus(f) = = { min[PSDMASKus(f), MAXMASKus, UPBOMASK(kl_0_*final*, f)], $f \notin$ (RFIBANDS ∪ IARBANDS) min[PSDMASKus(f), MAXMASKus,UPBOMASK(kl_0_*final*, f), TXPSDM_N], $f \in$ (RFIBANDS ∪ IARBANDS) with kl_0_*final* denoting the final electrical length.
Channel discovery PSD (CDPSD) (Note 2)	CDPSDds, expressed in dBm/Hz, is determined by the MTU-O and applies to both the PSF and NPSF for the downstream direction. CDPSDds(f) ≤ CDPSDMASKds(f) (Note 4) CDPSDus, CDPSD_NPus, CDPSD_NP1us and CDPSD_NP2us, expressed in dBm/Hz, are determined by the MTU-R, and for subcarriers from the SUPPORTEDCARRIERSus set: for PSF, CDPSDus(f) ≤ CDPSDMASKus(f) for NPSF, CDPSD_NPus(f) = CDPSDus(f) – CDCB_NPus for NPSF, CDPSD_NP1us(f) = CDPSDus(f) – CDCBUPDATE_NPus for NPSF, CDPSD_NP2us(f) ≤ CDPSDMASK_NPus(f) ≤ CDPSDMASKus(f) (Note 5)
Downstream V2PSD mask (V2PSDMASKds)	V2PSDMASKds (f) = min[CDPSDMASKds(f) , MAXMASKds]
Downstream V2PSD (V2PSDds) (Note 2)	V2PSDds, expressed in dBm/Hz, is determined by the MTU-O and applies to both the PSF and NPSF for the downstream direction. V2PSDds(f) ≤ V2PSDMASKds (f) (Note 4)
Downstream PRMPSD (PRMPSDds) (Note 2)	PRMPSDds, expressed in dBm/Hz, is determined by the MTU-O and applies to both the PSF and NPSF for the downstream direction. PRMPSDds(f) ≤ V2PSDMASKds(f) (Note 4)
MEDLEY reference PSD mask (MREF PSDMASK)	Calculated by the MTU-O for all frequencies as (Note 3): for both PSF and NPSF for the downstream direction, MREFPSDMASKds(f)= V2PSDMASKds(f) for PSF for the upstream direction, MREFPSDMASKus(f)≤ CDPSDMASKus(f) for NPSF for the upstream direction, MREFPSDMASK_NPus(f)≤ CDPSDMASKus(f)
MEDLEY reference PSD (MREFPSD) (Note 2)	MREFPSDds(f) ≤ (MREFPSDMASKds(f)) applies to both the PSF and NPSF the downstream direction. (Note 6) MREFPSDus(f) ≤ (MREFPSDMASKus(f)) in the PSF for the upstream direction. (Note 7) MREFPSD_NPus(f) ≤ (MREFPSDMASK_NPus(f)) and MREFPSD_NPus(f) ≤ (MREFPSDus(f)) in the NPSF for the upstream direction. (Note 7)
Showtime PSD (STPSD) (Note 2)	STPSDds(f) ≤ MREFPSDMASKds(f) applies to both the PSF and NPSF for the downstream direction. (Note 6) STPSDus(f) ≤ MREFPSDMASKus(f) in the PSF for the upstream direction. (Note 7) STPSD_NPus(f) ≤ MREFPSDMASK_NPus(f) in the NPSF for the upstream direction. (Note 7)

Table 7-4 – Formulae for transmit PSD and PSD mask calculations

Parameter	Calculation
NOTE 1 – Notched frequency bands (defined by parameters RFIBANDS and IARBANDS) are not incorporated in the transmit PSD mask (PSDMASK). NOTE 2 – For any valid setting of this parameter, the aggregate transmit power shall not exceed the MAXATP for the associated direction of transmission. MAXATPds and MAXATPus are DPU-MIB parameters. The MAXATP settings in the DPU-MIB shall not exceed the maximum aggregate transmit power specified in Table P.1 and Table Q.1. NOTE 3 – Notched frequency bands (defined by parameters RFIBANDS and IARBANDS) are incorporated in the STARTPSDMASK, CDPSDMASK, V2PSDMASK and MREFPSDMASK. NOTE 4 – The subcarriers to which this applies are specified in clause 10.2.1.4.4 (for non-sync symbols), clause 10.2.2.1 (for sync symbols) and in Table 12-44. NOTE 5 – The subcarriers to which each of these apply are specified in clause 10.2.1.4.4 (for non-sync symbols), clause 10.2.2.1 (for sync symbols) and in Table 12-45. NOTE 6 – The subcarriers to which this applies are specified in clause 10.2.1.4.4 (for non-sync symbols), clause 10.2.2.1 (for sync symbols) and in Table 12-74. NOTE 7 – The subcarriers to which this applies are specified in clause 10.2.1.4.4 (for non-sync symbols), clause 10.2.2.1 (for sync symbols) and in Table 12-75.	

All PSDs and PSD masks in Table 7-4 relate to the transmit signals on the U reference point. For precoded signals, the PSD mask is a limit for the total signal on the U reference point, including the pre-compensation components.

NOTE – Table 7-4 specifies PSDs and PSD masks at every frequency (i.e., in both the passband and the stopbands). To avoid communication of redundant information, the messages during the initialization corresponding to the PSDs in Table 7-4 do not describe all the PSDs in the full frequency range, nor do they describe the RFI bands and IAR bands. The PSDs in Table 7-4 may be computed from other PSDs and values that are communicated during the initialization.

The process of determining the transmit PSDs and PSD masks of the MTU during the initialization and showtime is summarized in Table 7-5.

Table 7-5 – Time aspects for determination, communication and use of PSDs and PSD masks

Parameter	When determined	When communicated between MTUs (Note 1)	When used (Note 3)
Limit PSD mask (LIMITMASK)	Configuration of the DPU-MIB before the start of initialization.	Not communicated	By the MTU-O, before the start of initialization, to calculate the downstream and upstream transmit PSD masks.
MIB PSD mask (MIBPSDMASK)	Configuration of the DPU-MIB before the start of initialization.	Not communicated	By the MTU-O, before the start of initialization, to calculate the downstream and upstream transmit PSD masks.
RFI bands (RFIBANDS)	Configuration of the DPU-MIB before the start of initialization.	RFIBANDS is sent by the MTU-O to the MTU-R during the ITU-T G.994.1 handshake phase of the initialization.	Notches are applied in designated bands in applicable transmission direction(s) from the start of the channel discovery phase of the initialization and thereafter.

Table 7-5 – Time aspects for determination, communication and use of PSDs and PSD masks

Parameter	When determined	When communicated between MTUs (Note 1)	When used (Note 3)
IAR bands (IARBANDS)	Configuration of the DPU-MIB before the start of initialization.	IARBANDS is sent by the MTU-O to the MTU-R during the ITU-T G.994.1 handshake phase of the initialization.	Notches are applied in designated bands in applicable transmission direction(s) from the start of the channel discovery phase of the initialization and thereafter.
Carrier masking (CARMASK)	Configuration of the DPU-MIB before the start of initialization.	Not communicated	By the MTU-O, before the start of initialization, to calculate the downstream and upstream SUPPORTEDCARRIERSG sets.
FDX masking (FDXMASK)	Configuration of the DPU-MIB before the start of initialization.	The *fdxmask_ds* and *fdxmask_us* are sent by the MTU-O to the MTU-R in the O-SIGNATURE message	By the MTU-O, before the start of initialization, to determine the downstream and upstream subcarriers not to be transmitted in the NPSF.
Tone masking (TONEMASK_NPus)	At the end of the channel discovery phase of the initialization; the MTU-O determines TONEMASK_NPus	TONEMASK_NPus is sent by the MTU-O to the MTU-R in the O-PRM message.	For all upstream signals in the NPSF during the channel analysis and exchange phase of the initialization.
SUPPORTEDCARRIERSG	By the MTU-O before the start of initialization.	SUPPORTEDCARRIERSG ds and SUPPORTEDCARRIERSG us are sent by the MTU-O to the MTU-R in the O-SIGNATURE message.	By the MTU-O, to determine SUPPORTEDCARRIERS. See Tables 12-44 and 12-45.
SUPPORTEDCARRIERS	By the MTU-O and MTU-R, at the start of channel discovery phase, and during showtime, based on SUPPORTEDCARRIERSG set and the P2MPOBs.	The P2MPOBs are sent to the MTU-R during ITU-T G.994.1 handshake (for downstream) and in O-SIGNATURE (for upstream) and may be updated during showtime by a dynamic bandwidth redistribution (DBR) procedure.	See Tables 12-44 and 12-45.
MEDLEYG	By the MTU-O during the parameter update stage of the channel discovery phase of the initialization.	MEDLEYGds is sent by the MTU-O to the MTU-R in the O-PRM message. MEDLEYGus is sent by the MTU-R to the MTU-O in the R-PRM message.	By the MTU-O, to determine MEDLEYds. By the MTU-R, to determine MEDLEYus. See Tables 12-74 and 12-75.

Table 7-5 – Time aspects for determination, communication and use of PSDs and PSD masks

Parameter	When determined	When communicated between MTUs (Note 1)	When used (Note 3)
MEDLEY	By the MTU-O and MTU-R, during the parameter update stage of the channel discovery phase, and during showtime, based on MEDLEYG set and the P2MPOBs.	The P2MPOBs are sent to the MTU-R during ITU-T G.994.1 handshake (for downstream) and in O-SIGNATURE (for upstream) and may be updated during showtime by a DBR procedure.	See Tables 12-74 and 12-75.
Transmit PSD mask (PSDMASK)	By the MTU-O and VCE before the start of initialization.	PSDMASKds and PSDMASKus are sent by the MTU-O to the MTU-R in the O-SIGNATURE message.	Applies to all signals during the channel discovery phase of the initialization.
UPBO PSD mask (UPBOMASK)	By the MTU-R at the beginning of the channel discovery phase of the initialization.	Not communicated.	Applies to all signals during the channel discovery phase of the initialization and thereafter.
Downstream start PSD (STARTPSDds)	At the beginning of initialization.	Not communicated.	During the O-VECTOR 1 stage of the channel discovery phase of the initialization for signal O-P-VECTOR 1. See Table 12-44.
Upstream start PSD (STARTPSDus)	At the beginning of the channel discovery phase of the initialization.	STARTPSDus is sent by the MTU-R to the MTU-O in the R-MSG1 message.	During the channel discovery phase of the initialization. See Table 12-45.
Upstream start PSD in NPSF (STARTPSD_NPus)	At the beginning of the channel discovery phase of the initialization, by the MTU-R. STARTPSD_NPus = STARTPSDus - STARTCB_NPus	Not communicated.	During the channel discovery phase of the initialization (Note 2). See Table 12-45.
Upstream start PSD cutback in NPSF (STARTCB_NPus)	At the beginning of the channel discovery phase of the initialization, by the MTU-O.	Sent by the MTU-O to the MTU-R in the O-EC-PRM message.	See STARTPSD_NPus
Downstream Channel discovery PSD(CDPSDds)	During channel discovery phase; the MTU-O determines CDPSDds.	CDPSDds is sent by the MTU-O to the MTU-R in the O-SIGNATURE message.	During the channel discovery phase of the initialization. See Table 12-44.
Upstream Channel discovery PSD (CDPSDus)	During the channel discovery phase, the MTU-R derives CDPSDus from the STARTPSDus by applying MAXMASKus constraints indicated in the received O-UPDATE message.	CDPSDus is sent by the MTU-R to the MTU-O in the R-UPDATE message.	During the channel discovery phase of the initialization. See Table 12-45.

Table 7-5 – Time aspects for determination, communication and use of PSDs and PSD masks

Parameter	When determined	When communicated between MTUs (Note 1)	When used (Note 3)
PSD ceiling upstream (MAXMASKus)	The MTU-O determines MAXMASKus during the channel discovery 2 stage.	MAXMASKus is sent by the MTU-O to the MTU-R in the O-UPDATE message.	Applies to upstream signals starting from R-P-VECTOR 1-1 in the channel discovery phase of the initialization. See Table 12-44.
Upstream Channel discovery PSD in NPSF (CDPSD_NPus)	The MTU-R determines CDPSD_NPus = CDPSDus – CDCB_NPus during the channel discovery phase	Not communicated.	During the channel discovery phase of the initialization (Note 2). See Table 12-45.
Upstream Channel Discovery PSD cutback in NPSF (CDCB_NPus)	The MTU-O determines CDCB_NPus during the channel discovery 2 stage.	CDCB_NPus is sent by the MTU-O to the MTU-R in the O-UPDATE message.	See CDPSD_NPus
Updated Upstream Channel discovery PSD in NPSF (CDPSD_NP1us)	The MTU-R determines CDPSD_NP1us = CDPSDus – CDCBUPDATE_NPus during the channel discovery phase	Not communicated.	During the channel discovery phase of the initialization (Note 2). See Table 12-45.
Updated Upstream Channel Discovery PSD cutback in NPSF (CDCBUPDATE_NPus)	The MTU-O determines CDCBUPDATE_NPus during the channel discovery 2 stage.	CDCBUPDATE_NPus is sent by the MTU-O to the MTU-R in the O-EC-PRM 1 message.	See CDPSD_NP1us
Upstream Channel discovery PSD mask in NPSF (CDPSDMASK_NPus)	The MTU-O determines CDPSDMASK_NPus during the channel discovery phase.	Sent by the MTU-O to the MTU-R in the O-SNR message.	See CDPSD_NP2us
Second updated Upstream Channel discovery PSD in NPSF (CDPSD_NP2us)	The MTU-R determines CDPSD_NP2us during the channel discovery phase. CDPSD_NP2us ≤ CDPSDMASK_NPus	Sent by the MTU-R to the MTU-O in the R-SNR message.	During the channel discovery phase of the initialization (Note 2). See Table 12-45.
PSD ceiling downstream (MAXMASKds)	The MTU-R determines MAXMASKds during the CHANNEL DISCOVERY 2 stage of the channel discovery phase of the initialization.	MAXMASKds is sent by the MTU-R to the MTU-O in the R-UPDATE message.	See V2PSDds.
V2PSDds	During the CHANNEL DISCOVERY 2 stage of the channel discovery phase of the initialization, the MTU-O derives V2PSDds by applying MAXMASKds constraints indicated in the received R-UPDATE message.	Not communicated.	During the channel discovery phase of the initialization. See Table 12-44.

Table 7-5 – Time aspects for determination, communication and use of PSDs and PSD masks

Parameter	When determined	When communicated between MTUs (Note 1)	When used (Note 3)
PRMPSD (PRMPSDds)	During the VECTOR 2 stage of the channel discovery phase of the initialization.	Not communicated.	During the channel discovery phase of the initialization. See Table 12-44.
MEDLEY reference PSD mask (MREFPSDMASK)	At the end of the channel discovery phase of the initialization; the MTU-O determines MREFPSDMASKus, and MREFPSDMASK_NPus. During showtime MREFPSDMASK_NPus may be updated.	The MTU-O communicates the MREFPSDMASKus, and MREFPSDMASK_NPus to the MTU-R in O-PRM message. During showtime MREFPSDMASK_NPus may be updated by an SPA procedure.	Applies to all signals starting from the beginning of the channel analysis and exchange phase of the initialization and thereafter during the initialization and showtime.
Downstream MEDLEY reference PSD (MREFPSDds)	The MTU-O determines MREFPSDds at the end of the channel discovery phase of the initialization.	MREFPSDds is not communicated.	During the channel analysis and exchange phase of the initialization for signals starting from O-P-MEDLEY up to and including O-P-SYNCHRO 6. See Table 12-74.
Upstream MEDLEY reference PSD (MREFPSDus)	The MTU-R determines MREFPSDus at the end of the channel discovery phase of the initialization.	MREFPSDus is sent by the MTU-R to the MTU-O in the R-PRM message.	During the channel analysis and exchange phase of the initialization for signal R-P-MEDLEY. See Table 12-75.
Upstream MEDLEY reference PSD in NPSF (MREFPSD_NPus)	The MTU-R determines MREFPSD_NPus at the end of the channel discovery phase of the initialization. During showtime MREFP_NPus may be updated.	MREFPSD_NPus is sent by the MTU-R to the MTU-O in the R-PRM message. During showtime MREFPSD_NPus may be updated by an SPA procedure.	During the channel analysis and exchange phase of the initialization, for signal R-P-MEDLEY (Note 2). See Table 12-75.
Showtime PSD (STPSD)	At the end of the channel analysis and exchange phase of the initialization. and may be updated during showtime.	Determined by the MREFPSD and in the upstream direction also by the gain values (g_i) communicated during the channel analysis and exchange phase (O-PMD message) and during the showtime (OLR).	During the showtime.
NOTE 1 – Only the minimum set of relevant parameters characterizing PSDs and PSD masks is communicated during the initialization. The communication protocols and formats are described in clause 12.3. NOTE 2 – In the upstream direction, the NPSF PSD parameters only apply to the NPSF in the case of FDX operation, while the PSD parameters without explicit reference to NPSF are applicable to the PSF in the case of FDX operation and to FUS is case of TDD mode. In the downstream direction, all PSD parameters are applicable to FDS in case of TDD mode and to both the PSF and the NPSF in the case of FDX operation and therefore do not have explicit reference to NPSF. NOTE 3 – See also Tables 12-44, 12-45, 12-74 and 12-75.			

8 Transport protocol specific transmission convergence (TPS-TC) function

8.1 Functional reference model

The functional reference model of the TPS-TC is presented in Figure 8-1 for an MTU-O and in Figure 8-2 for an MTU-R. The functionality defined in this clause is consistent with the generic MTU functional model presented in Figures 5-7 and 5-8. Transceivers complying with this Recommendation shall support the packet-based TPS-TC (PTM-TC) as defined in clause 8.3.

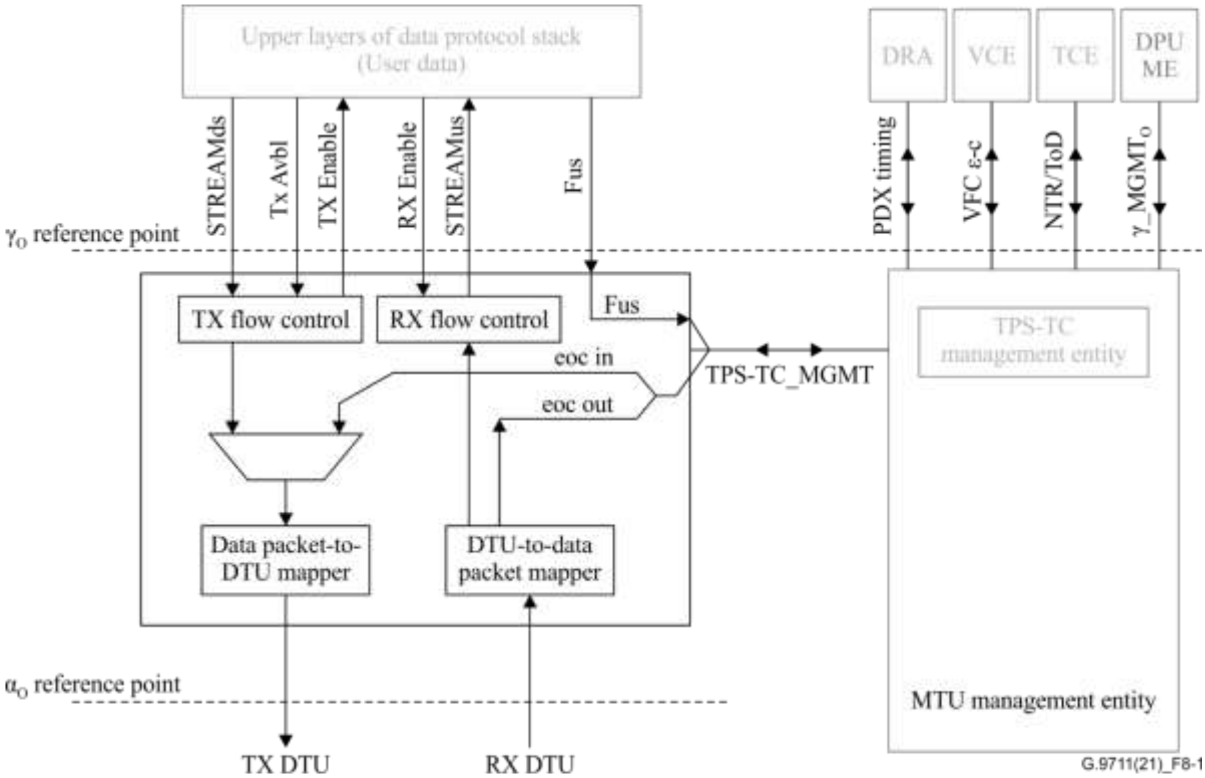


Figure 8-1 – Functional reference model of the TPS-TC (MTU-O)

At the MTU-O, in the transmit direction, the data packets (STREAMds) crossing the γ_O reference point are encapsulated into data transfer units (DTUs) that are passed to the PMS-TC across the α_O reference point. The STREAMds comprises of *NCds* downstream channels (STREAMds 0, STREAMds 1, …, STREAMds (*NCds*-1), $1 \le NCds \le 4$). The MTU-O supports at least 2 and may support up to 4 channels, see clause 5.5.1. The actual number of supported channels, i.e., 2 or 4, is determined at initialization (see clause 12.3.4) and is the minimum of those supported by the MTU-O and the MTU-R.

Each channel is identified by its CID, and with each channel, a particular QoS class is associated as defined in clause 5.5.1. Each QoS class is characterised by its priority (PRIORITY = 0, 1, 2, or 3), its value of the target maximum delay between γ_O and γ_R reference points (MAXDELAYds) and its proactive retransmission type (PROACTIVE_RTXds). The values of PRIORITYds, MAXDELAYds and PROACTIVE_RTXds are configured in the DPU-MIB. Each channel shall be configured with a different PRIORITYds values. Channels may be configured with the same MAXDELAYds value. A channel with a higher PRIORITYds value shall have an equal or lower MAXDELAYds value compared to all other channels with a lower PRIORITYds value.

The configuration is rejected by the ME-O if more QoS channels are configured than the number of channels supported by the MTU-O. If more QoS channels are configured than the number of channels supported by the MTU-R (as indicated during initialization in the R-MSG2 message), the ME-O shall derive QoS channel and associated QoS class control parameters from the QoS channels and associated QoS class configuration parameters in the DPU-MIB, which meets the MTU-R capabilities, while still meeting the associated QoS class requirements as configured in the DPU-MIB. The number of QoS channel shall be equal to the number supported by the MTU-R. The derived control parameters shall be sent in the O-TPS message of the ongoing initialization. If the ME-O is unable to derive such control parameters, an initialization failure shall occur (see clause 11.3.1.5); in this case, the derived control parameters are applied to the subsequent initialization.

NOTE 1 – The specification of how to derive such ITU-T G.9711 control parameters from the ITU-T G.997.3 DPU-MIB configuration parameters is for further study.

The TPS-TC collects the data packets submitted via all channels and encapsulates them into DTUs as defined in clause 8.3. The order in which packets are collected from the channels is determined by the channel priority (PRIORITYds) value: packets from channel with highest priority (PRIORITYds = 3) are collected first and packets from channel with lowest priority (PRIORITYds = 0) are collected the last. The presence of a packet available for transmission in a particular channel K is indicated to the TPS-TC by the Tx_Avbl K primitive of the corresponding STREAMds K (see Table 8-2).

The TX flow control function generates the TX Enable primitives (TxEn_0, TxEn_1…, TxEn_NCds-1) towards the DPU's L2+ functional block (see Figure 5-2) that prevent TPS-TC overflow per channel. Each of the primitives TxEn can be assigned a value of either TXon or TXoff. By setting the value of the TX Enable primitive TxEn_K to TXoff, the MTU-O indicates to the DPU's L2+ functional block that it is not ready to receive data packets from channel K. By setting the value of the TX Enable primitive TxEn_K to TXon, the MTU-O indicates to the DPU's L2+ functional block that it is ready to receive data packets from channel K.

NOTE 2 – Clause 6.3 of [b-ITU-T G.999.1] specifies a data flow control mechanism based on TXon/TXoff and RXon/RXoff signalling. This mechanism may be used to support the upstream flow control specified in this Recommendation.

The TPS-TC associates a particular QoS grade with each collected packet. Four QoS grades are defined with values Q0 (lowest QoS grade), Q1, Q2, and Q3 (highest QoS grade). Support of two QoS grades, grade Q0 and grade Q3, is mandatory. Support of grade Q1 and grade Q2 is optional (see clause 8.3). The value of the QoS grade determines the maximum latency (defined by *delay_max*, which is derived from the value of MAXDELAYds by the MTU-O in a vendor discretionary way) with which the packet will be transferred over the line. It also determines the priority with which the DTU encapsulating the packet will be retransmitted (see clause 9.8). The DTUs carrying packets tagged with a higher QoS grade will get a strictly higher priority when retransmitted. A higher QoS grade shall have the associated *delay_max* value that is equal or lower. The QoS grade tags of the packets are conveyed to the receive side (see clause 8.3), assisting latency and retransmission control at the receiver. The *delay_max* values associated with each QoS grade are conveyed to the receive side during initialization. The *delay_max_0* is defined as the largest *delay_max* over all QoS grades. The *delay_max_0* value is equal to the *delay max* value of the QoS grade 0.

The DTUs are passed to the PMS-TC together with the associated QoS grade tag (see Table 8-8) that includes QoS grades of the packets encapsulated into the DTU. These tags are used to schedule transmission and retransmission of DTUs carrying packets of different QoS grades (see clause 9.8).

NOTE 3 – The PMS-TC takes 2-4 QoS grades and translates to two retransmission classes, translating QoS grade parameters into retransmission class parameters. The QoS grade assigned to collected packets is associated with the respective channel. Table 8-1 lists the mapping of channels to QoS grades for the cases of 2 QoS grades (mandatory) and 4 QoS grades (optional) supported by both MTU-O and MTU-R. The number of QoS grades is determined at initialization, depending on the mutual capabilities of the MTU-O and MTU-R see clause 12.3.4.

Table 8-1 – Mapping by MTU of QoS channels to QoS grades

Number of QoS channels (*NC*)	**Channel PRIORITYs** (Note 1)	**Number of QoS grades supported by MTU**	**QoS grades associated** (Note 2)	**Notes**
1	P0	2 or 4	P0→Q0	Q1, Q2 and Q3 are not in use
2	P0 < P1	2 or 4	P0→Q0, P1→Q3	Q1 and Q2 are not in use
3	P0 < P1 < P2	4	P0→Q0, P1→Q2, P2→Q3	Q1 is not in use
4	P0 < P1 < P2 < P3	4	P0→Q0, P1→Q1, P2→Q2, P3→Q3	-
NOTE 1 – P0, P1, P2 and P3 represent the PRIORITYs in increasing order of priority, assigned to the QoS classes associated with the QoS channels, with P0 being the lowest value. NOTE 2 – Q0, Q1, Q2 and Q3 represent the QoS grades to which the QoS channels with given PRIORITY values are mapped.				

In the receive direction, data packets are recovered from the DTUs crossing the α_O reference point. The recovered data packets (STREAMus) are conveyed to the DPU's L2+ functional block across the γ_O reference point via *NCus* channels (1 ≤ *NCus* ≤ 4). The configuration is rejected by the ME-O if more upstream QoS classes are configured than the number of channels supported by the MTU-O. The QoS grade and the value of *delay_max* of each channel are determined by the transmitter at the MTU-R. The QoS grade tag associated with the received data packet indicates to which QoS channel at the receive side this data packet belongs (see Table 8-11). The TPS-TC submits packets of each QoS grade across the γ_O reference point in the order they were transmitted by the MTU.

The RX flow control function receives the RX Enable primitives (RxEn_0, RxEn_1…, RxEn_NCus-1) from the DPU's L2+ functional block, which together with the upstream flow control FCus primitives (FCus_0, FCus_1, …, FCus_NCus-1), prevents upper layer overflow per channel. Each of the primitives RxEn and FC can be assigned a value of either RXon or RXoff. By setting the value of the RX Enable primitive RxEn_K to RXoff, the DPU's L2+ functional block indicates to the MTU-O that it is not ready to receive data packets over channel K. In this case, the MTU-O may turn off the RX DTU Enable primitive at the α reference point (see clause 8.1.2) for the DTU's associated with channel K, and the PMS-TC receiver in the MTU-O (see Figure 9-1) may respond with NACKs to any received upstream normal DTU containing data frames of QoS grade associated with channel K when its buffer for channel K is full. By setting the value of the RX Enable primitive RxEn_K to RXon, the DPU's L2+ functional block indicates to the MTU-O that it is ready to receive data packets over channel K.

In addition to RX flow control, the MTU-O communicates the value of the FCus_K primitive (RXon/RXoff) to the peer MTU-R via upstream flow control bits in the RMC (see clause 9.6.4). By setting the value of the FC us primitive FCus K to RXoff, the DPU's L2+ functional block indicates to the MTU-R that it is not ready to receive data packets via upstream channel K. In this case the MTU-R shall set the corresponding primitive TxEn_K to TXoff. By setting the value of the FCus primitive FCus_K to RXon, the DPU's L2+ functional block indicates to the MTU-R that it is ready to receive data packets via upstream channel K. In this case the MTU-R may then set the corresponding primitive TxEn_K to TXon.

The QoS grades indicated in the received data packets (assigned by the MTU-R transmitter and conveyed to the MTU-O receiver in the DTUs, as defined in clause 8.3) are used by the receiver to facilitate latency requirement for each QoS class and associated channel of the STREAMus.

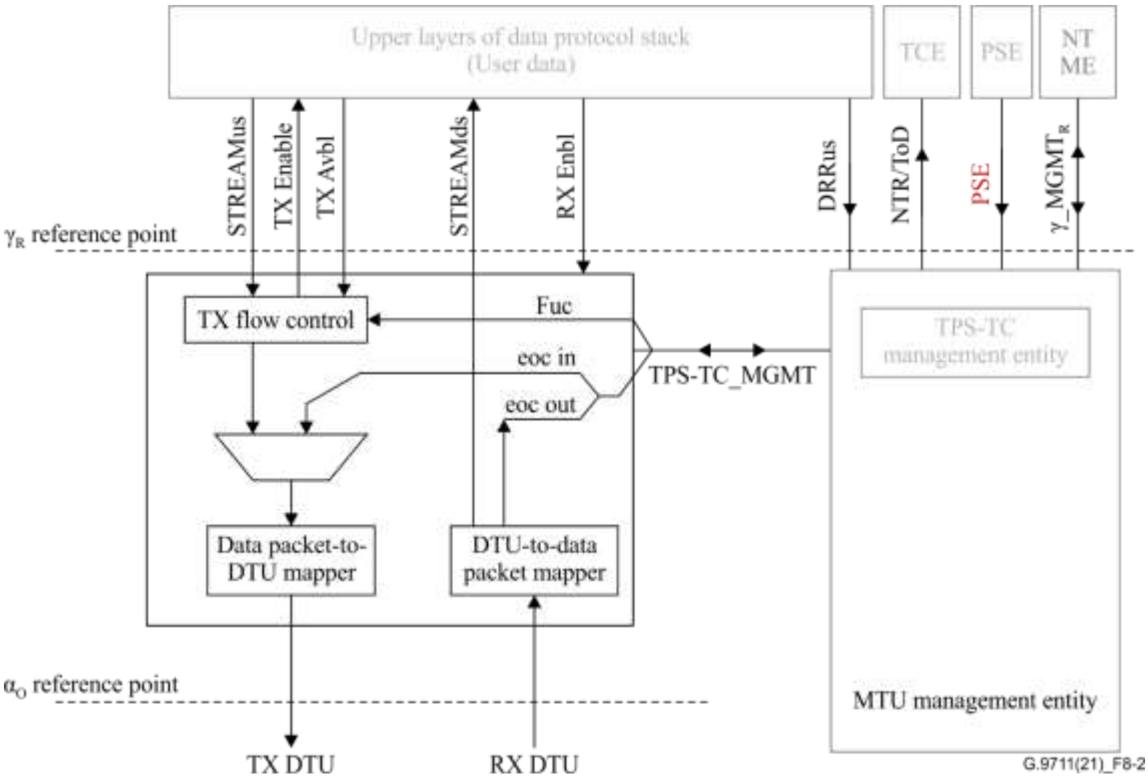


Figure 8-2 – Functional reference model of the TPS-TC (MTU-R)

At the MTU-R, in the transmit direction, the data packets (STREAMus) crossing the γ_R reference point are encapsulated into data transfer units (DTUs) that are passed to the PMS-TC across the α_R reference point. The STREAMus comprises of *NCus* upstream QoS channels (STREAMus 0, STREAMus 1, …, STREAMus (*NCus*-1), $1 \leq NCus \leq 4$). The MTU-R supports at least 2 and may support up to 4 channels, see clause 5.5.2. The actual number of supported channels, i.e., 2 or 4, is determined at initialization (see clause 12.3.4.2) and is the minimum of those supported by the MTU-O and the MTU-R.

Each channel is associated with a particular QoS class, as defined in clause 5.5.2, and identified by its CIDus. Each QoS class is characterised by its priority (PRIORITY=0, 1, 2, or 3), its value of the maximum delay between γ_R and γ_O reference points (MAXDELAYus) and its proactive retransmission type (PROACTIVE_RTXus). The values of PRIORITYus, MAXDELAYus and PROACTIVE_RTXus are configured in the DPU-MIB. Each channel shall be configured with a different PRIORITYus values. Channels may have the same MAXDELAYus values. A channel with a higher PRIORITYus value shall have an equal or lower MAXDELAYus value compared to all other channels with a lower PRIORITYus value. At initialization, for each upstream QoS channel, the MTU-O communicates the settings of PRIORITYus, MAXDELAYus and PROACTIVE_RTXus to the MTU-R, and in response, the MTU-R sends back to MTU-O the associated QoS grade (per Table 8-1) and *delay_max* values.

NOTE 4 – At the NT, the L2+ needs to be configured consistent with the QoS channel configuration of the MTU-R. Such configuration methods are beyond the scope of this Recommendation.

The TPS-TC collects the data packets submitted via all channels and encapsulates them into DTUs as defined in clause 8.3. The order in which packets are collected from the channels is determined by the channel priority (PRIORITYus value): packets from channel with highest priority (PRIORITY = 3) are collected first and packets from channel with lowest priority (PRIORITY = 0) are collected the last. The presence of a packet available for transmission in a particular channel K is indicated to the TPS-TC by the Tx_Avbl K primitive of the corresponding STREAMus K (see Table 8-2).

The TX flow control function generates the TX Enable primitives (TxEn_0, …, TxEn_NCus-1) towards the NT's L2+ functional block that prevent TPS-TC overflow per channel. Each of the primitives TxEn can be assigned a value of either TXon or TXoff. By setting the value of the TX Enable primitive TxEn_K to TXoff, the MTU-R indicates to the NT's L2+ functional block that either the MTU-R itself or the DPU's L2+ functional block (if the setting of the upstream channel K flow control, FCus_K, bit received from the MTU-O via the RMC is RXoff) is not ready to receive data packets from channel K. By setting the value of the TX Enable primitive TxEn_K to TXon, the MTU-R indicates to the NT's L2+ functional block that both the MTU-R itself and the DPU's L2+ functional block are ready to receive data packets from channel K. If the setting of the upstream channel K flow control bit primitive received from the MTU-O via the RMC is RXoff, the MTU-R shall set the value of the TX Enable primitive TxEn_K to TXoff.

The TPS-TC associates a particular QoS grade with each collected packet. Four QoS grades are defined with values Q0 (lowest QoS grade), Q1, Q2, and Q3 (highest QoS grade). Support of two QoS grades, grade Q0 and grade Q3, is mandatory. Support of grade Q1 and grade Q2 is optional (see clause 8.3). The value of the QoS grade determines the maximum latency (defined by *delay_max,* which is derived from the value of MAXDELAYus by the MTU-R in a vendor discretionary way) with which the packet will be transferred over the line. It also determines the priority with which the DTU encapsulating the packet will be retransmitted (see clause 9.8). The DTUs carrying packets tagged with a higher QoS grade will get a higher priority when retransmitted. A higher QoS grade shall have an associated *delay_max* value that is equal or lower than for lower QoS grade. The QoS grade tags of the packets are conveyed to the receive side (see clause 8.3), assisting latency and retransmission control at the receiver. The *delay_max* values associated with each QoS grade are conveyed to the receive side during initialization.

In the receive direction, data packets are recovered from the DTUs crossing the α_R reference point. The recovered data packets (STREAMds) are conveyed to the NT's L2+ functional block across the γ_R reference point via *NCds* channels ($1 \leq NCds \leq 4$). The number of channels and their parameters (CIDds, *delay_max*) are determined by the transmitter at the MTU-O. The QoS grade tag associated with the received data packet indicates to which channel at the receive side this data packet belongs (see Table 8-1 and Table 8-11). The TPS-TC submits packets of the same QoS grade across the γ_R reference point in the order they were transmitted by the MTU-O.

The RX flow control function receives the RX Enable primitives (RxEn_0, …, RxEn_NCds-1) from the NT's L2+ functional block to prevent upper layer overflow per channel. Each of the primitives RxEn can be assigned a value of either RXon or RXoff. By setting the value of the RX Enable primitive RxEn_K to RXoff, the NT's L2+ functional block indicates to the MTU-R that it is not ready to receive data packets over channel K. In this case the MTU-R may turn off the RX DTU Enable primitive at the α reference point (see clause 8.1.2) for the DTUs associated with channel K, and the PMS-TC receiver in the MTU-R (see Figure 9-1) may respond with NACKs to any received downstream normal DTU containing data frames of QoS grade associated with channel K when its buffer for channel K is full. By setting the value of the RX Enable primitive RxEn_K to RXon, the NT's L2+ functional block indicates to the MTU-R that it is ready to receive data packets over channel K.

NOTE 5 – The NT's L2+ functional block setting the value of the RX Enable primitive to RXoff across the γ_R reference point is expected to be used only when operating in a group with Ethernet-based multi-pair bonding (see ITU-T G.998.2) in order to facilitate delay equalization of the lines in the bonded group in the event of retransmissions.

The QoS grades indicated in the received data packets (assigned by the MTU-O and conveyed to the MTU-R receiver in the DTUs, as defined in clause 8.3) are used by the receiver to facilitate latency requirements for each QoS class and associated channel of the STREAMds. The respective values of *delay_max* for each channel in the downstream direction are passed to the MTU-R during initialization.

The MTU management entity (MME) controls the TPS-TC using primitives that are conveyed via the TPS-TC_MGMT interface; the same interface is used to retrieve relevant management primitives from the TPS-TC.

The TPS-TC also facilitates transport of eoc. The eoc packets containing one or more eoc messages are transferred transparently (except when non-correctable errors occur in the line) between the TPS-TC_MGMT interfaces of peer MTUs. The eoc messages assigned for transmission (eoc commands and responses), formatted as defined in clause 11.2.2.2, are encapsulated into eoc packets and submitted to the TPS-TC_MGMT interface by the MME in the order determined by their priority.

The NTR and ToD primitives submitted to the corresponding MME interfaces of the peer MTU are communicated using eoc messages defined in clauses 11.2.2.7 to 11.2.2.9. The DRA related primitives are defined in clause 8.1.1, and communicated using RMC messages defined in clause 9.6.4 and eoc messages defined in clause 11.2.2.16.

The transmitted eoc packets are multiplexed with the incoming data packets with ordering as described in clause 8.2.2, encapsulated into DTUs, and transferred to the TPS-TC of the peer MTU. When both eoc packets and data packets are available for transmission, the eoc packets shall have strict priority over data packets of QoS grade 0. The transmitter may give priority to eoc packet over data packets of other grades (despite the eoc packets are assigned QoS grade Q0).

For de-multiplexing of the eoc packets at the receive side, each eoc packet encapsulated into a DTU carries a flag that distinguishes it from data packets (see clause 8.3). The eoc packets recovered from the received DTUs are submitted to the MME via the TPS-TC_MGMT interface. From the QoS grade perspective, the received eoc packets shall be processed as data packets with QoS grade 0.

The maximum size of an eoc packet (see clause 11.2.2.1) and the number of eoc packets transmitted per second is limited to avoid potential reduction of QoS; this limit is determined by the eoc message format (see clause 8.1.3) and the maximum number of eoc bytes allowed per logical frame period. The maximum number of eoc bytes per any upstream logical frame period and any downstream logical frame period shall meet the requirements presented in Table P.1 and Table Q.1 for twisted pairs and coaxial cable, respectively.

8.1.1 γ reference point

The γ reference point is defined in the data plane between the MTU and the L2+ functional block. The order in which the data packets collected from the *NC* channels are mapped into DTUs is specified in clause 8.2.2. The order in which data packets are dispatched to particular channels is determined by the L2+ media access control mechanism, which is beyond the scope of this Recommendation. The data packets of each QoS class (in each channel) shall be passed from the TPS-TC to the L2+ functional block in the order that they were transmitted from the peer MTU.

The interface at the γ reference point is logical and is defined through primitives. For a packet-based TPS-TC (PTM-TC), the unit of data is a packet, which is a sequence of bytes. The content of the packet is application specific. The primitives that control the flow of data packets across the γ reference point are summarized in Table 8-2. The TX primitives in Table 8-2 control packet transfer from the upper layers to TPS-TC, while RX primitives control packet transfer from the TPS-TC to upper layers.

Table 8-2 – Flow control primitives at the γ reference point

Primitive	Direction	Description
RX Enable (RxEn_0, …RxEn_NC-1)	Upper layer → TPS-TC	Flow control primitive indicating that the upper layer is ready to receive packets from the TPS-TC over each of the *NC* channels (Note 1).
FCus (FCus 0,… FCus NC-1)		Upstream flow control primitive indicating to the MTU-R that the MTU-O upper layer is ready to receive packets; valid at the MTU-O only (Note 3).
TX Start Flags (TxF_0, …TxF_NC-1)		Indicates the first byte of the packet transmitted towards the TPS-TC over each of the *NC* channels (Note 5).
TX Stop Flags (TxSF_0, …TxSF_NC-1)		Indicates the last byte of the packet transmitted towards the TPS-TC over each of the *NC* channels (Note 5).
Tx_Avbl (Tx_Avbl 0, …Tx_Avbl NC-1)		Indicates that one or more user data packets associated with the particular channel are available in the upper layer for transmission and can be collected by the TPS-TC (Note 4).
TX Clock		Transmit data clock reference.
TX Enable (TxEn_0, …TxEn_NC-1)	TPS-TC → Upper layer	Flow control primitive indicating that the TPS-TC is ready to receive the next packet from the upper layer in each of the *NC* channels (Note 2).
RX Start Flags (RxF_0, …RxF_NC-1)		Indicates the first byte of the packet transmitted by the TPS-TC towards the upper layer in each of the *NC* channels (Note 5).
RX Stop Flags (TxSF_0, …TxSF_NC-1)		Indicates the last byte of the packet transmitted by the TPS-TC towards the upper layer in each of the *NC* channels (Note 5).
RX Clock	Upper layer → TPS-TC	Receive data clock reference.

NOTE 1 – If the RX Enable primitive is turned off during the transfer of a data packet, the MTU-O shall complete the transfer of this data packet.

NOTE 2 – If the TX Enable primitive is turned off during the transfer of a data packet, the upper layer shall complete the transfer of this data packet.

NOTE 3 – The MTU-O shall communicate the received setting of the FCus primitive (Rxon/Rxoff) via the upstream flow control bits in the RMC (see Table 9-5) as soon as possible. The MTU-R shall communicate the setting of the received FCus bits to the NT L2+ layers via the MTU-R TX Enable primitive as soon as possible. The status of the FCus primitive may change from one logical frame to the next.

NOTE 4 – The Tx_Avbl primitive is cleared after all user data packets are collected by the TPS-TC or discarded by the upper layer.

NOTE 5 – The flag also indicates the corresponding channel ID.

The data flow primitives defining the transmit and receive data transferred across the γ reference point at each of the MTU-O and MTU-R are summarized in Table 8-3.

Table 8-3 – Data flow primitives across the γ reference point

Primitive	Direction	Description
STREAMds	L2+ → TPS-TC	MTU-O transmit data, includes *NCds* channels (see clause 5-5)
	TPS-TC → L2+	MTU-R receive data, includes *NCds* channels
STREAMus	L2+ ← TPS-TC	MTU-O receive data, includes *NCus* channels
	TPS-TC ← L2+	MTU-R transmit data, includes *NCus* channels (see clause 5-5)

The data flow primitives given in Table 8-3 are shown in Figure 8-3.

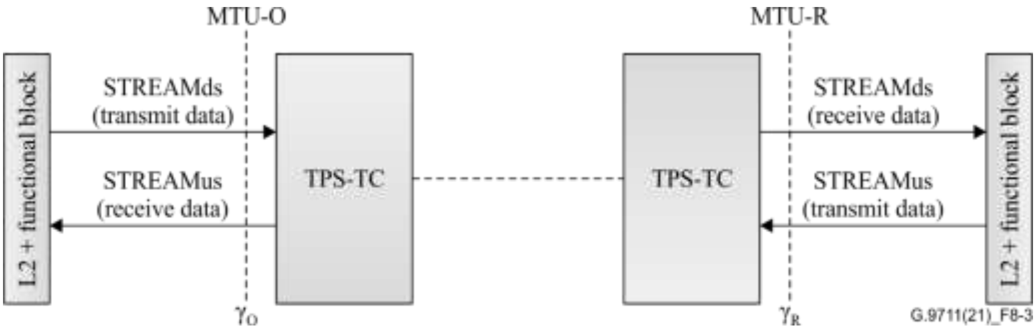


Figure 8-3 – Data flow primitives

At the MTU-O side, the upper layers include the control functionality required for coordination of the resource allocation, vectoring and timing (DRA, VCE and TCE functionality, respectively, as described in clause 5.1 and as shown in Figure 5-2) over various transceivers operating over the lines in the vectored group.

The DRA primitives at the γ_O reference point are summarized in Table 8-4. The physical implementation of these primitives is vendor discretionary.

The DRA primitives at the γ_R reference point are summarized in Table 8-5. The physical implementation of these primitives is vendor discretionary.

Table 8-4 – DRA related primitives of the data flow at the γ_O reference point

Primitive name (parameters)	Direction	Description
TXOPds.indicate ($TBUDGET_{ds}$, TTR_{PSFds}, TTR_{NPSFds}, TA_{ds}, IDF_{ds}, T_B1_{ds}, TA_B1_{ds}, $TDOI_{ds}$ $DTFOCtrl_{ds}$)	DRA → MTU-O	Indicates that the MTU-O shall be configured with downstream transmission opportunities according to the values of the $TBUDGET_{ds}$, TTR_{PSFds}, TTR_{NPSFds} $TA_{ds,}$ IDF_{ds}, T_B1_{ds}, $TA\_B1_{ds,}$, $TDOI_{ds}$, and $DTFOCtrl_{ds}$ parameters (defined in clause 10.7).
TXOPus.indicate ($TBUDGET_{us}$, TTR_{PSFus}, TTR_{NPSFus}, TA_{us}, IDF_{us}, T_B1_{us}, TA_B1_{us}, $TDOI_{us,}$, $DTFOCtrl_{us}$)	DRA → MTU-O	Indicates that the MTU-O shall communicate the configuration of the upstream transmission opportunities to the MTU-R according to the values of the $TBUDGET_{us}$, TTR_{PSFus}, TTR_{NPSFus}, TA_{us}, IDF_{us}, T_B1_{us}, TA_B1_{us}, $TDOI_{us}$ and $DTFOCtrl_{us}$ parameters (defined in clause 10.7).
DRRus.request (N_{DRR}, N_{RM})	DRA → MTU-O	Requests the MTU-O to send the values of N_{DRR} (Note 1) and N_{RM} (Note 2) to the MTU-R (see clause 11.2.2.16).
DRRus.confirm	MTU-O → DRA	Confirms that the MTU-R is configured with the

Table 8-4 – DRA related primitives of the data flow at the γ_O reference point

Primitive name (parameters)	Direction	Description
		N_{DRR} value requested by the DRRus.request primitive.
DRRus.indicate (DRRus)	MTU-O → DRA	Indicates the upstream dynamic resource report (defined in Table 9-17) as indicated by the MTU-R in the last sent upstream RMC message.
DRRus.config.request (DRRdata)	DRA → MTU-O	Requests the MTU-O to send the far-end DRR configuration request data to the MTU-R (defined in clause 11.2.2.16).
DRRus.config.confirm (DRRdata)	MTU-O → DRA	Far-end DRR configuration confirmation data in response to the DRRconfig.request primitive.
LinkState.request (LinkState)	DRA → MTU-O	Requests the link to either transition to or remain in the link state indicated by the LinkState parameter: L0, or L3 (see clause 12.1.1). Upon a change of the LinkState parameter, the link shall transition to the indicated new link state (Note 3).
LinkState.confirm (LinkStateResult)	MTU-O → DRA	Confirms that the requested link state is valid and has been accepted (LinkStateResult = LinkState) or that the requested link state change is invalid or could not be completed (LinkStateResult = FAIL).
DBR-R.request (direction, *SA*, *SDI*, CNT_{LF})	DRA->MTU-O	Requests the link to modify either the upstream P2MPOB or the downstream P2MPOB at the downstream logical frame count CNT_{LF}.
DBR-Rbidir.request(SA_{ds}, SDI_{ds}, SA_{us}, SDI_{us}, CNT_{LF})	DRA->MTU-O	Request the link to modify both the upstream P2MPOB and the downstream P2MPOB at the downstream logical frame count CNT_{LF}.
NOTE 1 – N_{DRR} is a parameter received by the MTU-O over the γ_O reference point indicating the time interval in logical frame periods between sequential upstream dynamic resource reports. It is communicated over the eoc to the MTU-R. The MTU-R generates a DRRus.request primitive every N_{DRR} logical frame periods. NOTE 2 – N_{RM} is a parameter received by the MTU-O over the γ_O reference point indicating the size of the resource metric in the DRRus command (see Table 9-17). It is communicated over the eoc to the MTU-R (see Table 11-52). NOTE 3 – The set value of the primitive shall be consistent with the rules of link state transitions defined in Table 12-1.		

If the MTU-O receives a TXOPds.indicate primitive during the downstream logical frame with $CNT_{LF,ds} = N$, the MTU-O shall transmit at downstream symbol positions according to this new configuration of downstream transmission opportunities starting from the downstream logical frame with $CNT_{LF,ds} = N + 2$.

If the MTU-O receives a TXOPus.indicate primitive during the downstream logical frame with $CNT_{LF,ds} = N + M_{SF}$, the MTU-O shall ensure that the MTU-R transmits at symbol positions according to this new upstream transmission opportunities configuration starting from the upstream logical frame with $CNT_{LF,us} = N + 3$ via proper communication of the upstream logical frame configuration request (see clause 9.6.4, Table 9-5 and Table 9-7) and operating procedure per clause 10.7.

If the MTU-O receives a DRRus.request primitive, the MTU-O shall use the eoc commands defined in clause 11.2.2.16 to indicate the new N_{DRR} value to the MTU-R. Upon receiving an acknowledgement of this new N_{DRR} value from the MTU-R, the MTU-O shall generate a DRRus.confirm primitive. The valid values of N_{DRR} shall be all integer values in the range from 0 to

M_{SF}, with N_{DRR} = 0 indicating that the MTU-O shall not generate DRRus.indicate primitives. The MTU-O and MTU-R shall support all valid values of N_{DRR}.

If the MTU-O receives a DRRus.config.request primitive from the DRA function, the MTU-O shall use the procedure defined in clause 11.2.2.16 to indicate the DRR configuration request data to the MTU-R. Upon receiving an acknowledgement from the MTU-R, the MTU-O shall generate a DRRus.config.confirm primitive to the DRA function with the DRR configuration confirmation data. The DRRus configuration request/confirmation data are transported transparently through the MTU-O.

If the MTU-O receives an upstream dynamic resource report (DRRus) in the upstream RMC of the upstream logical frame with $CNT_{LF,us} = N$, the MTU-O shall generate a DRRus.indicate primitive with this DRRus no later than during the upstream logical frame with $CNT_{LF,us} = N + 2$.

Table 8-5 – DRA related primitives at the γ_R reference point

Primitive name (parameters)	Direction	Description
DRRus.request	MTU-R → L2+	MTU-R request for an upstream dynamic resource report from the L2+ functionality in the NT.
DRRus.confirm (DRRus)	L2+ → MTU-R	Upstream dynamic resource report from the L2+ functionality in the NT sent to the MTU-R.
DRRus.indicate (N_{DRR}, N_{RM})	MTU-R → L2+	Indicates the values of N_{DRR} and N_{RM}.
DRR.config.request (DRRdata)	MTU-R → L2+	The DRR configuration request data.
DRR.config.confirm (DRRdata)	L2+ → MTU-R	The DRR configuration confirmation data.
LinkState.indicate (LinkState)	MTU-R → ME-R	Indication of the current link state: L0 or L3 (see clause 12.1.1).

Upon configuration of the N_{DRR} and N_{RM} values using the eoc commands defined in clause 11.2.2.16, the MTU-R shall indicate the configured values for N_{DRR} and N_{RM} to the L2+ function through the DRRus.indicate primitive. The MTU-R shall generate a DRRus.request primitive every N_{DRR} logical frame periods. If N_{DRR} = 0, the MTU-R shall not generate DRRus.request primitives. The latency in the L2+ functionality between receiving a DRRus.request primitive and generating the DRRus.confirm primitive (including the upstream dynamic resource report (DRRus) of N_{RM} bytes length) shall be constant and shall be no greater than one logical frame period.

If the MTU-R receives a DRRus.confirm primitive during the upstream logical frame with $CNT_{LF,us} = N$, the MTU-R shall transmit the DRRus in the RMC no later than during the upstream logical frame with $CNT_{LF,us} = N + 2$.

If the MTU-R receives DRR configuration request data through the eoc commands defined in clause 11.2.2.16, the MTU-R shall generate a DRRus.config.request primitive to pass the DRR configuration request data to the L2+ function. Upon receiving a DRRus.config.confirm primitive from the L2+ function, the MTU-R shall send an acknowledgment to the MTU-O with the DRR configuration confirmation data. The DRR configuration request/confirm data are transported transparently via the MTU-R.

The NTR and ToD related primitives at the γ reference point (see clauses 8.4 and 8.5 respectively, and see Figure 8-13) are presented in Table 8-6 for MTU-O and in Table 8-7 for the MTU-R. The primitives also indicate whether ToD and NTR are enabled and the synchronization option to be used.

Table 8-6 – ToD and NTR related primitives at the γ_O reference point

Primitive name (parameters)	Direction	Description
NTR_mc	TCE → MTU-O	The 8-kHz NTR clock sourced by the DP (master NTR clock).
NTR_FS_enbl	TCE → MTU-O	Indicates whether NTR frequency synchronization is enabled or not. This primitive is set at initialization.
ToD_mc_value	TCE → MTU-O	The value of ToD sourced by the TCE at the DPU associated with the ToD_mc_edge.
ToD_mc_edge	TCE → MTU-O	The instant of time associated with ToD_mc_value sourced by the TCE at the DPU.
ToD_mc	TCE → MTU-O	The ToD master clock, multiple of 8 kHz sourced by the TCE at the DPU.
ToD_enbl	TCE → MTU-O	Indicates whether ToD is enabled or not. This primitive is set at initialization.
ToD_FS_enbl	TCE → MTU-O	Indicates whether ToD frequency synchronization is enabled or not. This primitive is set at initialization.

Table 8-7 – ToD and NTR related primitives at the γ_R reference point

Primitive name (parameters)	Direction	Description
NTR_sc	MTU-R → TCE	Recovered NTR clock (slave clock).
ToD_sc_value	MTU-R → TCE	Recovered value of ToD at the NT associated with the ToD_sc_edge.
ToD_sc_edge	MTU-R → TCE	The instant of time associated with ToD_sc_value at the NT.
ToD slave clock	MTU-R → TCE	The recovered ToD clock at the NT (slave clock).

8.1.2 α reference point

The α reference point describes a logical interface of the data plane between the TPS-TC and PMS-TC sub-layers. The data at the α reference point in both transmit and receive directions is a stream of DTUs. The format of the DTU is unified for all types of TPS-TC, and is defined in clause 8.2. In the transmit direction, DTUs shall be sent across the α reference point in the same order in which user data packets sourcing these DTUs have entered the TPS-TC across the γ reference point.

Table 8-8 summarizes the DTU flow control primitives that cross the α reference point.

Table 8-8 – DTU flow control primitives at the α reference point

Primitive	Direction	Description
TX DTU Req	PMS-TC → TPS-TC	Primitive indicating that the PMS-TC is requesting a DTU from the TPS-TC (Note 1).
Dummy DTU Req		Primitive indicating that the PMS-TC is requesting a dummy DTU from the TPS-TC (Note 1).
Dummy DTU Ind	TPS-TC → PMS-TC	Primitive indicating that the DTU passed to the PMS-TC is a dummy DTU (Note 3).
RX DTU Enable (RX-DTU-Enbl_1, RX-DTU-		Primitive indicating whether the TPS-TC is ready to receive or not a DTU associated with channel K from the PMS-TC (Note 2).

Table 8-8 – DTU flow control primitives at the α reference point

Primitive	Direction	Description
Enbl_2,… RX-DTU-Enbl_NC-1)		
DTU QoS grade tag		The tag contains the QoS grades of the packets encapsulated in the DTU.
NOTE 1 – The TX DTU Req primitive is turned off if the PMS-TC is unable to receive a DTU (e.g., the DTU queue is full). The PMS-TC shall raise the Dummy DTU Req primitive if PMS-TC requires a dummy DTU (see clause 8.2.2) instead of a data DTU. NOTE 2 – The TPS-TC shall turn the RX DTU Enable primitive off in case the TPS-TC cannot receive DTUs from the PMS-TC, e.g., when the RX Enable primitive is off at the γ_O or γ_R reference point, respectively. NOTE 3 – The TPS-TC shall send a dummy DTU to the PMS-TC and raise the Dummy DTU Ind primitive when either: – The TX DTU Req primitive is turned on, but no DTU filled with user data or management data is available, or – The Dummy DTU Req primitive is turned on.		

In the receive direction, DTUs shall be sent across the α reference point in the order that they are recovered (and possibly partially re-ordered) by the PMS-TC.

NOTE – The re-ordering within the PMS-TC, if applied, should not prevent packets associated with higher grades to be sent by the TPS-TC at the first opportunity, to facilitate potentially stringent requirements on maximum latency for high QoS classes.

8.1.3 TPS-TC_MGMT interface

The TPS-TC_MGMT reference point (see Figure 8-1 for MTU-O and Figure 8-2 for MTU-R) is a logical interface between the TPS-TC and the MME. The TPS-TC gets control and management data via this reference point from the MME and returns to the MME the relevant TPS-TC management parameters to be reported. This reference point also acts as the interface for the eoc. The details of the TPS-TC_MGMT primitives are defined in Table 8-9.

Table 8-9 – Summary of the TPS-TC_MGMT primitives

Primitive	Direction	Description
K_{FEC}	MME → TPS-TC	The number of information bytes of a FEC codeword, see clause 9.3.
Q	MME → TPS-TC	The number of FEC codewords in a single DTU, see clause 8.5.
eoc message, TX	MME → TPS-TC	TX eoc message primitives, see clause 11.2.2.
eoc message, RX	TPS-TC → MME	RX eoc message primitives, see clause 11.2.2.
FCus	TPS-TC → MME	Upstream flow control primitive (FCus_0, FCus_1, …, FCus_NC-1) to be communicated over the RMC (see clause 9.6.4 and Table 9-5).
TPS_TESTMODE	MME → TPS-TC	A management primitive initiating the TPS-TC test mode (see clause 9.8.3.1.2).
Symbol count (CNT_{SYMB})	MME → TPS-TC	Count of DMT symbols (see clause 8.2.1.2 and clause 10.6).

8.2 Generic DTU format

A DTU at the α reference point shall contain a DTU header, a DTU payload and an error check sequence (ECS) as shown in Figure 8-4. This format shall be used with all types of TPS-TC. The total number of bytes in a DTU shall be:

$$N_{DTU} = Q \times K_{\mathrm{FEC}}$$

where:

K_{FEC} is the number of information bytes of the FEC codeword;

Q is an integer defining the number of FEC codewords in one DTU.

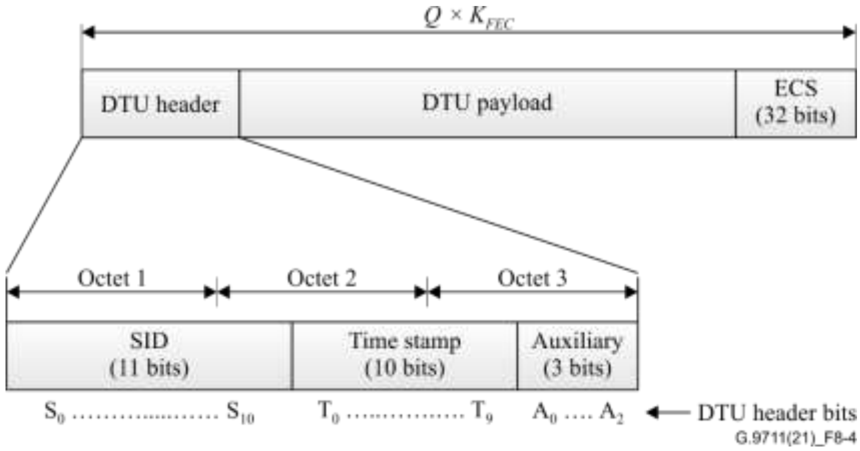


Figure 8-4 – Generic DTU format

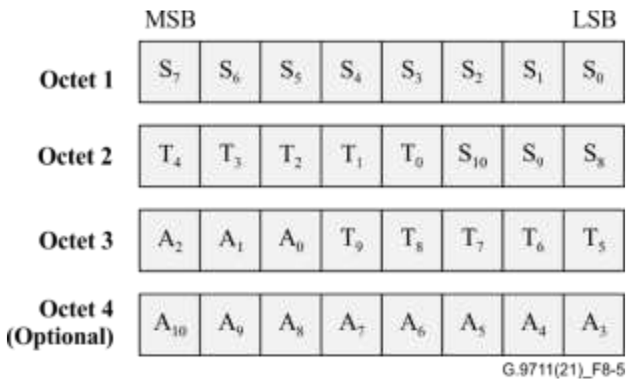


Figure 8-5 – Bit mapping generic DTU header bytes

The valid values for K_{FEC} are defined in clause 9.3. The valid values of Q are all integers from one to the maximum value specified for the selected profile. The selected value of Q depends on the applied FEC codeword size and the required DTU size. The actual values of K_{FEC} and Q are determined during the initialization and provided by the MME across the TPS-TC_MGMT interface (see Table 8-9). The values may be modified during the showtime via OLR procedures (see clause 13).

A dummy DTU shall have the same structure as presented in Figure 8-4.

The size of the DTU in bytes, N_{DTU}, shall meet the following requirement: $0.25 \leq (N_{\mathrm{DTU}}+Q \times R_{FEC})/(B_D) \leq 4$, where B_{D} is the number of DTU bytes allocated in a data frame (see Table 9-2) on which the DTU or a part of the DTU is mapped. The requirement shall be met for PSF NOI with Band 0 active (i.e., B_D=B_{DN0}), $\mathrm{NOI_{PSF}}$ with Band 0 and Band 1 active (i.e., $\mathrm{B_D}$=$\mathrm{B_{DN01}}$), PSF discontinous operation interva (DOI), $\mathrm{NOI_{NPSF}}$ except for RRC symbols (i.e., B_D=0), RMC symbols with Band 0 active (i.e., B_D=B_{DR0}) and RMC symbols with Band 0 and

Band 1 active (i.e., $B_D = B_{DR01}$). The requirement shall be met during the entire time period a particular value of DTU size is set, except short temporary violation, as defined in clause 13.3.1.1.

8.2.1 DTU header

The DTU header shall contain the following fields: a sequence identifier (SID), a time stamp and an auxiliary field. Octets 1, 2, and 3 of the DTU header are mandatory; octet 4 is optional. Octet 4 shall be included in the DTU header only if more than 2 QoS channels are enabled during initialization.

8.2.1.1 Sequence identifier (SID) field

An 11-bit SID field is used to identify the particular DTU in the transmitted sequence of DTUs. The SID of a DTU shall be assigned using a modulo 2048 counter. The transmitter shall increment the SID counter for every newly framed DTU. A retransmitted DTU shall have the same SID as for its first transmission. The SID shall be initialized to 00_{16} and this shall be the SID of the first DTU transmitted in showtime.

The SID of a dummy DTU shall also be assigned, but using a separate modulo 2048 counter that shall be incremented by one for each transmitted dummy DTU. The SID shall be initialized to 00_{16} and this shall be the SID of the first dummy DTU transmitted in showtime.

The SID field in the DTU header is shown in Figure 8-4. The value of the SID shall be coded as an unsigned integer on 11 bits [S_{10} … S_0], where S_0 is the LSB. Mapping of the SID bits to the DTU header bytes is shown in Figure 8-5.

8.2.1.2 Time stamp (TS) field

The TS field of a DTU shall contain the value of the symbol count (see Table 8-9) of the symbol (at the U reference point) that contains the bit S_0 of the header of this DTU, assuming that no retransmission occurs between the framing of the DTU and its transmission over the line. In the event of retransmission, the original time stamp value shall be preserved. The TS field value 1023 is a special value reserved by ITU-T for future use.

The TS field in the DTU header is shown in Figure 8-4. The value of TS shall be coded as an unsigned integer on 10 bits [T_9 … T_0], where T_0 is the LSB. Mapping of the TS bits to the DTU header bytes is shown in Figure 8-5.

8.2.1.3 Auxiliary field

A 5-bit auxiliary information field includes:

- bit [0] – DTU type (0 = normal DTU, 1 = dummy DTU)
- bit [1] – Indicates that at least one DTU frame from the highest QoS grade (Q3) is present in the DTU.
- bit [2] – Indicates that at least one DTU frame from the lowest QoS grade (Q0) is present in the DTU. For this purpose, the DTU frame carrying eoc packets or an idle are treated having the lowest QoS grade.
- bit [3] – Indicates that at least one DTU frame from QoS grade (Q2) is present in the DTU (optional).
- bit [4] – Indicates that at least one DTU frame from QoS grade (Q1) is present in the DTU (optional).
- bits [10:5] –Reserved by ITU-T and set to zero by the transmitter and ignored by the receiver (optional).

NOTE – For each QoS channel configured in the DPU-MIB, the transceiver derives the QoS grade tag from the configured QoS channel characteristics, as described in clause 8.1.

8.2.2 DTU payload

The DTU payload shall contain the data packets and eoc packets to be conveyed by the DTU. The format of the DTU payload and encapsulation of data packets into the DTU payload for a packet-based TPS-TC (PTM-TC) is specified in clause 8.3. The order in which data packets of each QoS grade are encapsulated into a DTU payload shall be the same as the order in which these packets cross the γ reference point. The order in which eoc packets are encapsulated into a DTU payload shall be the same as the order in which these packets enter from the TPS-TC_MGMT interface. Furthermore, the order in which DTUs are sent to the PMS-TC shall be the same order in which DTUs were encapsulated, to provide time integrity of the transmitted user data of each QoS class and eoc data.

Packets of different QoS classes may be encapsulated into DTUs not in the order in which they were collected by the TPS-TC from the corresponding channels at the γ reference point. In particular, the TPS-TC, while respecting the MAXDELAY requirements, may accumulate several packets of the same QoS class after collecting them at the γ reference point and then send them all in a single DTU. This concentration of DTU encapsulation may be a convenient way to reduce the number of QoS grades encapsulated in the same DTU. The use of concentration (how often and to which packets applied) is vendor discretionary.

NOTE – If concentration is used, reordering of packets belonging to different QoS classes may introduce additional latency, which is an offset in the *delay_max* value derived from the MAXDELAY value configured for the particular QoS class in the DPU-MIB (see clause 8.1).

Data packets of each QoS grade and eoc packets received by the peer TPS-TC shall be sent to the application entity (via the γ reference point) or to the MME (via the TPS-TC_MGMT interface) in the same order and via the same QoS channel as they were received via the γ reference point and the TPS-TC_MGMT interface, respectively, at the transmit end.

8.2.3 Error check sequence (ECS)

The ECS field is for DTU verification. The ECS shall contain a 32-bit cyclic redundancy check (CRC) that shall be computed over the DTU header and DTU payload bytes in the order that they are transmitted, starting with the LSB of the first byte of the DTU header (SID field in clause 8.2.1.1) and ending with the most significant bit (MSB) of the last byte of the DTU payload.

The ECS shall be computed using the following generator polynomial of degree 32:

$$G(D) = D^{32}+D^{28}+D^{27}+D^{26}+D^{25}+D^{23}+D^{22}+D^{20}+D^{19}+D^{18}+D^{14}+D^{13}+D^{11}+D^{10}+D^{9}+D^{8}+D^{6}+1$$

The value of ECS shall be the remainder after all bits of the DTU subject to CRC treated as an input polynomial, are multiplied by D^{32} and then divided by $G(D)$. For a t-bit input polynomial, the CRC shall be computed using the following equation:

$$crc(\mathrm{D}) = M(D) \times D^{32} \text{ modulo } G(D),$$

where:

$M(D)$ $= m_0D^{t-1} + m_1D^{t-2} + \ldots + m_{t-2}D + m_{t-1}$ is the t-bit polynomial where m_0 is the LSB of the first byte of the header and m_{t-1} is the MSB of the last byte of the DTU payload,

$crc(D)$ $= crc_0D^{31} + crc_1D^{30} + \ldots + crc_{30}D + crc_{31}$ is the CRC polynomial where crc_0 is the LSB of the first byte of the ECS field and crc_{31} is the MSB of the last byte of the ECS field, and

D is the delay operator.

The arithmetic in this clause shall be performed in the Galois Field GF(2).

8.3 Packet-based TPS-TC (PTM-TC)

8.3.1 PTM-TC DTU format

The generic format of a DTU is presented in Figure 8-4. This clause defines the format of the DTU payload that shall be used for a PTM-TC DTU. The format of the DTU payload is shown in Figure 8-6.

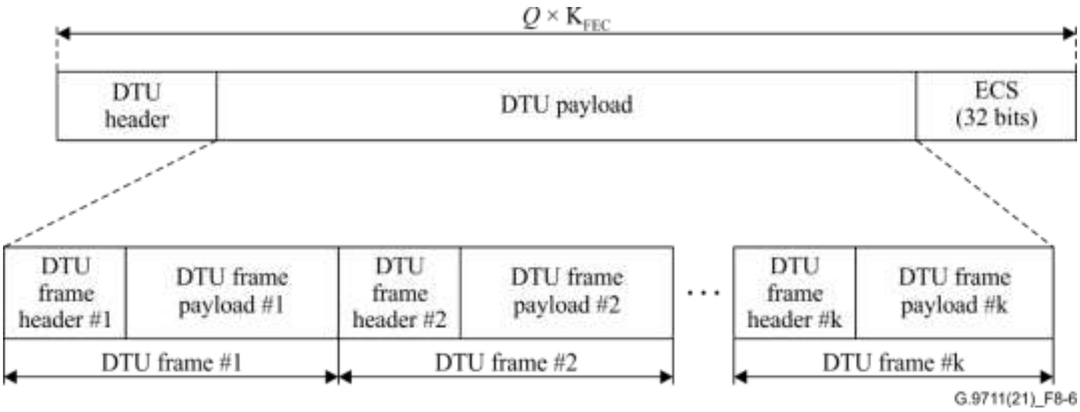


Figure 8-6 – PTM-TC DTU payload format

The DTU payload consists of a number of DTU frames, each DTU frame containing a DTU frame header and DTU frame payload.

The DTU frame header shall be either one byte or two bytes long and indicates:

– the type of the DTU frame and its QoS grade coded on four bits [t_3 t_2 t_1 t_0], where t_0 represents the LSB;

– the length of the DTU frame payload in bytes coded as either a 4-bit [l_3 ... l_0] or a 12-bit [l_{11}...l_0] unsigned integer, where l_0 represents the LSB.

The valid DTU frame types are presented in Table 8-11. The DTU frame type is indicated by the first four least significant bits of the DTU frame header. The length of the DTU frame header and maximum length of the DTU frame payload depends on the DTU frame type. For all DTU frame types except idle DTU frame, the length of the DTU frame header is extended to indicate longer DTU frame payloads.

The format of the DTU frame header is presented in Table 8-10 and Figure 8-7.

Table 8-10 – Format of the DTU frame header

Header byte number	Format (Note 1)
1 (Note 2)	[l_3 l_2 l_1 l_0 t_3 t_2 t_1 t_0]
2 (Note 2)	[l_{11} l_{10} l_9 l_8 l_7 l_6 l_5 l_4]
NOTE 1 – The LSB of each byte is represented at the right side. NOTE 2 – For an idle DTU frame, bits [l_3 l_2 l_1 l_0] shall be set to 0000, and the second byte shall not be present.	

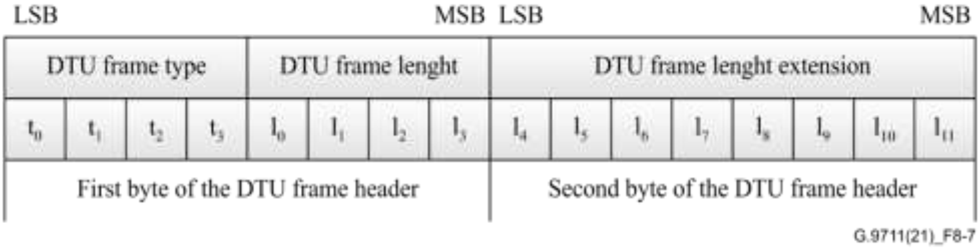


Figure 8-7 – Format of the DTU frame header

The valid DTU frame types and their coding are described in Table 8-11.

Table 8-11 – PTM-TC frame type and coding

DTU frame type	Coding $[t_3t_2t_1t_0]$	Header extension	Valid length (bytes) (Note)
Idle	0000	No	N/A
Complete data packet of QoS grade Q0	1110	Yes	1- 4071
Complete data packet of QoS grade Q1	0011	Yes	1- 4071
Complete data packet of QoS grade Q2	0101	Yes	1- 4071
Complete data packet of QoS grade Q3	0111	Yes	1- 4071
Complete eoc packet	1111	Yes	1- 1024
Start of data packet of QoS grades Q0-Q3	1100	Yes	1- 4071
Start of eoc packet	1101	Yes	1- 1024
Continuation of the packet (data of QoS grades Q0-Q3 or eoc)	1000	Yes	1- 1023 for eoc packet 1- 4070 for data packet
End of the packet (data of QoS grades Q0-Q3 or eoc)	1010	Yes	1- 1024 for eoc packet 1- 4071 for data packet
Reserved by ITU-T	All other values	N/A	N/A
NOTE – The maximum DTU size is 255 × 16 = 4080 bytes, and there is a minimum overhead of nine bytes (three bytes DTU header, four bytes ECS and two bytes DTU frame header). The component values in the maximum DTU size are as follows: 255 = maximum length in bytes of the FEC codeword, 0 = the minimum number of redundancy bytes in the FEC codeword and 16 is the maximum number of FEC codewords in one DTU as defined in Table P.1 and Table Q.1. With this, the maximum valid length of DTU frame is 4071 bytes.			

An idle DTU frame shall only be used as the last frame of the DTU payload, with the length equal to the number of remaining bytes of the DTU payload. The payload of an idle DTU frame is vendor discretionary. An idle DTU frame may follow any other type of DTU frame in the DTU payload. If no other DTU frame type is available for the DTU payload, an idle DTU frame shall be the only frame of the DTU payload.

A DTU generated in response to a dummy DTU request (see Table 8-8) shall contain only an idle DTU frame and shall always be marked as a dummy DTU in the auxiliary field of the DTU header.

A DTU generated in response to a TX DTU Req (see Table 8-8) and containing only an idle DTU frame shall be marked as either a dummy DTU or a normal DTU depending on the control parameter TPS_TESTMODE (see Table 8-9).

If the TPS-TC is configured with TPS_TESTMODE disabled, a DTU generated in response to a TX DTU Req primitive and containing only an idle DTU frame shall be marked as a dummy DTU in the auxiliary field of the DTU header (see clause 8.2.1.3) except if only dummy DTUs have been transmitted over the α reference point during a time interval equal to the duration of one superframe. In this last case, the DTU shall be marked as a normal DTU (using the SID of normal DTU) carrying a DTU frame with QoS grade Q0, and the count of time shall be reset.

NOTE 1 – This mechanism guarantees a minimum background rate of normal DTUs for performance monitoring purposes.

If the TPS-TC is configured with TPS_TESTMODE enabled, a DTU generated in response to a TX DTU Req primitive and containing only an idle DTU frame shall be marked as a normal DTU carrying a DTU frame with QoS grade Q0, in the auxiliary field of the DTU header (see clause 8.2.1.3).

All DTUs marked in the DTU header as dummy DTUs shall be discarded by the receiver. All idle DTU frames shall be identified at the receiver by decoding the DTU frame type (in the DTU frame header) and shall be discarded by the receiver.

The payload of a complete data packet DTU frame shall consist of the original user data packet. The payload of a complete eoc packet DTU frame shall consist of an eoc packet. If the original user data packet or eoc packet is bigger than the remaining space available in the given DTU payload or bigger than a payload of the entire DTU, it shall be spread over several DTUs using the following DTU frame types:

- start of data/eoc packet, followed by
- one or more continuation of this packet, followed by
- end of this packet.

Examples of packet split between DTUs for transmission in case only packets of a single QoS grade (QoS grade Q0) are being transmitted is shown in Figure 8-8.

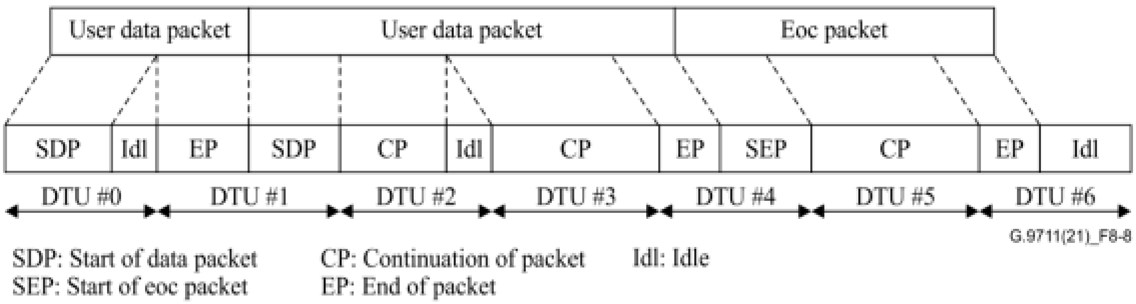


Figure 8-8 – Example of mapping of packets for transmission in DTUs

In Figure 8-8, the last DTU frame or the DTU frame preceding an idle DTU frame in the DTU payload may include a part of a data or eoc packet – this is indicated by a start of data packet DTU frame or start of eoc packet DTU frame, respectively, or continuation of the packet DTU frame. If used, the first frame of the next DTU payload shall be a continuation of the packet DTU frame, or an end of the packet DTU frame, or an idle DTU frame.

Data packets that are longer than a single DTU shall be transmitted in parts; the first part shall be transmitted in a start of data packet DTU frame. This shall be followed by zero, one or more continuation of the packet DTU frames, followed by an end of the packet DTU frame. The same applies for eoc packets.

A start of data packet, start of eoc packet or continuation of the packet DTU frame shall be either the last frame of a DTU payload or the frame preceding an idle DTU frame.

In case multiple QoS grades are used in a DTU, the DTU frames shall be placed in the DTU payload so that frames with higher QoS grade are always placed before the frames with lower QoS grade, with eoc DTU frames treated as being part of the lowest QoS grade (i.e., QoS grade Q0).

If there are any DTU frames of the highest QoS grade (i.e., grade Q3) present in the DTU, they shall always be placed at the start of the DTU. If a continuation of data packet DTU frame or end of data packet DTU frame belonging to the highest QoS grade (e.g., grade Q3) is pending, it shall be placed at the start of the DTU. The end of packet DTU frame (if there is a pending one) may be followed by complete data packets DTU frames belonging to the highest QoS grade, which may be followed by a start of data packet of that QoS grade. If the last DTU frame belonging to the highest QoS grade is an end of packet or a complete data packet, it shall be followed by all DTU frames belonging to the next lower QoS grade in the DTU (e.g., grade Q2). If there is a DTU frame continuation of data packet or a DTU frame end of data packet pending that belongs to this QoS grade, it shall be placed after the DTU frames of the highest QoS grade. The end of packet DTU frame (if one has been appended) of this QoS grade may be followed by complete data packets DTU frames belonging to the same QoS grade, which may be followed by a start of data packet of the same QoS grade. If the last DTU frame belonging to the second-highest QoS grade is an end of packet or a complete data packet, it shall be followed by all DTU frames belonging to the next lower QoS grade in the DTU (e.g., grade Q1), and so on, following the same structure as for the highest and second-highest QoS grades.

With the above, if the last DTU frame of the previous DTU is a DTU frame start of data packet or continuation of data packet of the QoS grade QX, the associated DTU frame end of data packet or continuation of data packet shall be placed right after DTU frames of QoS grades that are higher than QX, if present, in one of the following DTUs, on the first opportunity.

NOTE 2 – With the rules above, DTU frames start of data packet and continuation of data packet always belong to the lowest QoS grade used in this DTU.

A number of examples for the case of mandatory support of two QoS grades are presented in Figure 8-9. The particular QoS grade shown for each DTU frame is indicated by either the frame type (see Table 8-11) or can be derived from the auxiliary field of the DTU header (see clause 8.2.1.3).

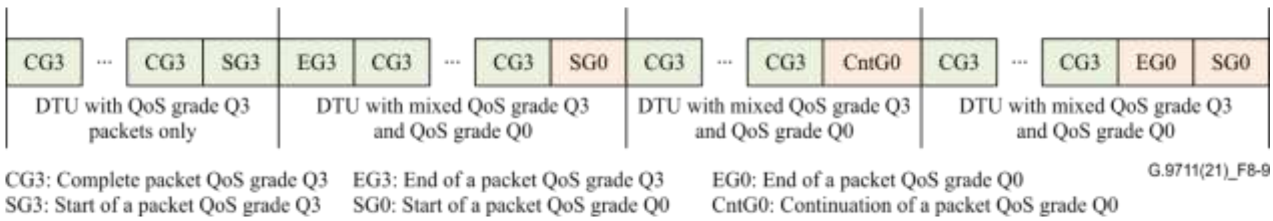


Figure 8-9 – Examples of DTU mappings for mandatory QoS grades (grade Q0 and grade Q3)

A number of examples for the case of optional support of four QoS grades are presented in Figure 8-10a. The particular QoS grade shown for each DTU frame is indicated by either the frame type (see Table 8-11) or derived from the auxiliary field of the DTU header (see clause 8.2.1.3).

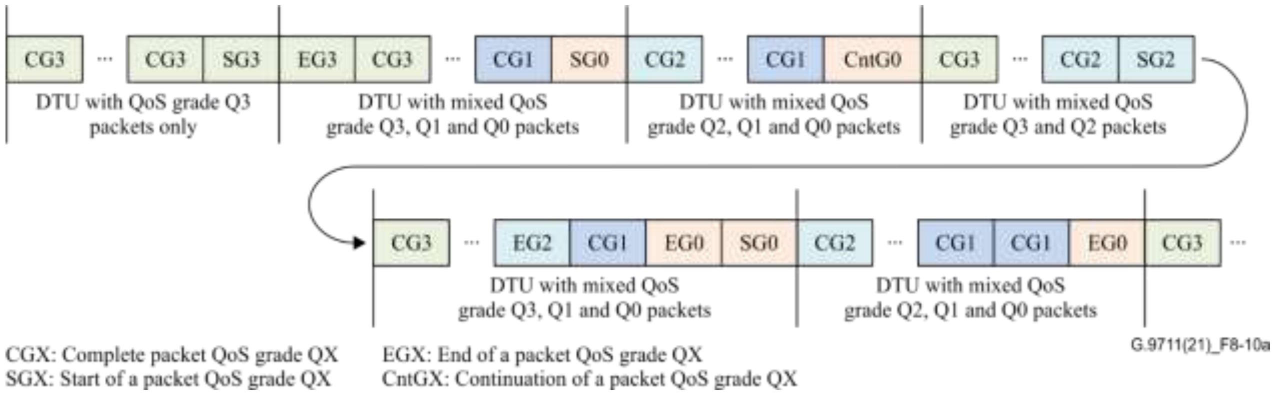


Figure 8-10a – Examples of DTU mappings for optional QoS grades (grades Q0, Q1, Q2, and Q3)

An example of eoc packet transmission with priority over data packets of all QoS grades, is presented in Figure 8-10b. It illustrates how the eoc packet gets strict priority over all QoS grades while being transmitted as a QoS grade Q0.

At the start of the DTU #1, three new data packets of QoS grade Q3, two new data packets of QoS grade Q0 and no eoc packets are available, while one data packet of QoS grade Q0 is already partially transmitted in the previous DTU and pending. During transmission of the DTU #1, one data packet with QoS grade Q3 is transmitted and the second data packet with QoS grade Q3 is started when the TPS-TC ME generates an eoc packet.

At the start of the next DTU (DTU #2), accordingly, the partially transmitted data packet of QoS Grade Q3 is completed first, and the pending data packet of QoS grade Q0 is completed right after. Then, the eoc packet, despite considered as of QoS grade Q0 and a QoS grade Q3 packet is waiting, is transmitted, followed by the start of the new QoS grade Q0 packet, which is inserted to fulfil the DTU#2. The remaining packets of QoS grade 3 and QoS grade 0 are transmitted in the following DTUs (DTU #3 and DTU #4), the using the normal priority rule.

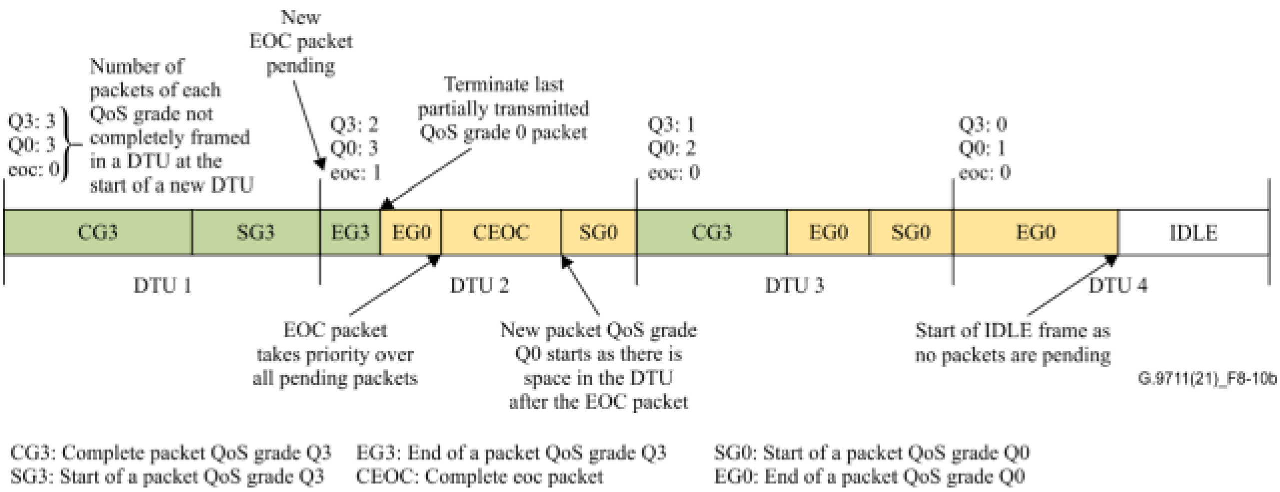


Figure 8-10b – Example of transmission of eoc packet with priority over all QoS grades

Complete eoc packet, start of eoc packet, continuation of packet (for an eoc packet), and end of packet (for an eoc packet) DTU frames, as well as complete packets of different QoS grades, shall be identified at the receiver by decoding the DTU frame type; the recovered eoc packet shall be forwarded to the MME (via the TPS-TC_MGMT interface). If a DTU carrying a part of a packet is lost, the TPS-TC shall discard all other received parts of this packet. Inside a DTU, all DTU frames containing eoc data shall be contiguous.

8.4 Network timing reference (NTR)

8.4.1 NTR transport

The 8-kHz NTR transport shall be performed after both the MTU-O and the MTU-R reach showtime and the MTU-R PMD sample clock is locked to the MTU-O PMD sample clock. Two cases may apply:

– the MTU-O PMD sample clock is locked to the NTR;

– the MTU-O PMD sample clock is independent of the NTR (free running).

If the MTU-O PMD sample clock is locked to the NTR, the MTU-R shall obtain its local 8-kHz NTR by direct division of the recovered PMD sample clock by an appropriate number. No action from the MTU-O is required.

If the MTU-O PMD sample clock is running independently of the NTR, the MTU-O shall facilitate frequency synchronization between the NTR at the MTU-O and the MTU-R as described in clause 8.4.1.1.

The MTU-O shall indicate to the MTU-R during the initialization whether the PMD sample clock is locked to the NTR or not (see clause 12.3.4.2.3).

8.4.1.1 NTR frequency synchronization

For NTR transport, the MTU-O shall generate an 8 kHz local timing reference (LTR) by dividing its PMD sample clock by an appropriate number. Furthermore, the MTU-O shall estimate the phase offset (φ) between the NTR and the LTR at time event t_1 of each superframe with an odd superframe count. The timing of the phase offset estimation is presented in Figure 8-11. Time event t_1 is defined as the time position of the reference sample in the downstream FDS sync symbol of the superframe; see the definition of the reference sample in clause 8.5.1 and Figure 8-14, and the definition of time event t_1 in Figure 8-15.

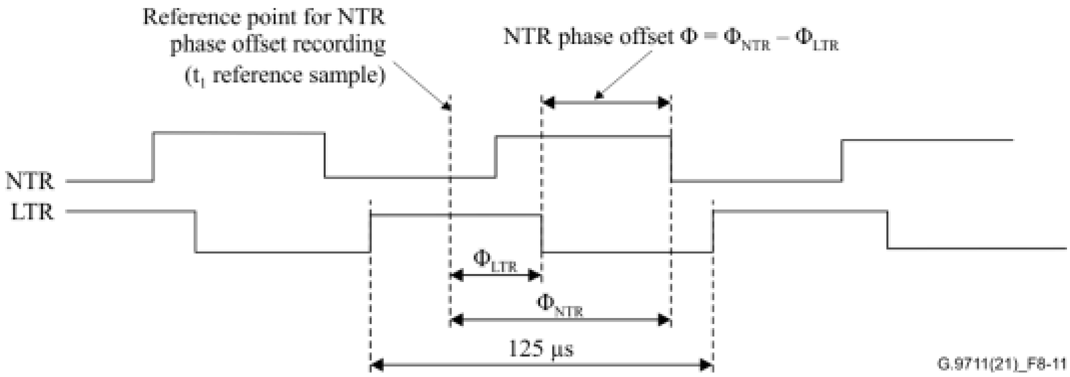


Figure 8-11 – NTR phase offset estimation

The estimated value of the NTR phase offset (φ) shall be expressed in cycles of a clock running at a reference frequency $F_S = 8192 \times f_{SC}$ (see clause 10.4.2).

The obtained value of φ shall be coded using the following rule:

$$coded\_value = \left(floor(\varphi + A)\right) \text{ MOD } (A)$$

$$A = 8192 \times f_{sc}/8000 = 52992$$

The coded value of φ shall be transmitted to the MTU-R using the NTR frequency synchronization eoc command (coded as a two-byte unsigned integer (see clause 11.2.2.7)). The eoc message shall be sent over the TPS-TC_MGMT interface as soon as possible but no later than 6 ms after the reference sample at which the NTR phase offset is measured.

Figure 8-12 shows the NTR offset recording and communication timeline.

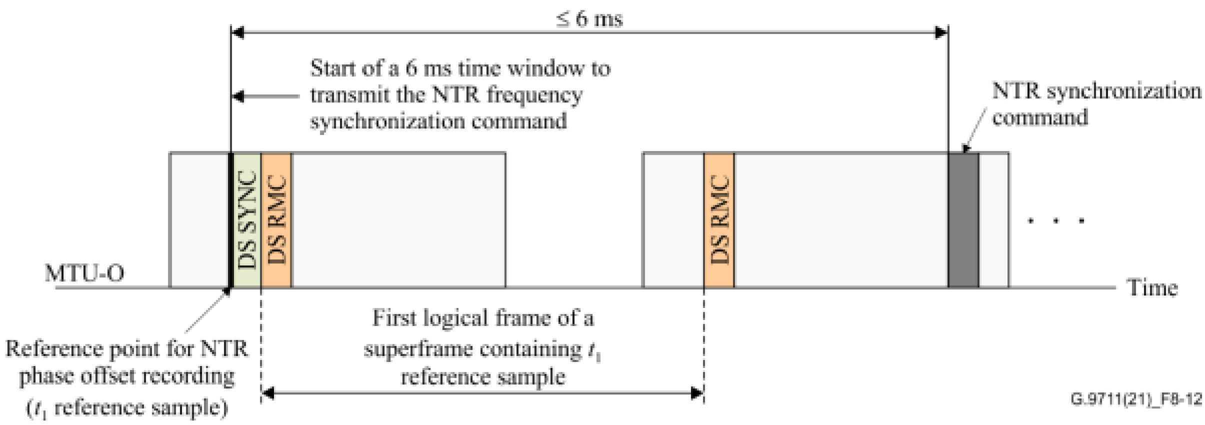


Figure 8-12 – NTR offset recording and communication timeline

The MTU-R shall reconstruct the 8 kHz NTR from the received values of the NTR phase offset.

NOTE – The MTU sample clock is proportional to the subcarrier spacing f_{SC}. Therefore, the LTR, being proportional to the sample clock, will have the same ±50 ppm frequency variation as f_{SC} (see clause 10.4.2). The NTR has a maximum frequency variation of ±32 ppm, thus the maximum difference in frequency between the NTR and the LTR will not exceed 82 ppm. This would result in a maximum NTR phase offset change between two subsequent reference points for NTR recording of $82 \times 10^{-6} \times 2T_{SF}$ = 0.984 µs if T_{SF} = 6 ms, where T_{SF} is the duration of the superframe (see clause 10.6). This is 0.8% of the 125 µs NTR period.

8.5 Time-of-day (ToD)

Transport of ToD from the MTU-O to the MTU-R shall be supported in order to support services that require accurate ToD at both sides of the ITU-T G.9711 link to operate the higher layers of the protocol stack.

The TCE at the DP is responsible for providing ToD reference primitives to all MTU-Os of the DPU (see Figure 5-2). The MTU-Os, in turn, shall support a capability to transport the ToD primitives to the peer MTU-Rs, which provide TCEs of the associated NTs with a local ToD synchronized with the DP (see Figure 5-3). The ToD transport to each particular MTU-R is enabled during the initialization (see clause 12.3.4.2) if the associated NT requires ToD and the network side provides it (see clause 12.3.4.2.3).

NOTE 1 – Exchange of information from the MTU-R to the MTU-O related to the quality of the ToD frequency and/or time recovery at the MTU-R is for further study.

NOTE 2 – Exchange of relevant clock information related to the transfer of ToD from its original source in the access node to the NT to support the ToD interface output from the NT is for further study. For precision time protocol (PTP) [b-IEEE 1588], this information includes source traceability, number of hops and leap seconds.

NOTE 3 – The γ_O to γ_R ToD accuracy requirements are for further study, but expected to be better than 50 ns.

8.5.1 Time-of-day distribution operational overview

Figure 8-13 shows the system reference model identifying the key elements in support of ToD transport across an ITU-T G.9711 link. The MTU-O receives a ToD signal from the master clock within the TCE at the DPU across the γ_O interface. The MTU-R outputs a ToD signal across the γ_R interface to the slave clock within the TCE at the NT. The ToD transport provides the slave clock at the MTU-R, which is synchronous in frequency, phase and time to the master clock. The ToD signal components provided by the master clock at the MTU-O include a time-of-day value (*ToD_mc_value*) associated with a clock edge (*ToD_mc_edge*) that is synchronous to the master clock's internal driving frequency. The ToD_mc_edge shall provide at least one edge per second. A derivative of the master clock driving frequency (f_{mc}) shall be available to the MTU-O and shall be at least 8 kHz and shall be frequency and phase synchronized with the *ToD_mc_edge* to facilitate time-of-day transport processing in the MTU-O. Similarly, the ToD signal at the MTU-R shall include a slave clock time-of-day value (*ToD_sc_value*) together with corresponding time edge marker (*ToD_sc_edge*) that is synchronous to the driving frequency of the master clock. A derivative of the slave clock driving frequency (f_{sc} in Figure 8-13) may be available from the MTU-R to facilitate time-of-day transport processing.

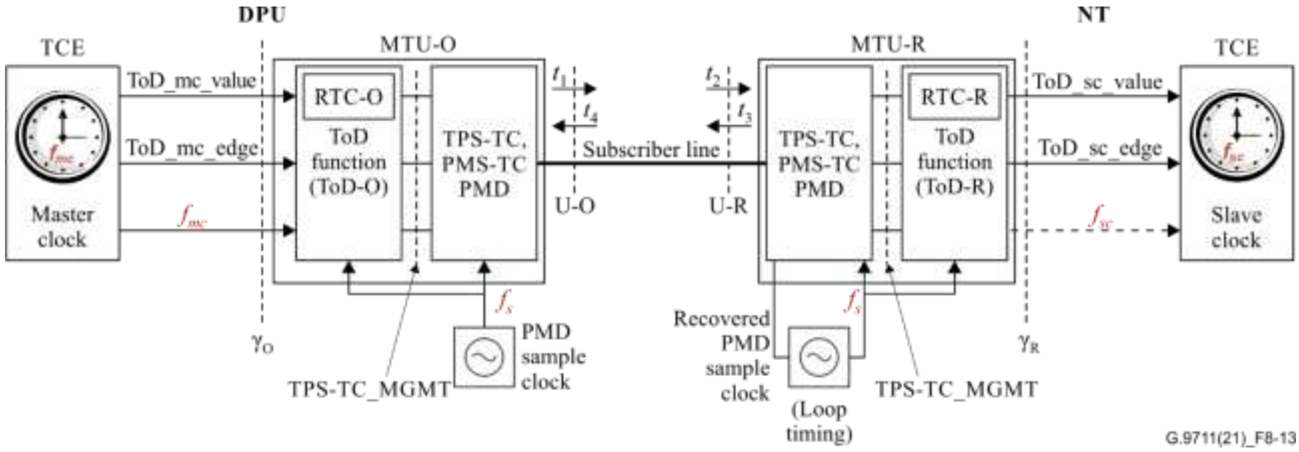


Figure 8-13 – End-to-end system reference model for time-of-day transport

The ToD functions of the MTU-O and MTU-R are denoted in Figure 8-13 as ToD-O and ToD-R, respectively. The ToD-O shall maintain a real-time clock (RTC-O) which is synchronized by frequency and phase with the incoming ToD signal (master clock). The ToD-R shall maintain a real-time clock (RTC-R) that initially has an arbitrary frequency, and phase; during the showtime, the RTC-R get synchronized by frequency and phase with the RTC-O using the time stamps of events t_1, t_2, t_3, t_4, as described in this clause. The RTC-O shall run at a frequency that is an integer multiple of 8 kHz with a frequency of at least f_s (PMD sample clock, see Figure 8-13), with time adjustment to the master clock at each f_{mc} edge.

The MTU-R's PMD sample is assumed to be frequency locked with the MTU-O's PMD sample clock through loop timing in the MTU-R. To record the time stamps in each of the upstream and downstream transmit signals, a reference sample for each direction of transmission is defined as the first time-domain representation sample (see Figure 8-14) of the corresponding sync symbol of the PSF in the superframe period assigned for ToD synchronization. The reference samples associated with the time events t_1, t_2, t_3 and t_4 in a superframe assigned for ToD synchronization are shown in Figure 8-15.

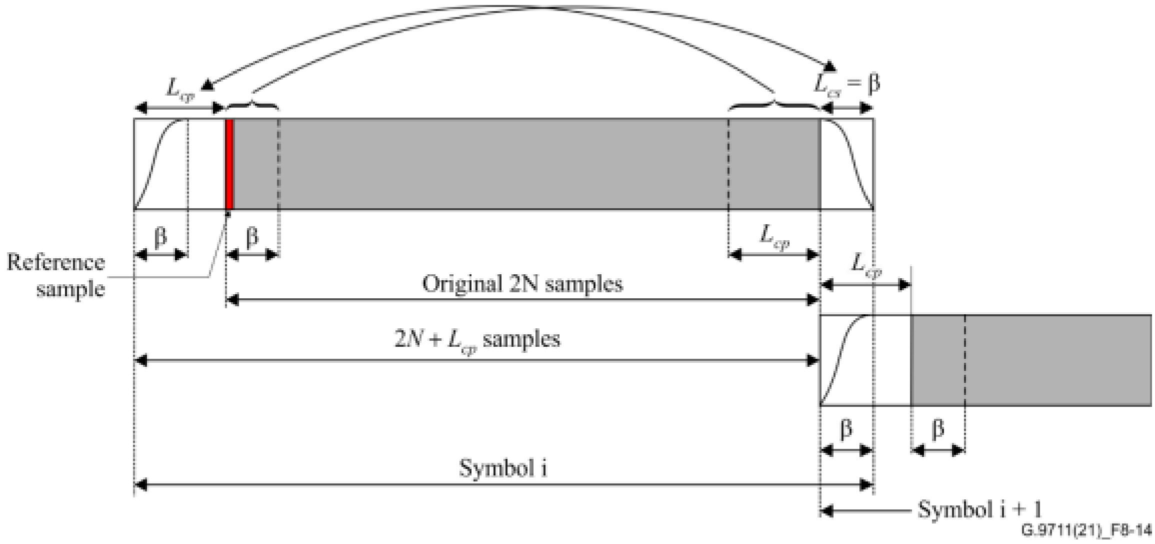


Figure 8-14 – Definition of reference sample in a symbol *i* (see clause 10.4.4 for details)

At the downstream sync symbol in the FDS of each superframe assigned for ToD transport, the PMD in the MTU-O identifies the moment at which the reference sample of the sync symbol crosses the U-O interface (event t_1) and the moment (within the same PDX frame) that the reference sample of the received upstream sync symbol in the FUS crosses the U-O interface (event t_4); at the instants that each of these two events occur, the ToD-O records the corresponding ToD values of its RTC-O (see Figure 8-16) to apply a time stamp to each of the respective events t_1 and t_4. Additionally, for event t_1 of each superframe with an odd superframe count, the MTU-O computes the ToD phase difference ($\Delta\phi$), as defined in clause 8.5.2. The RTC-O provides the time base used for applying time stamps and measurement of $\Delta\phi$ for ToD frequency synchronization.

The values of $\Delta\phi$, and t_1 and t_4 time stamps are transmitted to the MTU-R using, respectively, the ToD frequency synchronization eoc command and time synchronization eoc command (see clauses 11.2.2.8 and 11.2.2.9, respectively). The corresponding eoc message shall be sent over the TPS-TC_MGMT interface as soon as possible, but not later than 6 ms after the start of the first downstream logical frame of the superframe in which the reported events are recorded (see Figure 8-15).

Similarly, in the same superframe (see Figure 8-15), the PMD in the MTU-R identifies the moment at which the reference sample of the downstream sync symbol in the FDS crosses the U-R interface (event t_2) and the reference sample of the upstream sync symbol in the FUS crosses the U-R interface (event t_3); at the instants that each of these two events occur, the ToD-R records the corresponding time of the RTC-R to apply a time stamp to each of the respective events t_2 and t_3. The ToD-R processes ToD phase difference $\Delta\phi$ and the time stamp values of events t_1, t_2, t_3 and t_4 so as to synchronize in frequency, phase and time its local RTC-R to the MTU-O's RTC-O.

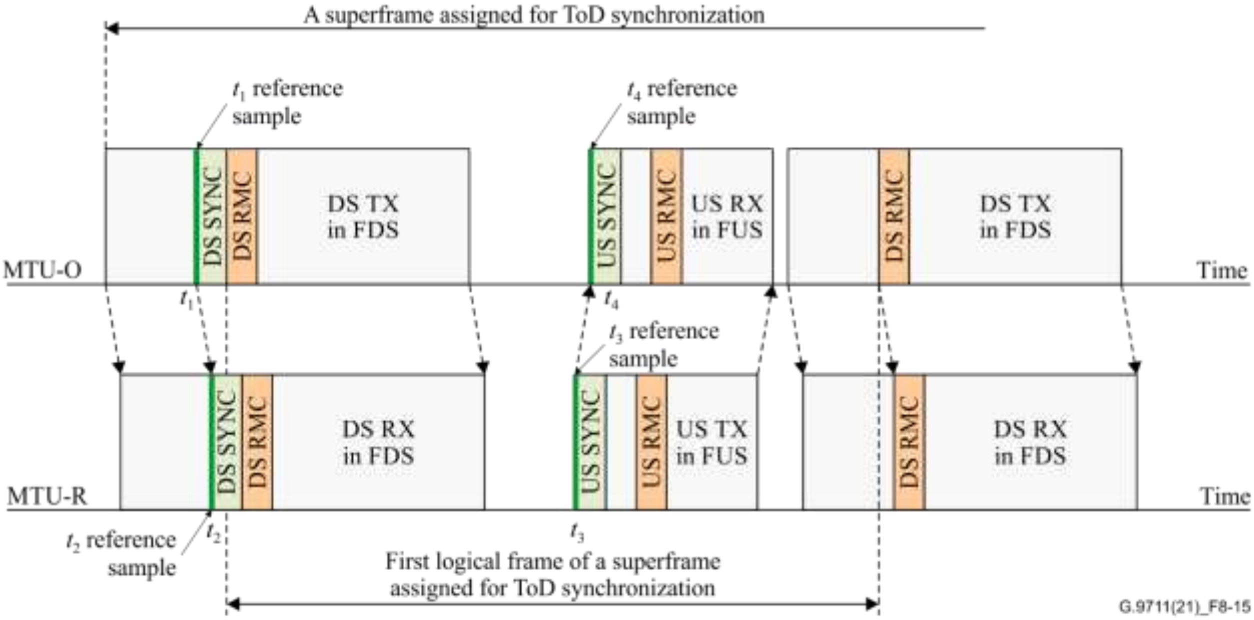


Figure 8-15 – Reference samples of events t_1, t_2, t_3, t_4 and a timeline of eoc command transmission

8.5.2 ToD frequency synchronization

The ToD-O and ToD-R shall implement functionality with the objective of synchronizing the RTC-R to the RTC-O in frequency, phase and time. Two methods are defined to achieve ToD frequency synchronization:

- ToD frequency synchronization through locking the PMD sample clock with the ToD frequency (f_{mc}): the MTU-R shall achieve frequency synchronization through loop timing, or
- Frequency synchronization using ToD phase difference values: the MTU-R achieves frequency synchronization through processing of ToD phase difference values $\Delta\phi$ measured at the MTU-O and communicated from the MTU-O to the MTU-R by the ToD frequency synchronization eoc command (see clause 11.2.2.8).

The ToD frequency synchronization method is determined by the MTU-O and communicated to the MTU-R during the initialization (see clause 12.3.4.2.3).

8.5.2.1 Computation of ToD phase difference

The MTU-O shall compute the value of $\Delta\phi$ using the RTC-O time base at every superframe with odd superframe count. The computed value $\Delta\phi$ and the superframe count for which this value of $\Delta\phi$ was recorded, shall be communicated to the MTU-R using the ToD frequency synchronization eoc command (see clause 11.2.2.8).

Figure 8-16 shows the computation of the ToD phase difference value ($\Delta\phi$). The top row in the figure represents the 8 kHz RTC-O clock waveform. The second row in the figure represents the superframe clock that is synchronous with the MTU-O's PMD sample clock; the rising edge of the superframe clock represents the t_1 event (the downstream reference sample crosses the U-O reference point) in the superframe $\Delta\phi$ shall be recorded (see Figure 8-15). The value of $\Delta\phi$ shall be recorded in nanoseconds modulo 125 000 ns, counted from the rising edge of the 8 kHz RTC-O clock down to the t_1 event, as shown in Figure 8-16.

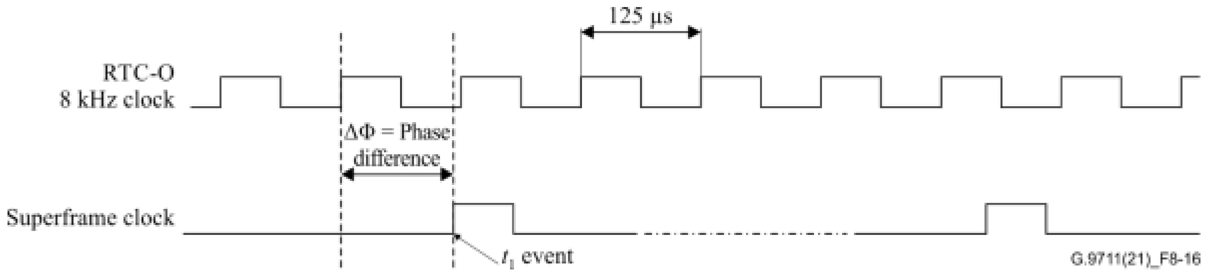


Figure 8-16 – ToD phase difference (Δϕ) computation

For communication via eoc (see clause 11.2.2.8), the recorded value of $\Delta\phi$ shall be divided by two and represented by a 16-bit unsigned integer, where the resolution of the least significant bit is 2 ns.

8.5.3 ToD time synchronization

For each of the defined frequency synchronization methods, the time-of-day synchronization shall be performed through the processing of time stamps of events t_1, t_2, t_3 and t_4 at the defined reference samples (see Figure 8-15). The first ToD time synchronization shall be performed at the 16th superframe of the showtime. Each Time synchronization command indicates the superframe count at which the next ToD time synchronization shall be performed. The time period between two consecutive ToD time synchronization events shall not exceed the value of parameter time synchronization period (TSP) that is set during the initialization (see Table 12-51).

For the superframe with count indicated for ToD time synchronization, the ToD-O shall record the time stamps of events t_1 and t_4 using RTC-O time base and the ToD-R shall record the time stamps of events t_2 and t_3, using the RTC-R time base, as defined in clause 8.5.1 and shown in Figure 8-15. The time stamps shall be represented in the format defined in clause 11.2.2.9.

The MTU-O shall communicate the recorded time stamps using Time synchronization command together with the superframe count associated with these events and the superframe count of the following ToD time synchronization. The command shall be sent in the time frame defined in clause 8.5.1.

Using the obtained values of time stamps ToD(t_1) through ToD(t_4) for events t_1, t_2, t_3 and t_4 of the same superframe assigned for ToD time synchronization, the ToD-R shall compute the time offset τ between the locally assigned time stamp ToD(t_2) and actual ToD time value of the event t_2 using the following equation:

$$\tau = \frac{\left(ToD(t_2) - ToD(t_1)\right) - \left(ToD(t_4) - ToD(t_3)\right)}{2}$$

The ToD-R passes the synchronized ToD signal value *ToD_sc_value*, together with the corresponding timing edge marker (*ToD_sc_edge*) and possibly a slave clock frequency f_{sc} across the γ_R interface to the TCE function of the MTU-R. The time stamp values ToD(t_2) and ToD(t_3) are sent back to the MTU-O in the Time synchronization response (see clause 11.2.2.9). The MTU-O passes these time stamps over the γ_O reference point to the TCE of the MTU-O. The use of these time stamps by the TCE is beyond the scope of this Recommendation. At the customer premises side, propagation delay asymmetry shall not be compensated for.

NOTE 1 – The ToD(t_2), ToD(t_3) time stamps (in conjunction with other information) may be used at the DPU e.g., for verification purposes or to compensate for propagation delay asymmetry.

NOTE 2 – The above computation of the offset value is based on the assumption that the downstream and upstream propagation delays between the U-O and U-R reference points are approximately the same. Any asymmetry in the propagation delay between the U-O and U-R reference points will result in an error in calculation of the offset value whose magnitude is approximately:

$$|error| = \left|\frac{(upstream\_propagation\_delay)-(downstream\_propagation\_delay)}{2}\right|$$

9 Physical media specific transmission convergence (PMS-TC) sub-layer

9.1 Functional reference model

Figure 9-1 shows the functional reference model of the PMS-TC. DTUs enter the PMS-TC via the α reference point. The incoming DTUs are scrambled, encoded using a Reed-Solomon FEC code, and interleaved using a block interleaver.

The PMS-TC also provides an RMC and retransmission return channel (RRC). The RMC carries acknowledgements for the DTUs received during the entire PDX frame (see clause 9.7) and delay-sensitive management data sourced from the MME and submitted to the PMS-TC via the PMS-TC_MGMT interface. The RMC message that includes acknowledgement data and management data communicated over the RMC is formatted by the RMC framer. The RMC message is encoded using a Reed-Solomon FEC code. The RRC is enabled only when transceiver is in FDX mode. The RRC message carries acknowledgement data for a few recently received DTUs, with the aim of reducing the roundtrip delay; the acknowledgement information is submitted to the PMS-TC via the PMS-TC_MGMT interface. The RRC message is formatted by the RRC framer and protected using a CRC-16 code.

The bytes of encoded DTUs (from the DTU buffer at the DTU interleaver output) are multiplexed with the bytes of the RMC frames (from the RMC buffer at the RMC encoder output) and with the bytes of the RRC frames (from the RRC buffer at the RRC encoder output) by the data frame multiplexer (data frame MUX) and mapped onto data frames that are further transferred to the PMD via the δ reference point (see clause 9.5). Each data frame contains an integer number of bytes (from the DTU buffer) to be loaded onto one symbol (see clause 10.5.2). The RMC frame shall be multiplexed together with encoded DTUs into the first data frame in a logical frame; this data frame, referred to as an RMC data frame, shall be further loaded onto an RMC symbol (see clause 10.5.5). All other data frames of a logical frame, referred to as normal data frames, shall carry RRC frame together with encoded DTUs. The time position of the RMC symbol in a PDX frame is defined during the initialization (see clause 12.3.2.1). In the L0 link state, one RMC symbol in each direction shall be transmitted in every PDX frame.

The transmitted DTUs are also stored in a retransmission queue buffer. A retransmission multiplexer (RTX MUX) selects for transmission either a new DTU or a DTU from the retransmission buffer (RTX queue), depending on the received acknowledgement. The DTU queue allows for prioritization of retransmitted DTUs and shall support meeting the delay requirement associated with flow control.

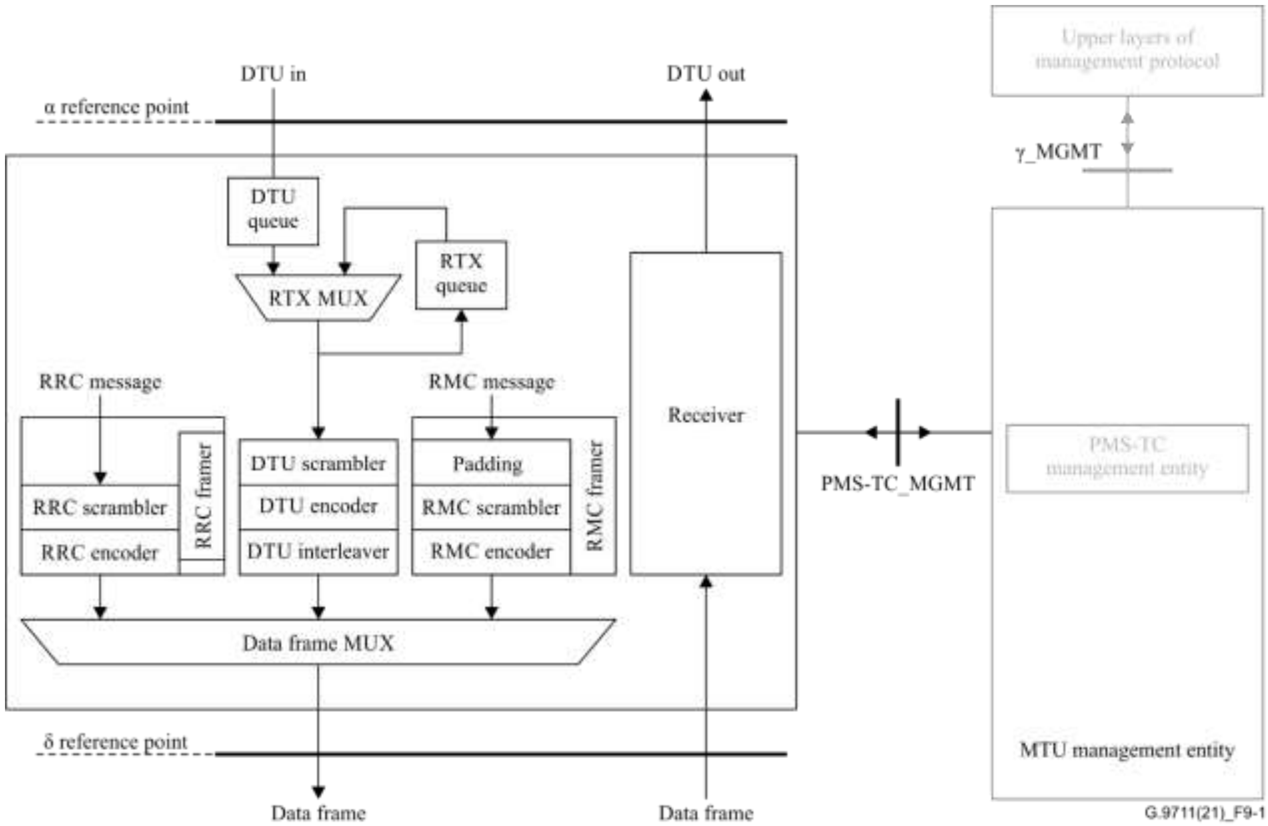


Figure 9-1 – Functional reference model of PMS-TC

NOTE – Figure 9-1 shows the DTU queue, the RTX queue and the RTX MUX between the α reference point and the scrambler for explanatory purposes only. The actual position of the DTU and retransmission buffers in implementations is vendor discretionary and can be at other points of the PMS-TC data transmission path.

In the receive direction, RMC frames and DTUs are recovered from the received data frames crossing the δ reference point. The recovered DTUs are de-interleaved, decoded, descrambled and checked for errors. Based on the error check, the PMS-TC generates acknowledgements to the peer MTU that indicate DTUs received error free; DTUs not acknowledged shall be retransmitted as defined in clause 9.8. Errored DTUs shall be discarded by the receiver. If the received DTU is error free and all relevant DTUs with smaller SIDs are also received error free or have timed out (see clause 9.8), the received DTU shall be passed to the TPS-TC via the α reference point. Otherwise, the received DTU is buffered until these conditions mentioned above are met. The maximum delay corresponding to parts of DTUs associated with different QoS grades may be different. Therefore, the same DTU may be passed to the TPS-TC at different times, in order to extract packets before their contents expire. The format of the acknowledgement and related rules are defined in clause 9.7. If the RX Enable primitive is set to RXoff, the PMS-TC of the MTU-O may send a negative acknowledgement to a DTU received correctly to avoid overloading of the receiver retransmission buffer (see clauses 8.1 and 8.1.1).

The recovered RMC frames and RRC frames are decoded and descrambled, and the received management parameters are passed to the MME via the PMS-TC_MGMT interface. Acknowledgements that are received error free are used to schedule retransmissions. Acknowledgements received in error shall be discarded. Management data received error free is used to manage and control the link.

If the downstream RMC frame is received in error, the values of TTR_{us}, $TBUDGET_{us}$, TA_{us}, TTR_{NPSFus}, $TDOI_{us}$, IDF_{us}, and $DTFO_{us}$ for the upstream transmission shall be same as the values indicated in the last correctly received RMC frame.

9.1.1 δ reference point

The δ reference point describes a logical interface of the data plane between the PMS-TC and PMD sub-layers. The data at the δ reference point in both transmit and receive directions is a stream of data frames. Two types of data frames are defined: data frames carrying RRC and DTUs (normal data frames) and data frames carrying RMC and DTUs (RMC data frame), both defined in clause 9.5.

In the transmit direction, the PMS-TC shall deliver a data frame to the PMD when the PMD sets the TX Enable primitive.

In the receive direction, the PMS-TC shall accept a data frame when the PMD sets the RX Enable primitive.

The timing of data frame transfers to and from the PMD is determined by the TX and RX clock sourced by the PMD: each transferred data frame is associated with a particular transmitted symbol or a particular received symbol, respectively (RMC symbol, data symbol, idle symbol or quiet symbol, as defined in clause 10.5). The flow control primitives describing data frame transfer are shown in Table 9-1.

Table 9-1 – Data frame flow control primitives at the δ reference point

Primitive	Direction	Description
TX Enable (TX Data Req)	PMD → PMS-TC	Primitive indicating that the PMD is requesting to receive the data frame from the PMS-TC (Note 1)
RX Enable	PMD → PMS-TC	Primitive indicating that a valid data frame (normal data frame or RMC data frame) is ready at the PMD for transfer to the PMS-TC
TX RMC	PMD → PMS-TC	Primitive indicating the RMC symbol position (start of the logical frame)
TX and RX clock	PMD → PMS-TC	Data frame transfer clock reference (symbol timing)
Data frame disabled	PMS-TC → PMD	Primitive indicating that an idle data frame is transferred by the PMS-TC (Note 2)
NOTE 1 – The TX Enable primitive shall only be turned off during the data frames associated with symbol position on which transmission is not allowed: those are *TA* symbol positions, symbol positions exceeding the allocated *TBUDGET*, sync symbol positions, and symbol positions assigned exclusively for opposite direction of transmission. NOTE 2 – Idle data frame is a normal data frame that contains only dummy DTUs and no RRC bytes; it is sent if no data is available for transmission and may be removed by the receiver PMD; on the symbol positions indicated by the data frame disabled primitive, the PMD may transmit either a data symbol, an idle symbol or a quiet symbol, using the rules described in clause 10.7.		

During the showtime, one data frame is pulled from the PMS-TC every symbol position assigned for transmission (see NOTE 1 in Table 9-1). The PMS-TC identifies the type of the data frame (RMC data frame or normal data frame) and also whether the normal data frame is for the NOI_{PSF} with only Band 0 or both Band 0 and Band 1 active, for the NOI_{NPSF} or for the DOI, based on the TX RMC primitive and the parameters of the logical frame (see clause 10.7). The size of these frames may be different (due to different bit loading in the corresponding symbols).

In the transmit direction, data frames shall be sent across the δ reference point in the same order as the packets encapsulated into the DTUs of these data frames (DTUs to be retransmitted are sent across the δ reference point prior to new DTUs – see clause 9.8). In the receive direction, data frames shall be sent across the δ reference point in the order that they are recovered by the PMD.

9.1.2 PMS-TC_MGMT interface

The PMS-TC_MGMT reference point describes a logical interface between the PMS-TC and the MME (see Figure 9-1). The interface is defined by a set of control and management parameters (primitives). These parameters are divided into two groups:

– parameters generated by the MME and applied to the PMS-TC;

– parameters retrieved by the PMS-TC from the received data frames and submitted to the PMS-TC ME.

The summary of the PMS-TC_MGMT primitives is presented in Table 9-2.

Table 9-2 – Summary of the PMS-TC_MGMT primitives

Primitive	Direction	Description
K_{FEC}	MME → PMS-TC	The number of FEC information bytes in the data path, see clause 9.3.
R_{FEC}	MME → PMS-TC	The number of FEC redundancy bytes in the data path, see clause 9.3.
Q	MME → PMS-TC	The number of FEC codewords in a single DTU, see clause 8.2.
K_{RMC}	MME → PMS-TC	The number of FEC information bytes in the RMC path (RMC frame size), see clause 9.6.3.
B_{DR}	MME → PMS-TC	The number of DTU bytes in an RMC data frame, B_{DR0}, B_{DR01} when Band 0 only or both Band 0 and Band 1 are used, respectively, see clause 9.5.
B_D	MME → PMS-TC	The number of DTU bytes in a normal (non-RMC) data frame, B_{DN0}, B_{DN01} in the NOI when Band 0 only or both Band 0 and Band 1 are used, respectively, and B_{DD} in the DOI, see clause 9.5.
N_{RMC}	MME → PMS-TC	The number of RMC bytes in RMC data frame that could be 48 or 80 bytes, see clause 9.6.1.
B_{RRC}	MME → PMS-TC	The number of RRC bytes in a normal data frame that could be 0 or 4 bytes, see clause 9.6.5.
CNT_{LF}	MME → PMS-TC	Logical frame count, see clause 10.5.5.
CNT_{SF}	MME → PMS-TC	Superframe count, see clause 10.6.
RMC message, TX	MME → PMS-TC	TX RMC message primitives, see clause 9.6.4.
RMC message, RX	PMS-TC → MME	RX RMC message primitives, see clause 9.6.4.
RRC message, TX	MME → PMS-TC	TX RRC message primitives, see clause 9.6.8.
RRC message, RX	PMS-TC → MME	RX RRC message primitives, see clause 9.6.8.
RTX_CTRL	MME → PMS-TC	Retransmission control parameters, see clause 9.8.2.
fec anomaly	PMS-TC → MME	See clause 11.3.1.1.
rtx-uc anomaly	PMS-TC → MME	See clause 11.3.1.1.
rtx-tx anomaly	PMS-TC → MME	See clause 11.3.1.1.
lor defect	PMS-TC → MME	See clause 11.3.1.3.

9.2 DTU scrambler

The scrambling algorithm shall be as represented by the equation below; the output bit of data $x(n)$ at the sample time n shall be:

$$x(n) = m(n) + x(n-18) + x(n-23),$$

where $m(n)$ is the input bit of data at the sample time n. The arithmetic in this clause shall be performed in the Galois Field GF(2).

The scrambler states shall be reset to all ONES before inputting the first bit of each DTU (the LSB of the SID field, see clause 8.2.1.1).

Incoming bytes shall be input to the scrambler LSB first. All bytes of every incoming DTU shall be scrambled.

9.3 DTU encoder

After scrambling, the DTU shall be fed into the DTU encoder.

A standard byte-oriented Reed-Solomon code shall be used for FEC. A FEC codeword shall contain $N_{FEC} = K_{FEC} + R_{FEC}$ bytes, comprised of R_{FEC} check bytes $c_0, c_1, ..., c_{R_{FEC}-2}, c_{R_{FEC}-1}$ appended to K_{FEC} data bytes $m_0, m_1, ..., m_{K_{FEC}-2}, m_{K_{FEC}-1}$. The check bytes shall be computed from the data bytes using the equation:

$$C(D) = M(D)D^{R_{FEC}} \bmod G(D)$$

where:

$M(D) = m_0 D^{K_{FEC}-1} \oplus m_1 D^{K_{FEC}-2} \oplus ... \oplus m_{K_{FEC}-2} D \oplus m_{K_{FEC}-1}$ is the data polynomial,

$C(D) = c_0 D^{R_{FEC}-1} \oplus c_1 D^{R_{FEC}-2} \oplus ... \oplus c_{R_{FEC}-2} D \oplus c_{R_{FEC}-1}$ is the check polynomial, and

$G(D) = \prod (D \oplus \alpha^i)$ is the generator polynomial of the Reed-Solomon code, where the index of the product runs from $i = 0$ to R_{FEC}-1.

The polynomial $C(D)$ is the remainder obtained from dividing $M(D)D^{R_{FEC}}$ by $G(D)$. The arithmetic in this clause shall be performed in the Galois Field GF(256), where α is a primitive element that satisfies the primitive binary polynomial $x^8 \oplus x^4 \oplus x^3 \oplus x^2 \oplus 1$. A data byte $(d_7, d_6, ..., d_1, d_0)$ is identified with the Galois Field element $d_7\alpha^7 \oplus d_6\alpha^6 \oplus ... \oplus d_1\alpha \oplus d_0$.

Parameters N_{FEC}, K_{FEC} and R_{FEC} shall be programmable.

The valid values of R_{FEC} are 0, 2, 4, 6, 8, 10, 12, 14 and 16.

The valid values of N_{FEC} are all integers from 32 to 255, inclusive. An MTU shall support all combinations of valid values of R_{FEC} and N_{FEC}.

The FEC encoder RS(N_{FEC}, K_{FEC}) shall insert R_{FEC} redundancy bytes after every K_{FEC} bytes, counting from the first byte of the DTU. The DTU size after FEC encoding is $Q \times N_{FEC}$ bytes.

The valid values of FEC encoding parameters for the RMC are specified in clause 9.6.3.

9.4 Interleaver

The interleaver shall apply block interleaving to each encoded DTU using the following rules. The interleaving block shall have a size of $Q \times N_{FEC}$ bytes (Q is the number of FEC codewords per DTU, Q = 1 corresponds to no interleaving).

Each byte B_k within an interleaving block (input at position k, with index k ranges between zero and $Q \times N_{FEC} - 1$) shall be located at the output of the interleaving function at position l given by the equation:

$$l = i \times Q + j,$$

where:

$i =$ k MOD N_{FEC}; and

$j =$ floor(k / N_{FEC}).

Operation of the block interleaver is illustrated in Figure 9-2.

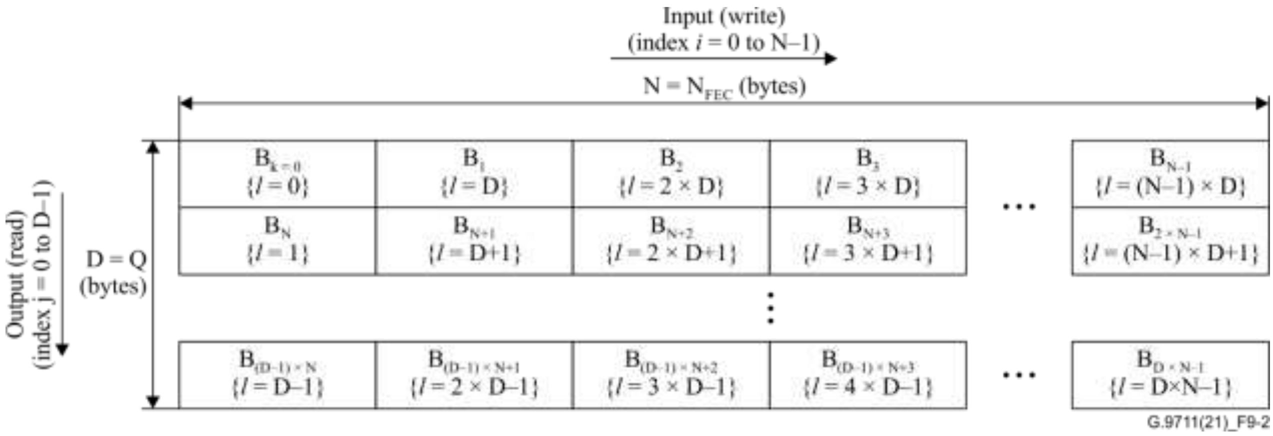


Figure 9-2 – Illustration of the block interleaver ($D = Q$ and $N = N_{FEC}$)

9.5 Data frame multiplexer

In showtime, the data frame multiplexer (data frame MUX) generates data frames by multiplexing an RMC frame (see clause 9.6.1), the RRC frames, and bytes of the encoded and interleaved DTUs extracted from the DTU buffer based on the primitives received from the PMD layer over the δ interface (see Table 9-1).

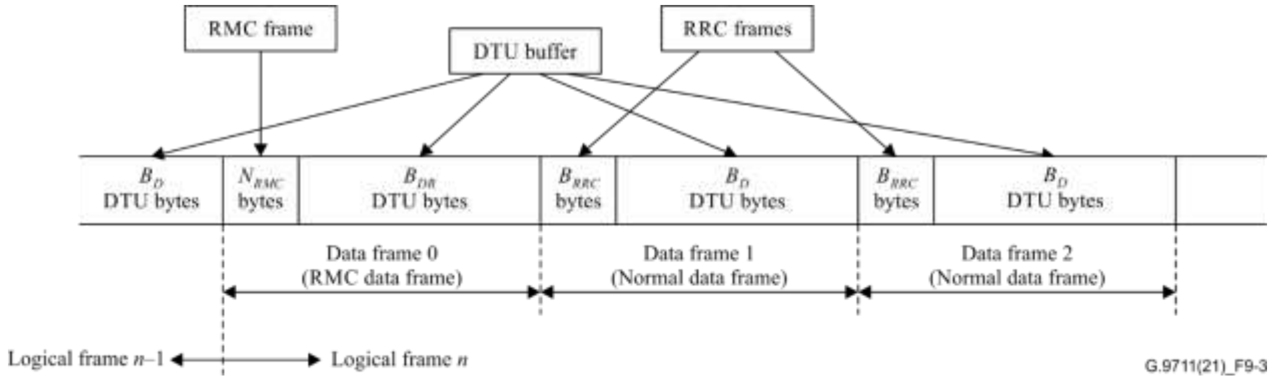


Figure 9-3 – Multiplexing of RMC frame, RRC frames, and DTUs into data frames

At every symbol position on which the PMD sets the Tx Data Req primitive, the data frame MUX shall generate one data frame and transfer it over the δ interface. The PMD may decide to not set Tx Data Req at certain symbol positions, as explained in clause 9.1.1. At these symbol positions, no data frame shall be generated.

The content of the data frame depends on the symbol type and position inside the logical frame. The first symbol position of the logical frame is called RMC symbol position (see clause 10.5.5) and shall be indicated by the Tx RMC primitive. The index of the RMC symbol position in the logical frame is zero. Afterwards, the symbol position index shall be incremented each time the Tx Clock primitive is received until the end of the logical frame. All symbol positions within a logical frame following the RMC symbol positions are called data symbol positions, except the sync symbol positions (see clause 10.6) and symbol positions that are not allowed for transmission (e.g., assigned for transmission in opposite direction when in TDD mode).

At the RMC symbol position (i.e., symbol index zero), the generated data frame shall be an RMC data frame. The RMC data frame shall contain an RMC frame of N_{RMC} bytes followed by B_{DR} bytes extracted from the DTU buffer. The total number of bytes in an RMC data frame is $B_R = (B_{DR} + N_{RMC})$. Figure 9-3 shows multiplexing of an RMC frame and bytes of DTUs into data frames. The first byte extracted from the DTU buffer of the first RMC data frame after transition into showtime shall be the first byte of a DTU (i.e., the first byte of the first DTU to be transmitted). The value of B_{DR} may be different depending on the symbol type transmitted on RMC symbol position, denoted B_{DR0} if only Band 0 is used and B_{DR01} if both Band 0 and Band 1 are used (see clause 10-5).

At data symbol positions (i.e., indices greater than zero) the generated data frame shall be a normal data frame. A normal data frame shall start from an RRC frame of B_{RRC} bytes followed by B_D bytes extracted from the DTU buffer. The value of B_D may be different for symbol positions of the NOI and the DOI, depending on the symbol type. The values of B_D in the NOI are denoted B_{DN0} *and* B_{DN01} if only Band 0 or both Band 0 and Band 1 are used, respectively. The value of B_D in the DOI is denoted B_{DD} (since both Band 0 and Band 1 are transmitted in all DOI data symbols, see clause 10.7.3).

In FDX mode, transmission of RRC frame of B_{RRC} bytes shall be supported in any normal data frame that is capable of carrying B_{RRC} bytes, including those filled with dummy DTUs and those with B_D=0. Each normal data frame shall carry at least B_{RRC} bytes. Use of normal data frames with B_D=0 is determined at initialization (see Table 12-46) and can be allowed for NPSF only and only if RRC is enabled. A normal data frame with B_D=0 is loaded on RRC symbols, encoded as described in clause 10.2.1.8. If use of normal data frame with B_D=0 (and RRC symbols, accordingly) is set, all symbol positions in NPSF on which data transmission is allowed in the corresponding transmission direction, shall be filled with RRC symbols. Use of normal data frames with B_D=0 can be modified by the OLR (SRA and FRA, see clauses 13.2 and 13.3) to normal data frame with B_D > 0 if bit-loading capacity of NPSF is sufficient; in this case RRC symbols in NPSF are replaced with data symbols.

NOTE 1 – If RRC is enabled, a normal data frame may either carry only RRC bytes (B_D=0) or RRC bytes and data bytes (user data or eoc) in an amount of at least 0.25 of a DTU. Use of less data bytes is inconsistent with the requirement in clause 8.2 and not allowed.

In TDD mode, B_{RRC} = 0 (RRC is disabled).

The RMC bytes shall be loaded into the RMC data frame in the order determined by the RMC frame format, specified in clause 9.6.1. The RRC bytes shall be loaded into the RMC data frame in the order determined by the RRC frame format, specified in clause 9.6.5. The DTU bytes shall be loaded into the data frame in the order determined by the DTU format, specified in clause 8.3.1.

If the current normal data frame and all subsequent normal data frames to be generated until the end of the logical frame consist only of dummy DTUs or split dummy DTUs (an idle data frame), the data frame disable primitive (see Table 9-1) may be set by the PMS-TC upon transferring a normal data frame over the δ interface (see clause 9.1.1). The data frame disabled primitive shall be set by the PMS-TC at all symbol positions where quiet symbols or idle symbols have to be transmitted. Therefore, the PMS-TC shall guarantee that all DTUs or split DTUs in the data frames mapped to quiet and idle symbols are dummy DTUs or fractions thereof.

The time position of the first byte of the first DTU transmitted in a logical frame is communicated in the "DTU sync value" field of the RMC message sent in this same logical frame. The "DTU sync value" field indicates the number of bytes, N_B, remaining from the last split DTU of the previous logical frame. These N_B bytes shall be transmitted in the complimentary part of the split DTU, following the RMC bytes in that logical frame. If the first DTU byte of the RMC data frame is the first byte of a new DTU, the value of N_B is 0.

For TDD mode, for the case when both Band 0 and Band 1 are used on all active symbol positions in the NOI, the value of $N_B(k+1)$ for the logical frame $(k+1)$ for the given values of *TTR* and *TBUDGET* (see clause 10.7.1) can be derived from $N_B(k)$ as follows:

If the logical frame k does not contain a sync symbol or if the sync symbol is outside the range of symbol positions allocated to *TBUDGET*:

$N_B\ (k + 1) = (N_{FEC} \times Q - (N_{FEC} \times Q + B_{DR} + (\min(TTR,\ TBUDGET) - 1) \times B_{DN01} + \max(0, TBUDGET - TTR) \times B_{DD} - N_B\ (k))\ \mathrm{mod}(N_{FEC} \times Q))\ \mathrm{mod}(N_{FEC} \times Q)$

If the logical frame k contains a sync symbol within the range of symbol positions allocated to *TBUDGET* in the NOI:

$N_B\ (k + 1) = (N_{FEC} \times Q - (N_{FEC} \times Q + B_{DR01} + (\min(TTR,\ TBUDGET) - 2) \times B_{DN01} + \max(0, TBUDGET - TTR) \times B_{DD} - N_B\ (k))\ \mathrm{mod}(N_{FEC} \times Q))\ \mathrm{mod}(N_{FEC} \times Q)$

If the logical frame k contains a sync symbol within the range of symbol positions allocated to *TBUDGET* in the DOI:

$$N_B\ (k + 1) = (N_{FEC} \times Q - (N_{FEC} \times Q + B_{DR01} + (\min(TTR,\ TBUDGET) - 1) \times B_{DN02} + \max(0, TBUDGET - TTR - 1) \times B_{DD} - N_B\ (k))\ \mathrm{mod}(N_{FEC} \times Q))\ \mathrm{mod}(N_{FEC} \times Q)$$

NOTE 2 – Parameters *TTR* and *TBUDGET* determine the index of the last active symbol positions in the logical frame (see 10.7.1).

For FDX mode, the value of $N_B(k+1)$ for the logical frame $(k+1)$ for the given values of TTR_{PSF}, TTR_{NPSF}, *TA* and *TBUDGET* (see clause 10.7.2) can be derived from $N_B(k)$ in a similar way.

9.6 RMC and RRC

9.6.1 RMC frame format

The RMC primitives comprise the acknowledgement data and management/control data formatted into an RMC frame (see clause 9.6.4). The RMC framer shall format the RMC message into an RMC frame, as presented in Figure 9-4. The RMC frame shall include an integer number of bytes. The total size of the RMC frame shall be as defined in clause 9.6.3. Padding shall be appended to the end of the last command of the RMC message to align with the total size of the RMC frame. The padding bytes shall be all 00_{16}.

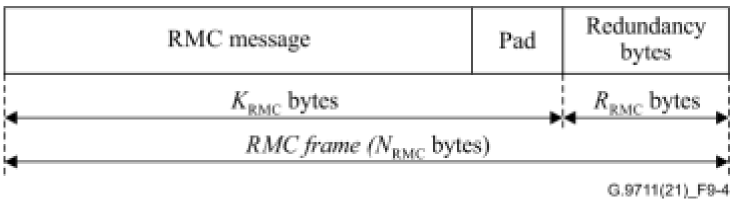


Figure 9-4 – RMC frame format

The first byte of an RMC frame is the first byte of the first command of the RMC message (see Figure 9-6) contained in this RMC frame.

9.6.2 RMC scrambler

The scrambling algorithm shall be as represented by the equation below and as illustrated in Figure 9-5; the output bit of RMC data $x(n)$ at the sample time n shall be:

$$x(n) = m(n) + x\ (n - 18) + x\ (n - 23),$$

where $m(n)$ is the input bit of the RMC at sample time n. The arithmetic in this clause shall be performed in the Galois Field GF(2).

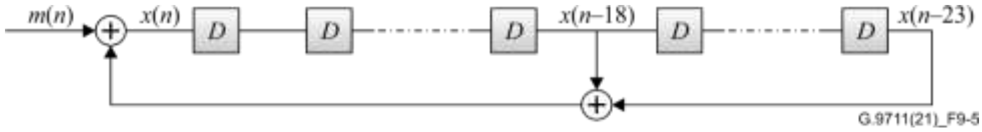


Figure 9-5 – RMC scrambler

The scrambler state $[x(n-1) : x(n-23)]$, shall be reset to the CNT_{LF} of the logical frame in which the RMC frame is transmitted before inputting the first bit of each RMC frame. Bit 0 (LSB) of the CNT_{LF} shall be used to initialize the scrambler delay element $x\ (n-23)$ and bit 15 (MSB) of the CNT_{LF} shall be used to initialize the delay element $x(n\text{-}8)$. Delay elements $[x(n\text{-}1) : x(n\text{-}7)]$ shall be reset to zero.

Incoming RMC bytes shall be input to the scrambler LSB first; the LSB of the first byte corresponds to time sample $n = 1$. All K_{RMC} bytes of the RMC frame (RMC message and pad) shall be scrambled.

9.6.3 RMC encoder

After scrambling, the RMC shall be protected by a Reed-Solomon FEC code using the same polynomial as that used for DTU encoding defined in clause 9.3. However, for the purpose of RMC encoding, parameters N_{FEC}, K_{FEC} and R_{FEC} are referred to as N_{RMC}, K_{RMC} and R_{RMC}, and the valid values of these parameters shall be as specified in this clause.

The encoder RS(N_{RMC}, K_{RMC}) shall insert R_{RMC} = 16 redundancy bytes after K_{RMC} data bytes, counting from the first byte of the RMC frame. The RMC frame size after FEC encoding shall be $N_{RMC} = K_{RMC}+16$ bytes.

The number of data bytes K_{RMC} allocated for an RMC frame shall be set during the initialization (see clause 12.3.4.2.5) and shall not be changed during the showtime. The range of valid values for K_{RMC} shall be from 32 to 64.

NOTE – The defined valid combinations of FEC parameters [K_{RMC}, N_{RMC}] provide error detection capability equivalent to or higher than a 32-bit CRC.

9.6.4 RMC message fields

Each RMC message shall be transmitted over one RMC symbol.

An RMC message comprises a number of different commands. The size of each command (see Table 9-2 to Table 9-9) shall be an integer number of bytes. Different sets of commands may be sent over different RMC messages.

The RMC message format is presented in Figure 9-6. The first byte sent of a particular RMC message shall be the first byte of the first command; the last byte sent shall be the last byte of the last command.

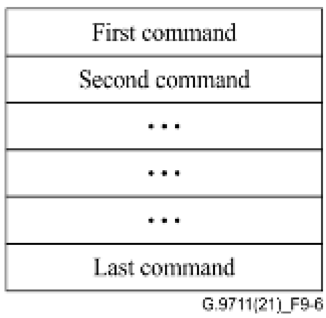


Figure 9-6 – RMC message format

The first command of an RMC message shall be the downstream RMC command (see Table 9-5) in the downstream direction and the upstream RMC command (see Table 9-8) in the upstream direction. All subsequent commands, transmitted by either the MTU-O or the MTU-R, shall use the same format and field structure as shown in Table 9-3, where the first byte is the command header holding a unique command ID. This is followed by the command data.

Table 9-3 – Structure of an RMC command

Field name	Format	Description
Command header (Note)	1 byte: [$b_7b_6$aa aaaa]	aaaaaa = command ID. The command ID is a unique six bit code that identifies the command. See Table 9-4 for a complete list of commands. b_6 and b_7 – Reserved for use by ITU-T
Command data		See specific commands' descriptions.
NOTE – Command header is not present for the first command of the RMC message.		

Table 9-4 summarizes the RMC commands defined in the Recommendation.

Table 9-4 – RMC commands

Command name	Command ID	Description/comments	Reference
Downstream RMC	N/A	Shall be included in every downstream RMC message.	See Table 9-5
Upstream RMC	N/A	Shall be included in every upstream RMC message.	See Table 9-8
Receiver initiated FRA request	03_{16}	May be included in any given RMC message. Up to two such commands may be used within a single RMC message, one command per sub-frame.	See Table 9-10
	04_{16}		See Table 9-11
Reply to FRA request (FRA-R)	05_{16}	Shall be included in response to an FRA request. Up to two such commands may be used within a single RMC message, one command per sub-frame.	See Table 9-13
	06_{16}		See Table 9-14
Reply to SRA request (SRA-R)	08_{16}	Shall be included in response to a request for seamless rate adaptation (SRA) including a request for bitswap or a TIGARESP to indicate the instant of parameter modification.	See Table 9-15
Reply to RPA request (RPA-R)	07_{16}	Shall be included in response to a RPA request	See Table 9-16
Upstream dynamic resource (DRRus)	10_{16}	Shall be sent in response to the DRA request. May be included in any given RMC message.	See Table 9-17
RMCR command	09_{16}	May be included in any given RMC message. Indicates that the initiating MTU has detected an RMC failure in the receive direction and requests	See Table 9-18

Table 9-4 – RMC commands

Command name	Command ID	Description/comments	Reference
		the peer MTU to apply the backup *RTSBL*, as specified in clause 13.3.1.2.	
Reply to DBR command	$0A_{16}$	Shall be sent in response to DBR request. May be included in any given RMC message.	See Table 9-19
MTU-O DTFO command	$0B_{16}$	Contains the downstream DTFO configuration parameters and the requested upstream DTFO configuration parameters.	See Table 9-20
MTU-R DTFO command	$0C_{16}$	Contains the upstream DTFO configuration parameters.	See Table 9-23

Table 9-5 – Downstream RMC command (sent by MTU-O only)

Field name	Format	Description
ACK bit-map	Six bytes: byte 0: [b_7 ... b_0] byte 1: [b_{15}... b_8] byte 2: [b_{23} ... b_{16}] byte 3: [b_{31} ... b_{24}] byte 4: [b_{39} ... b_{32}] byte 5: [b_{47} ... b_{40}]	ACK bit map [b47 ...b0], the bit b0 relates to the last transmitted DTU(s) in the ACK window (see clause 9.7). Any given bit of the ACK bit map shall be set to one for ACK and 0 for NACK.
ACK group size, RMC ACK, upstream flow control and indicator bits	Two bytes: byte 0: [e ddd aabc$_0$] byte 1: [00000 $c_3c_2c_1$]	aa = ACK group size (G_{ack}), coded as an unsigned integer with valid values one, two, three. b = acknowledgement of the RMC message; shall be set to one for ACK and zero for NACK. For K=0, 1, 2, 3, c_k = indicates the status of the FCus_K primitive (values RXon/RXoff for FCus_0, FCus_1, FCus_2, FCus_3) over the γ reference point (in the upstream direction). If c_K=0, upstream transmission is enabled (RXon). If c_K=1, upstream transmission is disabled (RXoff). If upstream transmission is disabled or the received RMC message is corrupted, the MTU-R shall accept no data packets over the γ reference point until the transmission is enabled again. The MTU-R shall apply the TX Enable primitive associated with the received RX Enable status immediately after decoding the RMC command. ddd = indicator bits, one bit per defect. The bits shall be placed according to the following order: [los lom lor]. An indicator bit shall be set to zero if the corresponding primitive/defect occurs and set to one otherwise (active low). e = positive acknowledgement on reception of a

Table 9-5 – Downstream RMC command (sent by MTU-O only)

Field name	Format	Description
		TIGARESP command (TIGARESP-ACK). e=1 indicates that a TIGARESP command was received and positively acknowledged. e=0 indicates that no TIGARESP command was received and positively acknowledged. The generation and use of this bit is defined in clause 13.2.2.1.
Downstream logical frame configuration	Three bytes	Logical frame configuration parameters to be used for the following frame, (see clause 10.7 and Table 12-53). The format of frame configuration parameters is defined in Table 9-6.
Upstream logical frame configuration request	Three bytes	Request for upstream logical frame configuration parameters (see clause 8.1.1 for the definition of its implementation). (Note 2) The format of Upstream logical frame configuration request is defined in Table 9-7.
DTU sync value (N_B)	Two bytes: byte 0 [s_7 ... s_0] byte 1 [0000 s_{11}... s_8]	The value of N_B, for the current logical frame (see definition of N_B in clause 9.5) expressed in bytes: The value is coded as a 12-bit unsigned integer [s11 ... s0] with s0 the LSB. The valid range for the DTU sync value is from 000_{16} to FEF_{16}.
Current active bit-loading table identifier	Two bytes: byte 0 [bbbb aaaa] byte 1 [0000 cccc]	Indication for the active bit-loading table to be used in the current logical frame, expressed as a value of FCCC (see clause 13.3.1.1.3). aaaa = Identifier for the active bit-loading table to be used over the NOI_{PSF}. bbbb = Identifier for the active bit-loading table to be used over the DOI (Note 1). See Table 9-10. cccc = Identifier for the active bit-loading table to be used over the NOI_{NPSF}. See Table 9-11.
Settings associated with supported options	One byte: [00 0bbbbb]	Contains settings associated with the supported options (Note 3). bbbbb = actual transmission time in the previous downstream logical frame, specified as the symbol position index of the last data symbol that has been transmitted (associated with INM facility) All other bits are reserved by ITU-T and shall be set to 0.

NOTE 1 – If only the NOI is used (i.e., if $TTR_{ds} \geq TBUDGET_{ds}$) for a given logical frame, the identifier corresponding to the DOI shall be set to 0000 by the transmitter and ignored by the receiver. For TDD mode or if Annex X is enabled, the identifier corresponding to the NOI_{NPSF} shall be set to 0000 by the transmitter and ignored by the receiver.

NOTE 2 – If the MTU-R receives a new upstream logical frame configuration request in the downstream RMC of downstream logical frame with $CNT_{LF,ds} = N + M_{SF}$, the MTU-R shall indicate this new configuration in the RMC starting from upstream logical frame with $CNT_{LF,us} = N + 1$ (see Figure 10-41) and apply this new configuration in the upstream logical frame with $CNT_{LF,us} = N + 2$.

Table 9-5 – Downstream RMC command (sent by MTU-O only)

Field name	Format	Description
NOTE 3 – This byte shall be present if and only if support of at least one of the options for which settings are conveyed via this byte is indicated by both MTUs during initialization (Bits [b_{15} … b_8] of the field "supported options", see clauses 12.3.4.2.1, 12.3.4.2.2).		

Table 9-6 – Format for downstream logical frame configuration

Field name	Format	Description
TTR_{ds}	One byte: [b0 aaaaaa]	aaaaaa = TTR_{ds}, the number of symbol positions in the NOI (TDD mode) or in the NOI_{PSF} (FDX/FDX in compatibility (FDXC) mode) of the downstream logical frame, coded as an unsigned integer. Within the valid range of values from 1 to 32, $TTR_{ds} \leq M_{ds}$. b = IDF_{ds}, idle-data flag indicating the symbol type to be used over the downstream NOI on the symbol positions starting from the index ($MNDSNOI_{ds}$ +1) to the index [min(TTR_{ds}, $TBUDGET_{ds}$) -1] in the downstream logical frame. b = 0 indicates that the MTU-O may transmit either idle or data symbols. b = 1 indicates that the MTU-O shall transmit only data symbols.
$TBUDGET_{ds}$	One byte: [00 aaaaaa]	aaaaaa = the value of the parameter $TBUDGET_{ds}$ (see clause 10.7), coded as an unsigned integer. Within the valid range of values from 1 to 36, $TBUDGET_{ds} \leq M_{ds}$.
TTR_{NPSFds}	One byte: [00 aaaaaa]	aaaaaa = TTR_{NPSFds}, the number of symbol positions in the NOI_{NPSF} of the downstream logical frame, coded as an unsigned integer. Within the valid range of values from 0 to 26, $TTR_{NPSFds} \leq M_F$-M_{ds}.

Table 9-7 – Format for upstream logical frame configuration request

Field name	Format	Description
TTR_{us}	One byte: [b0 aaaaaa]	aaaaaa = TTR_{us}, the number of symbol positions in the NOI (TDD mode) or NOI_{PSF} (FDX/FDXC mode) of the upstream logical frame, coded as an unsigned integer. Within the valid range of values from 1 to 26, $TTR_{us} \leq M_{us}$. b = IDF_{us}, idle-data flag indicating the symbol type to be used over the upstream NOI on the symbol positions starting from the index ($MNDSNOI_{us}$ +1) to the index [min(TTR_{us}, $TBUDGET_{us}$) -1] in the upstream logical frame. b = 0 indicates that the MTU-R may transmit either idle or data symbols. b = 1 indicates that the MTU-R shall transmit only data symbols.

Table 9-7 – Format for upstream logical frame configuration request

Field name	Format	Description
$TBUDGET_{us}$	One byte: [00 aaaaaa]	aaaaaa = the value of the parameter $TBUDGET_{us}$ (see clause 10.7), coded as an unsigned integer. Within the valid range of values from 1 to 36, $TBUDGET_{us} \le M_{us}$.
TTR_{NPSFus}	One byte: [00 aaaaaa]	aaaaaa = TTR_{NPSFus}, the number of symbol positions in the NOI_{NPSF} of the upstream logical frame, coded as an unsigned integer. Within the valid range of values from 0 to 32, $TTR_{NPSFus} \le M_F - M_{us}$.

Table 9-8 – Upstream RMC command (sent by MTU-R only)

Field name	Format	Description
Retransmission ACK bit-map	Six bytes byte 0: [b_7 ... b_0] byte 1: [b_{15}... b_8] byte 2: [b_{23} ... b_{16}] byte 3: [b_{31} ... b_{24}] byte 4: [b_{39} ... b_{32}] byte 5: [b_{47} ... b_{40}]	ACK bit map [b_{47} ...b_0], the bit b_0 relates to the last transmitted DTU(s) in the ACK window (see clause 9.7). Any given bit of the ACK bit map shall be set to 1 for ACK and 0 for NACK.
Retransmission ACK group size, RMC ACK, TIGA ACK and indicator bits	One byte: [dddd aabc]	aa = ACK group size (G_{ack}) coded as an unsigned integer with valid values 1, 2, 3. b = acknowledgement of the RMC message; shall be set to 1 for ACK and 0 for NACK. c = positive acknowledgement of reception of an OLR request type 3 (TIGA) eoc command (TIGA-ACK). c=1 indicates that a transmitter-initiated gain adjustment (TIGA) command was received and positively acknowledged. c=0 indicates that no TIGA command was received and positively acknowledged. The generation and use of this bit is specified in clause 13.2.2.1. dddd = indicator bits according to the following order: [*lpr los lom lor*]. An indicator bit shall be set to 0 if the corresponding primitive/defect occurs and set to 1 otherwise (active low).
Upstream logical frame configuration	Three bytes	Configuration parameters to be used for the following logical frame (see clause 10.7 and Table 12-48) The format of logical frame configuration parameters is specified in Table 9-9.
DTU sync value (N_B)	Two bytes: byte 0 [s_7 ... s_0] byte 1 [0000 s_{11}... s_8]	The value of N_B, for the current logical frame (see definition of N_B in clause 9.5) expressed in bytes: The value is coded as a 12-bit unsigned integer

Table 9-8 – Upstream RMC command (sent by MTU-R only)

Field name	Format	Description
		[s11 ... s0] with s0 the LSB. The valid range for the DTU sync value is 000_{16} to FFF_{16}.
Current active bit-loading table identifier	Two bytes byte 0: [bbbb aaaa] byte 1: [0000 cccc]	Indication for the active bit-loading table to be used in the current logical frame, expressed as a value of FCCC (see clause 13.3.1.1.3). aaaa = Identifier for the active bit-loading table to be used over the NOI in PSF. bbbb = Identifier for the active bit-loading table to be used over the DOI (Note 1). cccc = Identifier for the active bit-loading table to be used over the NOI_{NPSF}. See Table 9-11.
Settings associated with supported options	One byte: [aa 0 bbbbb]	Contains settings associated with the supported options (Note 2) aa = indicator bits for RPF in the following order [dgl ohp] (see clause 11.3.3.2). An indicator bit shall be set to 0 if the corresponding primitive occurs and set to 1 otherwise (active low). bbbbb = actual transmission time in the previous upstream logical frame, specified as the symbol position index of the last data symbol that has been transmitted (associated with INM facility). All other bits are reserved by ITU-T and shall be set to 0.
NOTE 1 – If only the NOI is used (i.e., if $TTR_{ds} \geq TBUDGET_{ds}$) for a given logical frame, the identifier corresponding to the DOI shall be set to 0000 by the transmitter and ignored by the receiver. For TDD mode or if Annex X is enabled, the identifier corresponding to the NOI_{NPSF} shall be set to 0000 by the transmitter and ignored by the receiver. NOTE 2 – This byte shall be present if and only if support of at least one of the options for which settings are conveyed via this byte are indicated by both MTUs during initialization (first byte of the field "supported options", see clauses 12.3.4.2.1 and 12.3.4.2.2).		

Table 9-9 – Format for upstream logical frame configuration

Field name	Format	Description
TTR_{us}	One byte: [00 aaaaaa]	aaaaaa = TTR_{us}, the number of symbol positions in the NOI (TDD mode) or NOI_{PSF} (FDX/FDXC mode) of the upstream logical frame, coded as an unsigned integer. Valid range is from one to 26 inclusive.
$TBUDGET_{us}$	One byte: [00 aaaaaa]	aaaaaa = the value of the parameter $TBUDGET_{us}$ (see clause 10.7), coded as an unsigned integer. Valid range is from one to 36 inclusive.
TTR_{NPSFus}	One byte: [00 aaaaaa]	aaaaaa = TTR_{NPSFus}, the number of symbol positions in the NOI_{NPSF} of the upstream logical frame, coded as an unsigned integer. Within the valid range of values from 0 to 32, $TTR_{NPSFus} \leq M_F\text{-}M_{ds}$.

Table 9-10 – Receiver initiated FRA request command for the PSF (sent by both the MTU-O and MTU-R)

Field name	Format	Description
Command header	One byte: [00 aaaaaa]	aaaaaa = 03_{16}
Configuration identifier	One byte: [bbbb aaaa]	aaaa = New FRA configuration change count (FCCC), identifier for the new active configuration (see clause 13.3.1.1.3). bbbb = Identifier specifying the baseline bit-loading table over which FRA adjustments shall be applied to construct the active bit-loading table, expressed as a value of SCCC (see clause 13.2.1.1.5).
FRA adjustment data	Five bytes	Defines the adjustments to be used to construct a new active bit-loading table. The format of the FRA adjustment data is defined in Table 9-12.
NOTE – The MTU shall be capable of handling up to two receiver initiated FRA requests conveyed over a single RMC message: one for the PSF and one for the NPSF (see Table 9-11).		

Table 9-11 – Receiver initiated FRA request command for the NPSF (sent by the MTU-O and MTU-R)

Field name	Format	Description
Command header	One byte: [00 aaaaaa]	aaaaaa = 04_{16}
Configuration data	One byte: [bbbb aaaa]	aaaa = New FRA configuration change count (FCCC), identifier for the new active configuration (see clause 13.3.1.1.3). bbbb = Identifier specifying the baseline table over which FRA adjustments shall be applied to construct the active bit-loading table, expressed as a value of SCCC (see clause 13.2.1.1.5).
FRA adjustment data	Five bytes	Defines the adjustments to be used to construct a new active bit-loading table. The format of the FRA adjustment data is defined in Table 9-12.
NOTE – The MTU shall be capable of handling up to two receiver initiated FRA requests conveyed over a single RMC message: one for the NPSF and one for the PSF (see Table 9-10).		

Table 9-12 – FRA adjustment data

Field name	Format	Description
BLT status	One byte: [aabb cd00]	Bit-loading adjustment status, see clause 13.3.1.1: aa = 00 – no adjustment aa = 01 – decrease the bit loading per sub-band by the specified parameter value aa = 10 – limit the maximum bit loading by the specified parameter value aa = 11 – reserved by ITU-T Frequency band(s), subject for adjustment, see clause 13.3.1:

Table 9-12 – FRA adjustment data

Field name	Format	Description
		bb = 00 – reserved by ITU-T; bb = 01 – Band 0 only (valid for NOI only); bb = 10 – Band 1 only (valid for NOI only Note 3) bb = 11 – Band 0 and Band 1 Operational interval subject for adjustment (Note 4): c = 0 – NOI. c = 1 – DOI (valid for PSF only).
SubBand01Params	One byte: [bbbb aaaa]	aaaa = parameter value to be used for sub-band 0 (Note 1 and 2) bbbb = parameter value to be used for sub-band 1 (Note 1 and 2)
SubBand23Params	One byte: [bbbb aaaa]	aaaa = parameter value to be used for sub-band 2 (Note 1 and 2) bbbb = parameter value to be used for sub-band 3 (Note 1 and 2)
SubBand45Params	One byte: [bbbb aaaa]	aaaa = parameter value to be used for sub-band 4 (Note 1 and 2) bbbb = parameter value to be used for sub-band 5 (Note 1 and 2)
SubBand67Params	One byte: [bbbb aaaa]	aaaa = parameter value to be used for sub-band 6 (Note 1 and 2) bbbb = parameter value to be used for sub-band 7 (Note 1 and 2)
NOTE 1 – The 4-bit SubBandParams fields specify the parameter values to be used for implementing the bit-loading adjustment over the various sub-bands as defined by the BLT status field. The valid parameter values are integers in the range between zero and 12, inclusive. Value 15 is a special value. NOTE 2 – The boundaries of the sub-bands are defined at initialization (see Table 12-66, Table 12-71) such that no sub-band overlaps the boundary between Band 0 and Band 1. If FRA is applied to only one band (Band 0 only or Band 1 only), the sub-bands associated with the other band shall be disabled by setting SubBandParams fields to 15. NOTE 3 – The FRA in NOI Band 1 only setting (bb=10) shall be used only for the DTFO restoration of the NOI. NOTE 4 – If the same active bit-loading tables apply to Band 1 in both NOI and DOI, any FRA adjustment requested for Band 1 of NOI shall apply to DOI and vice versa.		

Table 9-13 – Reply to FRA request command for PSF (sent by the MTU-O and MTU-R)

Field name	Format	Description
Command header	One byte: [00 aaaaaa]	aaaaaa = 05_{16}
FRA response data	One byte: [bbbb aaaa]	aaaa = LFDC (see clause 13.3.1.1.4) to the implementation of a new active configuration. (Note) bbbb = FCCC identifier of the configuration to be applied in the logical frame when LFDC reaches the value zero. The value of FCCC shall be the one received in the FRA request command.
NOTE – The reply to FRA request shall be repeated in subsequent logical frames with a decrementing count of LFDC until the count reaches the value zero.		

Table 9-14 – Reply to FRA request command for NPSF (sent by the MTU-O and MTU-R)

Field name	Format	Description
Command header	One byte: [00 aaaaaa]	aaaaaa = 06_{16}
FRA response data	One byte: [bbbb aaaa]	aaaa = LFDC (see clause 13.3.1.1.3) to the implementation of a new active configuration. (Note) bbbb = FCCC identifier of the configuration to be applied in the logical frame when LFDC reaches the value of zero. The value of FCCC shall be the one received in the FRA request command.
NOTE – The reply to FRA request shall be repeated in subsequent logical frames with a decrementing count of LFDC until the count reaches the value zero.		

Table 9-15 – Reply to SRA request (SRA-R) command (sent by the MTU-O and MTU-R)

Field name	Format	Description
Command header	One byte: [00 aaaaaa]	aaaaaa = 08_{16}
SRA response data	One byte: [bbbb aaaa]	aaaa = SFDC (see clause 13.2.1.1.5) to the implementation of a new baseline configuration. (Note 1) bbbb = new SCCC as received by the OLR request or special values SCCC=1111, 1110 and 1101 (see clause 11.2.2.5) (Note 2).
NOTE 1 – The reply to an SRA request shall be repeated in subsequent superframes with a decrementing superframe down count (SFDC) until the count reaches the value zero. NOTE 2 – The OLR request command may include updates to both NOI and DOI. However, the associated SRA-R command always includes one and only one SCCC value. The SRA-R shall use the following SCCC values: SCCC of the NOI if the OLR request related only to the NOI SCCC of the DOI if the OLR request related only to the DOI SCCC of the NOI if the OLR request related to both NOI and DOI. This SCCC shall be used to acknowledge the update over both NOI and DOI.		

Table 9-16 – Reply to RPA request (RPA-R) command (sent by the MTU-O and MTU-R)

Field name	Format	Description
Command header	One byte: [00 aaaaaa]	aaaaaa = 07_{16}
RPA response data	One byte: [000b aaaa]	aaaa = RPA configuration change count (RCCC) indicated in the received OLR command of OLR request type 4 (see Table 11-11). b shall be set to 1 if the RMC parameters requested by update RMC parameters command (see Table 11-11) are invalid (a reject response), otherwise b shall be set to zero (positive acknowledgement)
NOTE – The command shall be repeated in subsequent logical frames until the superframe count value indicated in the RPA request is reached, see clause 13.2.1.3.3.		

Table 9-17 – Upstream dynamic resource report (DRRus) command (sent by the MTU-R only)

Field name	Format	Description
Command header	One byte: [00 aaaaaa]	aaaaaa = 10_{16}
Resources metric	One to eight bytes	The resources metric is up to eight bytes long and shall be conveyed transparently between the γ_R and the γ_O reference point (see the DRRus.confirm primitive in Table 8-5). Annex Y contains the resources metric definition, configuration and representation.
NOTE – A valid DRR configuration has to be set before sending DRRus for the first time, see clause 11.2.2.16.		

Table 9-18 – RMCR command (sent by the MTU-O and MTU-R)

Field name	Format	Description
Command header	One byte: [00 aaaaaa]	aaaaaa = 09_{16}
Command data	One byte: [0000000a]	a = 1 indicates request to the peer MTU to replace the current *RTSBL* with the latest backup *RTSBL* in the transmit direction. It also indicates that the RMC recovery is in progress (Note). Other bits are reserved by ITU-T and shall be set to 0.
NOTE – The value a = 0 is invalid. This command shall not be sent with a = 0.		

Table 9-19 – DBR-R command (sent by the MTU-O only)

Field name	Format	Description
Command header	1 byte: [00 aaaaaa]	aaaaaa = $0A_{16}$
DBR logical frame down count (DBRLFDC)	1 byte: [0000 aaaa]	aaaa = The logical frame down count to implementation of the DBR, represented as an unsigned integer.
DBR configuration change count (DBRCCC)	1 byte: [bbce aaaa]	aaaa = a 4-bit DBR configuration change count (DBRCCC), an identifier for the new MTU-R band assignment; (NOTE) bb: type of DBR: bb = 01: indicates downstream DBR bb = 10: indicates upstream DBR bb = 11: indicates bidirectional DBR Other values are reserved by ITU-T c = downstream SDI e = upstream SDI
NOTE – The count is the one transmitted in the DBR-PR request that initiates the DBR procedure.		

Table 9-20 – MTU-O DTFO command (sent by MTU-O only)

Field name	Format	Description
Command header	One byte: [00 aaaaaa]	aaaaaa = $0B_{16}$
$DTFO_{ds}$	Four bytes	Downstream NOI & DOI DTFO configuration parameters See Table 9-21
$DTFOreq_{us}$	Four bytes	Upstream NOI & DOI DTFO configuration parameters request See Table 9-22 (Note 2)
NOTE 1 – The absence of the MTU-O DTFO command in the RMC message shall be interpreted by the MTU-R as: • the downstream DTFO is disabled (as when downstream DTFO enable bit is 0) and upstream DTFO is disabled. • the $TDOI_{ds}$ and T_B1_{ds} values are 0 • the $TDOI_{us}$ and T_B1_{us} values shall be set to 0 NOTE 2 – If the RMC message is received with error, the MTU-R shall assume that no MTU-O DTFO command was sent, i.e., the $TDOI_{ds}$ and T_B1_{ds} values are 0 and the value of $TDOI_{us}$ and T_B1_{us} in the $DTFOreq_{us}$ field shall be set to 0.		

Table 9-21 – Downstream NOI & DOI DTFO configuration parameters

Field name	Format	Description
TA_{ds}	One byte: [cb0 aaaaa]	aaaaa = TA_{ds}, the shift of the DOI DTFO block from the beginning of the DOI of the downstream logical frame, coded as an unsigned integer. Within the valid range of values from 0 to 31, $TA_{ds} \le M_{ds} - TBUDGET_{ds}$ (see clause 10.5). If $TBUDGET_{ds} \le TTR_{ds}$, $TA_{ds} = 0$. b = Downstream DTFO enable bit ($DTFOEnable_{ds}$) (Note 1) 0 – Downstream DTFO is disabled. 1 – Downstream DTFO is enabled. c = DTFO restoration indicator (*TxPreamble*): 0 – non-preamble symbols in all active DTFO blocks. Allowed non-preamble symbol types are specified in section 10.7. 1 – preamble symbol in either NOI or DOI DTFO block; valid if only one DTFO block is active in the next logical frame. If c=1 is intended to the DOI DTFO block, the value of T_B1_{ds} shall be set to 0. If c=1 is intended to the NOI DTFO block, the value of $TDOI_{ds}$ shall be set to 0.
$TDOI_{ds}$	One byte [000 aaaaa]	aaaaa = $TDOI_{ds}$, the number of symbol positions in the DOI DTFO block of the downstream logical frame, coded as unsigned integer. Within the valid range of values from 0 to 31, $TDOI_{ds} \le M_{ds}$-1 (Note 2). If *b* = 0 in the TA_{ds} field, $TDOI_{ds}$ shall be set to 0.
T_B1_{ds}	One byte: [00 aaaaaa]	aaaaaa = T_B1_{ds}, the number of symbol positions in the NOI DTFO block of the downstream logical frame, coded as an unsigned integer.

Table 9-21 – Downstream NOI & DOI DTFO configuration parameters

Field name	Format	Description
		Valid range is from 0 to 32 inclusive, $T\_B1_{ds} \le TTR_{ds}$. If bit *b* = 0 in the TA_{ds} field, T_B1_{ds} shall be set to 0.
TA_B1_{ds}	One byte: [00 aaaaaa]	aaaaaa = TA_B1_{ds}, the shift of the NOI DTFO block from the beginning of the downstream logical frame, coded as an unsigned integer. Valid range is from 0 to 31 inclusive, $TA\_B1_{ds} \le TTR_{ds} - 1$.
NOTE 1 – If this bit is set to 0, $TDOI_{ds}$ and T_B1_{ds} shall be set to 0, i.e., there are no symbol positions assigned to any of the DTFO blocks. NOTE 2 – If TDD or TDDZ framing mode is used, $TDOI_{ds} = TBUDGET_{ds}-TTR_{ds}-TA_{ds}$ if $TBUDGET_{ds} > TTR_{ds}$.		

Table 9-22 – Upstream NOI & DOI DTFO configuration parameters request

Field name	Format	Description
TA_{us}	One byte: [000 aaaaa]	aaaaa = TA_{us}, the shift of the DOI DTFO block from the beginning of the DOI of the upstream logical frame, coded as an unsigned integer. Within the valid range of values from 0 to 24, $TA_{us} \le M_{us} - TBUDGET_{us}$ (see clause 10.5). If $TBUDGET_{us} \le TTR_{us}$, $TA_{us} = 0$.
$TDOI_{us}$	One byte [000 aaaaa]	aaaaa = $TDOI_{us}$, the number of symbol positions in the DOI DTFO block coded as unsigned integer. Within the valid range of values from 0 to 25, $TDOI_{us} \le M_{us}-1$
T_B1_{us}	One byte: [00 aaaaaa]	aaaaaa = T_B1_{us}, the number of symbol positions in the NOI DTFO block of the upstream logical frame, coded as an unsigned integer. Valid range is from 0 to 26 inclusive, $T\_B1_{us} \le TTR_{us}$.
TA_B1_{us}	One byte: [bb aaaaaa]	aaaaaa = $TA\text{-}B1_{us}$, the shift of the NOI DTFO block from the beginning of the upstream logical frame, coded as an unsigned integer. Valid range is from 0 to 25 inclusive, $TA\_B1_{us} \le TTR_{us} - 1$. bb = DTFO restoration request (*ReqPreamble*): 00 – default (no restoration). 01 – request of upstream preamble for NOI DTFO block. 10 – request of upstream preamble for DOI DTFO block. 11 – reserved by ITU-T. If bb=10, the T_B1_{us} value shall be set to 0. If bb=01, the $TDOI_{us}$ value shall be set to 0.
NOTE 1 – If TDD or TDDZ framing mode is used, $TDOI_{us} = TBUDGET_{us}-TTR_{us}-TA_{us}$ if $TBUDGET_{us} > TTR_{us}$. NOTE 2 – The upstream NOI & DOI DTFO configuration parameters shall be applied with the same timing as the upstream logical frame configuration request contains in the downstream RMC command of the same RMC message (See table 9-5).		

Table 9-23– MTU-R DTFO command (sent by the MTU-R only)

Field name	Format	Description
Command header	One byte: [00 aaaaaa]	aaaaaa = $0C_{16}$ (Note 1)
TA_{us}	One byte: [cb0 aaaaa]	aaaaa = TA_{us}, the number of quiet symbols at the beginning of the DOI of the upstream logical frame, coded as an unsigned integer. Valid range is from zero to 24 inclusive. b = DTFO restoration indicator (*TxPreamble*): 0 – non-preamble symbol in all active DTFO blocks. Allowed non-preamble symbol types are specified in section 10.7. 1 – preamble symbol in either NOI or DOI DTFO block; valid if only one DTFO block is active in the next logical frame. If c=1 is intended to the DOI DTFO block, T_B1_{us} value shall be set to 0. If c=1 is intended to the DOI DTFO block, $TDOI_{us}$ value shall be set to 0.
$TDOI_{us}$	One byte [000 aaaaa]	aaaaa = $TDOI_{us}$, the number of symbol positions in the DOI DTFO block coded as unsigned integer. Within the valid range of values from 0 to 25, $TDOI_{us} \leq M_{us}$-1 (Note 2).
T_B1_{us}	One byte: [00 aaaaaa]	aaaaaa = T_B1_{us}, the number of symbol positions in the NOI DTFO block of the upstream logical frame, coded as an unsigned integer. Valid range is from 0 to 26 inclusive.
TA_B1_{us}	One byte: [bb aaaaaa]	aaaaaa = TA_B1_{us}, the shift of the NOI DTFO block from the beginning of the upstream logical frame, coded as an unsigned integer. Valid range is from zero to 25 inclusive. bb = DTFO restoration request (*ReqDTFORestoration*): 00 – default (no restoration). 01 – request for downstream NOI DTFO block restoration. 10 – request for downstream DOI DTFO block restoration. 11 – request for both downstream NOI DTFO and DOI DTFO blocks restoration
NOTE 1 – This command shall be sent if and only if the MTU-O DTFO command was present in the last received RMC message. NOTE 2 – If TDD or TDDZ framing mode is used, $TDOI_{us}=TBUDGET_{us}-TTR_{us}-TA_{us}$ if $TBUDGET_{us} > TTR_{us}$.		

9.6.5 RRC frame format

The RRC primitives comprise the acknowledgement data, formatted into an RRC message. The RRC framer shall format the RRC message into an RRC frame, as presented in Figure 9-7. The RRC frame shall include K_{RRC} = 2 information bytes followed by R_{RRC} = 2 protection bytes, B_{RRC} bytes in total. B_{RRC} = 4 bytes if FDX mode is applied. The size of RRC is 0 bytes if TDD mode is applied or if use of RRC in a particular symbol is disabled (see clause 9.5).

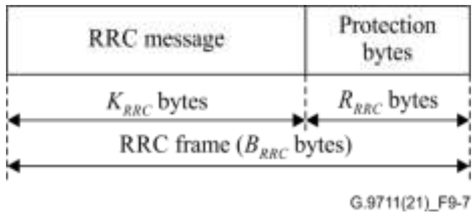


Figure 9-7 – RRC frame format

The first byte of an RRC frame shall be transmitted first. The formats of the RRC message fields are described in clause 9.6.8.

9.6.6 RRC scrambler

The scrambling algorithm shall be as represented by the equation below and as illustrated in Figure 9-8; the output bit of RRC data *x(n)* at the sample time *n* shall be:

$$x(n) = m(n) + x(n-18) + x(n-23),$$

where *m(n)* is the input bit of the RRC at sample time *n*. The arithmetic in this clause shall be performed in the Galois Field GF(2).

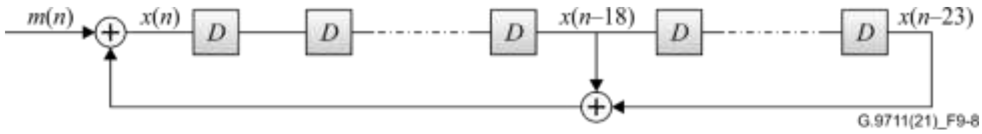


Figure 9-8 – RRC scrambler

The scrambler state $[x(n-1) : x(n-23)]$, shall be reset before inputting the first bit of the RRC frame in each symbol. The element $[x(n-2) : x(n-17)]$ shall be reset to the CNT_{LF} of the logical frame, such that bit 0 (LSB) of the CNT_{LF} shall be used to initialize the scrambler delay element $x(n-17)$ and bit 15 (MSB) of the CNT_{LF} shall be used to initialize the delay element $x(n\text{-}2)$. Delay elements $[x(n\text{-}18) : x(n\text{-}23)]$ shall be reset to the symbol position index of the symbol in which RRC is sent, such that bit 0 (LSB) shall be used to initialize delay element $x(n\text{-}23)$ and bit 5 (MSB) shall be used to initialize the delay element $x(n\text{-}18)$. Delay element $x(n\text{-}1)$ shall be reset to zero.

NOTE – Since the RRC frame is 16 bits only, the initial setting of $[x(n-1) : x(n-2)]$ does not affect the RRC scrambling.

Incoming RRC bytes shall be input to the scrambler LSB first; the LSB of the first byte of the RRC frame in the given symbol corresponds to time sample $n = 1$. All the K_{RRC} bytes of each RRC frame shall be scrambled.

9.6.7 RRC encoder

The R_{RRC} protection bytes for each scrambled RRC message shall contain a 16-bit cyclic redundancy check (CRC) that shall be computed over the RRC message bytes in the order that they are transmitted, starting with the LSB of the first byte and ending with the MSB of the last byte of the RRC message.

The CRC shall be computed using the following generator polynomial of degree 16:

$$G(D) = D^{16}+D^{12}+D^{5}+1$$

The bit value of the protection field shall be the remainder after all bits of the scrambled RRC message, treated as an input polynomial, are multiplied by D^{16} and then divided by *G(D)*. For a 16-bit input polynomial, the CRC shall be computed using the following equation:

$$crc(\mathrm{D}) = M(D) \times D^{16} \text{ modulo } G(D),$$

where:

$M(D)$ $= m_0 D^{15} + m_1 D^{14} + \ldots + m_{14} D + m_{15}$ is the 16-bit polynomial where m_0 is the LSB of the first byte of the RRC message and m_{15} is the MSB of the last byte of the scrambled RRC message,

$crc(D)$ $= crc_0 D^{15} + crc_1 D^{14} + \ldots + crc_{14} D + crc_{15}$ is the CRC polynomial where crc_0 is the LSB of the first byte of the RRC protection field and crc_{15} is the MSB of the last byte of the RRC protection field, and

D is the delay operator.

The arithmetic in this clause shall be performed in the Galois Field GF(2).

9.6.8 RRC message fields

The RRC message fields are described in Figure 9-9.

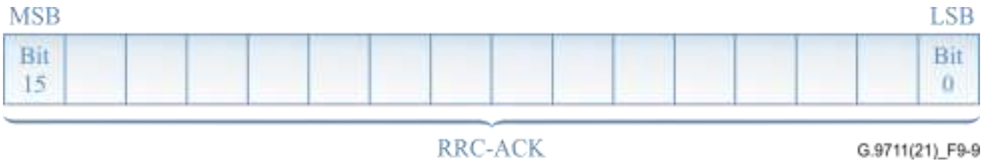


Figure 9-9 – RRC message format

9.6.8.1 The RRC-ACK

The ACK bit map of the RRC message shall be generated and formatted as shown in Figure 9-10:

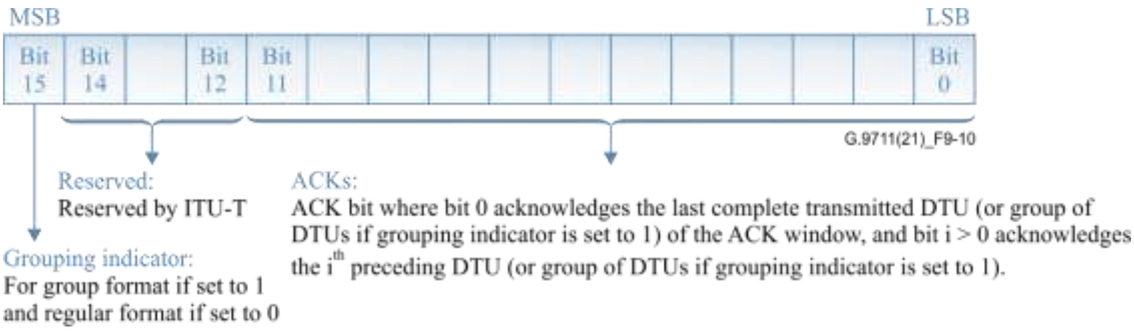


Figure 9-10 – RRC ACK field format

The regular RRC ACK bit map format (grouping indicator = 0) includes one bit per DTU in a RRC ACK window of 12 DTUs, where the LSB refers to the last complete transmitted DTU upon transmission of the last symbol of the RRC ACK window, determined by the RRC-ACK window shift (see clause 9.7.2). Setting of a bit to ONE indicates positive acknowledgement and to ZERO indicates NACK.

The group RRC ACK bit map format (grouping indicator = 1) includes one bit per pair of DTUs in a RRC ACK window of 24 DTUs, where the LSB refers to the last 2 complete transmitted DTUs upon transmission of the last symbol of the RRC ACK window, identified by the RRC-ACK window shift (see clause 9.7.2). Setting of a bit to ONE indicates positive acknowledgement for both DTUs associated with the bit and to ZERO indicates NACK for at least one of these DTUs.

9.7 Acknowledgement

9.7.1 Acknowledgement via RMC

The acknowledgement (ACK) via RMC shall be specified per ACK window. The ACK windows shall follow one another with no gaps and their duration shall be equal to the duration of one PDX frame.

The time position of the ACK window shall be shifted by "ACK window shift" symbol periods that shall be counted, relative to the end of the last symbol position in the PSF in the same direction as the transmission to be acknowledged. For the TDD mode, the position of ACK window is shown in Figure 9-11a for downstream transmission acknowledgment and in Figure 9-11b for upstream transmission acknowledgment. This means that the ACK window shift for the downstream direction is specified relative to the end of the last valid symbol position of PSF in FDS just before the upstream RMC symbol carrying the acknowledgements of this downstream ACK window. For the upstream direction, the ACK window shift is specified relative to the end of the last valid symbol position of PSF in FUS just before the downstream RMC symbol carrying the acknowledgements of this upstream ACK window.

The valid range for ACK window shift in a given transmission direction is any integer number of symbols from -D_{RMC} to 20, independent to the PDX frame length, subject to additional constraints (e.g., see clause 10.5.5), where D_{RMC} is the value applied in the opposite transmission direction. Negative values are only allowed if FDX with Zero-gap (FDXZ) mode is used. Negative value means that the ACK window is delayed from end of the PSF.

NOTE 1 – In TDD mode, the allowed ACK window shift value for a particular direction is limited by the maximum value for T_{ack} (see clause 9.8.1). For the selected RMC symbol offsets D_{RMCus}, D_{RMCds} the ACK window shift values within the valid range also comply with the following conditions:

$$\text{DS\_ACK\_WINDOW\_SHIFT} \times T_{symb} + T_{g1}' + D_{RMCus} \times T_{symb} \leq T_{ack\_max\_R}$$

$$\text{US\_ACK\_WINDOW\_SHIFT} \times T_{symb} + T_{g1} + D_{RMCds} \times T_{symb} \leq T_{ack\_max\_O}$$

The ACK window shift may be different for the downstream and upstream directions. The ACK window shift parameter is selected by the receiver and communicated to the peer transmitter during the initialization in O-PMS and R-PMS messages, respectively.

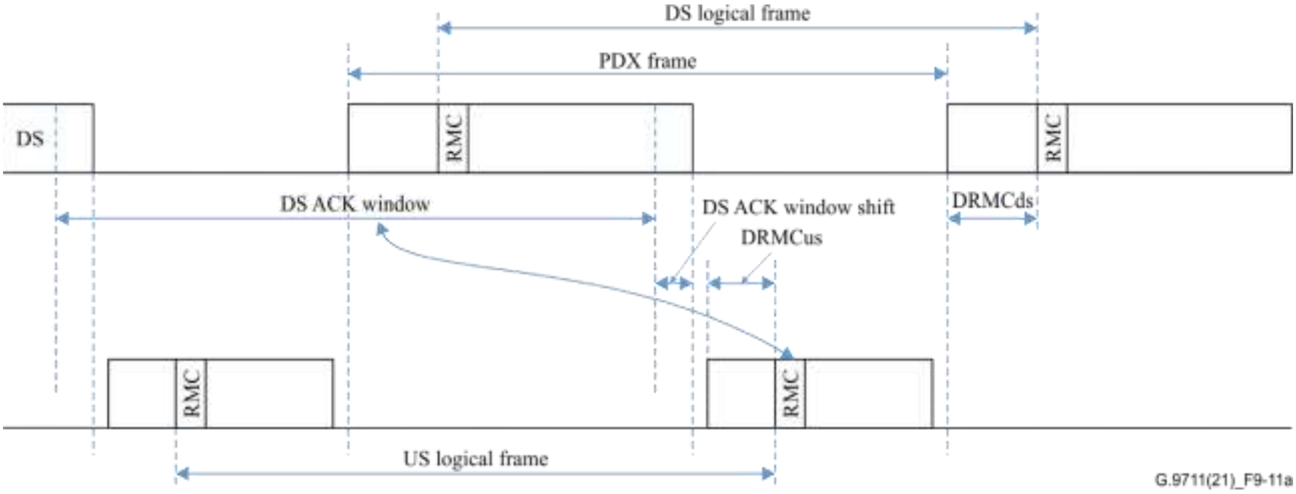


Figure 9-11a – Acknowledging downstream DTUs, U-R reference point, TDD mode

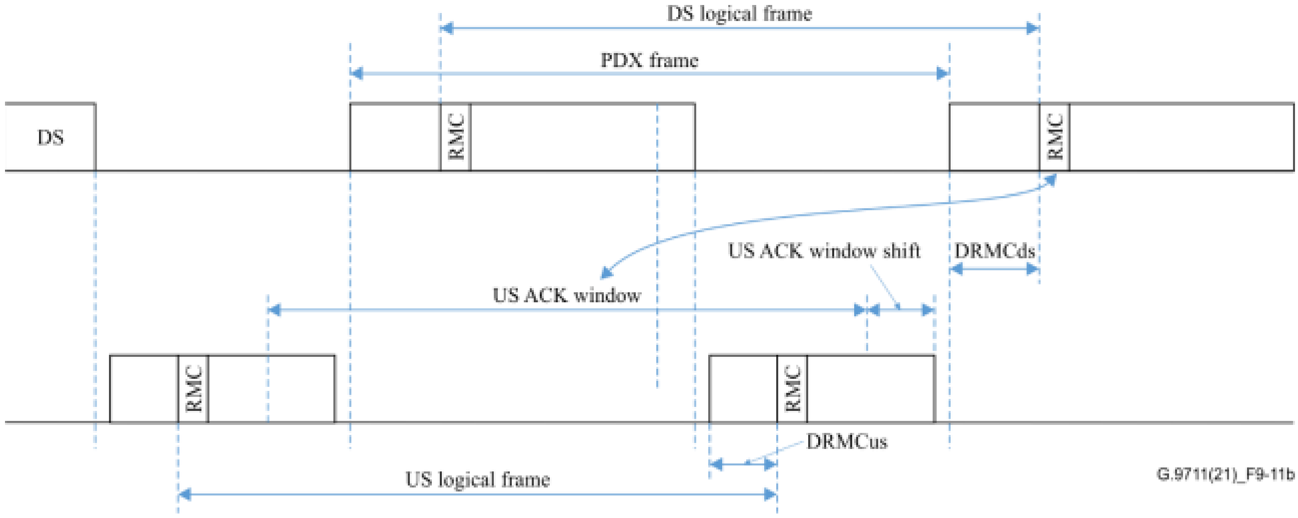


Figure 9-11b – Acknowledging upstream DTUs, U-O reference point, TDD mode

Figure 9-12 shows acknowledging of upstream and downstream transmissions in FDX (no time gaps between upstream and downstream transmissions in FDXC mode shown).

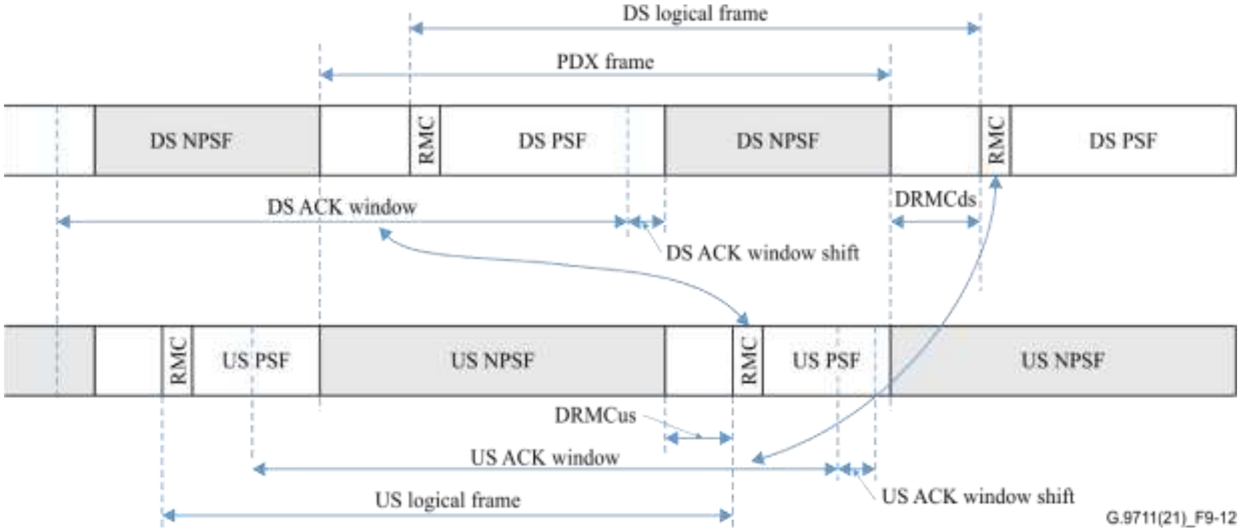


Figure 9-12 – Acknowledging of upstream and downstream DTUs in FDX mode

NOTE 2 – In FDX mode, for the selected RMC symbol offsets D_{RMCus}, D_{RMCds} the ACK window shift values within the valid range also comply with the following conditions:

$$DS\_ACK\_WINDOW\_SHIFT \times T_{symb} + T_{g1}' + D_{RMCus} \times T_{symb} \leq T_{ack\_max\_R}$$

$$US\_ACK\_WINDOW\_SHIFT \times T_{symb} + T_{g1} + D_{RMCds} \times T_{symb} \leq T_{ack\_max\_O}$$

where the values of T_{g1}', T_{g1} in FDXC and FDXZ framing mode shall be as defined in clause 10.5.2 and clause 10.5.3, respectively.

The ACK bit map field of the RMC command shall include acknowledgements for the received DTUs in the form of a bit map and an acknowledgement for the received RMC frame. Each bit in the ACK bit map relates to a single DTU or a group of consecutive DTUs contained in the received data frames within the associated ACK window. The bit map shall include DTU acknowledgements starting with the first DTU (complete or incomplete) ending within the ACK window and ending with the last complete DTU ending within the same ACK window.

The ACK bit map with no grouping shall incorporate acknowledgements to all DTUs received in the ACK window. Bits of the ACK bit map that relate to DTUs that were not transmitted shall be set to "0". In case of grouping, the value of the ACK bits for groups shall be determined only based on the received DTUs associated with the group.

The ACK bit map field size shall be 48 bits. The bits of the ACK bit map shall be ordered according to the order of the transmitted DTUs, where the acknowledgement to the last transmitted DTU in the ACK window shall be represented by the LSB of the ACK bit map field. One or more MSBs of the ACK bit map can remain unused.

The encoding of the ACK bit map shall be as shown in Table 9-5 (downstream) and Table 9-8 (upstream) where each bit in the bit map has the following meaning:

– "0" means NACK;

– "1" means ACK;

– unused bits of the bit map shall be coded as "1".

ACK grouping shall only be used if the number of DTUs per ACK window exceeds the size of the ACK bit map field. Each ACK group represents a number of consecutive DTUs. The number of DTUs per ACK group for a given ACK is an ACK group size. ACK group size is communicated together with the ACK bit map (see Table 9-5, Table 9-8) and may vary from one RMC message to another. The valid values of ACK group size, G_{ack}, is one, two or three DTUs.

In the case of ACK grouping, each bit of the ACK bit map carries the acknowledgement on all DTUs of the ACK group and shall be set to 0 if at least one DTU in the ACK group has to be NACKed. The first ACK group coded on the LSB of the ACK bit map shall contain the acknowledgements for the G_{ack} last transmitted DTUs in the ACK window. Subsequent groups shall be constructed by taking the acknowledgements for the previous G_{ack} transmitted DTUs. The last ACK group in the ACK bit map may hold acknowledgements for a smaller number of DTUs. One or more MSBs of the ACK bit map can remain unused.

The upstream and downstream RMC commands shall also include an acknowledgement on the last received RMC message. The RMC acknowledgement bit shall be encoded as shown in Table 9-5 (downstream) and Table 9-8 (upstream) where each bit in the bit map has the following meaning:

– "0" means NACK;

– "1" means ACK.

Error detection for the received RMC message is accomplished by using redundancy bytes of the RMC codeword (see clause 9.6.3).

9.7.2 Acknowledgement via RRC

The RRC-ACK field of the RRC message contains acknowledgement information on the DTUs transmitted during the RRC-ACK window (see clause 9.6.8). Acknowledgement via RRC shall use a RRC-ACK window comprising of 3 or more consecutive symbols and acknowledging 12 DTUs if grouping indicator is 0, or 24 DTUs if grouping indicator is 1, Figure 9-13. Grouping shall not be used if RRC-ACK in regular format can cover all the DTUs transmitted within 3 consecutive symbols.

The RRC transmitted in a particular symbol is associated with one particular RRC-ACK window the end of which is time-shifted back from this symbol by the RRC-ACK window shift, which is defined in symbol periods. For the given transmit symbol carrying RRC, the RRC ACK window shift shall be counted from the beginning of the corresponding receive symbol (see Figure 9-13).

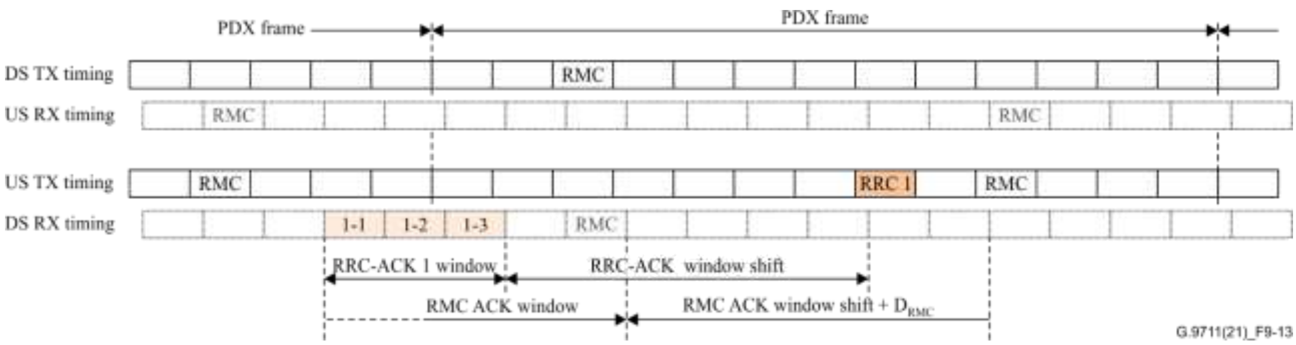


Figure 9-13 – Upstream RRC ACK window and window shifttimeline (FDXZ framing mode)

The timeline of upstream RRC transmission shown in Figure 9-13 illustrates the case of FDXZ mode: the RRC-ACK window size is 3 symbols and the RRC-ACK window shift is 6 symbols. The RRC window and window shift for downstream RRC shall be constructed in a similar way.

The RRC-ACK windows associated with RRCs of adjacent symbols overlap. Thus, the RRC-ACK information for every DTU in every received symbol is acknowledged at least 3 times, i.e., repeated at least twice, which improves robustness. The way to process multiple RRC-ACK bits per DTU is vendor discretionary.

The size of the RRC-ACK window shift shall not exceed 12 symbols. Smaller values, between 4 and 12, can be indicated by the receiver during initialization, see clauses 12.3.4.2.5 and 12.3.4.2.6.

To get the same round-trip latency for DTUs that are acknowledged via RMC as for those acknowledged via RRC, the value of the RMC ACK window shift plus the D_{RMC} value should be the same as the value of the RRC-ACK window shift, as shown in Figure 9-13. Since the size of the RMC ACK window is bigger than the RRC ACK window, the stream of acknowledgement information from RMC and RRC will be compatible.

NOTE – Since the RMC ACK window is PDX frame wide, RMC ACK offers additional protection against long erasures and can cover the cases, in which RRC is unavailable in some parts of the PDX frame.

9.8 Retransmission function

All DTUs marked as normal DTUs (see clause 8.2.1.3) that are NACKed or not acknowledged (due to loss of the corresponding RMC message) shall be assigned for retransmission. Dummy DTUs shall not be retransmitted.

The DTUs assigned for retransmission and the new incoming DTUs shall be scheduled for transmission in such a way that the number of DTUs, completely mapped on data symbols and RMC symbols sent between the end of transmission of a given DTU and the start of its subsequent retransmission, does not exceed Q_{tx} DTUs. The value of Q_{tx} is defined as the maximum number of DTUs that can be transmitted between the end of the first DTU associated with the ACK window (i.e., the oldest DTU of the ACK window) and the start of the last opportunity of this DTU's retransmission associated with the given value of T_{ret} defined in clause 9.8.1 (see Figure 9-15a).

NOTE 1 – An upper limit on Qtx for the downstream direction is the maximum number of DTUs that can be transmitted fully or partially in M_{ds} + $RetShift_{ds}$ + DS_ACK_WINDOW_SHIFT symbols, where the sum of $RetShift_{ds}$ and DS_ACK_WINDOW_SHIFT is the maximum value that can be obtained for the largest value of $T_{resp\_max\_act\_O}$, *RetShift_min_ds*, and T_{ack}, and any valid positions of the upstream RMC symbol (see clause 9.8.1). A similar limit can be obtained for the upstream direction.

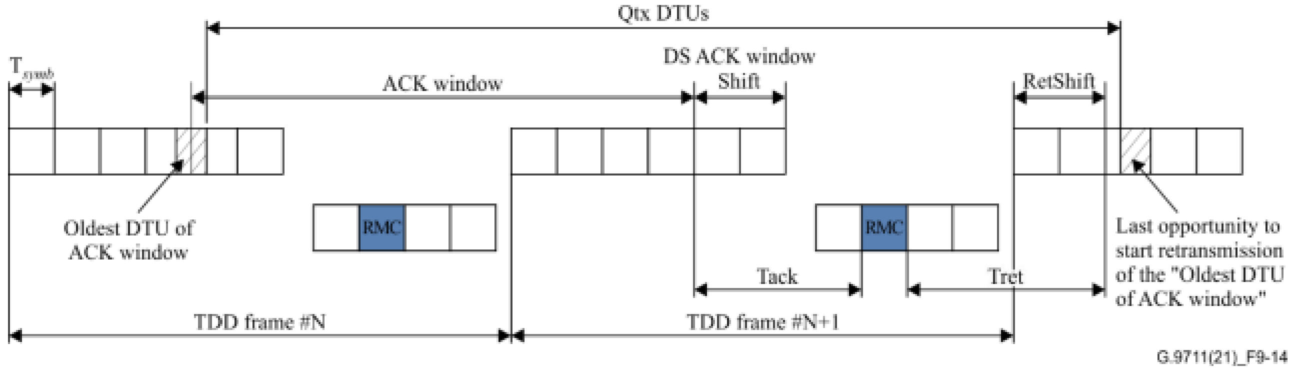


Figure 9-14 – Illustration of definition of Q_{tx}

To improve the robustness of transmission for higher QoS grades, the following additional rules of DTU retransmission may be applied by the transmitter:

1) The priority among DTUs to be retransmitted is determined by their highest QoS grade tag: DTUs with higher unaged tag are retransmitted first.

2) If a DTU to be transmitted next has the same highest QoS grade tag as the DTU to be retransmitted next, the DTU to be retransmitted has priority.

3) Retransmission of DTUs that are about to be aged (referred to as "last chance retransmission") is an exception from rules #1 and #2. Determination of the conditions for such DTUs to be eligible for this "last chance retransmission" is vendor discretionary.

   NOTE 2 – The intention of this exception is to reduce packet loss due to aging of DTUs.

4) Retransmission of DTUs carrying eoc packets is an exception to rules #1 and #2. Determination of the transmission/retransmission priority of DTUs carrying eoc packets is vendor discretionary.

   NOTE 3 – The intention of this exception is to avoid delays in time-critical management functions.

5) DTUs may be retransmitted proactively, regardless of whether the acknowledgement is received on time or not received due to excessive roundtrip delay or loss of the corresponding RMC message. For each particular QoS grade proactive retransmission can be forced by corresponding setting of the DPU MIB parameter PROACTIVE_RTX_ON (valid values 0, 1 and 2) for the associated QoS class.

If PROACTIVE_RTX_ON parameter is set (value 1 or 2) for the QoS class associated with a particular QoS grade, all DTUs carrying DTU frames of this QoS grade shall be retransmitted at least once (value 1) or twice (value 2), which may be regular or proactive retransmissions. These forced proactive retransmission shall be applied regardless of the *delay_max* value. In case *delay_max* is too short to allow regular retransmissions, the transceiver shall place one or more proactive retransmissions. In case more than one retransmission is applied, retransmissions should be spread out in time.

NOTE 4 – Proactive retransmission can be used to enhance the robustness of transmission for higher QoS grades with time critical requirements. However, it needs to be used with care as it impacts throughput. To balance the trade-off between the transmission robustness and achievable throughput, the following guidance can be considered:

– If delay_max is such that one regular retransmission is possible, but it will not be possible to do the second retransmission within delay_max, the system can wait for the ACK/NACK of the original transmission and only needs to send the first regular retransmission and an additional proactive one if a NACK was received. This will save bandwidth compared to the case when proactive retransmissions are sent without prior reception of a NACK.

– In case delay_max is too short for one regular retransmission only two proactive retransmissions are possible. These two should be spread out in time as much as possible. Since these two retransmissions are not based on ACK/NACK information, each DTU containing data from the considered QoS class will be transmitted three times. This consumes additional bandwidth. However, it is expected that this will apply to very low data volumes only.

If PROACTIVE_RTX_ON parameter is reset (value 0) for the QoS class associated with a particular QoS grade, proactive retransmission for the DTUs carrying DTU frames of this QoS grade is not required. However, proactive retransmission may still be used on vendor discretionary basis. Examples for such cases are:

- DTUs containing DTU frames of a QoS grade for which the associated *delay_max* value is too short to allow a regular retransmission (i.e., retransmission based on ACK bit maps from the receiver).
- DTUs marked for "last chance retransmission"
- DTUs containing QoS grades for which the number of potential retransmissions within *delay_max* is not sufficient to fulfil the particular packet loss requirements.

Both the transmitter and the receiver shall discard aged DTUs. The age of the DTU shall be computed in symbol periods, as the difference between the symbol count at which the symbol carrying the first bit of the DTU appears at the U reference point and the TS value of this DTU.

A transmitter shall discard a DTU assigned for retransmission if the age of the DTU is older than *delay_max_0* expressed in symbol periods ($delay\_max\_0 \times f_{DMT}$). The receiver shall discard a received DTU if the age of this DTU is older than the *delay_max_0* expressed in symbol periods associated.

Once the corresponding ACK to a DTU is correctly received by the transmitter, there is no need for the transmitter to retransmit that DTU.

9.8.1 Acknowledgement and retransmission latency requirements

The MTU shall be capable of decoding all DTUs contained in the received data frames within an ACK window and shall respond with the associated ACK bit map within T_{ack} µsec. T_{ack} shall be measured at the U reference point from the time the last symbol of the ACK window has ended at the receiver port until the beginning of the RMC symbol carrying the ACK bit mapfor that ACK window at the transmitter port. The value of T_{ack} shall not exceed 400 µsec for the MTU-O (denoted $T_{ack\_max\_O}$) and shall not exceed 300 µs for the MTU-R (denoted $T_{ack\_max\_R}$).

The retransmission time (T_{ret}) is measured from the time that the end of the RMC symbol (carrying the acknowledgement information) has reached the receiver until the start of transmission of the symbol carrying the first bit of the retransmitted DTU associated with this acknowledgement information, both measured at the U-reference point.

Figure 9-15a illustrates parameters T_{ack} and T_{ret} as they relate to retransmission in the downstream data direction.

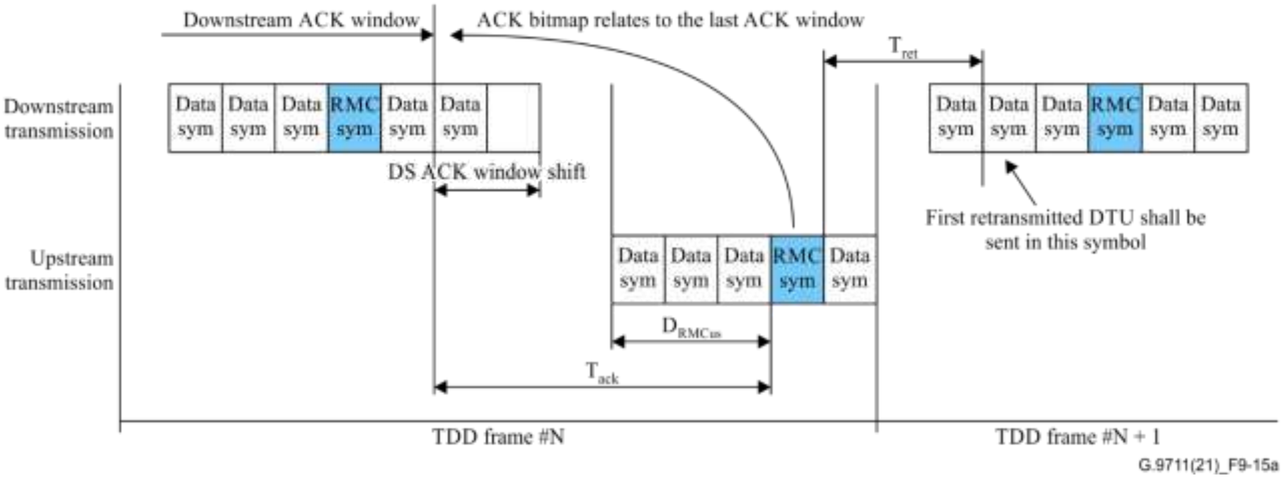


Figure 9-15a – Illustration of parameters T_{ack} and T_{ret}

NOTE 1 – T_{ack} for the downstream direction is measured at the U-R reference point. T_{ack} for the upstream direction is measured at the U-O reference point. T_{ret} for the downstream direction (retransmission of downstream DTUs) is measured at the U-O reference point. T_{ret} for the upstream direction (retransmission of upstream DTUs) is measured at the U-R reference point.

NOTE 2 – The above figure shows a simplified representation as the propagation delay is ignored.

The MTU-O shall be capable of decoding an ACK bit map and responding with retransmission of the relevant DTUs within 400 µsec. This maximum response time capability is denoted by $T_{resp\_max\_O}$. The MTU-R shall be capable of decoding an ACK bit map and responding with retransmission of the relevant DTUs within 300 µsec. This maximum response time capability is denoted by $T_{resp\_max\_R}$.

The value of T_{ret} depends on the setting of framing parameters (M_{ds}, D_{RMCds}, and D_{RMCus}) and the capabilities of the MTU, and might exceed T_{resp_max} for some settings of framing parameters.

The MTU shall communicate during initialization the actual response time capability ($T_{resp\_max\_act}$) expressed in DMT symbols and the minimum retransmission shift capability (*RetShift_min*), in order to convey to the other side the position of the last DMT symbol in which the oldest DTU of the ACK window corresponding to the latest RMC may be retransmitted. This position is shifted by *RetShift* symbols from the start of the first symbol position of the PSF transmitted in the opposite direction following this RMC symbol. The downstream and upstream *RetShift* shall be computed as follows:

$$RetShift_{ds} = \max(T_{resp\_max\_act\_O} - (M_{us} - D_{RMCus} - 1), RetShift\_min\_ds)$$

$$RetShift_{us} = \max(T_{resp\_max\_act\_R} - (M_{ds} - D_{RMCds} - 1), RetShift\_min\_us)$$

If *RetShift* is positive, this position is delayed by *RetShift* symbols.

When FDX mode is used, the value of *RetShift_min* may be negative. If *RetShift* is negative, the position of the last DMT symbol in which the oldest DTU of the ACK window corresponding to the latest RMC may be retransmitted is advanced by -*RetShift* symbols (the position is within the NPSF).

The relationship between the $RetShift_{ds}$, $T_{resp\_max\_act\_O}$, the upstream RMC position, and the first symbol position transmitted in the downstream direction is illustrated in Figure 9-15b in case of TDD framing mode with $RetShift_{ds}>0$ and in Figure 9-15c in case of FDXZ framing mode with $RetShift_{ds}<0$.

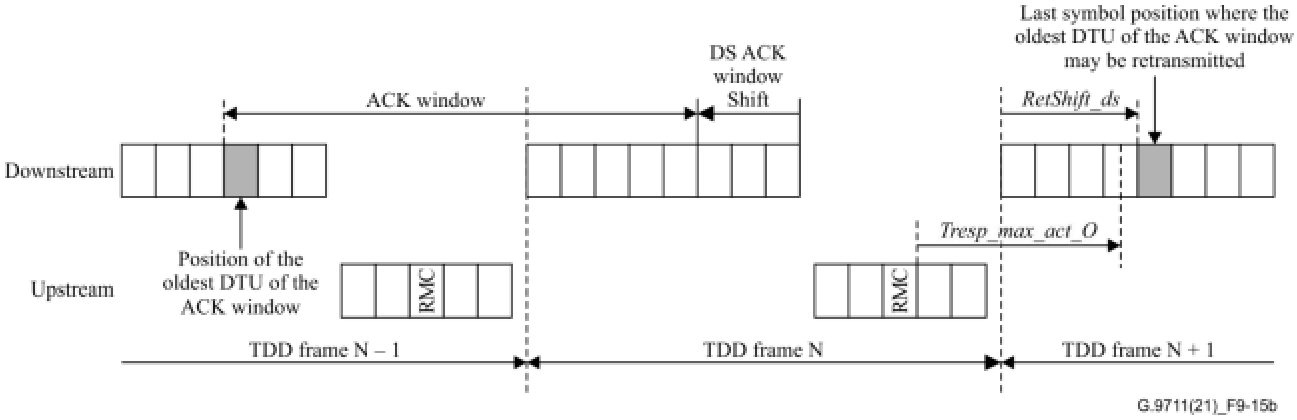


Figure 9-15b – Illustration of parameters *RetShift*, $T_{resp\_max\_act}$ for the downstream (for M_{us} = 5, M_{ds} = 8, $T_{resp\_max\_act\_O}$ = 6, $RetShift_{ds}$ = 4) in case of TDD framing

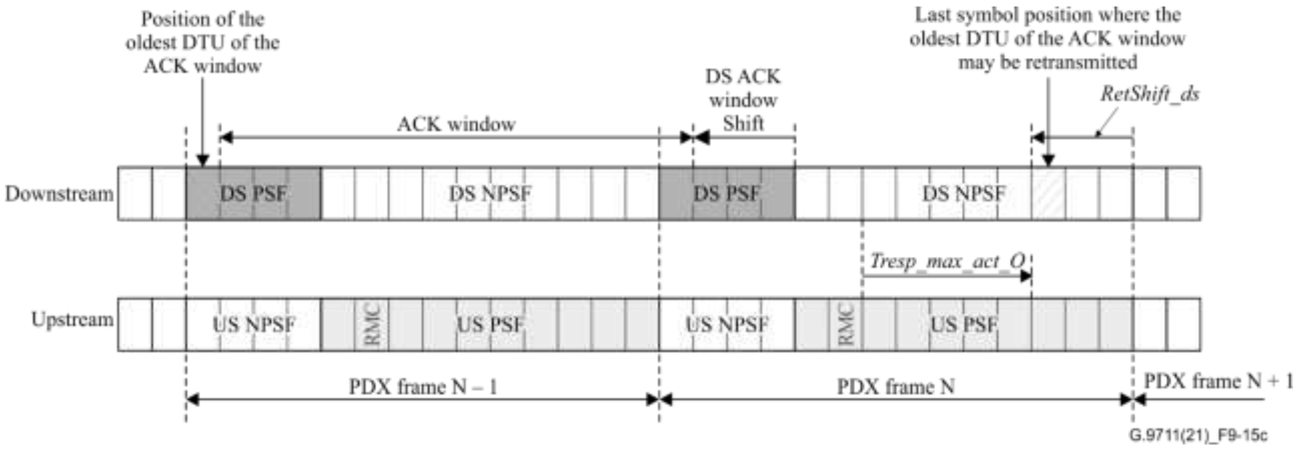


Figure 9-15c – Illustration of parameters *RetShift*, $T_{resp\_max\_act}$ for the downstream (for M_{us} = 10, M_{ds} = 4, $T_{resp\_max\_act\_O}$ = 5, $RetShift_{ds}$ = -3) in case of FDXZ framing

9.8.2 Retransmission control parameters

This clause specifies the primary and derived control parameters to support the retransmission function, along with the valid and mandatory configurations of these parameters.

9.8.2.1 Primary parameters

The primary control parameters for retransmission are defined in Table 9-24.

Table 9-24 – Control parameters

Parameter	Definition
NDR_max	Maximum allowed value for NDR in kbit/s (see clause 11.4.2.2).
ETR_min	Minimum allowed value for ETR in kbit/s (see clause 11.4.2.1).
INP_min_shine	Minimum INP against a single high impulse noise event (SHINE) in symbol periods (see clauses 9.8.3.3 and 11.4.2.4).
SHINEratio	The loss of NDR expressed as a fraction of NDR (see Table 9-27) due to a SHINE impulse noise environment expected by the operator to occur at a probability acceptable for the services (see clause 11.4.2.5).
INP_min_rein	Minimum INP against repetitive electrical impulse noise (REIN) in symbol periods (see clauses 9.8.3.3 and 11.4.2.6).
iat_rein_flag	Configuration flag indicating the inter-arrival time of REIN. The flag shall be set to 0,

Table 9-24 – Control parameters

Parameter	Definition
	1, 2 or 3 if the inter-arrival time is derived from REIN at 100 Hz, 120 Hz, 300 Hz or 360 Hz, respectively (see clauses 9.8.3.3 and 11.4.2.7). (Notes 1, 2)
delay_max	Maximum delay in increments of 0.25 ms (see clauses 9.8 and 11.4.2.3).
RTX_TESTMODE	A management primitive initiating the PMS-TC test mode for accelerated testing of MTBE (see clause 9.8.3.1.2).
rnratio_min	The minimum allowed ratio R_{FEC}/N_{FEC} of FEC code parameters (see clause 11.4.2.8). (Note 3)
NOTE 1 – This parameter is not relevant if the *INP_min_rein* is set to 0. NOTE 2 – The REIN periodicity is derived from the assumption of 2 or 6 equally spaced impulses per AC cycle of 50 Hz or 60 Hz. Consideration of cases where the impulses are not equally spaced is for further study. NOTE 3 – This parameter applies to data path only; the valid range for R_{FEC}/N_{FEC} of the RMC encoder is from 0.25 to 0.5.	

9.8.2.2 Valid configurations

A valid configuration shall consist of the configuration of each control parameter with one of their valid values specified in Table 9-25.

Table 9-25 – Valid configurations

Parameter	Capability
NDR_max	The valid values are all multiples of 96 kbit/s from *ETR_min* + 96 kbit/s to $(2^{16}-1) \times$ 96 kbit/s (Note).
ETR_min	The valid values are all multiples of 96 kbit/s from 0 kbit/s to $(2^{16}-1) \times$ 96 kbit/s.
INP_min_shine	The valid values are all integers from 0 to 520.
SHINEratio	The valid values are all multiples of 0.001 from 0 to 0.1.
INP_min_rein	The valid values are all integers from 0 to 63.
iat_rein_flag	The valid values are 0, 1, 2 and 3.
delay_max	The valid values are all multiples of 0.25 ms from 1 to 16 ms.
rnratio_min	The valid values are all multiples of 1/32 from zero to 8/32 that also satisfy the constraints of clause 9.3.
NOTE – *NDR_max* needs to be set higher than *ETR_min_eoc* to successfully reach showtime (see Table 9-27 and clause 12.3.7). Depending on the total number of subcarriers in the downstream MEDLEYG set and other parameters, *ETR_min_eoc* may exceed *ETR_min* by as much as approximately 32 Mbit/s.	

9.8.2.3 Mandatory configurations

The mandatory configurations to support are a subset of the valid configurations. They shall consist of the configuration of each control parameter with one of their mandatory values specified in the Table 9-26.

Table 9-26 – Mandatory configurations

Parameter	Capability
NDR_max	All valid values shall be supported.
ETR_min	All valid values shall be supported.
INP_min_shine	All valid values shall be supported.
SHINEratio	All valid values shall be supported.
INP_min_rein	All valid values shall be supported.
iat_rein_flag	All valid values shall be supported.
delay_max	All valid values shall be supported.
rnratio_min	All valid values shall be supported.

9.8.2.4 Derived parameters

Derived framing parameters are parameters that can be computed using the primary framing parameters as input. The derived parameters can be used to verify data rates or to identify additional constraints on the validity of the primary parameters. The derived parameters assume a utilization of the logical frame without idle or quiet symbols. Two cases are addressed in this section: with DTFO disabled and with full utilization of the DTFO.

The derived parameters presented in this clause are per link and applicable for both P2P mode and P2MP mode of operation.

Table 9-27 – Derived framing parameters

Parameter	Definition
f_{DMT}	Symbol rate of transmission expressed in Hz as specified in clause 10.4.4 (same for upstream and downstream).
$f_{D,PSF}^{DS}$	The downstream data symbol rate in PSF: $$f_{D,PSF}^{DS} = f_{DMT} \times \left(\frac{M_{ds} - 1 - \frac{1}{M_{SF}}}{M_F} \right)$$ where: 1 = overhead due to one RMC symbol per PDX frame $1/M_{SF}$ = overhead due to one sync symbol per superframe M_F = number of symbol periods per PDX frame
$f_{D,NPSF}^{DS}$	The downstream data symbol rate in NPSF (Note 7): $$f_{D,NPSF}^{DS} = f_{DMT} \times \left(\frac{M_{us} - \frac{1}{M_{SF}}}{M_F} \right)$$ where: $1/M_{SF}$ = overhead due to one sync symbol per superframe M_F = number of symbol periods per PDX frame

Table 9-27 – Derived framing parameters

Parameter	Definition
$f^{US}_{D,PSF}$	The upstream data symbol rate in PSF: $$f^{US}_{D,PSF} = f_{DMT} \times \left(\frac{M_{us} - 1 - \frac{1}{M_{SF}}}{M_F} \right)$$ where: 1 = overhead due to one RMC symbol per PDX frame $1/M_{SF}$ = overhead due to one sync symbol per superframe M_F = number of symbol periods per PDX frame
$f^{US}_{D,NPSF}$	The downstream data symbol rate in NPSF (Note 7): $$f^{US}_{D,NPSF} = f_{DMT} \times \left(\frac{M_{ds} - \frac{1}{M_{SF}}}{M_F} \right)$$ where: $1/M_{SF}$ = overhead due to one sync symbol per superframe M_F = number of symbol periods per PDX frame
f_{RMC}	The RMC symbol rate: $$f_{RMC} = f_{DMT} \times \left(\frac{1}{M_F} \right)$$
B_{eoc}	The maximum number of eoc bytes per direction per logical frame period $B_{eoc} = \min\left\{ B_{eoc-max}, \text{ceiling}\left(\frac{\frac{6 \times N_{DScarrier}}{M_{SF}} + 125000 \times \frac{M_F}{f_{DMT}}}{1-RTxOH} \right) \right\}$ (Note 3)
DPR	DTU payload rate: $DPR = DPR_D + DPR_{DR}$
DPR_D	The maximum DTU payload rate part corresponding to transmission of data symbols over all valid DTFO configurations: If $B_{DN01,PSF} \geq B_{DOI}$ $DPR_D = 8 \times (B_{DN01,PSF} \times f_{D,PSF} + B_{DN01,NPSF} \times f_{D,NPSF}) \times \left(\frac{K_{FEC}}{N_{FEC}}\right) \times (1 - DTUframingOH)$ If $B_{DN01,PSF} < B_{DOI}$ and the sync symbol is located in DOI if the full DOI is active. $DPR_D = 8 \times \left(\frac{MNDSNOI \times M_{SF} \times B_{DN01,PSF} + ((M - MNDSNOI - 1) \times M_{SF} - 1) \times B_{DO}}{M_F \times M_{SF}} \times f \right.$ $\left. + B_{DN01,NPSF} \times f_{D,NPSF} \right) \times \left(\frac{K_{FEC}}{N_{FEC}}\right) \times (1 - DTUframingOH)$

Table 9-27 – Derived framing parameters

Parameter	Definition
	If $B_{DN01,PSF}$<B_{DOI} and the sync symbol is located in NOI if the full DOI is active. $DPR_D = 8 \times \left(\frac{(MNDSNOI \times M_{SF} - 1) \times B_{DN01,PSF} + (M - MNDSNOI - 1) \times M_{SF} \times B_{DO}}{M_F \times M_{SF}} \times f \right.$ $\left. + B_{DN01,NPSF} \times f_{D,NPSF} \right) \times \left(\frac{K_{FEC}}{N_{FEC}}\right) \times (1 - DTUframingOH)$ (Note 1)
DPR_{DR}	DTU payload rate part corresponding to the data portion of the RMC symbol with full DTFO option: $DPR_{DR} = 8 \times B_{DR01} \times f_{RMC} \times \left(\frac{K_{FEC}}{N_{FEC}}\right) \times (1 - DTUframingOH)$
DPR_0	DTU payload rate with all DTFO blocks disabled (Note 4): $DPR_0 = DPR_{D0} + DPR_{DR0}$
DPR_{D0}	DTU payload rate part corresponding to data symbols with all DTFO blocks disabled (Note 4): $DPR_D = 8 \times (B_{DN0,PSF} \times f_{D,PSF} + B_{DN0,NPSF} \times f_{D,NPSF}) \times \left(\frac{K_{FEC}}{N_{FEC}}\right) \times (1 - DTUframingOH)$ (Note 1)
DPR_{DR0}	DTU payload rate part corresponding to the data portion of the RMC symbol with DTFO option disabled (Note 4): $DPR_{DR0} = 8 \times B_{DR0} \times f_{RMC} \times \left(\frac{K_{FEC}}{N_{FEC}}\right) \times (1 - DTUframingOH)$
DPR_{eoc}	The maximum DTU payload rate corresponding to eoc: DPR_{eoc} = (8 x B_{eoc}) / (M_F / f_{DMT})
DTUframingOH	The relative overhead due to DTU framing: If optional extension of auxiliary field is not used: $DTUframingOH = \frac{7}{Q \times K_{FEC}}$ Otherwise: $DTUframingOH = \frac{8}{Q \times K_{FEC}}$
NDR	The net data rate (for each direction): $NDR = DPR - 1000$ kbit/s (Note 2)
NDR_0	The net data rate (for each direction) with DTFO disabled (Note 4): $NDR_0 = DPR_0 - 1000$ kbit/s (Note 2)
ANDR	The aggregate net data rate: $ANDR = NDR^{DS} + NDR^{US}$
RTxOH	The retransmission overhead needed to protect against the worst-case impulse noise environment as configured in the DPU-MIB and stationary noise. $RTxOH = REIN\_OH + SHINE\_OH + STAT\_OH$ with If *INP_min_rein* > 0:

Table 9-27 – Derived framing parameters

Parameter	Definition
	$REIN\_OH = (INP\_\min\_rein + 1) \times \left[floor\left(\frac{f_{DMT}}{f_{REIN}} \right) \right]^{-1}$ with f_{REIN}, the repetition frequency of REIN in kHz. If *INP_min_rein*=0 then *REIN_OH*=0 $SHINE\_OH = SHINERatio\,o$ $STAT\_OH = 10^{-4}$ where STAT_OH is the statistical overhead due to retransmission
ETR	The expected throughput in kbit/s: $ETR = (1 - RTxOH) \times NDR$
ETR_0	The expected throughput with DTFO disabled (Note 4): $ETR_0 = (1 - RTxOH) \times NDR_0$
ETR_min_eoc (Note 6)	The minimum expected throughput including the eoc rate: *ETR_min_eoc=ETR_min + (1-RTxOH)x(DPReoc – 1000 kbit/s)*
NOTE 1 – f_D is either f_D^{US} for upstream or f_D^{DS} for downstream. *M* is either M_{us} for upstream or M_{ds} for downstream. *MNDSNOI* is either $MNDSNOI_{us}$ for upstream or $MNDSNOI_{ds}$ for downstream. NOTE 2 – This 1000 kbit/s is a reference value for the eoc overhead channel rate for the purpose of this calculation. NOTE 3 – The value of $B_{eoc\text{-}max}$ is the maximum number of eoc bytes per logical frame defined in Table P.1 and Table Q.1, and $N_{DScarrier}$ is the total number of subcarriers in the downstream MEDLEYG set. NOTE 4 – This rate is the rate that is achieved when all lines all links on of the vectored group are transmitting data symbols in every symbol position of the PDX frame (i.e., only NOI, no DOI) and use DTFO Band0 only. NOTE 5 – The ETR_0 is used to compare with *ETR_min_eoc* during the rate policy of initialization and OLR. NOTE 6 – The *ETR_min_eoc* is calculated by the MTU as the value of the *ETR_min* control parameter, increased by the expected throughput corresponding to the maximum eoc data rate allowed for the profile. NOTE 7 – In case of TDD framing mode, only PSF is active; the data symbol rate in NPSF is zero.	

9.8.3 Performance related parameters

9.8.3.1 Definition of mean time between error events (MTBE)

Mean time between error events (MTBE) is the average number of seconds between two error events. An error event is defined as a block of one or more consecutive uncorrected DTUs. The MTBE is referenced to the output of the PMS-TC function after retransmission (i.e., the α reference point at the receiver side).

If each error event consists of a single corrupted DTU (which is typical for stationary noise environment), MTBE can be calculated as:

$$MTBE = \left(\frac{Measurement\_Time}{Number\_of\_uncorrected\_DTUs} \right),$$

where:

$MTBE$ is expressed in seconds.

Measurement_Time is expressed in seconds.

Number_of_uncorrected DTUs is the number of *rtx-uc* anomalies (see clause 11.3.1.1) over the measurement time.

9.8.3.1.1 Definition of MTBE_min

The minimum MTBE (MTBE_min) is defined as 14 400 seconds.

NOTE – This value is taken from [b-BBF TR-126], corresponding to high definition television (HDTV) quality, quantified as an average of one error event in four hours.

9.8.3.1.2 Accelerated testing of MTBE

In order to facilitate testing, a special test mode is defined. This test mode shall be selected by enabling RTX_TESTMODE for the PMS-TC (see Table 9-24) at the transmitter and receiver, and enabling TPS_TESTMODE for the TPS-TC (see clause 8.1.3) at the transmitter. The remote MTU shall be forced into this test mode by sending a diagnostic command through the eoc (see clause 11.2.2.6).

When RTX_TESTMODE is enabled, retransmissions shall not be requested by the receiver (i.e., all DTUs shall be ACKed and all uncorrected DTUs shall be discarded) nor sent autonomously by the transmitter (even if the proactive retransmission is enabled). In this mode, the receiver shall count uncorrected DTUs as during the normal operation.

NOTE 1 – This test provides valid results only if performed in the presence of stationary noise only.

The MTU-R shall enter the test mode upon receiving the Start RTX_TESTMODE eoc command for the downstream testing and TPS-TESTMODE eoc command for the upstream testing (see Table 11-24 and clause 11.2.2.6.3).

NOTE 2 – In this test mode, the DRA function is configured in the DRA test mode. In the DRA test mode, for upstream and downstream, the DRA sets *TTR* = M and *TBUDGET* to the maximum value allowed within the bounds set by the ME-O and PCE, and additionally the DRA sets *TA_B1*=0 and *TB_B1*=*TBUDGET*.

P_{DTU} is defined as the probability that a DTU is corrupted, i.e., a DTU is not received correctly in a single transmission. In this test mode, it can be calculated for downstream and upstream separately from the DTU counters as:

$$P_{DTU} = \left(\frac{Number\_of\_uncorrected\_DTUs}{Measurement\_Time / T_{DTU}} \right)$$

where:

Measurement_Time is expressed in seconds.

T_{DTU} is the time duration of a DTU expressed in seconds.

Number_of_uncorrected DTUs is the number of *rtx-uc* anomalies (see clause 11.3.1.1) over the measurement time.

In this accelerated test, the requirement for P_{DTU} is:

$$P_{DTU} \leq \frac{8.3333 \times 10^{-3}}{\sqrt{f_{DMT}}} \times \left(T_{DTU\_in\_DMT}\right)^{1/2}$$

where f_{DMT} is the symbol rate in Hz (see clause 10.4.4) and $T_{DTU\_in\_DMT}$ is the average duration of a DTU expressed in symbol periods, which shall be computed as the average value of $(N_{DTU}+Q \times R_{FEC})/B_D$ during the measurement period (see clause 8.2).

NOTE 3 – Appendix III of [b-ITU-T G.9701] provides the calculations motivating this requirement.

NOTE 4 – The value of $T_{DTU\_in\_DMT}$ for downstream and upstream, and the value of f_{DMT} are reported in the DPU-MIB.

9.8.3.2 Definition of signal-to-noise ratio margin (SNRM)

The SNRM is equal to 1 dB plus the maximum increase (scalar gain, in dB) of the reference noise PSD (at all relevant frequencies and assuming only stationary noise is applied at the U reference point), for which the MTBE of the TPS-TC stream (see Figure 8-3) is not lower than the minimum MTBE (MTBE_min, see clause 9.8.3.1.1) specified for this TPS-TC stream, assuming only one retransmission of each DTU is allowed, without any change of PMD parameters (e.g., bits and gains) and PMS-TC parameters (e.g., FEC parameters) and with *RTXOHact* ≤ *STAT_OH* with *RTXOHACT* defined as in the definition of ANDEFTR (see clause 11.4.1.1.17) and *STAT_OH* as defined in Table 9-27.

NOTE 1 – At a 1 dB signal-to-noise ratio margin (SNRM) working point, the transceiver operates at an MTBE equal to or better than the MTBE_min.

NOTE 2 – During testing of the SNRM, only stationary noise is applied to the U-O or U-R reference point (i.e., no impulse noise is present), and *delay_max* is configured to correspond to allowing only one retransmission of each DTU, and the TPS-TC is configured with TPS_TESTMODE enabled (see Table 8-8), and the DRA is configured in the DRA test mode (see note 2 in clause 9.8.3.1.2). In this case, the condition (*RTXOHact* ≤ *STAT_OH)* is equivalent to EFTR ≥ ETR with EFTR the error-free throughput (see clause 11.4.1.1.5) and ETR as defined in Table 9-27.

The definition of the reference noise PSD depends on the control parameter SNRM_MODE.

In this edition of the Recommendation, only SNRM_MODE=1 (see clause 9.8.3.2.2) is defined. Other values are for further study.

9.8.3.2.1 Accelerated testing of SNRM

The accelerated testing method for MTBE can be used for accelerated testing of SNRM (see clause 9.8.3.1.2).

9.8.3.2.2 SNRM_MODE = 1

SNRM_MODE = 1 is a mandatory capability for both MTUs.

The reference noise PSD equals the received current-condition noise PSD at the U reference point measured by the near-end transceiver.

NOTE 1 – This noise PSD is equal to the PSD of the noise measured by the near-end transceiver at the constellation decoder or other relevant internal reference point when the only noise source is the external stationary noise applied to the U reference point and no internal noise sources are present.

NOTE 2 – Mathematically, this can be illustrated by:

> $Received\_External\_Noise\_PSD = |\ H_{RXfilter}(f)\ |^2 \times Noise\_PSD\_at\_U\_reference\_point$, with $|H_{RXfilter}(f)|^2$ the transfer function from U reference point to the above-mentioned internal reference point.

9.8.3.3 Impulse noise protection

The receiver shall guarantee protection (i.e., errored DTUs are successfully recovered by the retransmission function resulting in no errors at higher layers, regardless of the number of errors within the DMT symbol periods) against the worst-case impulse noise environment defined by the associated DPU-MIB parameters.

These DPU-MIB parameters are:

- *INP_min_shine*: Minimum INP against SHINE impulses, expressed in symbol periods at the δ reference point.
- *INP_min_rein*: Minimum INP against REIN impulses, expressed in symbol periods at the δ reference point.
- f_{REIN}: the repetition frequency of REIN expressed in kHz. Only four values (100, 120, 300 and 360 Hz) are possible (see clause 11.4.2.7) and configured through *iat_rein_flag*.

A worst-case impulse noise environment assumes that:

- Every impulse causes retransmission of all DTUs that overlap with the impulse.
- Every impulse is maximum length (either *INP_min_shine* or *INP_min_rein* symbol periods depending on the type of impulse).
- SHINE impulses have large inter-arrival times such that can be treated as independent.
- The inter-arrival time between a SHINE and REIN impulses is random. Therefore, REIN and SHINE are treated independently.
- The simultaneous presence of a stationary noise level at the MTBE reference SNRM (i.e., SNRM= 1 dB).

The mandatory values of *INP_min_shine* are from 0 to 520 symbol periods.

NOTE – This range is equivalent to 0 to approximately 10 ms SHINE impulse length.

The mandatory values of *INP_min_rein* are from 0 to 63 symbol periods.

Initialization shall be aborted if a receiver cannot guarantee the required INP within the latency bounds defined by the control parameter *delay_max_0*.

Indication shall be given in the DPU-MIB parameter "initialization success/failure cause" of a failure cause "configuration error".

9.8.3.4 Definition of signal-to-noise ratio margin for RMC (*SNRM_RMC*)

The *SNRM_RMC* is the maximum increase (scalar gain, in dB) of the reference noise PSD (at all relevant frequencies and assuming only stationary noise is applied at the U-reference point), for which the expected bit error ratio (BER) of the RMC channel does not exceed 10^{-7}, without any change of PMD parameters (e.g., RMC tone set, bits and gains) and PMS-TC parameters (e.g., FEC parameters). The expected BER is referenced to all bits of the RMC messages at the output of the RMC channel (see Figure 9-1), assuming that messages received in error are not discarded.

10 Physical media dependent (PMD) function

10.1 PMD functional reference model

Figure 10-1 provides an overview of a functional reference model of the PMD at the MTU-O. The bits for transmission on the subscriber line are received across the δ interface from the PMS-TC in the format of data frames; similarly, the data bits received from the data symbol decoder of the PMD are also transferred to the PMS-TC across the δ interface in the same format. The content of a single data frame is loaded onto one symbol.

Two types of data frames are exchanged via δ interface: a normal data frame, carrying bits of both RRC and DTU(s) and an RMC data frame, carrying both RMC bits and bits of DTU(s). The bits of RMC and DTU(s) are multiplexed into the RMC data frame as specified in clause 9.5; the bits of RRC and DTUs are multiplexed into a normal data frame, as specified in clause 9.5. For each logical frame, only one RMC data frame is transmitted. All other data frames are normal data frames. The number of bits in an RMC data frame and in a normal data frame may be different.

The data symbol encoder (see clause 10.2) divides the incoming data frame into groups of bits, where each group is assigned to modulate a specific subcarrier of the DMT signal. Each group is further encoded by an inner encoder and mapped to a particular point in a signal constellation. Similarly, bits of the initialization symbols, sync symbols, preamble symbols or DTFO concurrent monitoring (DCM) symbols, whichever need to be transmitted, are encoded and mapped onto a corresponding point in the signal constellation. The RMC symbols and data symbols have different bit loading and inner encoding rules, which are defined in clause 10.2. The data symbol encoder applies these rules accordingly.

Constellation points of the transmitted symbol, Z_i, are further precoded (per subcarrier) by combining with constellation points of symbols transmitted over other (n-1) lines of the vectored group (see clause 10.3) submitted via the ε(k,n) interface (where k is the index of the line in the vectored group). Precoding coefficients are provided by the VCE via ε-c interface (see Figure 10-27).

The set of precoded constellation points modulates the subcarriers of the symbol using an IDFT as defined in clause 10.4. After the IDFT, cyclic extension and windowing, the symbol is sent to the transmission medium over the U-O interface. In TDD mode, transmission is only at the time in the PDX frame assigned for downstream transmission (transmission control switch shown in Figure 10-1). In FDX mode, both the path is active in transmit and receive directions concurrently, without the transmission control switch between the two directions.

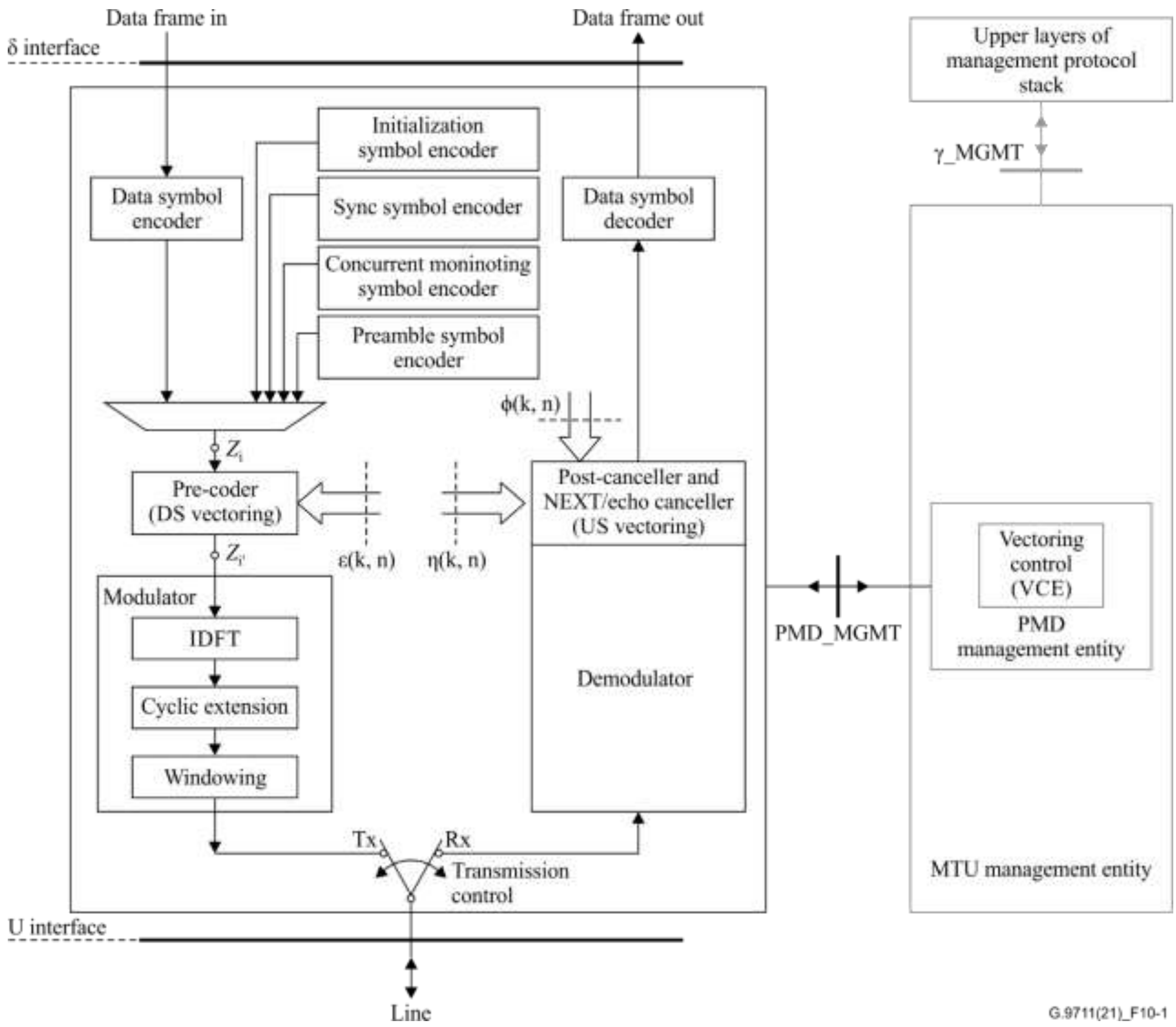


Figure 10-1 – PMD functional reference model of MTU-O (TDD mode)

In the receive direction, the incoming signal from the line (U-O refrence point) is demodulated. The recovered constellation points of the received symbol are vectored, to mitigate NEXT from the downstream transmission in FDX mode and FEXT accumulated in the line, and decoded to recover the data frame, which is then passed to the PMS-TC via the δ interface. The post-canceller uses demodulated symbols received from all other lines of the vectored group that are submitted via the η(*k*,*n*) interface; post-canceller coefficients are provided by the VCE via η-c interface. The ε(*k*,*n*), η(*k*,*n*), ε-c and η-care vendor discretionary interfaces (see clause 10.3).

In the TDD mode, the signal is received only during the time of reception depending on the transmission control (a transmission control switch in effect). In the FDX mode, the reception occurs at the time of transmission. For reception, the NEXT from the DPU transmitters serving other lines and the echo from the own transmitter are cancelled by the NEXT/echo canceller. The *φ(k, n)* reference point provides signals transmitted by other MTU-Os operating on other lines in the vectored group for NEXT cancellation. NEXT-canceller coefficients are provided by the VCE via *φ*-c interface. The *φ(k, n)* and *φ*-c interfaces are vendor discretionary.

The functional reference model of the MTU-R (shown in Figure 10-2) is the same as that of the MTU-O, except it does not include a precoder ($Z_i' = Z_i$) in the transmit direction and post-canceller in the receive direction. In the transmit direction, the signal constellation points obtained from the symbol encoder are directly passed to the modulator. In the receive direction, in TDD mode, the demodulated constellation points are passed to the data symbol decoder. Echo canceller facilitates operation in FDX mode, but no NEXT-canceller is used, since transmit signals of other MTU-Rs are not available.

In TDD mode, transmission is only at the time in the PDX frame assigned for downstream transmission (controlled by the transmission control which is a transmission control switch in effect). In FDX mode, the path is active in both transmit and receive directions concurrently, without the transmission control switch between the two directions.

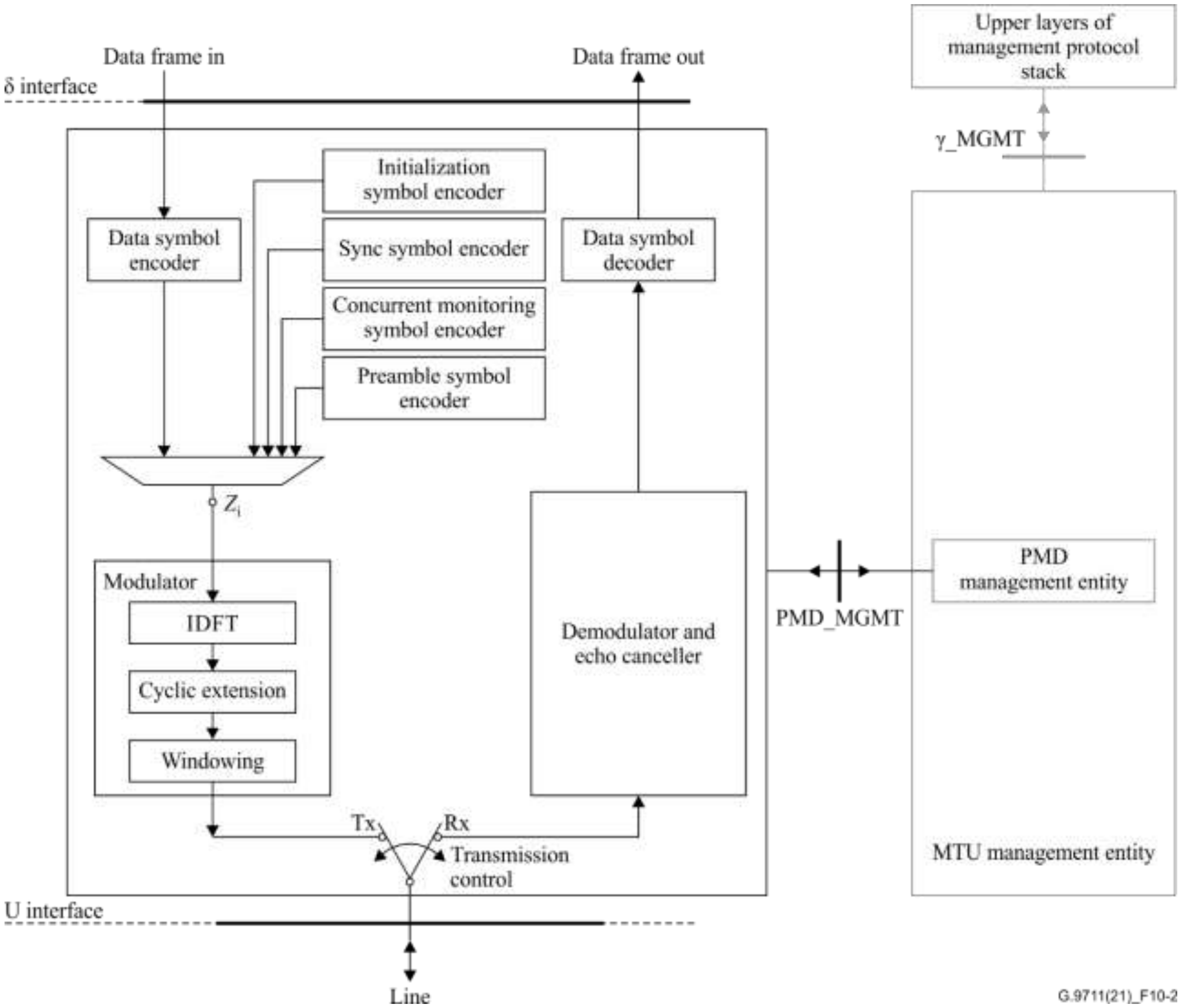


Figure 10-2 – PMD functional reference model of MTU-R (TDD mode)

10.1.1 U reference point

The U reference point describes both a physical and a logical interface of the data plane between the PMD and the transmission medium (twisted wire-pair). The data at the U reference point in both transmit and receive directions is a stream of symbols organized into PDX frames, as defined in clause 10.5. In TDD mode, the PDX frame format provides time separation between upstream and downstream transmission, so symbols are never transmitted and received simultaneously. In FDX mode, both upstream and downstream can be transmitted at the same time.

Groups of subsequent PDX frames form superframes, see clause 10.6; each superframe carries sync symbols used for PDX frame synchronization and channel estimation.

Each symbol is a time-domain object generated using IDFT, as defined in clause 10.4.3. Symbols are cyclically extended and transmitted onto the medium with an overlap, as defined in clause 10.4.4.

The electrical characteristics at the U reference point are defined in clauses 7.3 and clause 14, and include total aggregate wideband power; in-band and out-of-band transmit PSD, longitudinal balance and termination impedance.

10.1.2 Multiplexing of paths at the MTU-O in P2MP mode

Generic functional model of the PMD sublayer (Figure 5-7a) shows that in case of P2MP, the transmit PMD layer of the MTU-O multiplexes all paths of a P2MP group into a single output signal at the U_O reference point. Figure 10-2 shows the P2MP PMD functional model that multiplexes the signals of all paths into the common modulator, which converts the multiplexed frequency domain signals into a time domain signal to be transmitted over the line. The notations and referenced points used in Figure 10-3 for each path correspond to those used in Figure 10-1.

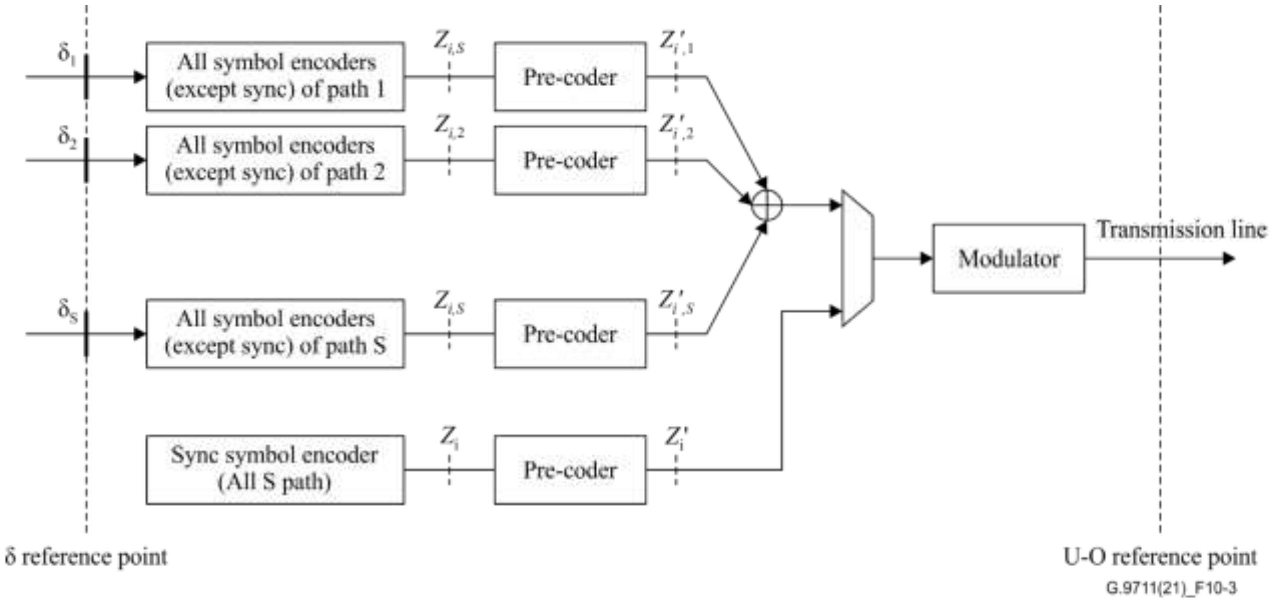


Figure 10-3 – Multiplexing of MTU-O paths into the transmission line

The PMD sublayer of each path at the MTU-O consists of one data symbol encoder, one initialization symbol encoder, one concurrent monitoring symbol encoder, one preamble symbol encoder and one precoder.

Each symbol encoder generates signal Z_i modulated on subcarrier i as defined in clause 10.4.1. The data symbol encoder (as defined in clause 10.2.1) of the k^{th} path takes as input the data frame sent over the δ_k reference point. The signal $Z_{i,k}$ of the k^{th} path generated by the symbol encoder (data symbol encoder or other symbol encoder specified in clauses 10.2.2.2-10.2.2.4) that inputs the precoder and the precoded signal ($Z_{i,k}'$) of the k^{th} path shall be both equal to 0 for all sub-carriers i of the Band 0 that belong to SUPPORTEDCARRIERSds sets of all other paths during initialization and showtime. The subcarriers of the Band 1 that belong to the SUPPORTEDCARRIERSGds can be used by only one of the paths at a time: if used in path k, both the signals Z_i of all other paths generated by the symbol encoder that input the precoder and the precoded signals (Z_i') of all other paths shall be equal to 0 for all subcarriers of Band 1. For each sub-carrier, the precoded signals of all the paths (S paths in Figure 10-3) are summed before being input into the IDFT of the modulator.

NOTE 1 – The $Z_{i,k}$ values for subcarriers generated by the symbol encoder of the k^{th} path that do not belong to the SUPPORTEDCARRIERS set of any path may have non-zero values for auxiliary purposes, as defined in clause 10.2.1.4.4.

NOTE 2 – As the operational set of sub-carriers (SUPPORTEDCARRIERS set) of any of the S paths do not overlap in the Band 0 with operational set of subcarriers of any other path and there is no DTFO block overlapping in both time and frequency in the same P2MP group (see clause 10.7.2), only one path contributes with a non-zero precoded signal to any sub-carrier input of the IDFT for each symbol.

The MTU-O shall select the same SUPPORTEDCARRIERSGds set for all the links of the P2MP group. For each subcarrier of the SUPPORTEDCARRIERSGds set, the MTU-O shall select the identical MREFPSDds value across all of the links of the P2MP group, while the MREFPSDds may be different for different subcarriers. The MREFPSDds is defined over all subcarriers of the SUPPORTEDCARRIERSGds set. The values of MREFPSDds are used over the MEDLEYds set of each link for downstream RMC and data symbols. For sync symbols, the values of MREFPSDds are used over the whole SUPPORTEDCARRIERSGds set.

NOTE 3 – Vendor discretionary values on subcarriers outside of the MEDLEYds set are specified in 10.2.1.4.4 for RMC and data symbols and in 10.2.2.1 for sync symbols.

The sync symbol encoder is defined in clause 10.2.2.1 and is common to all S paths of the P2MP group. The signal generated by the sync symbol encoder is precoded before being input to the IDFT. The precoder input signal (Z_i) generated by the sync symbol encoder is independent of the operational set of sub-carriers of any of the S paths, regardless of whether the path is in initialization or showtime.

10.1.3 PMD_MGMT interface

The PMD_MGMT reference point describes a logical interface between the PMD and the MME, see Figure 10-1. The interface is defined by a set of control and management parameters (primitives). These parameters are divided into two groups:

– parameters generated by the MME and applied to the PMD;

– parameters retrieved by the PMD from the received signal and submitted to the PMD ME.

The summary of the PMD_MGMT primitives is presented in Table 10-1.

Table 10-1 – Summary of the PMD_MGMT primitives

Primitive	Direction	Description	Reference
PDX frame and superframe (fixed in showtime)			
M_F	MME → PMD	The number of symbol periods in a PDX frame.	Clause 10.5
M_{ds}	MME → PMD	The number of downstream symbol positions in the PSF part of a PDX frame.	Clause 10.5
M_{us}	MME → PMD	The number of upstream symbol positions in the NPSF part of a PDX frame.	Clause 10.5
M_{SF}	MME → PMD	The number of PDX frames in a superframe.	Clause 10.6
D_{RMCds}	MME → PMD	The downstream RMC symbol offset, in symbols.	Clause 10.5.5
D_{RMCus}	MME → PMD	The upstream RMC symbol offset, in symbols.	Clause 10.5.5
MNDSNOI	MME → PMD	Minimum number of data symbols in transmit direction per logical frame. Fixed to MNDSNOI=2 (Note)	Clause 12.3.4.2

Table 10-1 – Summary of the PMD_MGMT primitives

Primitive	Direction	Description	Reference
PDX frame and superframe (dynamic in showtime)			
CNT_{SF}	MME → PMD	Superframe count.	Clause 10.6
CNT_{LF}	MME → PMD	Logical frame count.	Clause 10.5.5
TTR_{ds}	MME → PMD	Number of symbol positions in the. downstream NOI or downstream NOI_{PSF}	Clause 10.7, Table 8-4, and Table 9-6
TTR_{us}	MME → PMD	Number of symbol positions in the upstream NOI or in the upstream NOI_{PSF}.	Clause 10.7, Table 8-4, and Table 9-7
TTR_{NPSFds}	MME → PMD	Number of symbol positions in the NOI_{NPSF} of the downstream logical frame	Clause 10.7, Table 8-4, and Table 9-6
TTR_{NPSFus}	MME → PMD	Number of symbol positions in the NOI_{NPSF} of the upstream logical frame	Clause 10.7, Table 8-4, and Table 9-7
TA_{ds}	MME → PMD	Number of quiet symbol positions inserted at the beginning of the downstream DOI.	Clause 10.7, Table 8-4, and Table 9-6
TA_{us}	MME → PMD	Number of quiet symbol positions inserted at the beginning of the upstream DOI.	Clause 10.7, Table 8-4, and Table 9-7
IDF_{ds}	MME → PMD	Idle-data flag indicating the symbol type to be used over the downstream NOI	Clause 10.7, Table 8-4 and Table 9-6
IDF_{us}	MME → PMD	Idle-data flag indicating the symbol type to be used over the upstream NOI	Clause 10.7, Table 8-4, and table 9-7
$TBUDGET_{ds}$	MME → PMD	Transmission opportunity in the downstream direction.	Clause 10.7, Table 8-4, and Table 9-6
$TBUDGET_{us}$	MME → PMD	Transmission opportunity in the upstream direction.	Clause 10.7, Table 8-4, and Table 9-7
TIQ	MME → PMD	Idle/Quiet selector for the DOI in the downstream direction.	Clause 10.7 and Table 8-4
$TDOI_{ds}$	MME → PMD	The number of symbol positions in the DOI that could be filled with data symbols or sequential monitoring symbols	Clause 10.7, Table 8-4, and Table 9-6
$TDOI_{us}$	MME → PMD	The number of symbol positions in the DOI that could be filled with data symbols or sequential monitoring symbols	Clause 10.7, Table 8-4, and Table 9-7
T_B1_{ds}	MME → PMD	Number of symbol positions in the NOI DTFO block of the downstream logical frame	Table 9-21
T_B1_{us}	MME → PMD	Number of symbol positions in the NOI DTFO block of the upstream logical frame	Table 9-22
TA_B1_{ds}	MME → PMD	Shift of the NOI DTFO block from the	Table 9-21

Table 10-1 – Summary of the PMD_MGMT primitives

Primitive	Direction	Description	Reference
		beginning of the downstream logical frame	
TA_B1_{us}	MME → PMD	Shift of the NOI DTFO block from the beginning of the upstream logical frame	Table 9-22
Symbol (fixed in showtime)			
N	MME → PMD	IDFT size Determined during the ITU-T G.994.1 phase by the selected profile.	Clause 10.4.3
L_{cp}	MME → PMD	Cyclic extension, samples Determined during the ITU-T G.994.1 phase.	Clause 10.4.4
β	MME → PMD	Window, samples Determined during the channel discovery phase. (Note)	Clause 10.4.4
SUPPORTED CARRIERS set	MME → PMD (MTU-O)	List of the subcarriers in the SUPPORTEDCARRIERS set. (Note)	Clause 3.2.39
SUPPORTED CARRIERS-G set	MME → PMD (MTU-R)	List of the subcarriers in the SUPPORTEDCARRIERS-G set. (Note)	Clause 3.2.39
MEDLEYset	MME → PMD	List of the subcarriers in the MEDLEY set. (Note)	Clause 3.2.20
t	MME → PMD	Tone-ordering table for subcarriers in the MEDLEY set (RMC and data subcarriers). (Note)	Clause 10.2.1
tss	MME → PMD	Frequency-domain transmit spectrum shaping (Note)	Clause 10.2.1.5.3
Symbol (dynamic in showtime)			
L_D	MME → PMD	Number of data bits modulated over a data symbol. (Note)	Clause 10.2.1
L_R	MME → PMD	Total number of RMC and data bits modulated over an RMC symbol. (Note)	Clause 10.2.1
L_{RMC}	MME → PMD	Number of RMC bits modulated over an RMC symbol. (Note)	Clause 10.2.1
b	MME → PMD	Bit allocation table (data subcarriers in NOI and DOI). (Note)	Clause 10.2.1
g	MME → PMD	Gain table for subcarriers in the MEDLEYset. (Note)	Clause 10.2.1
RTS	MME → PMD	List of the subcarriers in the RMC tone set. (Note)	Clause 10.2.1
br	MME → PMD	Bit allocation table for subcarriers in the RMC tone set. (Note)	Clause 10.2.1
Initialization			
Symbol repetition rate	MME → PMD	Determined during the ITU-T G.994.1 initialization phase.	Clause 10.2.2.2.1
SOC tone repetition rate, DS	MME → PMD	Determined during the channel discovery phase	Clause 10.2.2.2.1

Table 10-1 – Summary of the PMD_MGMT primitives

Primitive	Direction	Description	Reference
SOC tone repetition rate, US	MME → PMD	Determined during the channel discovery phase	Clause 10.2.2.2.1
SOC message, TX	MME → PMD	Transmit SOC message primitives (see Table 12-10).	Clause 10.2.2.2.1
SOC message, RX	MME ← PMD	Receive SOC message primitives (see Table 12-10).	Clause 10.2.2.2.1
Defects and test parameters			
los defect	PMD → MME	Loss of signal defect.	Clause 11.3.1.3
lor defect	PMD → MME	Loss of RMC defect.	Clause 11.3.1.3
lom defect	PMD → MME	Loss of margin defect.	Clause 11.3.1.3
SNR	PMD → MME	SNR per subcarrier.	Clause 11.4.1.2.2
NOTE – This parameter is defined for both directions of transmission.			

10.1.4 Vectoring interfaces

Vectoring interfaces ε(k,n) and η(k,n) presented in Figure 10-1 (for downstream direction) and clarified in detail in Figure 10-27 are between the precoder and VCE and post-canceller and VCE, respectively. The primitives at vectoring interfaces provide the VCE with the signals necessary to perform channel estimation. The VCE, via vectoring interfaces, provides channel matrix coefficients to the precoder (via ε(k,n) interface, see Figure 10-27) and to the post-canceller (via η(k,n) interface), and TIGA settings to the MTU-O for communication to the MTU-R. Both vectoring interfaces are vendor discretionary.

10.2 Symbol encoder

10.2.1 Data symbol encoder

The data symbol encoder provides the following functions for both data symbols and RMC symbols:

– Bytes to bits padding;
– Tone ordering;
– Encoding and constellation mapping;
– Constellation point scaling.

The TCM encoding and constellation mapping shall be performed for data symbols and RMC symbols, as defined in clause 10.2.1.2. The PCS-LCM encoding and constellation mapping shall be performed for data and RMC symbols as defined in clause 10.2.1.3, respectively. The functional model of the data symbol encoder for both TCM and PCS-LCM is defined in Figure 10-4.

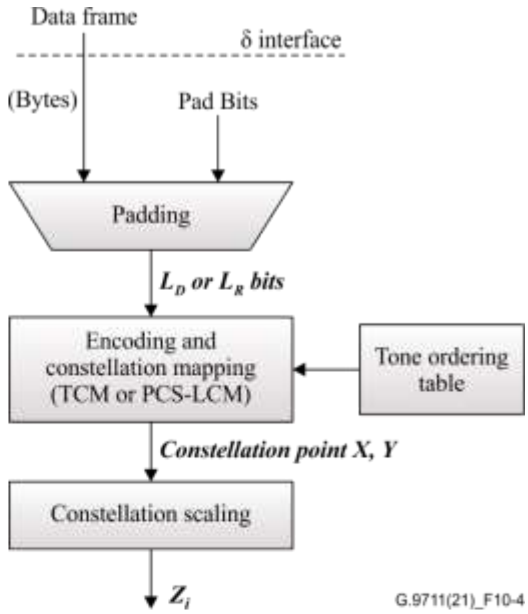


Figure 10-4 – Functional model of the data symbol encoder

The constellation mapping for TCM is defined in clause 10.2.1.2.3. The constellation mapping for PCS-LCM coding is defined in clause 10.2.1.3.6. The constellation scaling for both TCM and PCS-LCM is defined in clause 10.2.1.4.

10.2.1.1 Bytes to bits padding

The data frames crossing the δ interface from the PMS-TC include an integer number of bytes. Bits shall be extracted LSB first from the bytes received. Bit padding shall be used if the number of bits loaded onto one symbol is not an integer multiple of eight.

For data symbols in case of TCM, padding bits shall be appended separately to the part of the data frame mapped to the Band 0 and to the part of the data frame mapped to the Band 1 prior to the symbol encoding. Up to seven padding bits shall be appended to the part mapped to the subcarriers of the Band 0. The number of padding bits for the part mapped to the B and 0 shall be equal to the difference between the number of data bits modulated over the subcarriers of the Band 0 (L_{D0}) and the size of the data frame mapped to the Band 0 in bits (8 × (B_{RRC} + B_{D0})), with (B_{RRC} + B_{D0})=floor(L_{D0}/8). The number of padding bits for the part mapped to the Band 1 shall be equal to the difference between the number of data bits modulated over the sub-carriers of the Band 1 (L_{D1}) and the size of the data frame in bits (8 × B_{D1}) with B_{D1}=floor(L_{D1}/8). Figure 10-5a (at the top) shows the data symbol structure.

For RMC symbols in case of TCM, padding bits shall be appended separately to the RMC part and the user data part of the data frame mapped to the Band 0 and the part of the data frame mapped to the Band 1. The RMC part is always mapped to the Band 0. The number of padding bits added after the RMC data shall be equal to the difference between the number of data bits modulated on RMC subcarriers (L_{RMC}) and the size of the RMC frame in bits (8 × N_{RMC}), where N_{RMC} = floor(L_{RMC}/8). The number of padding bits for the part mapped to the Band 0 shall be equal to the difference between the number of data bits modulated over the subcarriers of the Band 0 (L_{DR0}) and the size of the data frame mapped to the Band 0 in bits (8 × B_{DR0}) with B_{DR0}=floor(L_{DR0}/8). The number of padding bits for the part mapped to the Band 1 shall be equal to the difference between the number of data bits modulated over the subcarriers of the Band 1 (L_{DR1}) and the size of the data frame in bits (8 × B_{DR1}) with B_{DR1}=floor(L_{DR1}/8). Figure 10-5a (at the bottom) shows the RMC symbol structure for TCM.

The values of L_{D0}, L_{D1}, L_{RMC}, L_{DR0} and L_{DR1} shall accommodate actual bit loading and TCM overhead, as defined in clause 10.2.1.2.2.

NOTE – The value of L_{D0} and L_{D1} depends on the position of the data symbols inside the logical frame. In particular, L_{D1} in NOI_{PSF} is equal to L_{DR1} and L_{D1} in NOI_{NPSF} is equal to 0.

For data symbols in case of PCS-LCM, up to seven padding bits shall be appended to the end of the data frame prior to the symbol encoding. The number of padding bits shall be equal to the difference between the number of data bits modulated over the symbol (L_D) and the size of the data frame in bits (8 × (B_{RRC} + B_D)) with (B_{RRC} + B_D)=floor(L_D/8). Figure 10-5 (on the top) shows the data symbol structure. L_D shall be the number of bits carried over the active DTFO bands (either on Band 0 or on Band 0 and Band 1 depending on the type of symbols) and the B_D the number of bytes carried with the corresponding data frame (see Table 10-31). Figure 10-5b (on the top) shows the data symbol structure.

For RMC symbols in case of PCS-LCM, the padding bits shall be appended to the end of the data frame, same as for data symbols. The number of padding bits shall be equal to the difference between the sum of RMC bits and data bits modulated over the symbol (L_R) and the size of the RMC data frame in bits 8×B_R, with B_R = floor(L_R/8). Figure 10-5 (at the bottom) shows the RMC symbol structure for PCS-LCM.

The content of padding bits is vendor discretionary.

With TCM, the order of the data extracted per symbol is presented in Figure 10-5a (shaded area shows padding bits). For normal data frames, the symbol encoder shall first extract B_{RRC}+B_D bytes from the incoming data frame and then add (L_{D0} − 8×(B_{RRC}+B_{D0})) padding bits. If the Band 1 is active in that symbol, the symbol encoder shall extract an additional B_{D1} bytes from the incoming data frame and then add (L_{D1} − 8×B_{D1}) padding bits. For RMC data frames, the symbol encoder shall first extract N_{RMC} bytes from the incoming data frame and add (L_{RMC} − 8×N_{RMC}) padding bits. Then it shall extract B_{DR} more bytes from the incoming data frame and add (L_{DR0} − 8×B_{DR0}) padding bits. If the Band 1 is active, it shall extract B_{DR1} more bytes from the incoming data frame and add (L_{DR1} − 8×B_{DR1}) padding bits. The total number of bits L_R is equal to L_{RMC} + L_{DR0} + L_{DR1} and the total number of bytes B_R is equal to N_{RMC} + B_{D0} + B_{DR1R}.

With PCS-LCM, the order of the data extracted per symbol is presented in Figure 10-5b. For normal data frames, the symbol encoder shall first extract B_{RRC}+B_D bytes from the incoming data frame and then add (L_D − 8×(B_{RRC}+B_D)) padding bits. For RMC data frames, the symbol encoder shall first extract N_{RMC} bytes from the incoming data frame, then it shall extract B_{DR} = B_R-N_{RMC} more bytes from the incoming data frame, and then add (L_R − 8×B_R) padding bits.

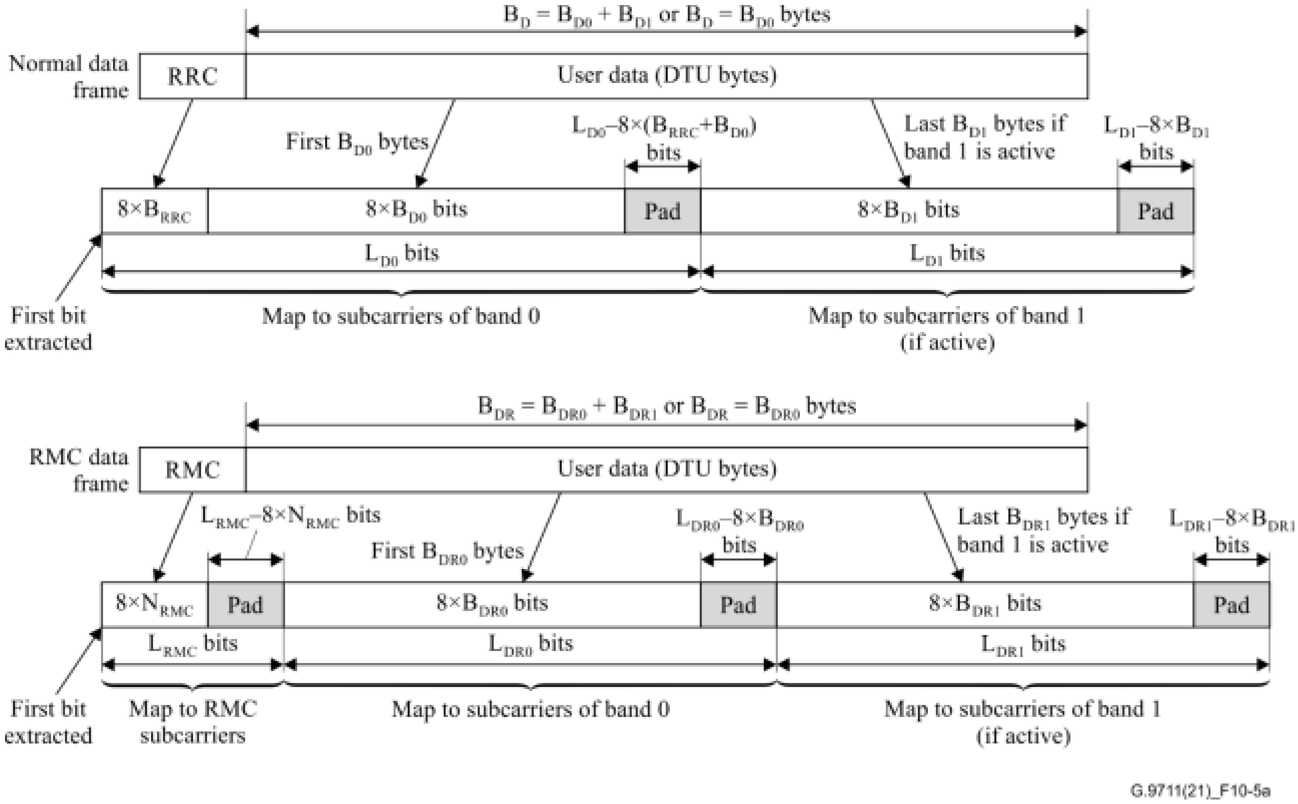


Figure 10-5a – Order of bit extraction from a data frame and padding with TCM

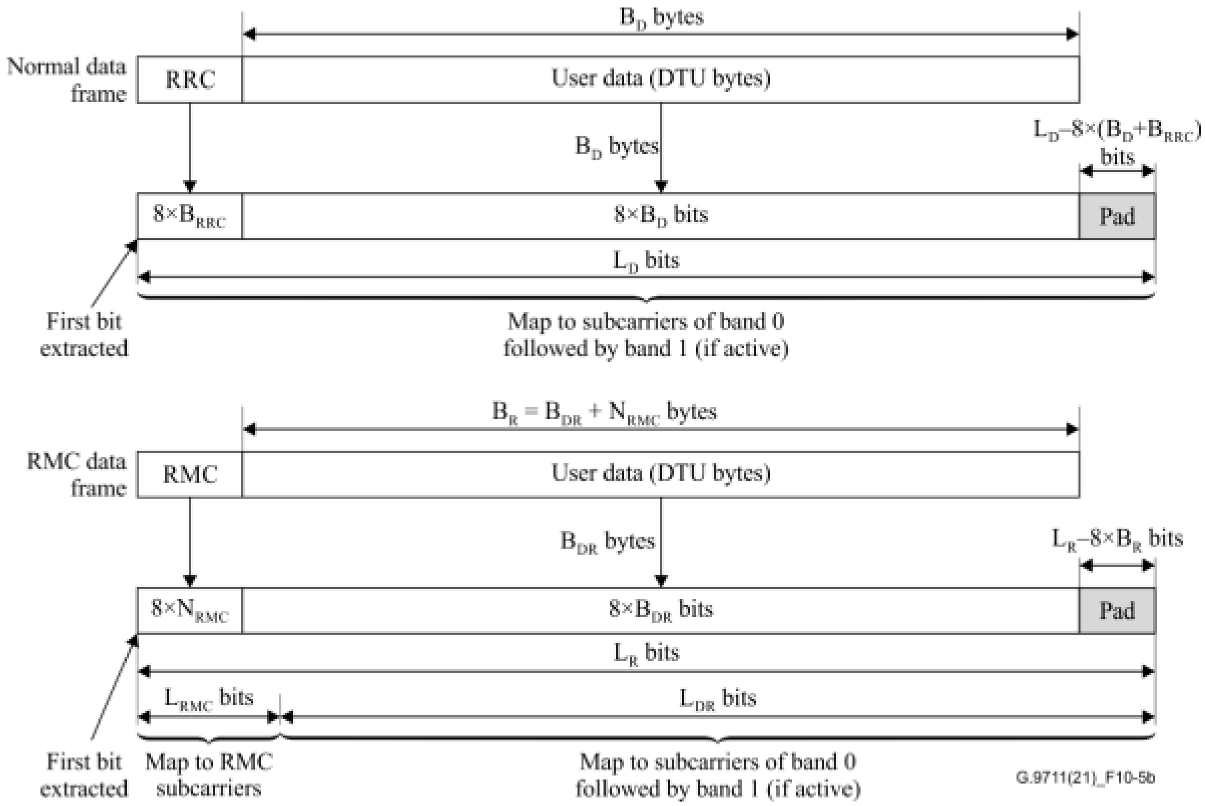


Figure 10-5b – Order of bit extraction from a data frame and padding with PCS-LCM

10.2.1.2 Symbol encoder with TCM

10.2.1.2.1 Tone ordering

During the initialization, the receive MTU shall calculate the number of bits and the relative gains to be used for every subcarrier in the MEDLEY set during data symbols and RMC symbols (either MEDLEYus or MEDLEYds, depending on the transmission direction), as well as the order in which subcarriers are assigned bits (i.e., the tone ordering). The number of bits and relative gains for a particular subcarrier in the NOI_{PSF}, in DOI_{PSF}, and in NOI_{NPSF} of the same transmission direction may be different. The number of subcarriers in the Band 0 and Band 1 of the upstream MEDLEYset is denoted NSC_{us0}, NSC_{us1}, respectively. The number of subcarriers in the Band 0 and Band 1 of the downstream MEDLEYset is denoted NSC_{ds0}, NSC_{ds1}, respectively. The RRC bits shall be processed as the rest of the data symbol, i.e., same as data bits. For supporting of DTFO (see clause 10.7), both MEDLEYds and MEDLEYus are divided into two nonoverlapping frequency bands, Band 0 and Band 1, respectively, defined during initialization.

In addition, the receive MTU shall select the subcarriers used to encode the RMC during the RMC symbols. The selected RMC tone set (RTS) is denoted by RTS_{us} and RTS_{ds} for upstream and downstream, respectively. The number of subcarriers in the RTS is denoted $NSCR_{ds}$ and $NSCR_{us}$ for the downstream and upstream directions, respectively. The tones from the RTS are exclusively for RMC and shall not carry any DTU bits. No subcarriers of the RTS shall be loaded with 1-bit for RMC symbols or for data symbols in the PSF in order to use the same re-ordered ordering tone table for data symbols in PSF and RMC symbols. The subcarriers of the RTS shall belong to the Band 0. The RTS may be modified in showtime through OLR. The MTU receiver determines the number of bits and the relative gains for every subcarrier in the RTS to be used during RMC symbols and sends them back to the peer MTU during initialization. The same gains shall be used on RTS tones in both RMC and data symbols in the NOI_{PSF}. The bits and gains to be applied to the subcarriers not belonging to the *RTS* shall be the same for RMC and data symbols in the NOI_{PSF}.

The pairs of bits and relative gains used for data symbols are defined in ascending order of frequency or subcarrier index *i* as a bit-allocation table *b* and gain table *g* containing, respectively, b_i and g_i values for all subcarrier indices *i* that belong to the MEDLEY set. The bit-allocation table *b* shall include an even number of 1-bit subcarriers (*NCONEBIT*) separately for Band 0 and for Band 1. The b_i and g_i values for the downstream or upstream or both of Band 1 may be forced by the MTU-O or MTU-R during initialization to be the same in both NOI_{PSF} and DOI.

The tone-ordering table *t* is defined as the sequence $\{t_k\}$ in which subcarriers from the MEDLEY set shall be assigned bits. Each value t_k (for k = 1 to $k = NSC_{us0}+NSC_{us1}$ for the upstream tones, k = 1 to $k = NSC_{ds0}+NSC_{ds1}$ for the downstream tones) equals to the index of the subcarrier to be assigned bits. Constellation mapping shall start from the subcarrier with index $i = t_1$ and end on the subcarrier with index $i = t_{NSC0+NSC1}$ (for example, t_{75} = 160 means that the subcarrier with index 160 is the 75th subcarrier to be assigned bits). The tone-ordering table *t* shall be created and exchanged during the initialization (see clause 12.3.4.2) and shall remain unchanged until the next initialization. The same tone-ordering table shall be used for both NOI and DOI and shall include subcarriers of both Band 0 and Band 1 when DTFO is applied.

The pairs of bits and relative gains used on the RTS during RMC symbols are defined in ascending order of frequency as a bit-allocation table *br* and gain table *gr* containing, respectively, br_i and gr_i values for all subcarrier indices *i* that belong to the RTS. The gr_i values shall be the same as the g_i values used in data symbols of the PFS NOI for the same subcarrier index. The bit-allocation table *br* shall not include 1-bit subcarriers.

Following reception of the tables *b* and *t*, and the RTS, both the transmit and the receive MTUs shall calculate a re-ordered bit-allocation table *b'* and a pre-ordered tone-ordering table *t*1 from the original tables *b* and *t*. The pre-ordered tone-ordering table *t*1 for the RMC symbol and the data symbols in the NOI shall be constructed by moving to the front of the original table all the values corresponding to the tones of the RTS using the same relative order as in table *t*. The pre-ordered tone-ordering table *t*1 for the data symbols of the DOI and of the NOI_{NPSF} shall be the same as the table *t*.

From the pre-ordered tone-ordering table *t*1, the transmitter shall calculate the re-ordered tone-ordering table *t*'. The re-ordering of table *t*1 shall be performed separately for Band 0 and Band 1. The re-ordered tone-ordering table *t'* for each of these bands shall be generated according to the following rules:

- Indices of all subcarriers supporting 0, two or more bits appear first in *t'*, in the same order as in table *t*1.
- Indices of all subcarriers supporting 1 bit appear last in table *t'*, in the same order as in table *t*1.

If the bit allocation does not include any 1-bit subcarriers, the re-ordered tone-ordering table *t'* is identical to the pre-ordered tone-ordering table *t*1.

The (even number of) 1-bit subcarriers shall be paired to form 2-dimensional constellation points as input to the trellis encoder. The pairing shall be in the order that the 1-bit subcarriers appear in the pre-ordered tone-ordering table *t*1.

The format of the re-ordered table t' is shown in Figure 10-6 for the NOI_{PSF}, DOI and NOI_{NPSF}.

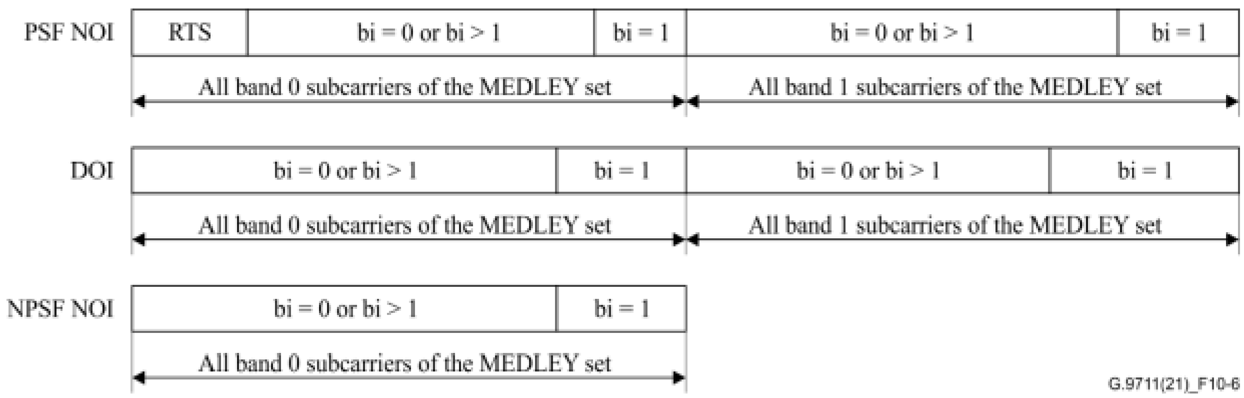


Figure 10-6 – Format of the re-ordered tone-ordering table *t'*

The table *b'* shall be generated by re-ordering the entries of table *b*, separately for Band 0 and Band 1, forming tables b_0' and b_1', according to the following rules:

- The first *NCONEBIT*/2 entries of *b'* shall be 0, where *NCONEBIT* (by definition, even) is the number of subcarriers supporting 1 bit.
- The next entries of *b'* shall be 0, corresponding to all subcarriers that support 0 bits, in order determined by the new tone-ordering table *t'*.
- The next entries of *b'* shall be non-zero, corresponding to the subcarriers that support two or more bits. These entries shall be in order determined by the new tone-ordering table *t'* in conjunction with the bit-allocation table *b*.
- The last *NCONEBIT*/2 entries of *b'* correspond to the paired 1-bit constellations (i.e., two bits per entry).

The total number of bits *L*' associated with bit-loading tables *b* and *b*' is the same:

$$L' = \sum b_i' = \sum b_i$$

Calculation of tables *b'* and *t'* from the original tables *b* and *t* by subcarrier pairing and bit re-ordering processes described above is shown below (for each of the bands Band 0 and Band 1).

```
/*** CONSTRUCT THE TONE RE-ORDERING TABLE ***/
/*
The tone-ordering table exchanged during initialization is denoted tg. The
tone-ordering table is computed independently for the Band 0 and Band1.
The tone-ordering table containing only the sub-carriers of the Band to be
re-ordered is denoted as array 't', pre-ordered tone-ordering table is
denoted as array 't1', tone re-ordering
table is denoted as array 'tp'. The indices to these arrays are
denoted as 't_index', 't1_idx' and 'tp_index', respectively.
*/

/* Construct the tone-ordering table containing only the sub-carriers of
the band to reorder */

t_index=1

NSC_Band =  0

for (tg_index = 1; tg_index ≤ NSC0+NSC1; tg_index++){

  tone = tg[tg_index]

  if tone in Band_to_reorder

     t[t_index] = tone

     t_index++

     NSC_Band++

}
/* Fill out the pre-ordered tone table in case of NOI by appending the tone
of the RTS first */
if(symbol in NOI_PSF and Band_to_reorder == Band_0){
  t1_idx     = NSCR+1; /* Index counting the tones above the RMC */
  t1_idx_RTS = 1;    /* Index counting the tones of the RMC */
  for (t_index = 1; t_index ≤ NSC_Band; t_index++) {
    tone = t[t_index];
    if(tone in RTS)
      t1[t1_idx_RTS++] = tone;
    else
      t1[t1_idx++] = tone;
  }
}
else{
  t1_idx = 1;
  for (t_index = 1; t_index ≤ NSC_Band; t_index++) {
      t1[t1_idx++] = t[t_index];
}
/*
Fill out tone re-ordering table with entries of tone-ordering table
but skip 1-bit tones.
*/
tp_index = 1;
for (t_index = 1; t_index ≤ NSC_Band; t_index++) {
  tone = t1[t_index];
  bits = b[tone];
  if (bits != 1) {
    tp[tp_index++] = tone;
  }
}
/*
Add the 1-bit tones to the end of tone re-ordering table.
*/
for (t_index = 1; t_index ≤ NSC_Band; t_index++) {
  tone = t1[t_index];
```

```
    bits = b[tone];
    if (bits == 1) {
      tp[tp_index++] = tone;
    }
  }
  /* RE-ORDERING THE BIT ARRAY */
  /*
  The bit-allocation table is denoted as array 'b' and the ordered bit-
  allocation table is denoted as array 'bp'.
  The indexes to these arrays are denoted as 'b_index' and bp_index',
  respectively.
  */
  /* First, count the number of loaded tones and also 1-bit tones. */
  NCONEBIT = 0; /* NCONEBIT is the number of subcarriers with 1 bit */
  NCUSED = 0; /* NCUSED is the number of loaded subcarriers */
  for (all i ∊ MEDLEY set ∩ Band_to_reorder) {
    if (b[i] > 0) {
      NCUSED++;
    }
    if (b[i] == 1) {
      NCONEBIT++;
    }
  }
  /* Fill initial zero entries for unloaded tones and half the number of
  1-bit tones */
  for (bp_index = 1; bp_index ≤ (NSC_Band - (NCUSED - NCONEBIT/2));
       bp_index++) {
    bp[bp_index] = 0;
  }
  for (tp_index = 1; tp_index ≤ NSC_Band; tp_index++) {
    tone = tp[tp_index];
    bits = b[tone];
    if (bits == 0) {
      /* skip unloaded tones */
    }
    if (bits == 1) {
      /* pair 2 consecutive 1-bit tones and add a
         single entry with 2 bits */
      bp[bp_index++] = 2;
      tp_index++;
    }
    if (bits > 1) {
      bp[bp_index++] = bits;
    }
  }
```

Figure 10-7 shows an example of tone ordering and pairing including one-bit subcarriers for Band 0. This example also reflects operation of Band 1.

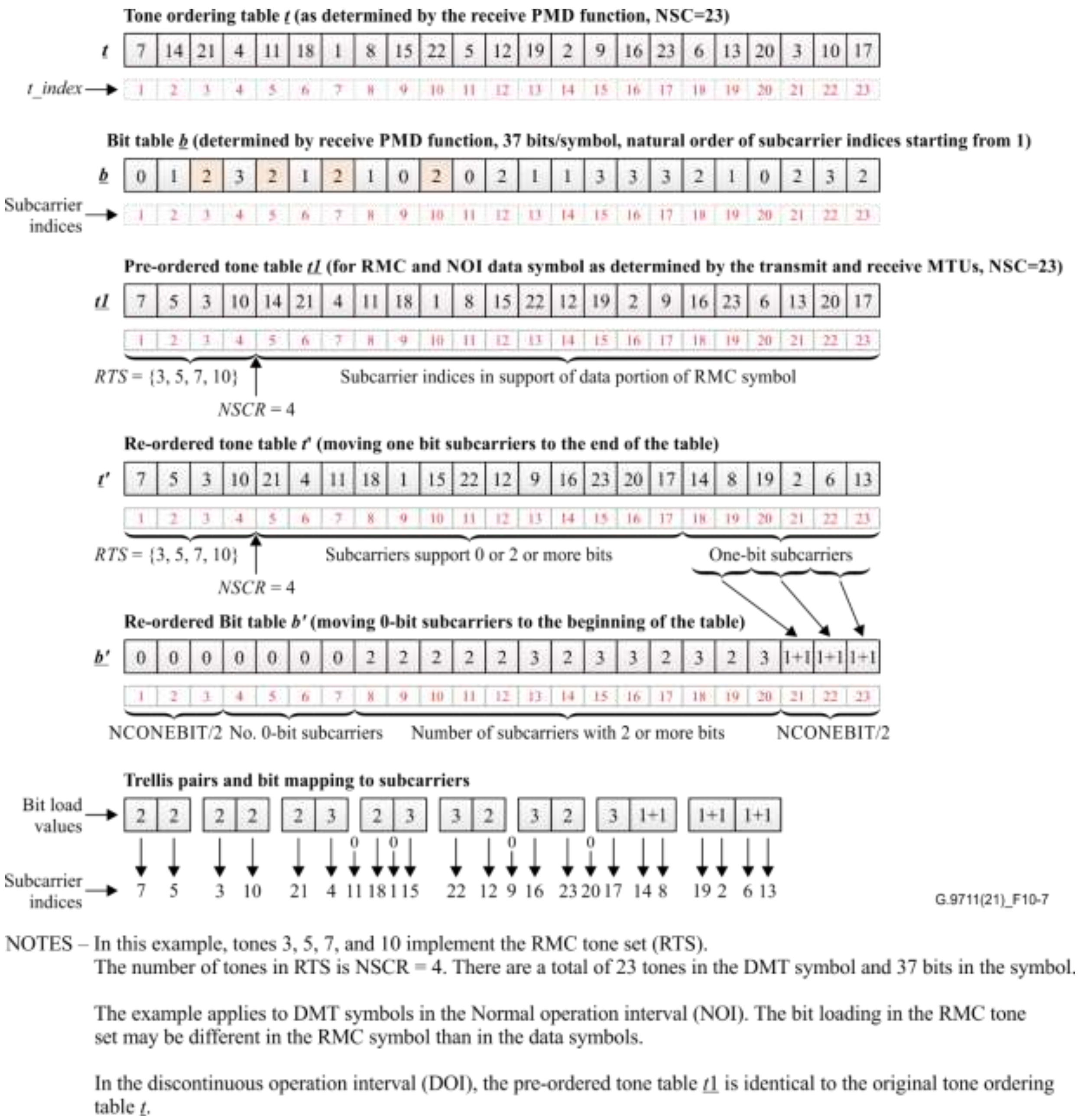


Figure 10-7 – Example of tone ordering and pairing including one-bit subcarriers

NOTE 1 – In this example, tones 3, 5, 7 and 10 implement the RTS. The number of tones in RTS is NSCR=4. There are a total of 23 tones in the DMT symbol and 37 bits in the symbol.

NOTE 2 – The example applies to the data symbols. The bit loadings in the RTS may be different in the RMC symbol than in the data symbols.

If OLR changes the number or indices of 0-bit subcarriers or 1-bit subcarriers, tables *t'* and *b'* shall be recalculated from the updated table *b* and the original table *t*. Upon FRA, table *t'* shall not be recalculated, and the ordering of table b' shall not change (see clause 13.3.1.1).

Trellis coding is performed according to the re-ordered bit-allocation table *b'* and re-ordered tone-ordering table *t'* (see clause 10.2.1.2.2). Constellation mapping is performed according to the re-ordered ordering tone table *t'*, with the number of bits per subcarrier as defined by the original bit-allocation table *b* (see clause 10.2.1.2.3).

Following reception of the table *br*, the transmit MTU shall calculate, according to the same rules described above for the table *b*, a re-ordered bit-allocation table *br'* and a re-ordered tone-ordering table *tr'* from the original table *br* and the first *NSCR* entries of the pre-ordered table *t1*. During the RMC symbol, trellis coding of the L_{RMC} bits is performed according to the re-ordered bit-allocation table *br'* and a re-ordered tone-ordering table *tr'*. Constellation mapping is performed according to the re-ordered tone table *tr'*, with the number of bits per subcarrier as defined by the original bit-allocation table *br* (see clause 10.2.1.2.3).

Both the transmit and the receive MTUs shall also calculate, according to the same rules described above for the table *b* separately for Band 0 and Band 1, a re-ordered bit-allocation table *bd'* and a re-ordered tone-ordering table *td'* from the original tables *b* and the entries of table *t1*. For the Band 0 of the NOI_{PSF}, only the last NSC_0-$NSCR$ entries of table *t1* shall be used.

During the RMC symbol, trellis coding of the L_{DR} data bits is performed according to the re-ordered bit-allocation table *bd'* and a re-ordered tone-ordering table *td'*. Constellation mapping is performed according to the re-ordered tone table *td'*, with the number of bits per subcarrier as defined by the original bit-allocation table *b* (see clause 10.2.1.2.3).

10.2.1.2.2 Trellis encoding

The trellis encoder shall use block processing of Wei's 16-state 4-dimensional trellis code.

For data symbols, the L_{D0}, L_{D1} bits associated, respectively, with Band 0 and Band 1 of a data frame shall be loaded onto one data symbol. Trellis encoder encodes the incoming L_{D0} bits of Band 0 into L_{D0}' bits, matching the re-ordered bit-allocation table *b'*. The values of L_{D0} and L_{D0}' relate as:

$$L'_{D0} = \sum b'_{0,i} = \sum b_{0,i} = L_{D0} + \text{ceiling}\left(\frac{NCUSED_0 - \frac{NCONEBIT_0}{2}}{2}\right) + 4$$

where $NCUSED_0$ is the number of subcarriers actually used for data transmission in Band 0 (with $b_{0,i} > 0$) , $NCONEBIT_0$ is the number of 1-bit subcarriers used in Band 0 and $b_{0,i}$ is the bit allocation of the subcarriers of the Band 0. The added 4 bits are to return the trellis in Band 0 to the zero state after the encoding of the L_{D0} bits, as described in clause 10.2.1.2.2.2. Those additional bits are loaded at the last subcarriers of Band 0 per the reordered tone-ordering table. The ratio $(L_{D0}'-L_{D0})/L_{D0}$ determines the overhead introduced by the trellis code in Band 0.

In the same way, if $L_{D1} > 0$, Trellis encoder encodes the incoming L_{D1} bits of Band 1 into L_{D1}' bits, matching the re-ordered bit-allocation table *b'*. The added 4 bits are to return the trellis in Band 1 to the zero state after the encoding of the L_{D1} bits, as described in clause 10.2.1.2.2.2. Those additional bits are loaded at the last subcarriers of Band 1 per the reordered tone-ordering table. The ratio $(L_{D0}'+L_{D1}'-L_{D0}-L_{D1})/(L_{D0}+L_{D1})$ determines the overall trellis overhead in symbols using both Band 0 and Band 1.

For RMC symbols, the L_R bits associated with an RMC data frame shall be loaded onto one RMC symbol. Trellis encoder first encodes the incoming L_{RMC} bits that carry the RMC data into L_{RMC}' bits, matching the re-ordered bit-allocation table *br'*.

The values of L_{RMC} and L_{RMC}' relate as:

$$L'_{RMC} = \sum br'_i = \sum br_i = L_{RMC} + \text{ceiling}\left(\frac{NCUSED_{RMC}}{2}\right) + 4$$

where $NCUSED_{RMC}$ is the number of subcarriers actually used for transmission of RMC bits (with $br_i > 0$) , and br_i is the bit allocation on the RMC subcarriers. The added 4 bits are to return the trellis in the RTS to the zero state after the encoding of the L_{RMC} bits. Those additional bits are loaded at the last subcarriers of the RTS per the reordered tone-ordering table.

Further, the trellis encoder encodes the incoming L_{DR0} bits of Band 0 into L_{DR0}' bits, matching the re-ordered bit-allocation table *bd'*. If the number of non-zero entries in the part of *bd'* corresponding to the Band 0 is greater or equal to 4, the values of L_{DR0} and L_{DR0}' relate as:

$$L'_{DR0} = \sum bd'_{0,i} = \sum bd_{0,i} = L_{DR0} + \text{ceiling}\left(\frac{NCUSED_{DR0} - \frac{NCONEBIT_{DR0}}{2}}{2}\right) + 4$$

where $NCUSED_{DR0}$ is the number of subcarriers actually used for transmission of DTU data bits mapped to Band 0 (with $bd_{0,i} > 0$), $NCONEBIT_{DR0}$ is the number of 1-bit subcarriers used for transmission of DTU data bits mapped to Band 0, and $bd_{0,i}$ is the bit allocation on the DTU subcarriers of the Band 0 of the RMC symbol. The added four bits are to return the trellis in Band 0 to the zero state after the encoding of the L_{DR0} bits of the RMC symbol. Those additional bits are loaded at the last subcarriers of Band 0 per the reordered tone-ordering table.

In the same way, if $L_{DR1} > 0$, Trellis encoder encodes the incoming L_{DR1} bits of Band 1 into L_{DR1}' bits, matching the re-ordered bit allocation table *bd'*. The added 4 bits are to return the trellis in Band 1 to the zero state after the encoding of the L_{DR1} bits of the RMC symbol. Those additional bits are loaded at the last subcarriers of Band 1 per the reordered tone-ordering table.

If the number of non-zero entries in $bd_{0,i}$ or $bd_{1,i}$ is less than 4, L_{DR0}' and L_{DR1}', respectively shall be set to 0 and the subcarriers corresponding to the non-zero entries shall carry a vendor discretionary point of any constellation selected from the set defined in clause 10.2.1.4.2 with an average power not greater than the average power of the constellation of the NOI data symbols for the given subcarrier. The average power of the selected constellation point may be 0, i.e., $X = 0$, $Y = 0$.

10.2.1.2.2.1 Bit extraction

10.2.1.2.2.1.1 Data symbols

After tone ordering, bits of the data frame after padding (reference point A in Figure 10-8) shall be extracted in sequential order according to the re-ordered bit-allocation table *b*'. The first bit of the data frame (that is the first bit of the RRC if present) shall be extracted first. Because of the 4-dimensional nature of the code, the extraction is based on pairs of consecutive *b*' entries. Furthermore, due to the constellation expansion associated with trellis coding, the bit-allocation Table *b'* specifies the number of coded bits per subcarrier, which can be any integer from two to 12, 13 or 14 (based on the "MTU-O maximum bit loading" and "MTU-R maximum bit loading" capability indicated during initialization in the O-MSG 1 and R-MSG 2 messages for the MTU-O and MTU-R, respectively).

Trellis encoding shall be performed on pairs of consecutive *b'* values, separately for Band 0 and Band 1, as described in clause 10.2.1.2.2. If the number of non-zero entries in the part of the *b'* table that belongs to Band 0 is even, trellis encoding shall start with the first non-zero entry in the *b*' table. If the number of non-zero entries in the part of *b'* table that belongs to Band 0 is odd, trellis encoding shall start from a zero entry preceding the first non-zero entry in table *b'* (to make an integer number of pairs). The same way trellis shall address the part of the *b'* table that belongs to Band 1.

NOTE 1 – An FRA procedure may result in 0-bit subcarriers that are not at the beginning of the re-ordered bit-allocation table; in this case, trellis encoding uses only the non-zero entries following the determined starting entry.

For a given pair of consecutive *b*' values (x, y), $x + y - 1$ bits (reflecting a constellation expansion of one bit per four dimensions, or one half bit per subcarrier) are extracted from the data frame buffer, except for the last two 4-dimensional elements. These $z = x + y - 1$ bits $(t_z, t_{z-1}, \ldots, t_1)$ are used to form the binary word *u* as shown in Table 10-2. Refer to clause 10.2.1.2.2.2 for the reason behind the special form of the word *u* for the case $x = 0$, $y > 1$.

Table 10-2 – Forming the binary word *u*

Condition	Binary word/comment
$x > 1, y > 1$	$u = (t_z, t_{z-1}, ..., t_1)$ (Note)
$x = 1, y \geq 1$	Condition not allowed.
$x = 0, y > 1$	$u = (t_z, t_{z-1}, ..., t_2, 0, t_1, 0)$ (Note)
$x = 0, y = 0$	Bit extraction not necessary, no data bits being sent.
$x = 0, y = 1$	Condition not allowed.
NOTE – t_1 is the first bit extracted from the data frame buffer.	

The last two 4-dimensional elements in the parts belonging to Band 0 and Band 1 of each symbol, and at the end of the RMC part of an RMC symbol, shall be chosen to force the convolutional encoder state to the zero state. For each of these elements, the two LSBs of *u* are predetermined, and only $(x + y - 3)$ bits shall be extracted from the data frame buffer and shall be allocated to (t_z t_{z-1} …. t_4 t_3).

NOTE 2 – The above requirements imply a minimum size of the *b*' table of four non-zero entries associated with Band 0 and Band 1. The minimum number of non-zero entries in the corresponding *b* table could be higher.

10.2.1.2.2.1.2 RMC symbols

Bits of the RMC portion of the RMC data frame after padding shall be extracted in sequential order according to the re-ordered bit-allocation table *br*'. The first bit of the RMC portion of the RMC data frame shall be extracted first. The extraction is based on pairs of consecutive *br*' entries. Furthermore, due to the constellation expansion associated with trellis encoding, the bit-allocation table *br'* specifies the number of coded bits per subcarrier of the RMC portion of the RMC symbol.

Trellis encoding shall be performed on pairs of consecutive *br'* values. If the number of non-zero entries in the *br'* table is even, trellis encoding shall start with the first non-zero entry in the *br*' table. If the number of non-zero entries in the *br'* table is odd, trellis encoding shall start from a zero entry preceding the first non-zero entry in table *br'* (to make an integer number of pairs).

Bits of the DTU part of the RMC data frame after padding shall be extracted in sequential order according to the re-ordered bit-allocation table *bd*', first for Band 0 and then for Band 1, if used. The rules of extraction are the same as for the RMC portion.

10.2.1.2.2.2 Bit conversion

The described bit conversion is the same for the parts of the data frame associated with Band 0 and Band 1. The binary word $u = (u_{z'}, u_{z'-1}, ..., u_1)$ constructed from bits (t_z t_{z-1}… t_1) extracted LSB first from the data frame buffer as defined in Table 10-2 is converted into two binary words: $v = (v_{z'-y}, ..., v_0)$ and $w = (w_{y-1}, ... , w_0)$, which are both inserted LSB first in the encoded data buffer and used to look up constellation points in the constellation mapper (see Figure 10-8).

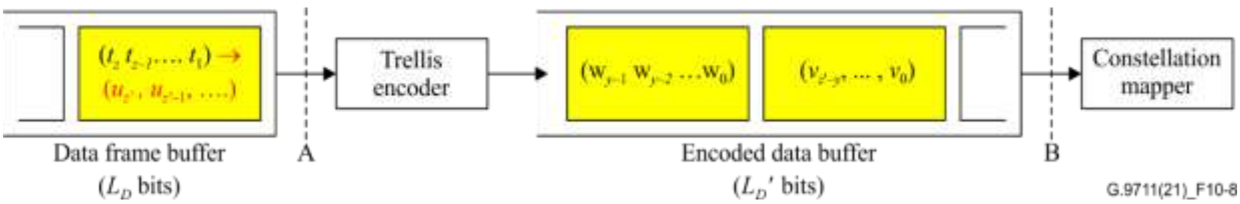


Figure 10-8 – Bit conversion by trellis encoder

NOTE – L_D is a general notation for any of the following values L_{D0}, L_{D1}, L_{DR0} and L_{DR1}. Similar for L_D'.

The binary word v shall be input first to the constellation mapper, LSB first, followed by the binary word w, also LSB first (reference point B in Figure 10-8).

NOTE – For convenience of description, the constellation mapper identifies these x and y bits with a label whose binary representation is (v_{b-1}, v_{b-2}, ..., v_1, v_0). The same constellation mapping rules apply to both the v (with $b = x$) and the w (with $b = y$) vector generated by the trellis encoder (see clause 10.2.1.2.3.1).

For the usual case of $x > 1$ and $y > 1$, $z' = z = x + y - 1$, and binary words v and w contain x and y bits, respectively. The bits (u_3, u_2, u_1) determine (v_1, v_0) and (w_1, w_0) and the remaining bits of v and w are obtained, respectively, from the LSBs and MSBs of the word ($u_{z'}$, $u_{z'-1}$, ... , u_4), according to Figure 10-8, i.e., if $x > 1$ and $y > 1$, $v = (u_{z'-y+2}, u_{z'-y+1}, ... , u_4, v_1, v_0)$ and $w = (u_{z'}, u_{z'-1}, ... , u_{z'-y+3}, w_1, w_0)$.

For the special case of $x = 0$ and $y > 1$, $z' = z + 2 = y + 1$, $v = (v_1, v_0) = (0, 0)$ and $w = (w_{y-1}, ... , w_0)$.

The convolutional encoder shown in Figure 10-9 is a systematic encoder (i.e., u_1 and u_2 are passed through unchanged) as shown in Figure 10-10. The convolutional encoder state (S_3, S_2, S_1, S_0) is used to label the states of the trellis shown in Figure 10-10. At the beginning of a symbol, the convolutional encoder state shall be initialized to (0, 0, 0, 0).

In order to force the final state of the convolutional encoder to the zero state (0, 0, 0, 0), the two LSBs u_1 and u_2 of the final two 4-dimensional elements in the symbol are constrained to $u_1 = S_1 \oplus S_3$, and $u_2 = S_2$.

For data symbols, the convolutional encoder state shall be terminated to (0, 0, 0, 0) twice first at the end of the part of the data frame mapped to Band 0 and second at the end of the part of the data frame mapped to the Band 1. For RMC symbols, the convolutional encoder state shall be terminated to (0, 0, 0, 0) thrice: first at the end of the RMC frame, second at the end of the user data part mapped to the Band 0 and finally at the end of the user data part mapped to the Band 1.

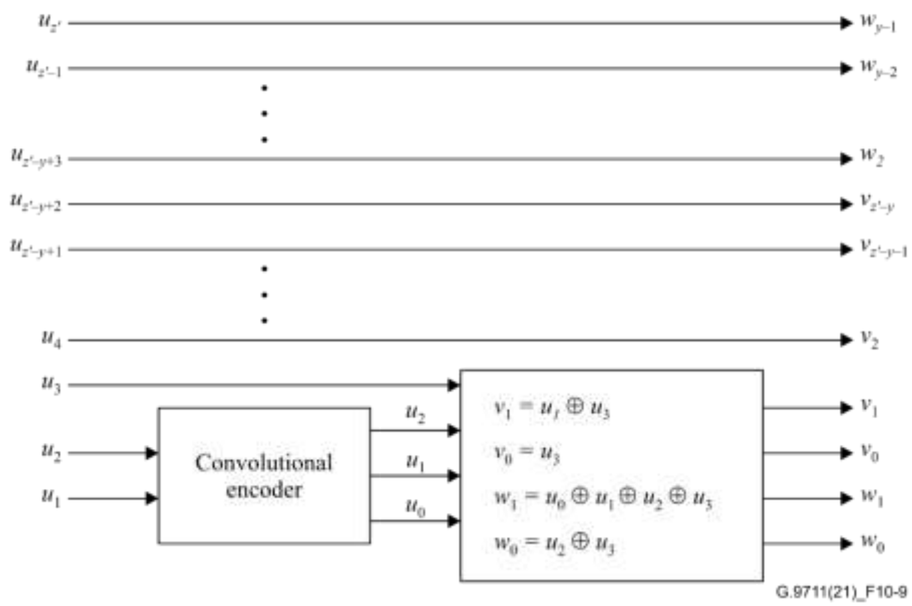


Figure 10-9 – Conversion of *u* to *v* and *w*

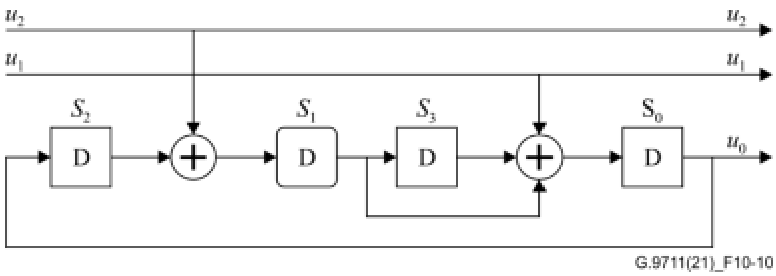


Figure 10-10 – Convolutional encoder: Finite state machine representation

10.2.1.2.3 Constellation mapper

The constellation mapper maps a set of bits to a constellation point. For each symbol, L_D' bits shall be extracted from the encoded data buffer (see Figure 10-8, reference point B) as defined in clause 10.2.1.2.3.1. The extracted bits shall be mapped to constellation points as defined in clause 10.2.1.2.3.2.

10.2.1.2.3.1 Bit extraction

The bit extraction mechanism described in this clause is applicable only for RMC symbols and data symbols (during showtime); for other types of symbols, see clause 10.2.2. Groups of bits shall be extracted from the incoming data frames or from a pseudo random binary sequence (PRBS) generator for mapping to individual subcarriers, based on the subcarrier order defined by the re-ordered tone table *t*' (see clause 10.2.1.2.1). The data bits and scrambler bits for the monitor tones shall be extracted for the subcarriers of the Band 1 only if Band 1 band is used on that symbol.

For each subcarrier *i* of the MEDLEY set with $b_i > 0$, the mapper shall extract $b = b_i$ bits from the data frame. The number of bits extracted for each subcarrier is determined by the original bit-allocation table *b*. The set of *b* extracted bits shall be represented as a binary word (v_{b-1} v_{b-2} ... v_1 v_0), where the first bit extracted shall be v_0, the LSB. The encoder shall select a point (*X*, *Y*) from the constellation based on the *b*-bit word (v_{b-1} v_{b-2} ... v_1 v_0) as defined in clause 10.2.1.4.2.

For each subcarrier of the MEDLEY set with $b_i = 0$ (monitored tones, pilot tones, and sub-carrier with g_i=0, see Table 10-22), no bits shall be extracted from the data frame. Instead, for each of those subcarriers, the encoder shall extract $b = 2$ bits (v_1 v_0) from the PRBS generator defined in Clause 10.2.1.5, where the first bit extracted (LSB) shall be v_0. For the pilot tone subcarrier(s), the bits extracted from the PRBS generator shall be overwritten by bits 00 (i.e., the two bits from the PRBS generator are effectively ignored).

For subcarriers that are not in the MEDLEY set ($b_i = 0$ by definition), no bits shall be extracted from the encoded data buffer and no bits shall be extracted from the PRBS generator. Instead, in the downstream direction the constellation mapper may select a vendor-discretionary (*X*, *Y*) point (which may change from symbol to symbol, and which does not necessarily coincide with any of the constellation points defined in this Recommendation), and in the upstream direction the constellation mapper shall select the (*X*,*Y*) = (0,0) point.

10.2.1.2.3.2 Constellations

The defined algorithmic constellation mapper shall be used to construct subcarrier quadrature amplitude modulation (QAM) constellations with a minimum number of bits equal to one and a maximum number of bits equal to 12, 13 or 14 (based on the "MTU-O maximum bit loading" and "MTU-R maximum bit loading" capability indicated during initialization in the O-MSG 1 and R-MSG 2 messages for the MTU-O and MTU-R, respectively.

NOTE – Supporting a maximum bit loading of 13 or 14 may lead to increased power consumption at the transmitter or the receiver or both relative to supporting a maximum bit loading of 12.

The constellation points are denoted (X, Y). The valid values of X and Y are odd integers ±1, ±3, ±5, etc. For convenience of illustration, each constellation point in Figure 10-11 through Figure 10-15 is labelled by an integer in base-10 whose unsigned binary representation is (v_{b-1} v_{b-2} ... v_1 v_0).

10.2.1.2.3.2.1 Even values of *b*

For even values of b, the values X and Y of the constellation point (X, Y) shall be determined from extracted set of the b bits (v_{b-1}, v_{b-2},...,v_1,v_0) as follows. The values X and Y shall be odd integers with two's complement binary representations (v_{b-1} v_{b-3} ... v_1 1) and (v_{b-2} v_{b-4} ... v_0 1), respectively. The MSBs, v_{b-1} and v_{b-2}, shall be the sign bits for X and Y, respectively. Figure 10-11 shows example constellations for b = 2 and b = 4.

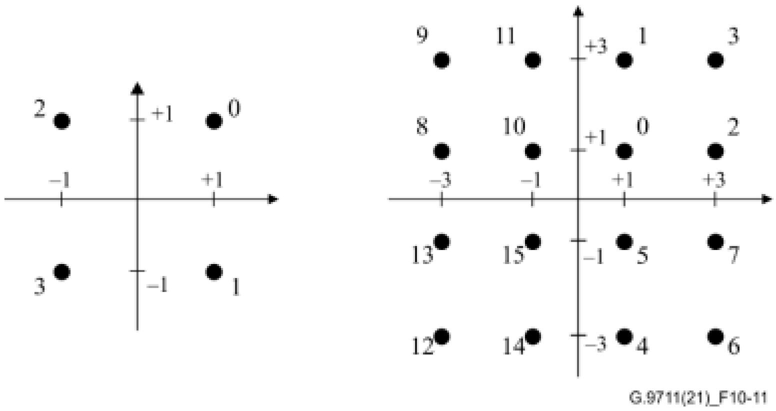


Figure 10-11 – Constellation labels for *b* = 2 and *b* = 4

NOTE – The 4-bit constellation may be obtained from the 2-bit constellation by replacing each label n by the 2 × 2 block of labels:

4n+1	4n+3
4n	4n+2

The same procedure may be used to construct the larger even-bit constellations recursively. All the constellations defined for even values of b are square in shape.

10.2.1.2.3.2.2 Odd values of *b*

Figure 10-12 shows the constellation for the case b = 1.

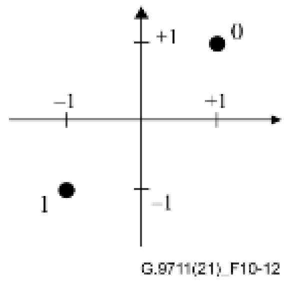


Figure 10-12 – Constellation labels for *b* = 1

The *NCONEBIT*/2 2-bit words generated by the trellis encoder shall be mapped on two 1-bit subcarriers using the same labelling for 1-bit constellations as described above. An example for mapping of a 2-bit word (v_1 v_0) for v_0 = 1 and v_1 = 0 is shown in Figure 10-13.

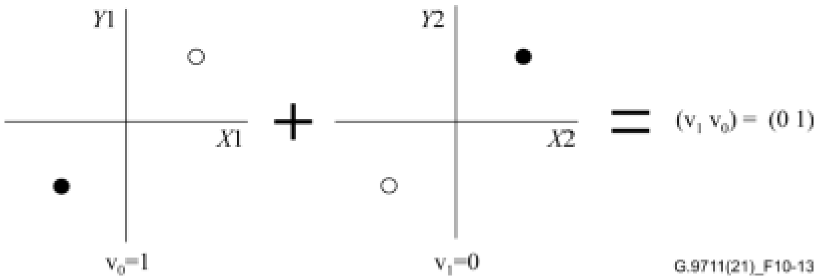


Figure 10-13 – Combination of a pair of 1-bit constellations to build a 2-bit constellation

Figure 10-14 shows the constellation for the case $b = 3$.

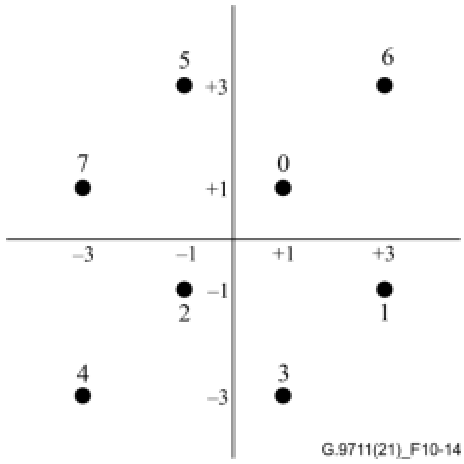


Figure 10-14 – Constellation labels for *b* = 3

For odd values of *b* that are greater than three, the two MSBs of *X* and the two MSBs of *Y* shall be determined by the five MSBs of the *b* bits ($v_{b–1}$ $v_{b–2}$ ... v_1 v_0). Let c = (*b*+1)/2, then *X* and *Y* shall have the two's complement binary representations (X_c $X_{c–1}$ $v_{b–4}$ $v_{b–6}$...v_3 v_1 1) and (Y_c $Y_{c–1}$ $v_{b–5}$ $v_{b–7}$ ...v_2 v_0 1), where X_c and Y_c are the sign bits of *X* and *Y* respectively. The relationship between X_c, $X_{c–1}$, Y_c, $Y_{c–1}$, and ($v_{b–1}$ $v_{b–2}$...$v_{b–5}$) shall be as shown in Table 10-3.

Table 10-3 – Determining the top two bits of X and Y

$v_{b–1}$ $v_{b–2}$...$v_{b–5}$	X_c $X_{c–1}$	Y_c $Y_{c–1}$	$v_{b–1}$ $v_{b–2}$...$v_{b–5}$	X_c $X_{c–1}$	Y_c $Y_{c–1}$
0 0 0 0 0	0 0	0 0	1 0 0 0 0	0 1	0 0
0 0 0 0 1	0 0	0 0	1 0 0 0 1	0 1	0 0
0 0 0 1 0	0 0	0 0	1 0 0 1 0	1 0	0 0
0 0 0 1 1	0 0	0 0	1 0 0 1 1	1 0	0 0
0 0 1 0 0	0 0	1 1	1 0 1 0 0	0 0	0 1
0 0 1 0 1	0 0	1 1	1 0 1 0 1	0 0	1 0
0 0 1 1 0	0 0	1 1	1 0 1 1 0	0 0	0 1
0 0 1 1 1	0 0	1 1	1 0 1 1 1	0 0	1 0
0 1 0 0 0	1 1	0 0	1 1 0 0 0	1 1	0 1
0 1 0 0 1	1 1	0 0	1 1 0 0 1	1 1	1 0
0 1 0 1 0	1 1	0 0	1 1 0 1 0	1 1	0 1
0 1 0 1 1	1 1	0 0	1 1 0 1 1	1 1	1 0

Table 10-3 – Determining the top two bits of X and Y

v_{b-1} v_{b-2}…v_{b-5}	X_c X_{c-1}	Y_c Y_{c-1}	v_{b-1} v_{b-2}…v_{b-5}	X_c X_{c-1}	Y_c Y_{c-1}
0 1 1 0 0	1 1	1 1	1 1 1 0 0	0 1	1 1
0 1 1 0 1	1 1	1 1	1 1 1 0 1	0 1	1 1
0 1 1 1 0	1 1	1 1	1 1 1 1 0	1 0	1 1
0 1 1 1 1	1 1	1 1	1 1 1 1 1	1 0	1 1

Figure 10-15 shows the constellation for the case $b = 5$.

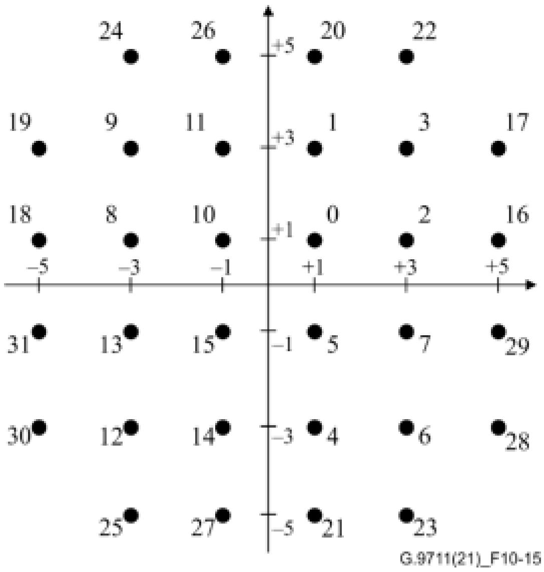


Figure 10-15 – Constellation labels for *b* = 5

NOTE – The 7-bit constellation may be obtained from the 5-bit constellation by replacing each label n by the 2 × 2 block of labels:

$4n+1$	$4n+3$
$4n$	$4n+2$

The same procedure may then be used to construct the larger odd-bit constellations recursively.

10.2.1.3 Symbol encoder with PCS-LCM

10.2.1.3.1 Overview

Figure 10-16 shows the functional model of the PCS-LCM symbol encoder. Bytes incoming from the PMS-TC sublayer are split by the LDPC bit extractor into amplitude bits, sent to the amplitude encoder, and LDPC information bits, sent to the LDPC encoder. The amplitude encoder converts the amplitude bits, using the tone-ordering table, into binary labels of shaped amplitudes, which are forwarded to the constellation mapper. The LDPC encoder encodes the LDPC information bits and sends the generated parity bits together with the LDPC information bits coming from the LDPC bit extractor to the constellation mapper. The constellation mapper converts its inputs to two-dimentional (2D) QAM constellation points.

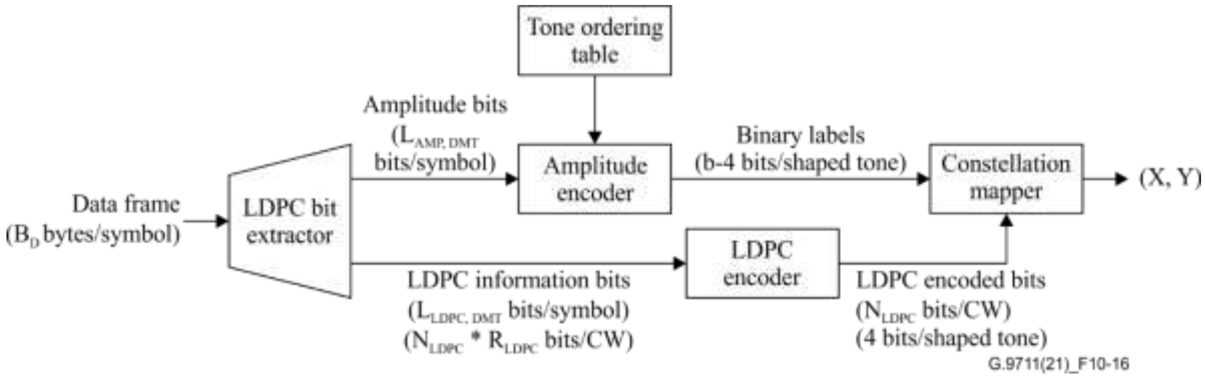


Figure 10-16 – Functional model of the PCS-LCM symbol encoder

10.2.1.3.2 Tone Ordering

During initialization, the receiving MTU shall determine the order in which subcarriers are assigned bits (the tone-ordering table) and calculate the modulation indices and the relative gains to be used for every subcarrier in the MEDLEY set for both data symbols and RMC symbols (either MEDLEYus or MEDLEYds, depending on the transmission direction). The number of subcarriers in the Band 0 and Band 1 of the upstream MEDLEYset is denoted NSC_{us0}, NSC_{us1}, respectively. The number of subcarriers in the Band 0 and Band 1 of the downstream MEDLEYset is denoted NSC_{ds0}, NSC_{ds1}, respectively. The RRC bits are the first bits of the data symbol and RRC symbol and shall be processed same as the DTU bits of the data symbol.

The receive MTU shall also select the subcarriers used to encode the RMC during the RMC symbols. The selected RMC tone set (RTS) is denoted by RTS_{us} and RTS_{ds} for upstream and downstream, respectively. The RMC tones shall belong to the Band 0. The number of subcarriers in the RTS is denoted $NSCR_{ds}$ and $NSCR_{us}$ for the downstream and upstream directions, respectively. The sum of loaded bits on the RTS (L_{RMC}) shall be greater than or equal to the number of RMC bits ($8 \times N_{RMC}$). If $L_{RMC} > 8 \times N_{RMC}$, the remaining bits of the RTS shall be loaded with data bits (see Figure 10-5). The RTS may be modified in showtime through OLR. The MTU receiver determines the number of bits and the relative gains for every subcarrier in the RTS during RMC symbols and sends them back to the peer MTU during initialization. The same gains shall be used on RTS subcarriers in both RMC and data symbols in the NOI_{PSF}. The modulation indices and gains used to encode the subcarriers not belonging to the RTS shall be the same in both RMC and data symbols in the NOI_{PSF}. In the data symbols of DOI and NOI_{NPSF}, the modulation indices may be different, while in DOI the same gains shall be used as in NOI_{PSF}.

NOTE 1 – RTS subcarriers in RMC symbols always have SCI=0 or m_i=0, so that the raw bit loading equals the modulation index (see Table 10-4).

The pairs of modulation indices and relative gains used for data symbols are defined in ascending order of frequency or sub-carrier index i as a modulation index allocation table m and gain table g containing, respectively, m_i and g_i values for all sub-carrier indices i that belong to the MEDLEY set. The total number of subcarriers that have modulation index m_i that correspond to the same shaping code index SCI (see Table 10-4) shall be a multiple of the shell mapping (SM) group size K (see clause 10.2.1.3.4.1 and 10.2.1.3.4.2) for SCI=1, 2: for Band 0, the total number of subcarriers with SCI=1 shall equal $M_{10} \times K$ and the total number of subcarriers with SCI=2 shall equal $M_{20} \times K$, and for Band 1, the total number of subcarriers with SCI=1 shall equal $M_{11} \times K$ and the total number of subcarriers with SCI=2 shall equal $M_{21} \times K$, where M_{10}, M_{11}, M_{20} and M_{21} are integers. The total number of RTS sub-carriers in both upstream and downstream ($NSCR_{ds}$ and $NSCR_{us}$, respectively) shall be a multiple of K.

The tone-ordering table t is defined as the sequence $\{t_k\}$ in which sub-carriers from the MEDLEY set shall be assigned bits. Each value t_k (for k = 1 to $k = NSC_{us0}+NSC_{us1}$ for the upstream tones, k = 1 to $k = NSC_{ds0}+NSC_{ds1}$ for the downstream tones) equals to the index of the subcarrier to be assigned bits. Constellation mapping shall start from the subcarrier with index $i = t1$ and end on the subcarrier with index $i = t_{NSC0+NSC1}$ (for example, t_{75} = 160 means that the sub-carrier with index 160 is the 75-th subcarrier to be assigned bits). The tone-ordering table *t* for a particular direction shall be created by the receiver and exchanged during initialization (see clause 12.3.4.2), and shall remain unchanged until the next initialization. The same tone-ordering table *t* shall be used for both NOI (both data and RMC symbols) and DOI, and shall include subcarriers of both Band 0 and Band 1 when DTFO (see clause 10.7) is applied.

The pairs of modulation indices and relative gains used on the RTS during RMC symbols are defined in ascending order of frequency as a modulation index table *mr* and gain table *gr* containing, respectively, mr_i and gr_i values for all subcarrier indices *i* that belong to the RMC tone set. The gr_i values shall be the same as the g_i values used in data symbols of the NOI_{PSF} for the same subcarrier index. The mr_i values in table *mr* may be different from the table *m*. All subcarriers selected for RTS in RMC symbols shall be assigned m_i values corresponding to *SCI*=0 (m_i=1 to 4) or m_i=0. In the PSF, all subcarriers of the RTS in data symbols shall be assigned either modulation indices corresponding to the same SCI, i.e., 0, 1, or 2, or modulation indices corresponding to a mix of *SCI*=0 and m_i=0. This way, the same actual tone ordering is applied in NOI data symbols and in RMC symbols, and the RRC bits are always loaded on the subcarriers of the RTS set. In NOI_{NPSF} and DOI, subcarriers of the RTS in data symbols may be assigned modulation indices corresponding to different *SCI* or m_i=0.

Following reception of the tables *m*, *mr* and *t*, and the RTS, both the transmit and the receive MTUs shall calculate a re-ordered tone-ordering table *t'* from the original tone-ordering table *t*.

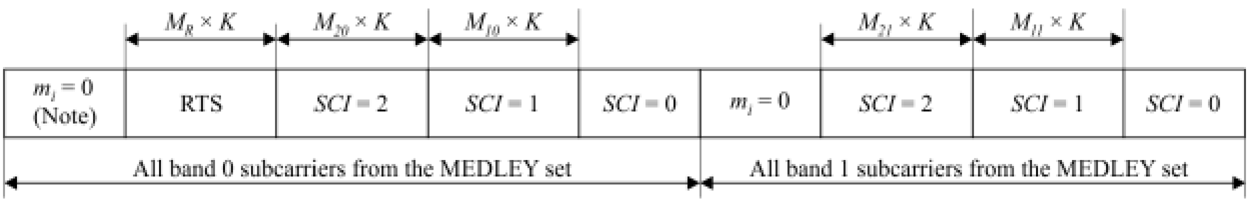
In the NOI_{PSF}, the re-ordered tone-ordering table *t'* shall be constructed so that:

– for Band 0, all the subcarriers with modulation index 0 except those of the RTS appear first, followed by all RTS subcarriers, in the same order they were in table *t*. Then there shall appear all the subcarriers supporting modulation indices corresponding to the *SCI*=2, in the same order they appeared in table *t*, after which shall appear all the subcarriers supporting modulation indices corresponding to *SCI*=1 in the same order they appeared in table *t*. The subcarriers supporting modulation indices corresponding to *SCI*=0 (unshaped subcarriers not belonging to RTS) shall appear the last, in the same order they appeared in table *t*.

– for Band 1, the construction shall be the same as for Band 0, except there are no RTS subcarriers in Band 1.

NOTE 2 – The RRC bits of data symbols are encoded first (see Figure 9-3) and thus will be loaded on the subcarriers assigned for RMC bits.

The format of the re-ordered tone-ordering table *t'* is shown in Figure 10-17a in the NOI_{PSF}. A re-ordered modulation index table *m'* shall be generated by re-ordering the entries of table *m* according to the order determined by the new tone table *t'*.



NOTE – This block does not include the subcarriers of the RTS with $m_i = 0$

Figure 10-17a – Format of the re-ordered tone-ordering table *t'* in NOI_{PSF}

In DOI and NOI_{NPSF} the re-ordered tone-ordering table *t'* shall be constructed separately for Band 0 and Band 1. All the subcarriers with modulation index 0 shall appear first. Then there shall appear all the subcarriers supporting modulation indices corresponding to the SCI=2, in the same order they appeared in table t, after which appear all the subcarriers supporting modulation indices corresponding to SCI=1 in the same order they appeared in table t. The subcarriers supporting modulation indices corresponding to SCI=0 shall appear the last, in the same order they appeared in table t. Figure 10-17b depicts the format of the re-ordered tone-ordering table t' in DOI and NOI_{NPSF}.

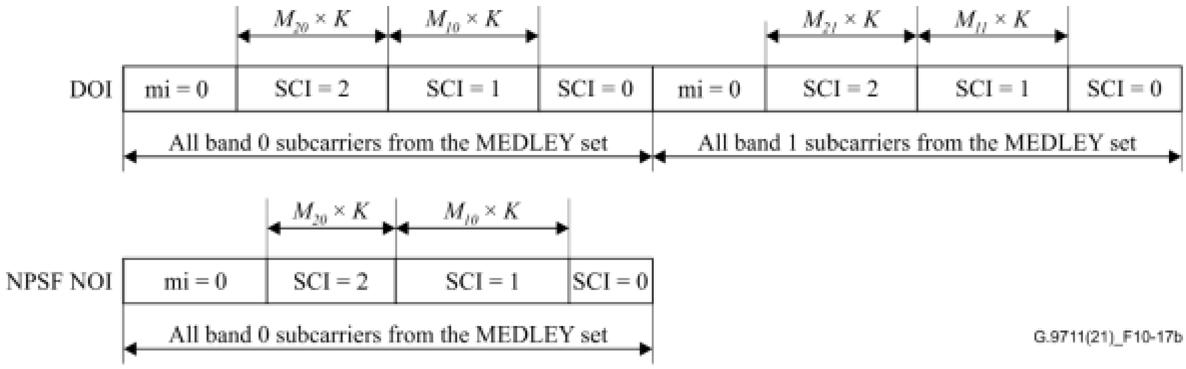


Figure 10-17b – Format of the re-ordered tone-ordering table t' in DOI and NOI_{NPSF}

The subcarriers that belong to Band 0 and Band 1 are set at initialization. The number of subcarriers in different SCI groups and the m' tables for Band 0 are the same in all NOI symbols, and may be different than those in the DOI symbols. The m_i and g_i values for the downstream or upstream or both of Band 1 may be forced by the MTU-O or MTU-R during initialization to be the same in both NOI_{PSF} and DOI. The NOI symbols that use only Band 0 shall apply only the corresponding part of t' and m' tables. All DOI symbols shall use complete t' and m' tables, containing both Band 0 and Band 1 parts.

The data bits and scrambler bits for the monitor tones shall be extracted first for the subcarriers of the Band 0, followed by the subcarriers of the Band 1, if Band 1 is active on that NOI symbol. Bit extraction for both Band 0 and Band 1 shall be done based on the re-ordered tone-ordering tables, as shown in Figures 10-17a and 10-17b.

NOTE 3 – The defined format of the re-ordered tone-ordering table (see Figure 10-17a) guarantees that the actual m_i' values are the same in Band 0 regardless of whether Band 1 in a particular NOI symbol is active or not.

10.2.1.3.3 LDPC bit extractor

The LDPC bit extractor shall extract the bits associated with a data frame including the padding bits (the L_D bits associated with the B_{RR}=B_{RRC}+B_D bytes of a normal data frame or the L_R bits associated with B_R bytes of an RMC data frame, Figure 9-3) in their original order, LSB-first. The extracted LDPC information bits are encoded by the LDPC encoder into one or more LDPC codewords (see clause 10.2.1.3.3.5.2) and the extracted amplitude bits are encoded by the amplitude encoder. All encoded bits of a normal data frame are loaded onto one data symbol, and all encoded bits of an RMC data frame are loaded onto one RMC symbol.

NOTE – The RMC bits (L_{RMC}) are part of LDPC payload of an RMC data frame (L_R bits) and are therefore LDPC encoded (see Figure 10-5).

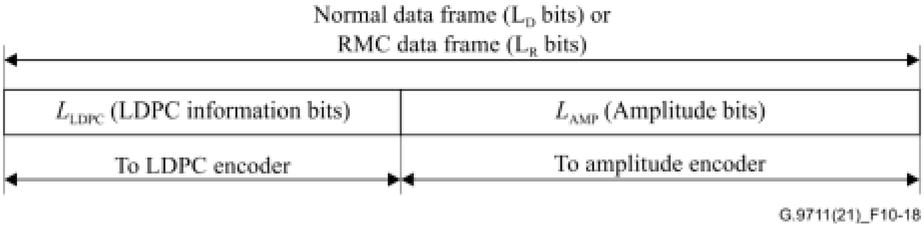


Figure 10-18 – Bit extraction from a data frame

Figure 10-18 shows the extraction order: the first L_{LPDC} bits extracted from the data frame are LDPC information bits, and the remaining L_{AMP} bits extracted from the data frame are amplitude bits.

The number of LDPC information bits (L_{LDPC}) that shall be extracted from a particular data frame depends on the associated LDPC codeword size, which is determined as specified in clause 10.2.1.3.5.2.

10.2.1.3.4 Amplitude encoder

10.2.1.3.4.1 Overview

The amplitude encoder encodes the L_{AMP} amplitude bits into labels of shaped amplitudes. A functional model of the amplitude encoder is shown in Figure 10-19. The incoming amplitude bits are first split into SM input bits, amplitude selection bits, and unshaped amplitude bits. The SM input bits are encoded by the shell mapper into shell indices. These are combined with the amplitude selection bits in the shell-to-amplitude mapper forming two amplitudes, each mapped to a binary amplitude label ($u_{b/2-3},\ldots,u_{bU/2+1}$, $u_{bU/2}$) for each tone, where b denotes the raw bit loading of the tone and b_U denotes the number of unshaped amplitude bits of the tone. The unshaped amplitude bits are mapped by the unshaped amplitude mapper to a binary amplitude label ($u_{bU/2-1}$, …, u_1, u_0) for each tone. The binary amplitude labels ($u_{bU/2-1}$, …, u_1, u_0) and ($u_{b/2-3}$, …, $u_{bU/2+1}$, $u_{bU/2}$) together constitute the binary amplitude labels ($u_{b/2-3},\ldots$, u_1,u_0) that are forwarded to the constellation mapper. For each shaped tone with modulation index larger than 4, two such binary amplitude labels are forwarded, each of b/2-2 bits (the two sign bits as well as the 2 LSBs are excluded, yielding 2(b/2-2)=b-4 amplitude bits per tone).

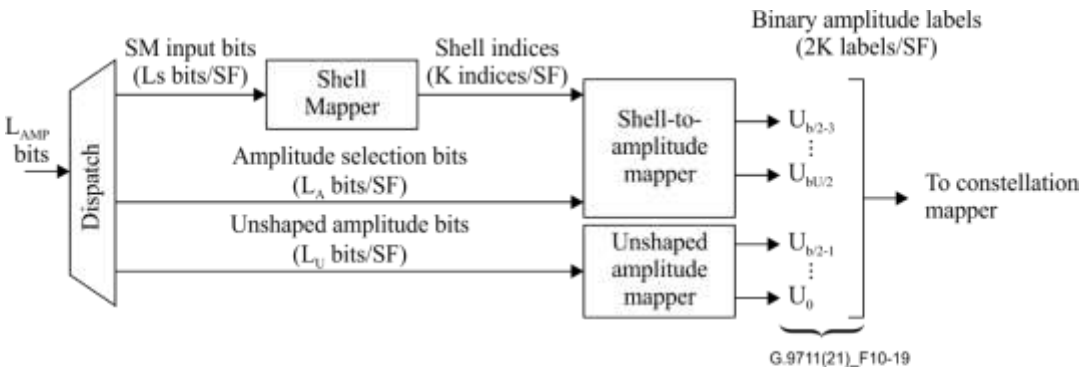


Figure 10-19 – Functional model of the amplitude encoder

The shaping code (SC) used by the shaping encoder, as well as the number of amplitude selection bits (b_A) and the number of unshaped amplitude bits (b_U) used for a subcarrier depend on the modulation index (m) of that subcarrier. Table 10-4 lists as a function of the modulation index m of a subcarier, the shaping code index (SCI) as well as b_A, b_U and the raw bit loading (b). Index m=0 corresponds to an unloaded subcarrier; unloaded subcarriers have no SCI assigned.

For m=1, 2, 3, 4 (which corresponds to unshaped BPSK, QPSK, 8-QAM, and 16-QAM respectively) no shaping is applied (i.e., *SCI*=0) and the amplitude encoder does not output any binary labels. Subcarriers with m=5 and 6 use shaping code indices 1 and 2, respectively, and have no unshaped amplitude bits. Subcarriers with *m*=7, 8, 9 differ from those with m=6 by having more amplitude selection bits (respectively b_A=1, 2, 3), but all have the same shaping code index of 2. For *m*=10, 12, 14, the same shaping code index of 2 and the same number of amplitude selection bits as those for m=8 are used, but with b_U=2, 4, 6 unshaped bits. Similarly, for subcarriers with *m*=11, 13, 15, the same shaping code of 2 and the same number of amplitude selection bits as those for *m*=9 are used with b_U=2, 4, 6 unshaped bits.

The raw bit loading *b* in Table 10-4 refers to the constellation order of the constellation mapper (see clause 10.2.1.3.6) for the respective modulation index, i.e., the constellation mapper can output 2^b different 2D constellation points. For modulation indices 6, 8, 10, 12, and 14, the amplitudes generated by the amplitude encoder are shaped so that only half of the constellation points are ever generated resulting in only 2^{b-1} different 2D constellation point that are organized in a circular QAM constellation shape (see clause 10.2.1.3.4.4).

Table 10-4 – Shaping parameters in function of the modulation index

Modulation Index (*m*)	**Raw Bit Loading (*b*)**	**Shaping Code Index (*SCI*)**	**Number of Amplitude Selection bits (b_A)**	**Number of unshaped amplitude bits (b_U)**
0	0	Not applicable	0	0
1	1	0	0	0
2	2	0	0	0
3	3	0	0	0
4	4	0	0	0
5	6	1	0	0
6	8 (Note)	2	0	0
7	8	2	1	0
8	10 (Note)	2	2	0
9	10	2	3	0
10	12 (Note)	2	2	2
11	12	2	3	2
12	14 (Note)	2	2	4
13	14	2	3	4
14	16 (Note)	2	2	6
15	16	2	3	6
NOTE – The raw bit loading *b* refers to the QAM constellation order used by the constellation mapper (see clause 10.2.1.3.6) for the respective modulation index, i.e., the constellation mapper can output 2^b different 2D constellation points. For modulation indices 6, 8, 10, 12, and 14, the encoded amplitudes are however shaped so that only half of the 2D constellation points are possible, so that only 2^{b-1} different 2D constellation points will be outputted.				

An MTU shall support all values of *m* from 1 to the maximum value of 13, 14, or 15. The maximum value of the applied modulation index is set at initialization based on the "MTU-O maximum bit loading" and "MTU-R maximum bit loading" capabilities indicated during initialization in the O-MSG 1 and R-MSG 2 messages by the MTU-O and MTU-R, respectively.

NOTE – Supporting maximum modulation index of 14 or 15 may lead to increased power consumption at the transmitter or the receiver or both relatively to supporting maximum modulation index of 13.

10.2.1.3.4.2 Dispatcher

The dispatcher extracts $L_{AMP,DMT}$ amplitude bits of the data frame into shaping frames (SF) according to Figure 10-20. Each SF contains the bits used to generate amplitudes for a group of K subcarriers with the same *SCI*. The value of K = 16 shall be supported. The sequence in which the subcarriers are processed shall be determined by the re-ordered tone table t' (see clause 10.2.1.3.2), i.e., SF(0) shall be used for subcarriers 0 to K-1 of the re-ordered tone table t', SF(1) shall be used for subcarriers K to $2K$-1, etc. Here the numbering of the re-ordered tone table t' excludes unloaded tones, i.e., subcarrier 0 is the first subcarrier with a nonzero m in the re-ordered tone table t'.

A SF consists of (L_S+L_A+L_U) bits, where

- L_S is the number of SM input bits in the shaping frame and is determined by the *SCI* (see Table 10-4 and Table 10-5).
- L_A is the total number of amplitude selection bits in the shaping frame and is determined as the sum of the numbers of amplitude selection bits b_A for the subcarriers of the shaping frame (and where the b_A are determined using Table 10-4):

$$L_A = \sum_{k=0}^{K-1} b_{A,k}.$$

- L_U is the total number of unshaped amplitude bits in the shaping frame and is determined as the sum of the unshaped amplitude bits b_U for the subcarriers of the shaping frame (and where the b_U are determined using Table 10-4):

$$L_U = \sum_{k=0}^{K-1} b_{U,k}.$$

The number of bits in a shaping frame depends on the modulation indices loaded on the specific tones that are part of the shaping frame (the tones determine L_A and L_U).

The first L_S bits of the shaping frame shall be used by the shell mapper to generate shell indices for the tones in the shaping frame, the next L_A bits by the shell-to-amplitude mapper to generate the shaped amplitude levels, and the last L_U bits by the unshaped amplitude mapper to generate the unshaped amplitude levels. The total number of amplitude bits L_{AMP} transmitted in a symbol shall equal the sum of the $(L_S + L_A + L_U)$ bits over all shaping frames SF with shaping frame index *sfi* = 0 to N_{SF}-1.

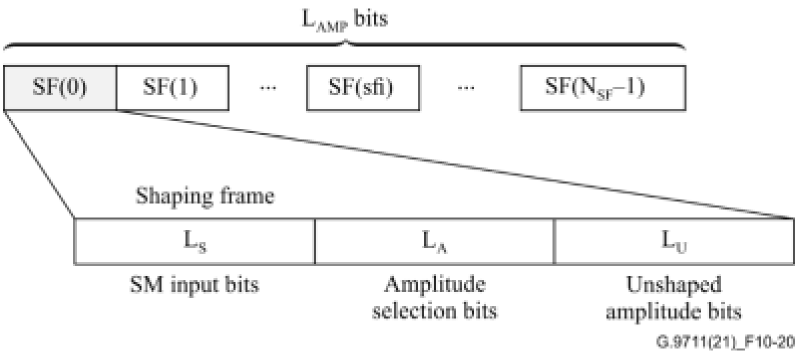


Figure 10-20 – Structure of the shaping frames

10.2.1.3.4.3 Shell mapper encoder

10.2.1.3.4.3.1 Overview

The shell mapper encoder maps the L_S input bits to a set of K shell index labels ($m_{S,0}$, $m_{S,1}$, …, $m_{S,K-1}$), where each of the integers $m_{S,k}$ satisfies $0 \leq m_{S,k} \leq M-1$. The values of L_S and M depend on the *SCI* and shall take the values listed in Table 10-5.

Table 10-5 – Shaping code parameters for K=16

Shaping code index (*SCI*)	Number of shell values levels (*M*)	Number of SM input bits (L_S)
1	4	16
2	8	32

The mapping is based on the weight of the set of shell index labels, which shall be computed as the sum of the shell labels:

$$D = \sum_{k=0}^{K} m_{S,k}$$

The L_S bits shall be extracted from the buffer and converted LSB-first (i.e., the first extracted bit is assigned to the LSB) to an integer X, where $0 \leq X < 2^{L_S}$. The mapping of X to a set of shell index labels is done so that a smaller X value results in a set of shell index labels with a smaller weight D. This shall be performed as described in this clause.

10.2.1.3.4.3.2 Weight calculation

The weight D of the labels corresponding to the integer X is determined. This is done based on the number N_D of sets of shell index labels that have a weight smaller than D as specified in Table 10-6 for *SCI*=1 and in Table 10-7 for *SCI*=2. The value of D corresponding to X shall be calculated as the largest D for which $N_D \leq X$. For the resulting D, the remainder R_1 shall be calculated as $R_1 = X - N_D$. The remainder R_1 is used to sequence all the sets of shell index labels that have the same weight D.

Table 10-6 – Weight characteristics for *SCI*=1 (*M*=4)

Weight *D*	Number of sets N_D
0	0
1	1
2	17
3	153
4	969
5	4829
6	20077

Table 10-7 – Weight characteristics for *SCI*=2 (*M*=8)

Weight D	Number of sets N_D	Weight D	Number of sets N_D
0	0	11	5309287
1	1	12	13022391
2	17	13	30344235
3	153	14	67538331
4	969	15	144228867
5	4845	16	296617683
6	20349	17	589312974
7	74613	18	1134117550
8	245157	19	2118992030
9	735455	20	3851438910
10	2042703		

NOTE – The numbers N_D in Table 10-6 and Table 10-7 can be calculated following the method described in [b-ITU-T V.34], clause 9.4, Equation [9-3]-[9-6]. This corresponds to an iterative method for calculating generator functions g_i describing the weight of a set of i shell index labels. The number N_D can be computed from the function g_{16} as: $N_D = \sum_{d=0}^{D-1} g_{16}(d)$.

10.2.1.3.4.3.3 Determine bit weights

Each shell label consists of b_S=log$_2$$(M)$ bits and accordingly, $b_S \times K$ shell bits are associated to each set of shell index labels. The corresponding $b_S \times K$ bit values can be represented with a matrix $\boldsymbol{W} \in \{0,1\}^{b_S \times K}$. The shell label $m_{S,k}$ shall be computed as $m_{S,k} = \sum_{i=0}^{b_S-1} w_{i,k} 2^i$, where $w_{i,k}$, is the element of the i-th row and k-th column of $\boldsymbol{W}$. The sequence weights ω_i are defined as $\omega_i = \sum_{k=0}^{K-1} w_{i,k}$ and are equal to the number of ones in the corresponding row of $\boldsymbol{W}$. There is a strict dependency between $\boldsymbol{W}$ and D given by $D = \sum_{i=0}^{b_S-1} \omega_i 2^i$.

For each value of D, there is a small set of possible sequence weights ω_i. Table 10-8 shows the possible sequence weights for *SCI*=1 up to *D*=4, and Table 10-9 shows the possible sequence weights for *SCI*=2 up to *D*=4.

Table 10-8 – Sequence weights up to *D*=4 for *SCI*=1 (*M*=4)

Weight D	Sequence weights		$\omega_1(K+1)+\omega_0$	Index I	Number of sequences $N_{D,I}$
	ω_1	ω_0			
0	0	0	0	0	1
1	0	1	1	0	16
2	0	2	2	0	120
	1	0	17	1	16
3	0	3	3	0	560
	1	1	18	1	256
4	0	4	4	0	1820
	1	2	19	1	1920

	2	0	34	2	120

Table 10-9 – Sequence weights up to *D*=4 for *SCI*=2 (*M*=8)

Weight *D*	Sequence weights			$\omega_2(K+1)^2+\omega_1(K+1)+\omega_0$	Index *I*	Number of sequences $N_{D,I}$
	ω_2	ω_1	ω_0			
0	0	0	0	0	0	1
1	0	0	1	1	0	16
2	0	0	2	2	0	120
	0	1	0	17	1	16
3	0	0	3	3	0	560
	0	1	1	18	1	256
4	0	0	4	4	0	1820
	0	1	2	19	1	1920
	0	2	0	34	2	120
	1	0	0	289	3	16

For a given *D*, the possible sets of sequence weights $\{\omega_i\}$ are sorted in ascending order based on the value of $\sum_{i=0}^{b_S-1}\omega_i(K+1)^i$. Each set is labeled with the index *I*, in that sorted list. The first element of that list is labeled with 0. For a given weight *D* and label *I*, the number of different bit sequences $N_{D,I}$ that have the corresponding set of sequence weights ω_i is:

$$N_{D,I} = \prod_{i=0}^{b_S-1}\binom{K}{\omega_i}.$$

Here $\binom{n}{k}$ is the binomial coefficient. Table 10-8 and Table 10-9 list the sequence weight values for the different *I* and $N_{D,I}$ values.

The weight vector index *I* shall be calculated as the smallest I for which $R_1 < \sum_{i=0}^{I} N_{D,i}$. The remainder R_2 shall be calculated as $R_2 = R_1 - \sum_{i=0}^{I-1} N_{D,i}$ if *I*>0 and $R_2 = R_1$ if *I*=0. This remainder R_2 is used to sequence the sets of shell index labels that have the sequence weights corresponding to *D* and *I*.

10.2.1.3.4.3.4 Calculation of shell labels

From the remainder R_2, a set of b_S remainders R_{3i} shall be calculated with i=0, …, b_S-1. For *SCI*=1, the different integer values R_{30}, R_{31} shall be calculated from R_2 according to:

$$R_{30} = \text{mod}\left(R_2, \binom{K}{\omega_0}\right)$$

$$R_{31} = \text{floor}\left(R_2 / \binom{K}{\omega_0}\right)$$

For *SCI*=2, the different integer values R_{30}, R_{31}, and R_{32} shall be calculated from R_2 according to:

$$R_{30} = \mathrm{mod}\left(R_2, \binom{K}{\omega_0}\right)$$

$$R_{31} = \mathrm{mod}\left(\mathrm{floor}\left(R_2/\binom{K}{\omega_0}\right), \binom{K}{\omega_1}\right)$$

$$R_{32} = \mathrm{floor}\left(R_2/\left(\binom{K}{\omega_0}\binom{K}{\omega_1}\right)\right).$$

The permutation associated to R_2 and the corresponding full matrix $\boldsymbol{W}$ shall be created using the following pseudocode to generate each row of the matrix $\boldsymbol{W}$ (the row $\boldsymbol{w}_i$ is given by $\boldsymbol{w}_i = schalkwijk(R_{3i}, \omega_i)$) :

```
w=schalkwijk(R,ω)
      initialize w=[w0=0,…, wK-1=0]
      initialize r= ω +1
      initialize c= ω
      for k = 0 to K-1 do
      if c < K and (r+K-c-2 choose K-c-1)>R then
            c=c+1
      else
            if c<K then
             R=R-(r+K-c-2 choose K-c-1)
            end if
            r=r-1
            wk=1
            ω= ω-1
      end if
      if ω≤0 then
            stop
         end if
      end for
```

NOTE – The pseudocode implements the Schalkwijk algorithm [b-IEEE SJ]. The Schalkwijk algorithm w=schalkwijk(R,ω) returns the binary vector $\boldsymbol{w} = [\boldsymbol{w_0}, \ldots, \boldsymbol{w_{K-1}}]$ which satisfies:

$R = \sum_{i=0}^{K-1} w_i \binom{K-1-i}{\sum_{k=i}^{K-1} w_k}$ and $\sum_{k=0}^{K-1} w_k = \omega$ with $\binom{n}{k}$ the binomial coefficient if $n \geq k$, otherwise 0.

The matrix $\boldsymbol{W}$ shall be translated into the corresponding shell labels according to the formula $m_{S,k} = \sum_{i=0}^{b_S-1} w_{i,k} 2^i$.

10.2.1.3.4.4 Shell-to-amplitude mapper

The shell-to-amplitude mapper converts shell indices and amplitude selection bits to binary labels of shaped amplitude levels. For one shaping frame, it takes as input K shell indices and L_A amplitude selection bits, and generates 2K amplitude levels ($a_{s,0}$, $a_{s,1}$, …, $a_{s,2K-1}$). Here L_A equals the sum of the number of amplitude selection bits b_A of each subcarier in the shaping frame (see Table 10-4). Every amplitude level is converted to a binary label ($u_{b/2-3}$, …, $u_{bU/2}$), with b the raw bit loading and b_U the number of unshaped amplitude bits of the corresponding subcarier.

Sequentially, for subcarier k=0,…,K-1, each $b_{A,k}$ bits of the L_A amplitude selection bits shall be extracted from the buffer and converted LSB-first (i.e., the first extracted bit is assigned to the LSB) to a selection integer $m_{A,k}$ using non-signed natural binary code. The shell index $m_{S,k}$ and the selection integer $m_{A,k}$ shall then be mapped onto two shaped amplitude levels $a_{s,2k}$ and $a_{s,2k+1}$

according to Table 10-10, Table 10-11, Table 10-12, Table 10-13, and Table 10-14 (for Table 10-10 and Table 10-11, $b_{A,k}$=0 and no $m_{A,k}$ is used). These two amplitude levels correspond to the real and imaginary amplitudes of subcarier k.

NOTE – Table 10-11 and Table 10-13 do not generate all combinations of amplitude levels that are possible for the corresponding raw bit loading. For instance, Table 10-11 can only generate 8 of the possible 4^2=16 combinations that are possible with 2×4-level amplitudes, and Table 10-13 only 32 of the 8^2=64 combinations possible with 2×8-level amplitudes. The amplitude combinations of these table have been selected so that the corresponding QAM constellation have a circular shape. In contrast the other Table 10-10, Table 10-12, and Table 10-14 have no restrictions and lead to square QAM constellations.

Table 10-10 – Mapping table: 4 shell indices to 2×2 amplitude levels (modulation index 5)

Shell index $m_{S,k}$	Amplitude level	
	$a_{s,2k}$	$a_{s,2k+1}$
0	0	0
1	0	1
2	1	0
3	1	1

Table 10-11 – Mapping table: 8 shell indices to 2×4 amplitude levels (modulation index 6)

Shell index $m_{S,k}$	Amplitude level	
	$a_{s,2k}$	$a_{s,2k+1}$
0	0	0
1	0	1
2	1	0
3	1	1
4	0	2
5	2	0
6	1	2
7	2	1

Table 10-12 – Mapping table: 8 shell indices to 2×4 amplitude levels (modulation index 7)

Shell index $m_{S,k}$	Amplitude level			
	$m_{A,k}$ = 0		$m_{A,k}$ = 1	
	$a_{s,2k}$	$a_{s,2k+1}$	$a_{s,2k}$	$a_{s,2k+1}$
0	0	0	0	1
1	1	0	1	1
2	0	2	2	0
3	1	2	2	1
4	0	3	2	2
5	3	0	1	3

6	3	1	2	3
7	3	2	3	3

Table 10-13 – Mapping table: 8 shell indices to 2×8 amplitude levels (modulation index 8, 10, 12, and 14)

Shell index $m_{S,k}$	**Amplitude level**							
	$m_{A,k}$ = 0		$m_{A,k}$ = 1		$m_{A,k}$ = 2		$m_{A,k}$ = 3	
	$a_{s,2k}$	$a_{s,2k+1}$	$a_{s,2k}$	$a_{s,2k+1}$	$a_{s,2k}$	$a_{s,2k+1}$	$a_{s,2k}$	$a_{s,2k+1}$
0	0	0	0	1	1	0	1	1
1	0	2	2	0	1	2	2	1
2	0	3	2	2	3	0	1	3
3	3	1	2	3	3	2	0	4
4	4	0	1	4	4	1	3	3
5	2	4	4	2	0	5	5	0
6	3	4	4	3	1	5	5	1
7	2	5	5	2	4	4	0	6

Table 10-14 – Mapping table: 8 shell indices to 2×8 amplitude levels (modulation indices 9, 11, 13, and 15)

Shell index $m_{S,k}$	**Amplitude Level**															
	$m_{A,k}$=0		$m_{A,k}$=1		$m_{A,k}$=2		$m_{A,k}$=3		$m_{A,k}$=4		$m_{A,k}$=5		$m_{A,k}$=6		$m_{A,k}$=7	
	$a_{s,2k}$	$a_{s,2k+1}$	$a_{s,2k}$	$a_{s,2k+1}$	$a_{s,2k}$	$a_{s,2k+1}$	$a_{s,2k}$	$a_{s,2k+1}$	$a_{s,2k}$	$a_{s,2k+1}$	$a_{s,2k}$	$a_{s,2k+1}$	$a_{s,2k}$	$a_{s,2k+1}$	$a_{s,2k}$	$a_{s,2k+1}$
0	0	0	0	1	1	0	1	1	0	2	2	0	1	2	2	1
1	0	3	2	2	3	0	1	3	3	1	2	3	3	2	0	4
2	4	0	1	4	4	1	3	3	2	4	4	2	0	5	5	0
3	3	4	4	3	1	5	5	1	2	5	5	2	4	4	0	6
4	5	3	3	5	6	0	1	6	6	1	2	6	6	2	4	5
5	5	4	3	6	6	3	0	7	7	0	1	7	7	1	5	5
6	2	7	6	4	4	6	7	2	3	7	7	3	5	6	6	5
7	4	7	7	4	6	6	5	7	7	5	6	7	7	6	7	7

Each amplitude level $a_{s,j}$ is then converted to a binary amplitude label ($u^{(j)}_{a,b/2-3} \dots u^{(j)}_{a,bU/2}$) based on Table 10-15, where b is the raw bit loading, and b_U the number of unshaped amplitude bits of the corresponding subcarier. This labelling is defined to be consistent with the double Gray labelling of the 1D constellation coordinates defined by the constellation mapper in clause 10.2.1.3.6.

Table 10-15 – Mapping amplitude levels to binary labels. The binary labels are ordered MSB-first

Amplitude level ($a_{s,j}$)	Modulation index 5	Modulation indices 6 and 7	Modulation indices 8 and 9	Modulation indices 10 and higher
0	0	00	000	000
1	1	01	001	001
2		10	010	011
3		11	011	010
4			110	110
5			111	111
6			100	101
7			101	100

The binary amplitude labels $(u^{(j)}_{a,b/2-3} \dots u^{(j)}_{a,bU/2})$ are forwarded to the constellation mapper. The binary amplitude labels $(u^{(2k)}_{a,b/2-3} \dots u^{(2k)}_{a,bU/2})$ and $(u^{(2k+1)}_{a,b/2-3} \dots u^{(2k+1)}_{a,bU/2})$ are the binary amplitude labels corresponding to subcarier k in the shaping frame.

10.2.1.3.4.5 Unshaped amplitude mapper

The unshaped amplitude mapper maps the L_U unshaped amplitude bits of a shaping frame onto 2K binary amplitude labels $(u^{(j)}_{bU/2-1} \dots u^{(j)}_1 u^{(j)}_0)$.

The total number of unshaped amplitude bits in the shaping frame equals the sum of the number of unshaped bits $b_{U,k}$ of each subcarier in the shaping frame (see Table 10-4). The total number of unshaped amplitude bits in the shaping frame varies between $0 \leq L_U \leq (6 \times K) - 1$.

The first binary amplitude label $(u^{(0)}_{bU/2-1} \dots u^{(0)}_1 u^{(0)}_0)$ of the first subcarier in the shaping frame shall be generated by extracting the $b_{U,0}/2$ bits from the buffer and assigning them to the label LSB-first: the first bit extracted from the buffer is used for $u^{(0)}_0$, the second for $u^{(0)}_1$, and so on. The second binary amplitude label $(u^{(1)}_{bU/2-1} \dots u^{(1)}_1 u^{(1)}_0)$ of the first subcarier is generated by similarly extracting the next $b_{U,0}/2$ bits and writing them into the label LSB-first. The same is repeated to generate two binary amplitude labels $(u^{(2)}_{bU/2-1} \dots u^{(2)}_1 u^{(2)}_0)$ and $(u^{(3)}_{bU/2-1} \dots u^{(3)}_1 u^{(3)}_0)$ for the second subcarier of each $b_{U,1}/2$ bits long, and so on.

The binary labels $(u^{(j)}_{bU-1} \dots u^{(j)}_1 u^{(j)}_0)$ are forwarded to the constellation mapper.

10.2.1.3.5 LDPC encoder

The LDPC encoder encodes its input bits by an LDPC code with a code rate r_{LDPC}. Figure 10-21 shows the structure of the LDPC codewords.

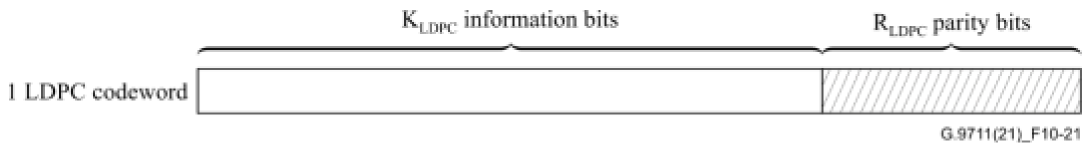


Figure 10-21 – Structure of the LDPC codewords

A codeword shall contain K_{LDPC} input bits that are encoded using the LDPC code to generate R_{LDPC} parity bits. The K_{LDPC} input bits of each codeword shall be filled up by taking K_{LDPC} information bits in the order those are received from the LDPC bit extractor.

For each codeword, the K_{LDPC} information bits followed by the R_{LDPC} parity bits, totalling $N_{\text{LDPC}} = K_{\text{LDPC}} + R_{\text{LDPC}}$ encoded bits, shall be outputted by the LDPC encoder to the constellation mapper. N_{LDPC} is the LDPC codeword size (the total length of the codeword), and the number of parity bits for the given codeword and the given code rate is $R_{\text{LDPC}} = N_{\text{LDPC}}\times(1\text{-}r_{\text{LDPC}})$.

The LDPC encoder shall compute the parity bits as defined in clause 10.2.1.3.5.1. For each particular data frame with its particular values of N_{LDPC}, the corresponding values of K_{LDPC} and R_{LDPC} depend on the applied puncturing and shortening, and shall be determined as defined in clause 10.2.1.3.5.2.

10.2.1.3.5.1 Generation of parity bits

The parity bits shall be generated from a parity check matrix, $\boldsymbol{H}$. In order to accommodate variable codeword size and code rate, multiple parity check matrices are defined as values of a function of a circulant matrix size M_c. The valid values of M_c are 64, 96, 128, 192, 256, 384 and 512. All valid values shall be supported. For each M_c, a parity check matrix of dimension $7M_c\times25M_c$ shall be generated using the base graph matrix of dimension 7×25 defined in Table 10-16 where any "0" element is replaced by an all-zero matrix of dimension $M_c\times M_c$ and any "1" element is replaced by a circulant matrix of dimension $M_c\times M_c$ which is circularly right shifted from an identity matrix by a variable number of positions depending on both the value of M_c and the position of the "1" element in the base graph. The Table 10-17 contains the number of circularly right shifted positions as a function of both the appropriate value of M_c and the position of the "1" element in the base graph defined in Table 10-16.

Table 10-16 – Base graph matrix with "0" and "1" elements of dimension 7×25

0	1	0	0	1	0	1	0	0	1	0	1	0	1	0	1	1	0	0	0	1	0	1	0	1
0	1	0	1	0	0	0	1	0	1	0	0	1	0	1	0	0	1	1	0	0	1	1	0	1
0	0	1	1	0	0	0	1	1	0	1	0	0	1	0	0	1	0	1	0	1	1	0	0	1
1	1	0	0	0	1	1	0	1	0	0	1	0	0	1	1	0	0	0	1	0	0	0	1	1
1	0	1	0	0	1	1	1	0	0	1	0	1	0	0	0	0	0	0	1	0	1	0	1	1
1	0	0	1	1	0	0	0	1	1	0	0	1	0	1	0	0	0	1	0	1	0	0	1	1
0	0	1	0	1	1	0	0	0	0	1	1	0	1	0	1	0	1	0	1	0	0	1	0	1

Table 10-17 – Number of circularly right shifted positions as a function of position of "1" element in the base graph (Table 10-16) and the circulant matrix size, M_c

		Matrix circulant size (M_c)									Matrix circulant size (M_c)						
Row	**Col**	**64**	**96**	**128**	**192**	**256**	**384**	**512**	**Row**	**Col**	**64**	**96**	**128**	**192**	**256**	**384**	**512**
1	2	0	0	0	0	0	0	0	4	15	37	62	40	166	65	286	215

Table 10-17 – Number of circularly right shifted positions as a function of position of "1" element in the base graph (Table 10-16) and the circulant matrix size, M_c

		Matrix circulant size (M_c)									Matrix circulant size (M_c)						
Row	**Col**	**64**	**96**	**128**	**192**	**256**	**384**	**512**	**Row**	**Col**	**64**	**96**	**128**	**192**	**256**	**384**	**512**
	5	0	0	0	0	0	0	0		16	7	91	61	7	26	310	62
	7	0	0	0	0	0	0	0		20	0	0	0	0	0	0	0
	10	0	0	0	0	0	0	0		24	0	0	0	0	0	0	0
	12	0	0	0	0	0	0	0		25	60	38	59	52	101	190	161
	14	0	0	0	0	0	0	0	5	1	13	32	28	131	203	337	49
	16	0	0	0	0	0	0	0		3	41	77	64	9	98	361	459
	17	0	0	0	0	0	0	0		6	59	36	20	155	133	288	100
	21	0	0	0	0	0	0	0		7	22	51	14	39	207	35	283
	23	0	0	0	0	0	0	0		8	21	60	44	173	166	374	207
	25	0	0	0	0	0	0	0		11	62	67	63	88	136	257	307
2	2	15	68	30	147	66	6	341		13	26	67	25	175	13	196	19
	4	0	0	0	0	0	0	0		20	8	89	94	183	135	303	63
	8	0	0	0	0	0	0	0		22	22	11	114	162	203	171	189
	10	36	88	95	123	80	351	180		24	61	65	112	94	10	363	132
	13	0	0	0	0	0	0	0		25	43	89	62	70	145	40	396
	15	0	0	0	0	0	0	0	6	1	1	18	52	156	103	67	314
	18	0	0	0	0	0	0	0		4	11	14	107	35	54	58	280
	19	0	0	0	0	0	0	0		5	33	76	119	42	150	318	329
	22	0	0	0	0	0	0	0		9	18	25	119	32	169	159	147
	23	3	28	54	172	38	69	12		10	38	67	90	161	205	335	141
	25	38	2	125	167	185	381	386		13	8	9	6	12	110	352	476
3	3	0	0	0	0	0	0	0		15	24	87	120	185	188	291	37
	4	32	32	6	107	1	56	456		19	6	28	61	104	222	255	174
	8	61	57	87	154	234	61	299		21	18	66	41	1	153	361	424
	9	0	0	0	0	0	0	0		24	30	56	119	89	27	325	427
	11	0	0	0	0	0	0	0		25	16	52	63	78	47	33	462
	14	34	69	39	125	87	242	154	7	3	32	17	7	186	79	249	21
	17	30	83	51	17	239	373	183		5	37	11	103	176	21	144	7
	19	51	70	86	167	138	220	75		6	40	48	23	74	218	106	510
	21	50	44	106	72	200	178	28		11	14	2	73	93	217	219	221
	22	17	59	80	33	225	82	33		12	54	35	31	114	191	221	246
	25	60	65	62	178	31	224	235		14	40	80	75	93	51	28	453
4	1	0	0	0	0	0	0	0		16	63	56	70	71	154	104	368
	2	5	76	41	109	128	7	215		18	43	60	7	34	154	354	30
	6	0	0	0	0	0	0	0		20	36	47	110	115	74	379	335
	7	53	94	126	105	187	94	106		23	35	18	39	162	109	366	231

Table 10-17 – Number of circularly right shifted positions as a function of position of "1" element in the base graph (Table 10-16) and the circulant matrix size, M_c

		Matrix circulant size (M_c)									Matrix circulant size (M_c)						
Row	**Col**	**64**	**96**	**128**	**192**	**256**	**384**	**512**	**Row**	**Col**	**64**	**96**	**128**	**192**	**256**	**384**	**512**
	9	59	20	33	185	175	103	415		25	14	64	94	5	197	271	405
	12	47	72	19	41	110	364	222									

For each valid value M_c of the circulant, the parity check matrix corresponds to one mother code with a codeword length of 25×M_c bits containing 18×M_c information bits and 7×M_c parity bits. To accommodate the desired shorter codeword length N_{LDPC} with K_{LDPC} information bits and R_{LDPC} parity bits using the same parity check matrix, the first S = 18×M_c-K_{LDPC} information bits of the mother code are shortened and the last P = 7×M_c-R_{LDPC} parity bits of the mother code are punctured. The applied values of M_c, S, and P shall be selected as defined in clause 10.2.1.3.5.2.

The valid ranges of puncturing for different M_c is presented in Table 10-18.

Table 10-18 – Valid range of puncturing for different values of M_c

M_c	512	384	256	192	128	96	64
Range of *P*	0-1024	0-960	0-512	0-480	0-256	0-192	0-128, 448 (Note)
NOTE – A value of 448 punctures all parity bits from the LDPC codewords, i.e., only the systematic bits are transmitted.							

The valid values of puncturing within the valid ranges are: $P = k \times 0.25 \times M_c$, where k shall be a nonnegative interger. All the valid values of both M_c and P are mandatory.

The R_{LDPC} parity bits (p_1, …, p_{RLDPC}) shall be generated as follows from the K_{LDPC} information bits (b_1, …, b_{KLDPC}) with b_1 to be the first bit outputted by the LDPC bit extractor, using a parity check matrix, ***H*** of dimension (7×M_c)×(25×M_c):

– 18×M_c bits (d_1, …, $d_{18\text{Mc}}$) shall be constructed by prepending S = 18×M_c – K_{LDPC} bits to the information bits, i.e.,

$$d_k = 0 \; for \; 1 \le k \le S$$

$$d_{k+S} = b_k \; for \; k = 1 \; to \; K_{LDPC}$$

– 7×M_c bits (s_1,…,s_{7Mc}) shall be generated by solving the system of 7×M_c equations mod(**H**.[d_1 …d_{18Mc} s_1…s_{7Mc}]^T,2) = **0** where **0** is a column vector of 7×M_c zeros.

– The R_{LDPC} parity bits shall be obtained by removing the last P=7M_c-R_{LDPC} of "s" bits, i.e.,

$$p_k = s_k \; for \; k = 1 \; to \; R_{LDPC}.$$

– The bits of a codewords shall be outputted by the LDPC encoder in the order (b_1, …, b_{KLDPC}, p_1, … p_{RLDPC}).

10.2.1.3.5.2 Selection of LDPC parameters

The total number of the LDPC encoded bits for a normal data frame is determined by the *m'* table (see clause 10.2.1.3.2) and shall be computed as:

1) For data frames employing both Band 0 and Band 1:

NS_{LDPC} = 4×(M_{20}+M_{10}+M_{21}+M_{11})×K + sum{$m_i(SCI=0)$} if SCI=0 for the RTS is set, and

NS_{LDPC} = 4×(M_R+M_{20}+M_{21}+M_{10}+M_{11})×K + sum{$m_i(SCI=0)$} if SCI >0 for the RTS is set, where $m_i(SCI=0)$ are modulation indices of all subcarriers of Band 0 and Band 1 supporting $SCI=0$, including the RTS subcarriers.

2) For data frame employing only Band 0:

- M_{11} and M_{21} shall be set to 0;
- the term sum{$m_i(SCI=0)$} shall only include m_i values that belong to Band 0.

All codewords of a particular data frame shall use the same circulant value M_c and the same number of punctured bits P. These values are determined by the receiver and exchanged between the transmitter and the receiver (see clause 12.3.4).

The number d of LDPC codewords in a normal data frame containing NS_{LDPC} encoded bits shall be computed as:

$$d = \text{ceiling}[NS_{LDPC}/(25\times M_c - P)],$$

where the values of M_c and P shall be chosen (by the receiver) so that the value of d does not exceed $dmax$ = ceiling[NS_{LDPC}/8192].

With the selected M_c and P, the size of each codeword in the data frame is determined by the number of shortened bits S, which for normal data frame shall be calculated as:

If $d = 1$, $S_1 = (25\times M_c - P) - NS_{\text{LDPC}}$;

If $d > 1$, then for the first $(d - 1)$ codewords $S_1 = (25\times M_c - P) - \text{ceiling}[NS_{LDPC}/d]$ and for the last codeword $S_{\text{last}} = (25\times M_c - P) - [NS_{\text{LDPC}} - (d - 1) \times (25\times M_c - P - S_1)]$.

The values of M_c and P shall be chosen so that:

- S_1 is between 0 and $(18\times M_c - 8\times N_{RMC} - \Delta S_{RMC})$, where ΔS_{RMC} is the difference in the number of LDPC bits loaded on the RTS subcarriers of a normal data frame and of an RMC data frame, and
- S_{last} is between 0 and $18\times M_c$.

For the RMC data frame, the settings for M_c and P shall be the same as for a normal NOI data frame using that same bands, and the number of shortened bits in the first codeword shall accommodate the difference between the number of LDPC bits loaded on RTS in a normal data frame and in RMC data frame (ΔS_{RMC}), while all other codewords in RMC data frame shall have the same size as in the corresponding normal NOI data frame. The value of ΔS_{RMC} shall be positive if the number of bits is greater in a normal data frame than in an RMC data frame. Otherwise, the value shall be negative.

NOTE – The upper bound on S_1 guarantees that the RMC bits and RRC bits, respectively, assigned to RTS will be all encoded only as LDPC payload bits.

The L_{LDPC} information bits received from the LDPC bit extractor per data frame (see clause 10.2.1.3.3) shall be encoded into d LDPC codewords as their input bits. The number of these extracted bits for a particular data frame can be computed as:

RMC data frame: $L_{LDPC} = d\times 18\times M_c - (d-1)\times S_1 - S_{last} - \Delta S_{RMC}$

Normal data frame: $L_{LDPC} = d\times 18\times M_c - (d-1)\times S_1 - S_{last}$.

10.2.1.3.6 Constellation mapper

The constellation mapper combines the binary amplitude labels $\left(u_{b/2-3}^{(j)} \dots u_1^{(j)} u_0^{(j)}\right)$ outputted by the amplitude encoder with LDPC encoded bits to generate 2D QAM constellation points (X,Y). In case of modulation indices above 4, it combines two binary amplitude labels with four LDPC encoded bits. In case of modulation index 1 to 4, it takes no binary amplitude labels, but b LDPC encoded bits, with b the raw bit loading.

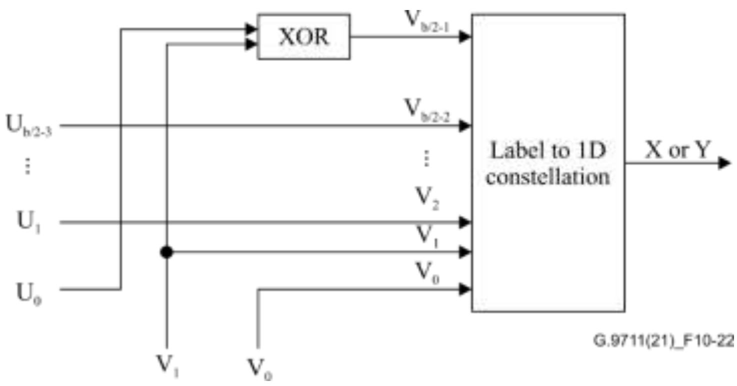


Figure 10-22 – Functional model of the constellation mapper for modulation indices>4

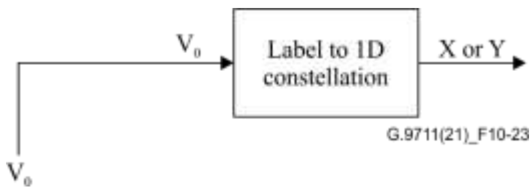


Figure 10-23 – Functional model of the constellation mapper for modulation index=1,2

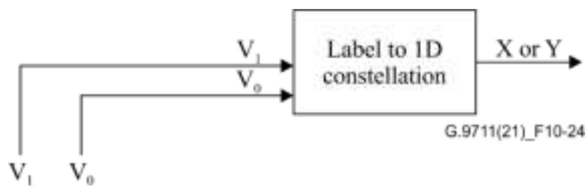


Figure 10-24 – Functional model of the constellation mapper for modulation index=4

For all modulation indices not equal to 3, the constellation mapper generates separately two 1D constellation coordinates for each subcarrier, an X coordinate (for the in-phase or I component) and a Y coordinate (for the quadrature or Q component).

Figure 10-22 shows the functional diagram of the constellation mapper that is applied for a shaped subcarrier with a modulation index>4 to generate one 1D constellation coordinate (X or Y). The next two available LDPC encoded bits from the output stream of the 'LDPC encoder' block are retrieved LSB-first and assigned to $v_1^{(j)}$ and $v_0^{(j)}$ LSB-first. These two bits are combined with the next binary amplitude label $\left(u_{b/2-3}^{(j)} \dots u_1^{(j)} u_0^{(j)}\right)$ and converted to a signed binary 1D label $\left(v_{b/2-1}^{(j)} \dots v_1^{(j)} v_0^{(j)}\right)$. This is done by setting the sign bits as $v_{b/2-1}^{(j)} = XOR(u_0^{(j)}, v_1^{(j)})$. All the other remaining bits are taken equal to a corresponding bit from the binary amplitude label $v_l^{(j)} = u_{l-1}^{(j)}$ for $1 < l \leq b/2 - 2$. For subcarier *k*, the *X* and *Y* coordinates are then calculated from the binary 1D labels $\left(v_{b/2-1}^{(2k)} \dots v_1^{(2k)} v_0^{(2k)}\right)$ and $\left(v_{b/2-1}^{(2k+1)} \dots v_1^{(2k+1)} v_0^{(2k+1)}\right)$ respectively according to the formulae:

$$X = \mathrm{XOR}\left(v_0^{(2k)}, v_1^{(2k)}\right).2 + v_1^{(2k)}.4 + \sum_{l=2}^{b/2-2} \mathrm{XOR}\left(v_l^{(2k)}, \ldots, v_{b/2-1}^{(2k)}\right).2^{l+1} - v_{b/2-1}^{(2k)}.2^{b/2} + 1$$

$$Y = \mathrm{XOR}\left(v_0^{(2k+1)}, v_1^{(2k+1)}\right).2 + v_1^{(2k+1)}.4 + \sum_{l=2}^{b/2-2} \mathrm{XOR}\left(v_l^{(2k+1)}, \ldots, v_{b/2-1}^{(2k+1)}\right).2^{l+1} - v_{b/2-1}^{(2k+1)}.2^{b/2} + 1$$

Here $\bar{v}$ represents NOT v. This is mapping function corresponds to double Gray-coded labelling suited for LDPC coded modulation, defined in a way that is consistent with the labelling of the amplitude levels defined in clause 10.2.1.3.4.4.

For modulation index=1, only 1 LDPC encoded bit is assigned to v_0 (see Figure 10-23). The 1D constellation coordinates X and Y shall be equal and calculated as:

$$X, Y = -v_0.2 + 1$$

For modulation index=2, also only 1 LDPC encoded bit is assigned to v_0 (see Figure 10-24), but this is done first for $v_0^{(X)}$ and then for $v_0^{(Y)}$. The 1D constellation coordinates X and Y are then calculated as:

$$X = -v_0^{(X)}.2 + 1$$

$$Y = -v_0^{(Y)}.2 + 1$$

For modulation index=4, 2 LDPC encoded bit are assigned to v_1 and v_0 LSB-first (see Figure 10-23), and this is done first for ($v_1^{(X)} v_0^{(X)}$) and then for ($v_1^{(Y)} v_0^{(Y)}$). The 1D constellation coordinates *X* and *Y* are then calculated as:

$$X = \mathrm{XOR}\left(v_0^{(X)}, v_1^{(X)}\right).2 - v_1^{(X)}.4 + 1$$

$$Y = \mathrm{XOR}\left(v_0^{(Y)}, v_1^{(Y)}\right).2 - v_1^{(Y)}.4 + 1$$

Table 10-19 illustrates the mapping functions for modulation indices 1, 2 and 4 to 7. The 1D X and Y coordinates shall be combined for all modulation indices≠3 into a 2D constellation point (*X*,*Y*).

Table 10-19 – Example of the binary labels of 1D constellation coordinates for modulation indices 1, 2, and 4 to 7. The binary labels are ordered MSB-first

1D Constellation (*X* or *Y*)	Modulation indices 1 and 2	Modulation index 4	Modulation index 5	Modulation indices 6 and 7
–15				1100
–13				1101
–11				1111
–9				1110
–7			100	1000
–5			101	1001

Table 10-19 – Example of the binary labels of 1D constellation coordinates for modulation indices 1, 2, and 4 to 7. The binary labels are ordered MSB-first

1D Constellation (*X* or *Y*)	Modulation indices 1 and 2	Modulation index 4	Modulation index 5	Modulation indices 6 and 7
–3		11	111	1011
–1	1	10	110	1010
1	0	00	000	0000
3		01	001	0001
5			011	0011
7			010	0010
9				0100
11				0101
13				0111
15				0110

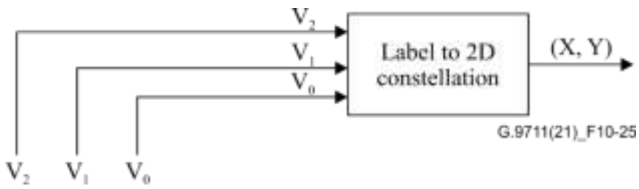


Figure 10-25 – Functional model of the constellation mapper for modulation index=3

For modulation index 3, the constellation mapper directly generates a 2D constellation point (*X*,*Y*).

There are no binary amplitude label bits. Instead, three LDPC encoded bits are assigned to v_2, v_1 and v_0 LSB-first (see Figure 10-25). The binary label $(v_2 v_1 v_0)$ is used to generate a 2D constellation point $X+iY$ according to Table 10-20.

Table 10-20 – Mapping of the binary labels onto 2D constellation points for modulation index=3. The binary labels are ordered MSB-first

2D Constellation (*X*+*i Y*)	Binary label
1	000
1+2*i*	001
1-2*i*	010
+3	011
–1	100
–1+2*i*	101
–1-2*i*	110
–3	111

For each subcarrier, the constellation point (*X*, *Y*) is outputted.

For each subcarrier of the MEDLEY set with modulation index = 0 (monitored tones, pilot tones, and sub-carrier with g_i=0, see Table 10-22), no bits shall be extracted from the data frame. Instead, for each of those subcarriers, the encoder shall extract 2 bits $v_0^{(Y)}$ and $v_0^{(X)}$ from the PRBS generator defined in Clause 10.2.1.5, where the first bit extracted shall be $v_0^{(Y)}$. For the pilot tone subcarrier(s), the bits extracted from the PRBS generator shall be overwritten by bits 00 (i.e., the two bits from the PRBS generator are effectively ignored). The 1D constellation coordinates X and Y are then calculated as:

$$X = -v_0^{(X)}.2 + 1$$

$$Y = -v_0^{(Y)}.2 + 1$$

NOTE – The mapping of two consecutive bits of the PRBS has been chosen such that in monitored tones it maps on the same constellation coordinates (X,Y) for data symbols with TCM (first bit is v_0 bit), for data symbols with PCS-LCM (first bit is $\boldsymbol{v_0^{(Y)}}$) and for RRC symbols.

For subcarriers that are not in the MEDLEY set (modulation index = 0 by definition), no bits shall be extracted from the encoded data buffer and no bits shall be extracted from the PRBS generator. Instead, in the downstream the constellation mapper may select a vendor discretionary (X, Y) point (which may change from symbol to symbol, and which does not necessarily coincide with any of the constellation points defined in this Recommendation), and in upstream the constellation mapper shall select the (X, Y) = (0, 0) point.

10.2.1.4 Constellation scaling

Constellation points shall be scaled to normalize their average power, to achieve a frequency-dependent transmit PSD, and to adjust the transmit power of each individual subcarrier.

For subcarriers in the MEDLEY set, each constellation point (X_i, Y_i), corresponding to the complex value $X_i + jY_i$ at the output of the constellation mapper, shall be scaled by the power-normalization factor χ_i, the gain adjuster g_i, and a frequency-domain spectrum shaping coefficient tss_i. After scaling each constellation point is a complex number Z_i, defined as:

$$Z_i = g_i \times tss_i \times \chi_i \times (X_i + jY_i)$$

NOTE – The above scaling components are for description purposes and independent of the actual implementation. For example, a vendor may collapse g_i, tss_i and χ_i into one transmit multiplier in the transceiver implementation.

For non-MEDLEY subcarriers from the SUPPORTEDCARRIERS set, if used, the same scaling rules shall be applied, while the constellation points are generated as defined in clause 10.2.1.2.3.1 for TCM and 10.2.1.3.6 for PCS-LCM.

10.2.1.4.1 Power normalization

For subcarriers in the MEDLEY set, the values (X, Y) shall be scaled such that all constellations, regardless of size, have the same average power. The required scaling χ_i, is a function only of the constellation size (b_i) for TCM and of the modulation index (m_i) for PCS-LCM.

For PCS-LCM, the inverse of the value of $\chi(m_i)$ normalized by $\chi(m_i=2)$ shall be as defined in Table 10-21.

Table 10-21 – Inverse of $\chi(m_i)$ normalized by $\chi(m_i=2)$ for PCS-LCM constellations

mi	$\chi(m_i=2)/\chi(m_i)$
0	1.0000
1	1.0000
2	1.0000
3	1.5811
4	2.2361
5	3.1099
6	4.2113
7	5.8744
8	8.2045
9	11.5972
10	16.4394
11	23.2159
12	32.8940
13	46.4427
14	65.7955
15	92.8907

For non-MEDLEY subcarriers from the SUPPORTEDCARRIERS set, if used, the same average power or lower shall apply.

10.2.1.4.2 Gain adjuster

The gain adjuster g_i is intended for adjustment of the transmit power of each subcarrier, which may be used for PSD adjustments, to adjust the signal-to-noise ratio (SNR) margin for some or all subcarriers, or turn the subcarrier off to prevent unnecessary crosstalk.

The g_i values in dB shall be defined as the $20 \times \log10(g_i)$. The values of g_i for all MEDLEY subcarriers shall be assigned during the initialization, as described in clause 12.3.3 and stored in the bits-and-gains table (b_i and g_i values for TCM, see clause 10.2.1.2.1, or m_i and g_i values for PCS-LCM, see clause 10.2.1.3.2).

The g_i settings (in the bits-and-gains table) shall comply with the following requirements:

– If $b_i > 0$ (with TCM) or $m_i > 0$ (with PCS-LCM), then g_i shall be one (linear scale) in the downstream direction and [−30, 0] (dB) range in the upstream direction.

– If $b_i = 0$ (with TCM) or $m_i = 0$ (with PCS-LCM), then g_i shall be either equal to zero (linear scale) or in the same range as for $b_i > 0$ or $m_i > 0$, respectively.

– During the showtime, the upstream g_i values may also be updated via an OLR procedure described in clause 11.2.2.5. This may result in different g_i values in NOI_{PSF}, the DOI_{PSF} and the NOI_{NPSF}.

For subcarriers not in the MEDLEY set, the valid range of g_i is the same as for subcarriers in MEDLEY set (see Table 10-22, clause 10.2.1.4.4).

10.2.1.4.3 Frequency-domain transmit spectrum shaping (tss_i)

The PSD shaping mechanism, both in the upstream and the downstream is based on tss_i coefficients. Shaping by tss_i shall be in addition to any other shaping introduced by time-domain filters (if used).

The tss_i are intended for frequency-domain spectrum shaping, both upstream and downstream. The tss_i values are vendor discretionary and shall be in the range between zero and one. Smaller values of tss_i provide power attenuation and the value $tss_i = 0$ corresponds to no power transmitted on the particular subcarrier. If no frequency-domain spectrum shaping is applied, the tss_i values shall be equal to one for all subcarriers.

In the downstream direction, the transmitter of the MTU-O shall set the tss_i values such that, prior to the gain adjustment (i.e., assuming g_i =1) and prior to precoding (i.e., assuming the precoder is bypassed), the PSD of the transmit signal as measured in the termination impedance at the U reference point shall not deviate from the value of CDPSDds by more than 1 dB from the start of early stages of channel discovery phase (O-P-CHANNEL-DISCOVERY 1-1) until the start of O-P-VECTOR 2. The PSD shaping, including the PSD ceiling by MAXMASKds to generate the V2PSDds, shall be done through the tss_i. In downstream direction, the same tss_i values shall be used in NOI_{PSF}, DOI and NOI_{NPSF}.

In the upstream direction, the transmitter of the MTU-R, shall set the tss_i values such that, prior to the gain adjustment (i.e., assuming g_i =1), the PSD of the transmit signal as measured in the termination impedance at the U reference point, in the early stages of channel discovery phase shall not deviate from the value of STARTPSDus by more than 1 dB; in the later stages of channel discovery phase (R-P-CHANNEL DISCOVERY 2) until the end of channel discovery phase, shall not deviate from the value of CDPSDus by more than 1 dB; and in the analysis and exchange phase, shall not deviate from the value of MREFPSDus by more than 1dB. The PSD shaping to generate the MREFPSDus based on the request from the MTU-O shall be done through the tss_i.

The values of tss_i in the upstream direction may be different in PSF and NPSF; the PSD of the transmit signal in NPSF, as measured in the termination impedance at the U reference point, shall not deviate from the corresponding values of CDPSD_NPus, CDPSD_NP1us, CDPSD_NP2us (see Table 12-45) by more than 1dB; and in the analysis and exchange phase, shall not deviate from the value of MREFPSD_NPus by more than 1dB.

The tss_i settings shall take into consideration any additional spectrum shaping included in the transmission path between the output of the modulator and U reference point.

10.2.1.4.4 Summary of the subcarrier modulation and constellation point scaling

Table 10-22 summarizes the subcarrier modulation and constellation point scaling requirements for initialization and during showtime for the subcarriers belonging to a SUPPORTEDCARRIERS set. Table 10-22 is valid for all symbol types. In case of P2P operation, SUPPORTEDCARRIERS are all subcarriers of the SUPPORTEDCARRIERSG set.

Table 10-22 – Modulation and constellation point scaling of subcarriers belonging to the SUPPORTEDCARRIERS set during initialization and showtime

Phase	Subcarrier index (i)		Z_i
Initialization	Channel discovery (clause 12.3.3)	$i \notin$ FDXMASK	$tss_i \times (X_i + jY_i)$
		$i \in$ FDXMASK	0
	Channel analysis and exchange (clause 12.3.4)	$i \in$ MEDLEY and $i \notin$ TONEMASK_NPus and $i \notin$ FDXMASK (Note 2)	$tss_i \times (X_i + jY_i)$

Table 10-22 – Modulation and constellation point scaling of subcarriers belonging to the SUPPORTEDCARRIERS set during initialization and showtime

Phase	Subcarrier index (*i*)		Z_i
		$i \in$MEDLEY and either $i \in$TONEMASK_NPus or $i \in$FDXMASK (Note 2)	0
		$i \notin$MEDLEY	0
Showtime	$i \in$MEDLEY	Data/RRC and RMC subcarriers (b_i or $m_i > 0$, $g_i > 0$)	$g_i \times tss_i \times \chi_i \times (X_i + jY_i)$
		Monitored tones (b_i or $m_i = 0$, $g_i > 0$, modulated by 4-QAM)	$g_i \times tss_i \times \chi_i(b = 2) \times (X_i + Y_i)$
		Pilot tones (b_i or $m_i = 0$, $g_i > 0$, modulated by 4-QAM)	$g_i \times tss_i \times \chi_i(b = 2) \times (X_i + Y_i)$
		Others with b_i or $m_i = 0$, $g_i = 0$ (including TONEMASK_NPus and FDXMASK, Note 2)	0
	$i \notin$MEDLEY	$i \in$SUPPORTEDCARRIERS, and $i \in$BLACKOUT	0
		$i \in$ SUPPORTEDCARRIERS, and $i \notin$BLACKOUT	Downstream: Vendor discretionary (Note 1) Upstream: 0
		i$\notin$ SUPPORTEDCARRIERS	0
NOTE 1 – Constellations for these subcarriers are defined as in clause 10.2.1.2.3 for TCM and 10.2.1.3.6 for PCS-LCM. The g_i values on these subcarriers shall be one (on linear scale) and the valid range for vendor discretionary tss_i values shall be limited by the MREFPSDds. NOTE 2 – TONEMASK_NPus condition applies to upstream only and has to be ignored for the downstream.			

For subcarriers that are outside of the SUPPORTEDCARRIERS set, the following rules shall apply.

In P2P mode, the constellation point scaling for subcarriers outside the SUPPORTEDCARRIERS set shall be Z_i=0 for all symbol types.

In P2MP mode, the constellation point scaling for sync symbols is defined in clause 10.2.2.1.

In P2MP mode, for all other symbol types, the constellation point scaling shall be as following:

1) For all upstream subcarriers outside the SUPPORTEDCARRIERSus it shall be Z_i=0;

2) For all downstream subcarriers that belong to the SUPPORTEDCARRIERSds set of another paths of the P2MP group, it shall be Z_i=0. Assigning Z_i=0 to those downstream subcarriers results that only one path of the P2MP group determines the actual constellation on these subcarriers inside its corresponding SUPPORTEDCARRIERSds set (see clause 10.1.2).

3) For all downstream subcarriers belonging to none of the SUPPORTEDCARRIERSds sets of all paths of the P2MP group but still belonging to the SUPPORTEDCARRIERSGds set, the Z_i values are vendor discretionary, however only one path is allowed to transmit a

vendor discretionary Z_i value that is different from 0. The subcarriers assigned vendor discretionary Z_i values shall use constellations defined as in clause 10.2.1.2.3 for TCM and 10.2.1.3.6 for PCS-LCM, with a g_i values equal to one (on linear scale) and the valid range for tss_i values limited by the CDPSDds during the Channel Discovery phase and limited by the MREFPSDds during Channel Analysis and Exchange phase and during showtime.

4) For all downstream subcarriers outside the SUPPORTEDCARRIERSGds set it shall be Z_i =0.

10.2.1.5 PRBS generator for unloaded subcarriers

Unloaded subcarriers (b_i=0, or m_i=0) of the MEDLEY set are modulated with 4-QAM constellation carrying bits taken from the PRBS generator defined below.

The output bits d_n of the PRBS generator shall be defined by:

$$d_n = 1 \text{ for } n = 1 \text{ to } n = 23 \text{ and}$$
$$d_n = d_{n-18} \oplus d_{n-23} \text{ for } n > 23.$$

The PRBS generator shall be restarted at the symbol with index 0 of the first logical frame of each superframe. The index n is incremented after each bit extraction from the PRBS generator. Upon the restart of the PRBS, d_1 shall be the first bit extracted, followed by d_2, d_3, etc. For each symbol position of the NOI and DOI interval except the positions in the *TA* interval, the sync symbol position, and symbol positions outside of *TBUDGET*, the number of bits extracted from the PRBS generator shall be twice the number of subcarriers in the MEDLEY set with b_i=0 or m_i=0 that would be needed if the symbol position contains a data symbol or an RMC symbol with the respective bit-loading table. No bits shall be extracted from the PRBS generator during sync symbols (see clause 10.2.2.1).

10.2.1.6 Quiet symbol encoding

For all subcarriers from the SUPPORTEDCARRIERS set of a quiet symbol in both the downstream and the upstream, the symbol encoder shall generate a constellation point Z_i (see clause 10.1) equal to zero (i.e., X_i = 0, Y_i = 0).

In the downstream, regardless of whether or not the precoding is used, the modulator input Z_i' (see Figure 10-1) shall be set to zero for all subcarriers of the SUPPORTEDCARRIERS set.

Transmission of downstream and upstream quiet symbols over a particular link results in zero transmit power at the U-O and U-R reference points, respectively, on all subcarriers of the SUPPORTEDCARRIERS set associated with this link.

NOTE – Transmission of a quiet symbol in P2P mode results in zero transmit power at the corresponding U reference points. In P2MP mode, zero transmit power at U reference point is established on a particular symbol position by transmission quiet symbols on all links of the P2MP group.

During transmission of quiet symbols, power consumption in the analogue front end should be minimized.

10.2.1.7 Idle symbol encoding

Idle quiet symbol encoder operates over all subcarriers that belong to the SUPPORTEDCARRIERS set and the Band 0 only, while Z_i' = 0 zero power is applied to all subcarriers that belongs to the SUPPORTEDCARRIERS set and the Band 1. Idel-idle symbol encoder operates over all subcarriers of the SUPPORTEDCARRIERS set (i.e., both Band 0 and Band 1).

For all applicable subcarriers of an idle_quiet or an idle_idle symbol in both the downstream and upstream, the symbol encoder shall generate a constellation point Z_i equal to zero (i.e., X_i = 0, Y_i = 0).

If precoding is enabled, transmission of an idle or a full-idle symbol in the downstream may result in non-zero power at the U reference point due to adding of FEXT pre-compensation signals conveyed across ε(k,n) reference point (see Figure 10-1).

If precoding is disabled, transmission of idle_quiet or idle_idle symbols in the downstream results in zero power at the U reference point, i.e., as in a quiet symbol period.

In the upstream direction transmission of an idle_quiet or an idle_idle symbol results in a quiet symbol period.

10.2.1.8 RRC symbol encoding

On the 16 RRC subcarriers of the RRC symbol the symbol encoder shall modulate RRC bits using bit loading b_i=2 and 4-QAM modulation with constellation mapping as defined in clause 10.2.1.2.3.2.1 for TCM (if TCM is selected in initialization), and using modulation index m_i=2 and 4-QAM modulation with constellation mapping as defined in clause 10.2.1.3.6 for PCS-LCM (if PCS-LCM is selected in initialization).

The tone-ordering table for RRC symbols shall be the original table *t*. The bit-loading table (for TCM) or modulation index table (for PCS-LCM) for RRC symbols is determined at initialization over the MEDLEY set and shall include 16 RRC subcarriers loaded with b_i, m_i =2 while all other subcarriers are loaded with b_i, m_i =0. The indices of the RRC subcarriers may be modified in showtime.

The bits of the RRC frame shall be loaded on RRC subcarriers uncoded, in sequential order, starting from the LSB of the RRC frame to the MSB of the RRC frame (see Figure 9-7). The first pair of bits (b_1,b_0) extracted from the RRC frame shall be mapped on the first RRC subcarrier using 4-QAM constellations. The second pair of bits (b_1,b_0) extracted from the RRC frame shall be mapped on the second RRC subcarrier using 4-QAM constellation and so on.

For subcarriers of the MEDLEY set with b_i, m_i = 0, no bits shall be extracted from the RRC frame. Instead, for each of those subcarriers, the encoder shall extract b = 2 bits (b_1 b_0) from the PRBS generator defined in clause 10.2.1.5, where the first bit extracted (LSB) shall be b_0, as defined in clause 10.2.1.2.3.1. For the pilot tone subcarrier(s), the bits extracted from the PRBS generator shall be overwritten by bits 00 (i.e., the two bits from the PRBS generator are effectively ignored). The gains g_i applied to the subcarriers of the MEDLEY set with b_i = 0 may be 0 or non-zero, and are determined at initialization.

For subcarriers that are not in the MEDLEY set, no bits shall be extracted from the RRC frame and no bits shall be extracted from the PRBS generator. These subcarriers shall follow the rules defined in Table 10-22 for $i \notin$MEDLEY.

10.2.2 Symbol encoders for sync symbols, initialization symbols and concurrent monitoring symbols

10.2.2.1 Sync symbol encoder

Sync symbols shall be able to carry a probe sequence during initialization and showtime. Each element in the probe sequence shall be from the finite set {−1, 0, 1}. The length and content of a probe sequence are determined by the VCE. They may be different for upstream and downstream. They are communicated to the MTU-R during initialization, and may be updated by request of the VCE during showtime.

The valid length of the probe sequences shall be any multiple of four elements from 4 to 632.

In the P2P mode in the upstream and in both the P2P and P2MP mode in the downstream, a given element of probe sequence shall be modulated on all subcarriers of the SUPPORTEDCARRIERS set during one sync symbol.

The elements with values −1 and 1 of a probe sequence shall be represented by 2-bit constellations as defined in clause 10.2.1.2.3.2.1 (Figure 10-11) using the following encoding:

– elements with value –1 shall be mapped to constellation point labelled 0;

– elements with value 1 shall be mapped to constellation point labelled 3.

The elements with value zero shall be represented by subcarriers transmitting $Z_i = 0$.

The constellation points on all subcarriers shall be rotated based on the 2-bit number provided by the quadrant scrambler described in clause 10.2.2.5. The scrambler shall be used in reset mode; it shall be initiated at the beginning of each sync symbol with an 11-bit initialization seed. The seed for each link is determined by the VCE and is communicated to the MTU-R during ITU-T G.994.1 handshake. Cyclic extension of sync symbols shall be the same as applied for data symbols.

All probe sequences transmitted in a particular direction shall start at the same sync symbol position in all lines of the vectored group. The length of probe sequences is denoted $Nprobe_{us}$ and $Nprobe_{ds}$ for upstream and downstream, respectively.

In both the P2P and P2MP mode, in both upstream and downstream, a given element of probe sequence shall be modulated on all subcarriers of the SUPPORTEDCARRIERSG set of a sync symbol. The χ_i , g_i and tss_i values shall be applied to the subcarrier i of the sync symbol in the same way as to the same subcarrier of data symbols of the same sub-frame (see clause 10.2.1.4). The χ_i is equal to the value defined for a 4-QAM constellation. The particular settings for g_i and tss_i are the following.

1) For subcarriers of the SUPPORTEDCARRIERS set of a path that is in the Channel Discovery phase of the initialization, the g_i values shall be one (linear scale) in both upstream and downstream and the tss_i values shall be identical to the one of the initialization symbols in the same sub-frame.

2) For MEDLEY subcarriers of the SUPPORTEDCARRIERS set of a path that is in the Channel Analysis and exchange phase of the initialization or in showtime, both in upstream and downstream, the g_i and tss_i values shall be identical, respectively, to the g_i and tss_i values of the data symbols of the same sub-frame, except for the upstream g_i values, if modified by an SSA procedure (see clause 11.2.2.24 and 13.2.1.6). For all subcarriers outside of the MEDLEY set (but within the SUPPORTEDCARRIERS set), in both upstream and downstream, the values of g_i and of tss_i shall be as defined in Table 10-22 (for $i \notin$MEDLEY), except in the downstream direction in the case of P2MP operation. In the downstream direction, in the case of P2MP operation, those subcarriers shall use:

   – tss_i values that result in the transmit PSD being equal to the MREFPSDds (instead of being limited by MREFPSDds), if they are outside the BLACKOUT set;

   – Z_i=0, if they are inside the BLACKOUT set.

3) For the upstream subcarriers that are outside of the SUPPORTEDCARRIERSus set but are within the SUPPORTEDCARRIERSG set, during the Channel Discovery Phase, the MTU-R shall set the values of g_i to 1 (on linear scale) and the values of tss_i shall be those determined by the transmit PSD (STARTPSDus, CDPSDus and STARTPSD_NPus, CDPSD_NPus, CDPSD_NPus1, CDPSD_NPus2, respectively), for the PSF and the NPSF, respectively. During the Channel Analysis and Exchange phase and in showtime, on those subcarriers that are also inside the MEDLEYGus set, the MTU-R shall set the values of g_i to 1 (on linear scale) and the values of tss_i shall be those determined by the MREFPSDus and MREFPSD_NPus for the PSF and the NPSF, respectively. However, the g_i's of the subcarriers belonging to the FDXMASKus and TONEMASK_NPus shall be set to 0. For the subcarriers that are outside of MEDLEYGus set, Z_i=0 shall be transmitted. The SSA procedure can modify the g_i's of the subcarriers of the MEDLEYG set (see clause 11.2.2.24).

4) For the downstream subcarriers that do not belong to the SUPPORTEDCARRIERSds set of any path but are within the SUPPORTEDCARRIERGds set, during the Channel Discovery phase, Channel Analysis and Exchange phase, and in showtime, the values of g_i shall be set to 1 (on linear scale). During the Channel Discovery phase, the values of tss_i can be vendor discretionary within the valid range defined by the STARTPSDds for the PSF and the NPSF, respectively. During the Channel Analysis and Exchange phase, and in showtime the tss_i values shall be chosen such that the transmit PSD of each of those subcarriers shall be equal to the corresponding MREFPSDds (see clause 10.1.2). The subcarriers assigned vendor discretionary Z_i values shall use 2-bit constellations defined as in clause 10.2.1.2.3 for TCM and 10.2.1.3.6 for PCS-LCM.

NOTE 1 – The applied vendor discretionary values of the tss_i can be used for crosstalk channel estimation over the currently unused subcarriers and also for assisting the MTU-R receivers to tune their AFEs.

5) On all subcarriers, in both upstream and downstream, that are outside of the SUPPORTEDCARRIERSG set, or belong to BLACKOUT subcarriers, or are masked by either the FDXMASK or TONEMASK_NPus (except if modified by SSA procedure), Z_i=0 shall be transmitted.

NOTE 2 – For P2MP operation, as a consequence of this clause and clause 10.1.2, the PSD on the sync symbol is equal to MREFPSDds for each subcarrier of the SUPPORTEDCARRIERSG set, for all the links of the P2MP group.

NOTE 3 – The MIB configuration of all links of a P2MP group allows the MTU-O to generate sync symbols with identical constellation scaling per subcarrier for all links of that P2MP group (see clause 7.3.1).

10.2.2.2 Initialization symbol encoder

The following types of initialization symbols are defined:

– Quiet symbol: see definition in clause 3.2.36;

– SOC symbol (used for transmission symbols containing SOC IDLE or SOC messages, or

O-P-SYNCHRO signals as defined in clause 12.3.3.3).

The χ_i, g_i and tss_i values shall be applied to the initialization symbols in the same way as they are applied to data symbols (see clause 10.3.4). The g_i values are one (linear scale) in both upstream and downstream (the PSD shaping of initialization symbols is determined by the tss_i). The details of subcarrier constellation point scaling for initialization symbols are defined in Table 10-22.

10.2.2.2.1 Bit mapping of SOC symbols

Two types of SOC bit mapping are defined:

- Robust mapping;
- Normal mapping.

Robust SOC bit mapping of an SOC byte [b7, b6, b5, b4, b3, b2, b1, b0], where b7 is the MSB and b0 is the LSB, is presented in Table 10-23. With robust bit mapping, one SOC byte is transmitted per symbol.

Table 10-23 – Robust SOC bit mapping

Sub-carrier index	Constellation point
Even 1, 11, 21, …, 10*n*+1, … 3, 13, 23, …, 10*n*+3, … 5, 15, 25, …, 10*n*+5, … 7, 17, 27, …, 10*n*+7, … 9, 19, 29, …, 10*n*+9, …	00 SOC message bits [b1, b0] SOC message bits [b3, b2] SOC message bits [b5, b4] SOC message bits [b7, b6] 00

Normal SOC bit mapping is presented in Table 10-24. With normal bit mapping, $N = 2p$ SOC bytes are transmitted per symbol, where $p_{us} = 3, 4, \ldots, 36$ for the upstream and $p_{ds} = 1, 2, \ldots, 12$ for the downstream. The particular value of the SOC tone repetition rate (p_{us} for upstream and p_{ds} for downstream) is set during initialization, see clause 12.3.3.2.10 and clause 12.3.3.2.14, respectively.

Table 10-24 – Normal SOC bit mapping

Sub-carrier index (Note)	2-bit constellation point
5, 10, 15,…, 5*n*, …	00
1, *M*+1, 2*M*+1, ..., *nM* + 1, ...	SOC message bits [b_1, b_0]
2, *M*+2, 2*M*+2, ..., *nM* + 2, ...	SOC message bits [b_3, b_2]
…	…
10*k*+*m*, *M*+10*k*+*m*, 2*M*+10*k*+*m*, …, *nM*+10*k*+*m*, … with $k = 0, 1, 2, \ldots, \frac{M}{10}-1$ and $m = 1, 2, 3, 4, 6, 7, 8, 9$	SOC message bits [$b_{16k+f(m)+1}$, $b_{16k+f(m)}$], where $f(m)=\begin{cases}2m-2 & \text{if } m=1,2,3,4\\ 2m-4 & \text{if } m=6,7,8,9\end{cases}$
…	…
M–1, 2*M*–1, 3*M*–1, …, *nM*–1, …	SOC message bits
NOTE – In this table, a notation $M = 10p$ is used.	

10.2.2.2.2 Identification sequence (IDS) modulation

The downstream SOC symbols may be modulated with an IDS. If an SOC symbol is modulated by an IDS, and if the IDS bit modulating the symbol is equal to 1, the constellation points of all subcarriers in this symbol shall be rotated by 180 degrees (inverted). If an SOC symbol is modulated by an IDS, and if the IDS bit modulating the symbol is equal to 0, the constellation points of all subcarriers in this symbol shall be rotated by 0 degrees (no rotation). An IDS is a binary sequence whose length and content is determined by the VCE for every joining line and communicated to the MTU-R during the ITU-T G.994.1 handshake (see clause 12.3.2.1). When applied, the IDS shall start or restart at the symbol position 0 of the first downstream logical frame that follows every O-P-SYNCHRO signal (except for O-P-SYNCHRO 1-1, for which it starts at the beginning of the first downstream logical frame of the second superframe after transmission of O-P-SYNCHRO 1-1). During an initialization stage with IDS active, IDS shall be applied over all downstream SOC symbols located at or after the IDS was started or restarted.

The first bit of the IDS shall be applied to the first SOC symbol located at or after the position where the IDS is started or restarted, the second bit to the next SOC symbol, etc., until the end of the IDS. When the last bit of the IDS is applied, the next bit shall be again the first bit of the IDS. After starting or restarting, the IDS shall be repeated periodically until the end of the following O-P-SYNCHRO signal. The last repetition of the IDS may be incomplete.

NOTE – Sync symbols and quiet symbols are not modulated by IDS. The IDS is not advanced on sync symbol and quiet symbol positions.

10.2.2.2.3 SOC symbol repetition

To increase the robustness of the downstream SOC, each downstream SOC symbol, except those contained in O-P-SYNCHRO signals, may be repeated to form a group of consecutive identical SOC symbols. The SOC symbols shall be repeated before the IDS is applied to them. The number of repetitions in a group is selected during the ITU-T G.994.1 handshake phase. When SOC symbol repetition is applied, the SOC symbol repetition shall be started or restarted at the same time as the IDS is started or restarted, respectively. When the SOC symbol repetition is started or restarted, the first transmitted SOC symbol shall be the first element of the group of identical symbols. The last group of identical symbols before an O-P-SYNCHRO signal may be incomplete.

10.2.2.3 Concurrent monitoring symbol encoder

DCM symbols shall carry a monitoring sequence during showtime. Each element in the monitoring sequence shall be from the finite set {−1, 0, 1}. The length and content of a monitoring sequence are determined by the DRA. They may be different for upstream and downstream. They are communicated to the MTU-R during initialization and are updated in showtime by request of the DRA.

In the P2P mode in the upstream and in both the P2P and P2MP mode in the downstream, a given element of monitoring sequence shall be modulated on all DTFO subcarriers (see clause 10.7.2) in the corresponding DCM symbol.

In the P2MP mode in the upstream, the MTU-R shall modulate a given element of monitoring sequence on all DTFO subcarriers assigned to this particular MTU-R in the corresponding DCM symbol.

The elements with values −1 and 1 of a monitoring sequence shall be represented by 2-bit constellations as defined in clause 10.2.1.2.3.2.1 (Figure 10-11) using the following encoding:

– elements with value –1 shall be mapped to constellation point labelled 0;

– elements with value 1 shall be mapped to constellation point labelled 3.

The elements with value zero shall be represented by subcarriers transmitting $Z_i = 0$.

The constellation points on all subcarriers shall be rotated based on the 2-bit number provided by the quadrant scrambler described in clause 10.2.2.5. The scrambler shall be used in reset mode; it shall be initiated at the beginning of each DCM symbol with an 11-bit initialization seed. The seed for each link is identical to the seed used for sync symbols (see clause 10.2.2.1). Cyclic extension of DCM symbols shall be the same as applied for data symbols.

The χ_i, tss_i and g_i values applied to a DCM symbol shall be the same as of a data symbol in Band 1 of the NOI_{PSF}. The details of subcarrier constellation point scaling for data symbols, both within and outside of the MEDLEY set, are defined in Table 10-22.

10.2.2.4 Preamble symbol encoder

The preamble symbols shall be generated as the concurrent monitoring symbols (see clause 10.2.2.3) modulated with the element +1. In NOI, this encoding is applied in Band 1 only. In DOI, this encoding is applied in both Band 0 and Band 1.

The χ_i, tss_i and g_i values applied to a preamble symbol shall be the same as of data symbol (see Table 10-22), respectively, as of a data symbol in Band 1 of the NOI_{PSF} and of a data symbol in Band 0 and Band 1 in DOI. The details of subcarrier constellation point scaling for **data** symbols, both within and outside of the MEDLEY set, are defined in Table 10-22.

10.2.2.5 Quadrant scrambler

The scrambler rotates constellation point of each subcarrier pseudo-randomly, by 0, π/2, π or 3π/2 depending on the value of a 2-bit pseudo-random number. The rotation shall be implemented by transforming the (*X*, *Y*) coordinates of the constellation point as shown in Table 10-25, where *X* and *Y* are the coordinates before scrambling and d_{2n}, d_{2n+1} is a 2-bit number:

Table 10-25 – Pseudo-random transformation

d_{2n}, d_{2n+1}	Angle of rotation	Final coordinates
0 0	0	(*X*, *Y*)
0 1	π/2	(−*Y*, *X*)
1 1	π	(−*X*, −*Y*)
1 0	3π/2	(*Y*, −*X*)

The 2-bit number shown in the first column of Table 10-25 shall be the output of a PRBS bit generator defined by the equation:

$$d_n = d_{n-9} \oplus d_{n-11}$$

The PRBS bit generator is illustrated in Figure 10-26.

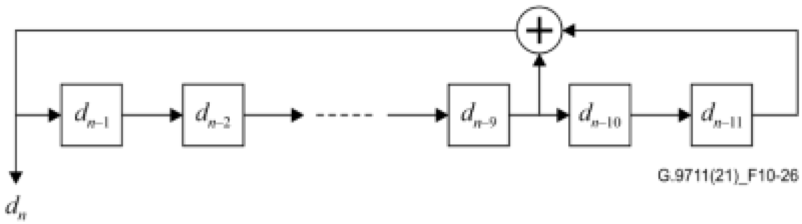


Figure 10-26 – Bit generator

Two bits from the scrambler shall be mapped to each subcarrier, including DC. The two bits corresponding to DC shall be overwritten with 00.

For a modulator that uses an IDFT size = 2*N*, 2*N* bits shall be generated by the scrambler every symbol (b_0 b_1 b_2 ... b_{2N-2} b_{2N-1}) in each transmission direction. The first two bits (b_0 b_1) shall correspond to subcarrier 0, the next two bits (b_2 b_3) to subcarrier 1, etc.; bits (b_{2i} b_{2i+1}) shall correspond to subcarrier *i*. Bits shall be generated for all *N* subcarriers, not just those being used for transmission. Bits generated for subcarriers that are not in use shall be discarded.

At the beginning of operation, all registers of the scrambler shall be set to a certain 11-bit initial value (seed). Two modes of scrambler operation are used: reset mode and free-running mode.

10.2.2.5.1 Reset mode

In the reset mode, the scrambler shall be initialized (reset to the required seed) at the beginning of every symbol period. Therefore, the same 2*N* bits will be generated for each symbol, and each subcarrier will be assigned the same two-bit pseudo-random number for rotation of its constellation point in successive symbols.

10.2.2.5.2 Free-running mode

In the free-running mode, the scrambler shall not be reinitialized at the beginning of each symbol period, but instead shall continue running from one symbol to the next. Practically, this means the scrambler generates 2*N* bits that are allocated to symbol *s*. The next 2*N* bits from the scrambler are then allocated to symbol *s*+1, etc.

In the TDD and TDDZ framing mode, in the downstream direction, the scrambler shall advance during all M_{ds} symbol positions and shall not advance during other symbol positions; in the upstream direction, the scrambler shall advance during all M_{us} symbol positions and shall not advance during other symbol positions.

In the FDXC and FDXZ framing modes, in both upstream and downstream directions, the scrambler shall advance at all $M_{ds}+M_{us}+K$ symbol positions, where K = 0 for FDXC mode and K = 1 for FDXZ mode.

10.3 Precoder (downstream vectoring)

10.3.1 Overview

Figure 10-27a and 10-27b provide an overview of the functional model for the inclusion of downstream FEXT cancellation precoding at the DPU for all transmission lines in the vectored group for a single subcarrier. It is therefore complementary to Figure 10-1 (for P2P operation) and Figure 10-3 (for P2MP operation), which show functions applied to all subcarriers for a single MTU-O. The model shows an array of the downstream symbol encoders (which represent the data, sync, concurrent monitoring, preamble or initialization symbol encoders shown in Figure 10-1) and the modulation by the IDFT functional blocks of the MTU-O paths, with the FEXT cancellation precoder inserted between the symbol encoders and the modulation by the IDFT blocks.

In the functional model for P2P operation (Figure 10-27a), the MTU-O's are numbered 1 to *N*. An MTU-O only comprises a single path. The symbol encoder of this path in each MTU-O provides an input for a single subcarrier to the precoder. The matrix of FEXT cancellation precoders has size $N \times N$, where *N* is the number of transmission lines in the vectored group for P2P operation. The output of each precoder gives an input for a single subcarrier to the IDFT modulator of the corresponding transmission line.

In the functional model for P2MP operation (Figure 10-27b), the MTU-O's are numbered 1 to *N*. The MTU-O labeled *MTU-O-n* has *S(n)* paths, however only the particular path *s(n)* (*with* $1 \le s(n) \le S(n)$) which contains subcarrier *i* is shown. The symbol encoder of this particular path *s(n)* in each MTU-O-n provides a corresponding input for a single subcarrier to the precoder. The total number of paths (over all used subcarriers) in the vectored group of *N* transmission lines is $NP=S(1)+S(2)+\ldots+S(N)$ with $NP \ge N$. However, only *N* of the *NP* paths are actively transmitting on a given subcarrier, and therefore Figure 10-27b shows only *N* paths and shows an *N*x*N* matrix of FEXT cancellation precoders, where *N* is the number of transmission lines in the vectored group for P2MP operation. The output of the precoder corresponding to the path of a particular MTU-O gives an input for a single subcarrier to the IDFT modulator of the corresponding transmission line.

The VCE of the vectored group learns and manages the channel matrix per vectored subcarrier, which reflects the channel characteristics of the managed group of transmission lines.

In the functional model for P2P operation (Figure 10-27a), the channel matrix in the VCE for each vectored subcarrier is of size $N \times N$ where *N* is the number of transmission lines in the vectored group.

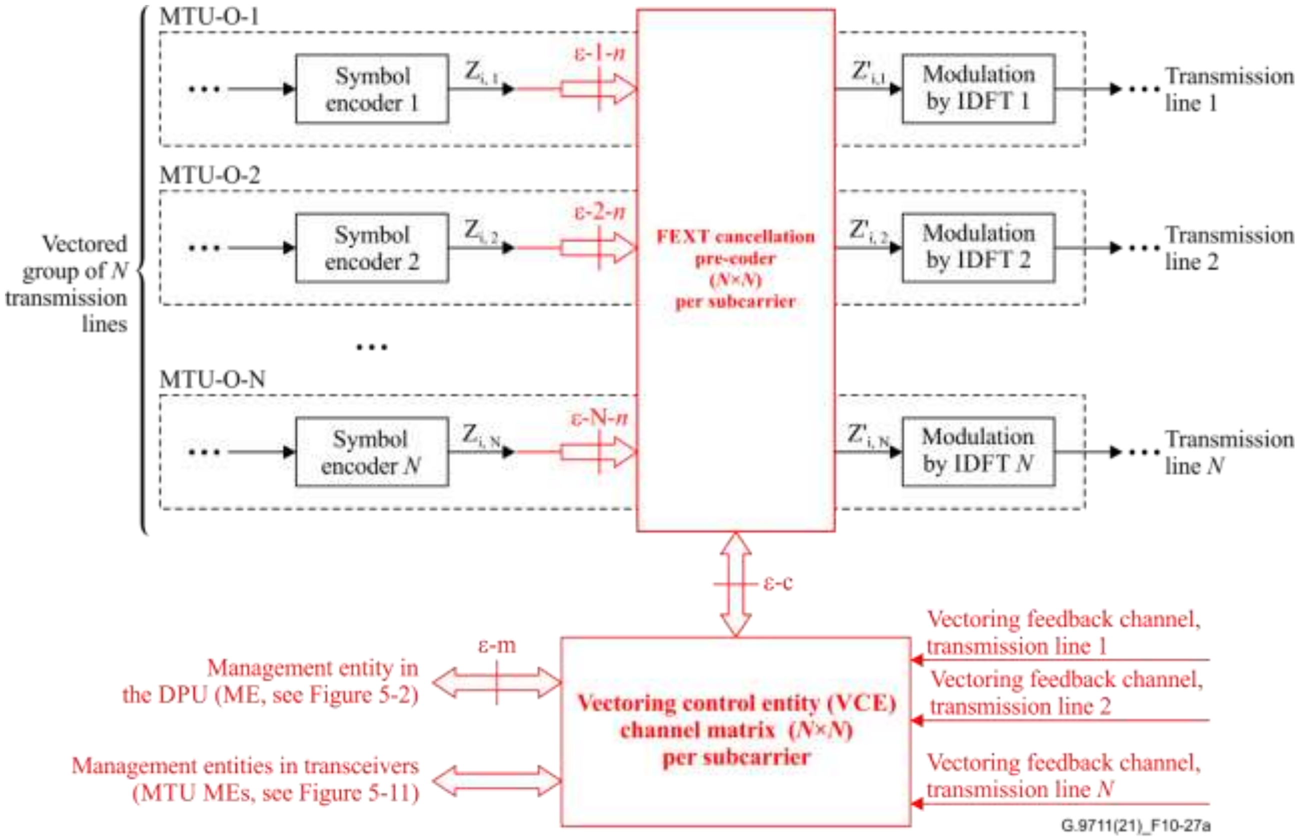
In the functional model for P2MP operation (Figure 10-27b), the channel matrix in the VCE for each vectored subcarrier for a particular path assignment is $(N \times N)$, while for all possible combinations of path assignments required to support DBR, it is of size $(NP \times NP)$, where *NP* is the total number of paths over all subcarriers and also the total number of links in use on the *N* transmission lines in the vectored group.

From the channel matrix, a VCE derives a FEXT precoder matrix, which is used to compensate the FEXT from each transmission line in the vectored group. Knowing the transmit symbols on each disturbing channel, the precoder precompensates the actual transmit symbol such that at the far-end receiver input, the crosstalk is significantly reduced. As a part of the channel matrix or separately, the VCE shall set the precoder such that the precoder output signals (Z_i' values shown in Figure 10-27a and 10-27b) shall not lead at the U reference point to violation of the PSD limit corresponding with the tss_i (see clause 10.2.1.4.3).

The channel matrix and the resulting FEXT cancellation precoder matrix are assumed to be entirely managed inside the DPU. An information exchange between the MTU-O and MTU-R is required in each link to learn, track and maintain the channel matrix and associated FEXT cancellation precoder matrix (see vectoring feedback channel definition in clause 10.3.2 and initialization in clause 12.3). The actual algorithms for processing this information to obtain the channel matrix and to generate the FEXT cancellation precoder are vendor discretionary. Depending on the implementation, it may be possible for the VCE to directly determine the FEXT cancellation precoder matrix and only have an implicit learning of the channel matrix.

NOTE 1 – In P2MP operation, only an ($N \times N$) subset of the full channel matrix ($NP \times NP$) is used to derive the FEXT precoder matrix ($N \times N$) for a particular subcarrier. In P2MP operation, *NP* is typically larger than *N* ($NP=N$ only in the case when in each P2MP group only one MTU-R is active). Therefore, typically, not all elements of the channel matrix need to be estimated by the VCE for every sub-carrier.

NOTE 2 – In some implementations, in P2MP operation, the VCE may maintain a channel matrix that is *N*x*N*, assuming updating this matrix every time when the P2MPOB of a path is updated by the DBR. This update, however, usually increases the time of the DBR procedure (see clause 13.5.2.2).



NOTE – All functionalities in this figure apply to a single subcarrier with index i

Figure 10-27a – Vectored group functional model of PMD sub-layer for a single subcarrier for P2P operation using *N*×*N* precoder for downstream vectoring

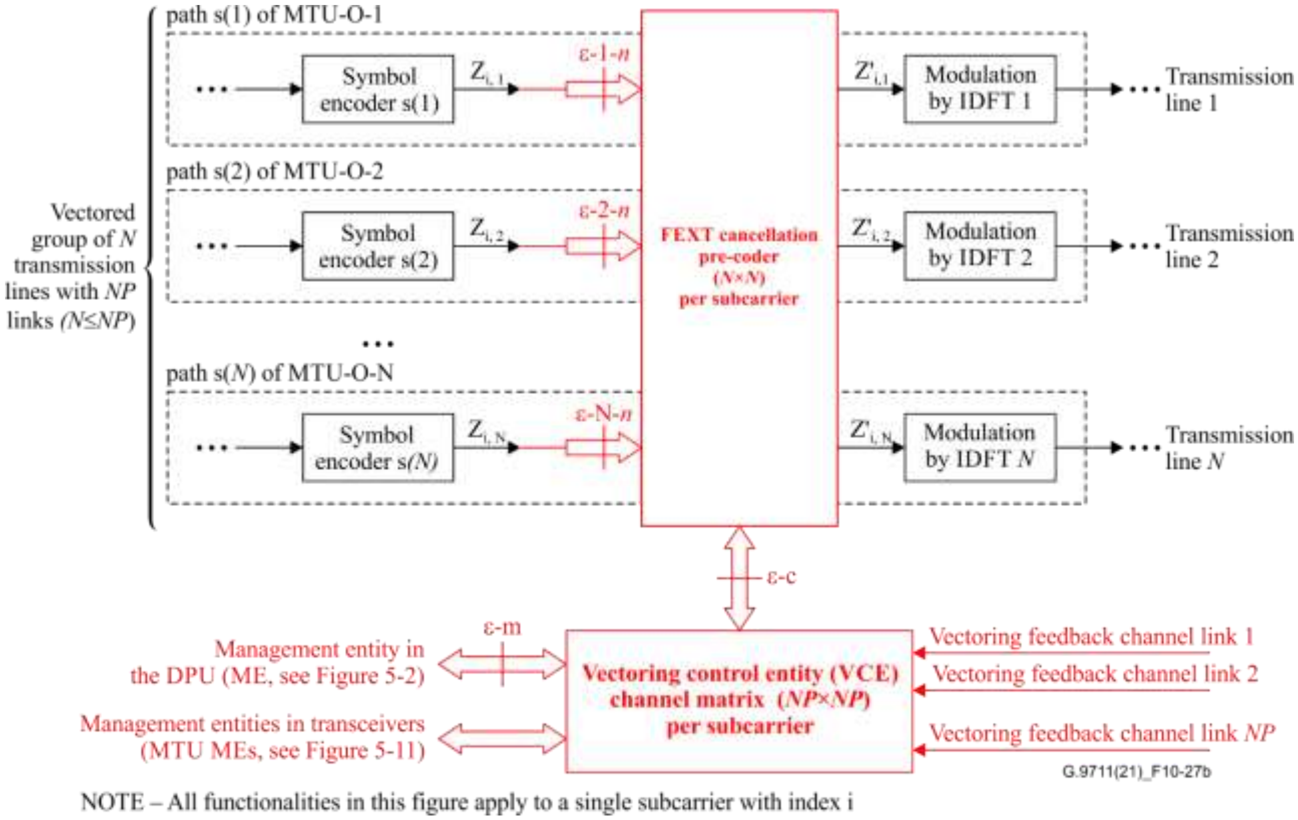


Figure 10-27b – Vectored group functional model of PMD sub-layer for a single subcarrier for P2MP operation using *N*×*N* precoder and *NP*×*NP* channel matrix for downstream vectoring

An MTU-O supporting P2P operation shall support FEXT cancellation precoding, as shown in Figure 10-1 and Figure 10-27a. An MTU-O supporting P2MP operation shall support FEXT cancellation precoding, as shown in Figure 10-3 and Figure 10-27b. At its own discretion, the VCE may apply to sync symbols precoding coefficients that are different (including any diagonal precoder matrix) from those used for other symbol positions.

NOTE 1 – Symbol encoder in Figure 10-27a and 10-27b represents the data, sync, concurrent monitoring, preamble or initialization symbol encoder shown in Figure 10-1.

NOTE 2 – The VCE may use an identity matrix resulting in non-precoded sync symbols, which may be beneficial in the cases of strong FEXT, vectored P2MP or NEXT cancellation.

10.3.2 Vectoring feedback channel

10.3.2.1 Definition of normalized error sample

The MTU-R converts the received time domain signal into frequency domain samples, resulting in a complex value *Z* for each of the received subcarriers. The subsequent constellation de-mapper associates each of these complex values *Z* with a particular constellation point, represented by a value *C*. Figure 10-28 shows the computation of a normalized error sample *E* for a particular subcarrier in a particular sync symbol. The normalized error sample represents the error between the received complex data sample *Z* normalized to the 4-QAM constellation and the corresponding expected constellation point *C*, referred to the input of the quadrant descrambler. This expected constellation point corresponds to the constellation point obtained after the quadrant scrambler and before the constellation point scaling in the generation of the sync symbol at the MTU-O (see clauses 10.2.2.2 and 10.2.1.4).

For each of the subcarriers, the complex normalized error sample E is defined as $E = Z - C$, where E is the complex error defined as $E = e\_x + j \times e\_y$ with real component e_x and imaginary component e_y, and z is the received normalized data sample defined as $Z = z\_x + j \times z\_y$ with real component z_x and imaginary component z_y , and C is the expected constellation point associated with the received data sample Z, defined as $C = c\_x + j \times c\_y$ with real component c_x and imaginary component c_y (with $c\_x = -1, 0, +1$ and $c\_y = -1, 0, +1$). The gain stage of the receiver shall be independent of the expected value of C.

NOTE – The MTU-R can identify the expected constellation point C for each subcarrier by the element value of the probe sequence modulating the sync symbol, communicated to MTU-R during the initialization (see clause 12.3.3.2.1) or by the probe sequence update command (see clause 11.2.2.15) during the showtime.

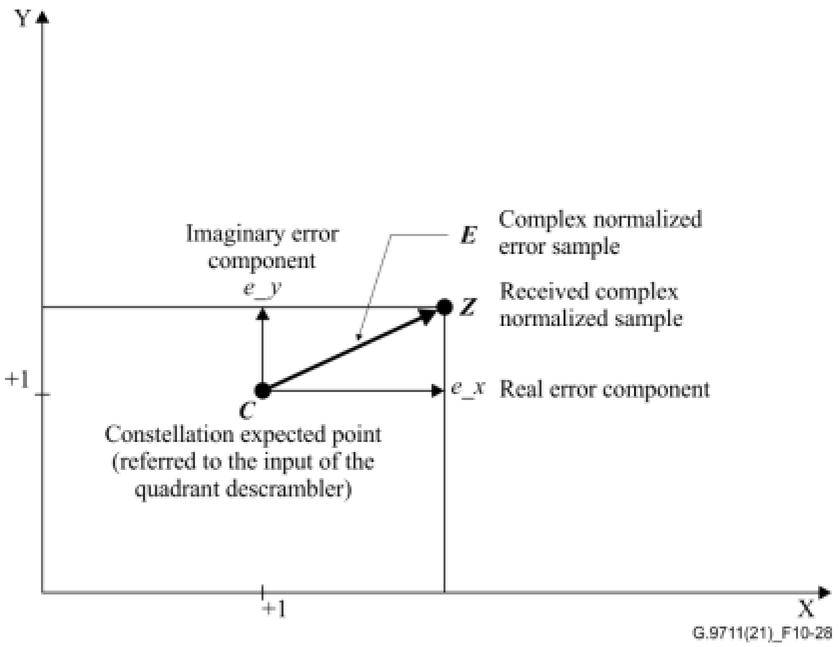


Figure 10-28 – Definition of the normalized error sample *E*

The real and imaginary components of each normalized error sample E shall be clipped and quantized to integer values for the clipped error sample components q_x and q_y respectively, as follows:

$$q\_x = \max\left(-2^{B\_\max}, \min\left(\left\lfloor e\_x \times 2^{N\_\max-1} \right\rfloor, 2^{B\_\max} - 1\right)\right)$$
$$q\_y = \max\left(-2^{B\_\max}, \min\left(\left\lfloor e\_y \times 2^{N\_\max-1} \right\rfloor, 2^{B\_\max} - 1\right)\right)$$

where $Q = q\_x + j \times q\_y$ represents the clipped error sample and N_max represents the MTU-R's maximum quantization depth of normalized error samples and shall be set to 12, and B_max represents the upper bound of the bit index for reporting clipped error sample components q_x and q_y ($B\_max < N\_max + 6$, with B_max configured by the VCE, see Tables 10-26 and 10-27). The parameter B_max is configured by the VCE.

The values of both clipped error sample components q_x and q_y shall be represented using the two's complement representation of (B_max+1) bits. The format of the clipped error sample for reporting over the vectoring feedback channel shall be as defined in clause 10.3.2.3. The particular subcarriers on which clipped error samples shall be reported during the initialization and the showtime shall be configured as described in clause 12.3.3.2.10 and Table 11-43.

10.3.2.2 Definition of DFT output samples

The MTU-R shall support reporting of DFT output samples referred to the U-R reference point (F_k) for sync symbols. The DFT output samples, F'_k, are defined by the functional reference model depicted in Figure 10-29.

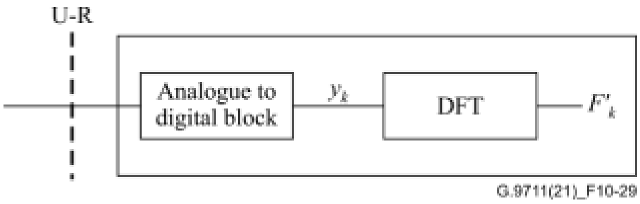


Figure 10-29 – Functional reference model of MTU-R for the definition of DFT output samples over the sync symbol

The analogue-to-digital block converts the analogue signal from the U reference point to a stream of time domain samples, y_n. These time domain samples are transformed to N frequency domain samples, denoted F'_k, by the DFT block implementing the Discrete Fourier Transform (DFT), at a vendor discretionary internal reference point. The same DFT is used during the sync symbols and data symbols. For data symbols, it is followed by frequency domain processing to result in an estimate of the originally transmitted constellation points ($X_i + jY_i$) (see clause 10.2.1.4).

The reported DFT output samples F_k shall be represented as a complex value where the real and imaginary components are calculated by dividing the samples F'_k by the transfer function between the U-R reference point and the DFT output (see Figure 10-29), normalizing to the reference PSD at the U-R reference point, rounding to the nearest integer, and clipping it to a vendor discretionary value.

Any change to the transfer function between the U-R reference point and the DFT output should be compensated by the scaling factor such that the reported DFT output samples remain consistently accurate.

The MTU-R shall compute the reported DFT output samples $F_k = (f\_x+j\times f\_y)\times 2^{B\_M}$ such that the PSD calculated using the following reference equation corresponds with the actual PSD at U-R reference point referenced to the termination impedance of the the metallic wire, see [ITU-T G.9710] Annex P and Annex Q:

$$PSD\left(\frac{dBm}{Hz}\right) = 20 \times log10(|f\_x + j \times f\_y| \times 2^{B\_M - L_w + 1}) - 140\ dBm/Hz,$$

where *f_x and f_y* are the real and imaginary part of the mantissa and *B_M* is the exponent of the reported DFT output sample, and the -140 dBm/Hz is the reference PSD at the U-R reference point referenced to the termination impedance of the the metallic wire, see [ITU-T G.9710] Annex P and Annex Q, based on the profile (see Tables P.1 and Q.1) selected during the ITU-T G.994.1 phase of initialization.

NOTE – The maximum PSD value that can be represented is achieved for $f\_x=-2^{Lw-1}$, $f\_y=0$, $B\_M=15$ and is –49.7 dBm/Hz. The minimum value is achieved for $f\_x=1$, $f\_y=0$, $B\_M=0$, and depends on the selected *Lw* value: for *Lw*=10, *Lw*=6, and *Lw*=4, the minimum values are -194 dBm/Hz, -170 dBm/Hz, and -158 dBm/Hz, respectively.

10.3.2.3 Reporting of vectoring feedback (VF) samples

The MTU-R shall send vectoring feedback (VF) samples (either clipped error samples as defined in clause 10.3.2.1 or DFT output samples as defined in clause 10.3.2.2) to the MTU-O through the vectoring feedback channel established between the MTU-O and the MTU-R in each link operating over a transmission line of the vectored group, as defined in Table 11-46 (vectoring feedback responses) in clause 11.2.2.14 for showtime or in clause 12.3.3.2.12 (R-VECTOR-FEEDBACK message) during initialization. The MTU-O conveys the received VF samples to the VCE of the vectored group.

The MTU-R shall support reporting of the DFT output samples on all subcarriers in the SUPPORTEDCARRIERSGds set.

The MTU-R shall report a special value for a subcarrier if it is not able to measure the DFT output sample for that subcarrier.

10.3.2.3.1 Control parameters for vectoring feedback reporting

The VCE communicates to the MTU-O a set of control parameters for vectoring feedback reporting defined in Table 10-26.

Table 10-26 – Control parameters for vectoring feedback reporting

Parameter name	Definition
Vectored bands	The downstream frequency bands for which the MTU-R shall send VF samples for the subcarriers through the vectoring feedback channel. The vectored bands shall be defined by indices of the lowest frequency and the highest frequency subcarriers. N_band denotes the number of vectored bands configured. No more than eight bands shall be configured (i.e., N_band ≤ 8). The configured bands shall be identified by their numbers: *vb* = 0, 1, 2, 3, 4, 5, 6, 7 assigned in the ascending order of subcarrier indices associated with the band. *N_carrier(vb)* denotes the number of subcarriers in frequency band number vb, and can be computed as the index of the stop subcarrier minus the index of the start subcarrier plus one. The vectored bands shall not overlap one another.
F_sub	The sub-sampling factor to be applied to the vectored bands. For every vectored band, the VF sample of the subcarrier with the starting index shall be transmitted first, followed by the VF sample of every F_sub^{th} subcarrier within the vectored band. Selection of the starting index is specified in clause 10.3.2.5.1 for frequency identification and in clause 10.3.2.5.2 for time identification. Configured by the VCE and applied for each vectored band separately.
F_block	The block size (number of subcarriers) for grouping of VF samples. Configured by the VCE. The same block size configuration shall be used for all vectored bands (see Tables 10-11 and 11-44).
B_min	Lower bound of the bit index for reporting of a VF sample component (see clause 10.3.2.3.2). Configured by the VCE for each vectored band separately.
B_max	Upper bound of the bit index for reporting of a VF sample component (see clause 10.3.2.1). Configured by the VCE for each vectored band separately.
L_w	Maximum number of bits for reporting of a VF sample component. Configured by the VCE for each vectored band separately. If *L_w* is set to zero for a particular vectored band, that band shall not be reported. *L_w* shall be set to a non-zero value for at least one vectored band.

Table 10-26 – Control parameters for vectoring feedback reporting

Parameter name	Definition
Padding	Indicates whether or not the MTU-R shall pad VF samples through sign extension or zero padding (Note) to maintain using *L_w* bits for reporting of a VF sample component if $S < L\_w - 1$ (see clause 10.3.2.3.2). Configured by the VCE. The same padding configuration shall be used in all vectored bands. Padding is enabled by setting this bit to ONE.
Rounding	Indicates whether or not the MTU-R shall round half-up (see clause 10.3.2.3.2) the reported VF sample based on the MSB that is not reported. Configured by the VCE. The same rounding configuration shall be used in all vectored bands.
VF Sub-frame type	Indicates the sub-frame type over which the MTU-R shall report VF samples. Configured by the VCE. The same VF sub-frame type configuration shall be used in all vectored bands.
NOTE – Selection of zero padding or sign extension is vendor discretionary by the MTU-R	

In case of reporting of error samples, Table 10-27 defines the mandatory values for the vectoring feedback control parameters. In particular, it defines the valid values for the VCE to configure and the mandatory values for the MTU-R to support. The MTU-O shall support all valid values for VCE to configure.

Table 10-27 – Values of vectoring feedback control parameters

Parameter	Mandatory values for MTU-R to support
Vectored bands: N_band	1, 2, 3,...,8
Vectored bands: *Index of subcarriers*	Full range from "Index of the lowest supported downstream data-bearing subcarrier" to "Index of the highest supported downstream data-bearing subcarrier" as indicated in Tables P.-1 and Q.1 for the supported profile(s)
F_sub	1, 2, 4, 8
F_block	1, 2 and 4
B_min	2, … , 17
B_max	*B_min*, … , 17
L_w	0, 1, … , 10
Padding	1 (enable); with *F_block* = 1, 2 or 4 0 (disable) only with *F_block* = 2 or 4
Rounding	1 (enable); 0 (disable)
VF Sub-frame type	1 (FDS only), 2 (FUS only)

In case of reporting of DFT output samples, the valid values for the VCE to configure and the mandatory values for the MTU-R to support are: *F_block* = 1, *L_w* = 10, 6, 4, and *padding* = 1 (see Table 10-26). *B_min* and *B_max* do not apply.

For each vectored band assigned by the MTU O for vectoring feedback reporting, the MTU R shall report the VF samples for all subcarriers with indices $X = X\_L + n \times F\_sub$, where n gets all integer values 0, 1, 2, … for which $X\_L \le X \le X\_H$ and with *X_L* and *X_H* respectively, the indices of the starting subcarrier and the highest subcarrier of the vectored band. VF samples of other subcarriers shall not be reported. Selection of the starting index is specified in clause 10.3.2.5.1 for frequency identification and in clause 10.3.2.5.2 for time identification.

10.3.2.3.2 Grouping of VF samples

10.3.2.3.2.1 Grouping of VF samples in case of error samples reporting

In case of reporting of error samples, the MTU-R shall group VF samples into blocks. Valid block sizes for the parameter *F_block* are defined in Table 10-27. For each block, the MTU-R shall calculate parameters *B_M* and *B_L*. The parameters *B_M* and *B_L* represent the highest and the lowest bit indices of the reported VF sample, in assumption that bit index is counted from the LSB to the MSB, starting from 0. If *rounding*=1, and B_L>0 then the content of the bit with index B_L-1 (the MSB that is not reported) shall be examined. If the content of this bit is "1", the binary value of the reported bits shall be incremented by one. In case the increment causes representation overflow (can be examined by the sign bit B_M) then the increment shall be cancelled, and the original contents shall be reported (see Figure 10-32).

Figure 10-30 depicts the example of *F_block*=1, *B_min*=2, *B_max*=10, *L_w*=4, and *padding*=1. Two registers each (*B_max*+*L_w*) bits wide contain a VF sample component in the bits labelled from *B_max* (VF sample MSB) down to zero (VF sample LSB), while the $L\_w – 1 = 3$ remaining bits of each register are set to zero and labelled with a negative bit index –1 down to $1 – L\_w = –3$. For each component in the block, only the $B\_M – B\_L + 1$ bits with indices from *B_M* down to *B_L* inclusive are included in the vectoring feedback report block (VFRB) format defined in clause 10.3.2.4.1. Parameters *B_M* and *B_L* shall be computed for each block as described below. The MTU-R shall examine all VF sample components in each block and determine for each component *ec* (ec = 1 to 2×*F_block*) a data-dependent scale parameter s_{ec}, defined to be the sign bit index of the shortest two's complement representation of the component. For a component value V_{ec}, the scale parameter s_{ec} is:

$$s_{ec} = \begin{cases} floor(\log_2(V_{ec})) + 1, & V_{ec} > 0 \\ 0, & V_{ec} = 0 \\ ceiling(\log_2(-V_{ec})), & V_{ec} < 0 \end{cases}$$

For example, as depicted in Figure 10-30, the first VF sample component, having the 11-bit two's complement representation 11110010101, has shortest representation 10010101 and hence its scale is $s_1 = 7$. Likewise, the second component 00000010010 has shortest representation 010010 and hence its scale is $s_2 = 5$.

The MTU-R then computes for each block a data-dependent block scale parameter $S = \max_{ec}(s_{ec})$, where the maximization index *ec* runs over all 2×*F_block* VF sample components in the block.

For example, as depicted in Figure 10-30, *F_block* = 1 and the block scale parameter *S* is the maximum of s_1 and s_2, hence $S = 7$.

If *padding* = 0, for each block in the given vectored band, the MTU-R shall set:

$$B\_M = \max(S, B\_\min), \quad B\_L = \max(B\_M - L\_w + 1, B\_\min) \tag{10-1}$$

In this case, the final reported VF sample components are:

$$r\_x = \max\left\{-2^{B\_M-B\_L}, \min\left\{\mathrm{R}\left(q\_x \times 2^{B\_M-B\_L} \times 2^{-B\_M}\right), 2^{B\_M-B\_L} - 1\right\}\right\}$$

$$r\_y = \max\left\{-2^{B\_M-B\_L}, \min\left\{\mathrm{R}\left(q\_y \times 2^{B\_M-B\_L} \times 2^{-B\_M}\right), 2^{B\_M-B\_L} - 1\right\}\right\}$$

where $\mathrm{R}(\bullet)$ is the rounding half-up function if *rounding*=1 or the floor function if *rounding*=0

$$\mathrm{R}(x)=\begin{cases} floor(x+0.5) & rounding=1 \\ floor(x) & rounding=0 \end{cases}$$

If *padding* = 1, for each block in all the vectored bands, the MTU-R shall set:

either $B\_M = \max(S, L\_w-1, 2)$ (sign extension) or $B\_M = \max(S, 2)$ (zero padding);

and

$$B\_L = B\_M - L\_w + 1 \text{ (with bits set to 0 for bit indices < 0).} \qquad (10\text{-}2)$$

In the case of sign extension with $S \geq L\_w-1$, and the case with zero padding, the final reported VF sample components are:

$$r\_x = \max\left\{-2^{L\_w-1}, \min\left\{\mathrm{R}\left(q\_x \times 2^{L\_w-1} \times 2^{-S}\right), 2^{L\_w-1}-1\right\}\right\}$$
$$r\_y = \max\left\{-2^{L\_w-1}, \min\left\{\mathrm{R}\left(q\_y \times 2^{L\_w-1} \times 2^{-S}\right), 2^{L\_w-1}-1\right\}\right\}$$

In the case of sign extension with $S < L\_w-1$, the final reported VF sample components are:

$$r\_x = \max\left\{-2^{L\_w-1}, \min\left\{\mathrm{R}\left(q\_x\right), 2^{L\_w-1}-1\right\}\right\} = q\_x$$
$$r\_y = \max\left\{-2^{L\_w-1}, \min\left\{\mathrm{R}\left(q\_y\right), 2^{L\_w-1}-1\right\}\right\} = q\_y$$

The values of the reported VF sample components shall be represented using the two's-complement representation of *L_w* bits. The parameters *B_M* and *B_L* shall always satisfy the relations *B_L* ≤ *B_M* and:

$$2 \leq B\_M \leq B\_max$$

Selection of zero padding or sign extension is vendor discretionary by the MTU-R. However, the MTU-R shall not change the selection after the first report until the next initialization.

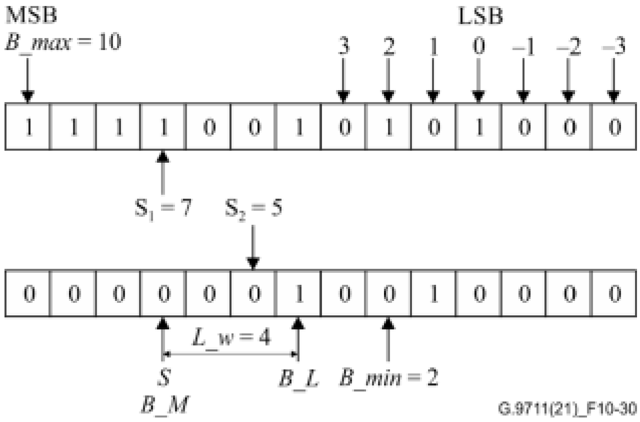


Figure 10-30 – Example of two registers, each representing a VF sample component

Figure 10-31(a) depicts an example of the reported bits (shown shaded) for a block of VF samples for different padding types, with *F_block*=2, *B_min*=2, *B_max*=7, *L_w*=5, *rounding*=0, and Figure 10-31(*b*) uses *L_w*=6.

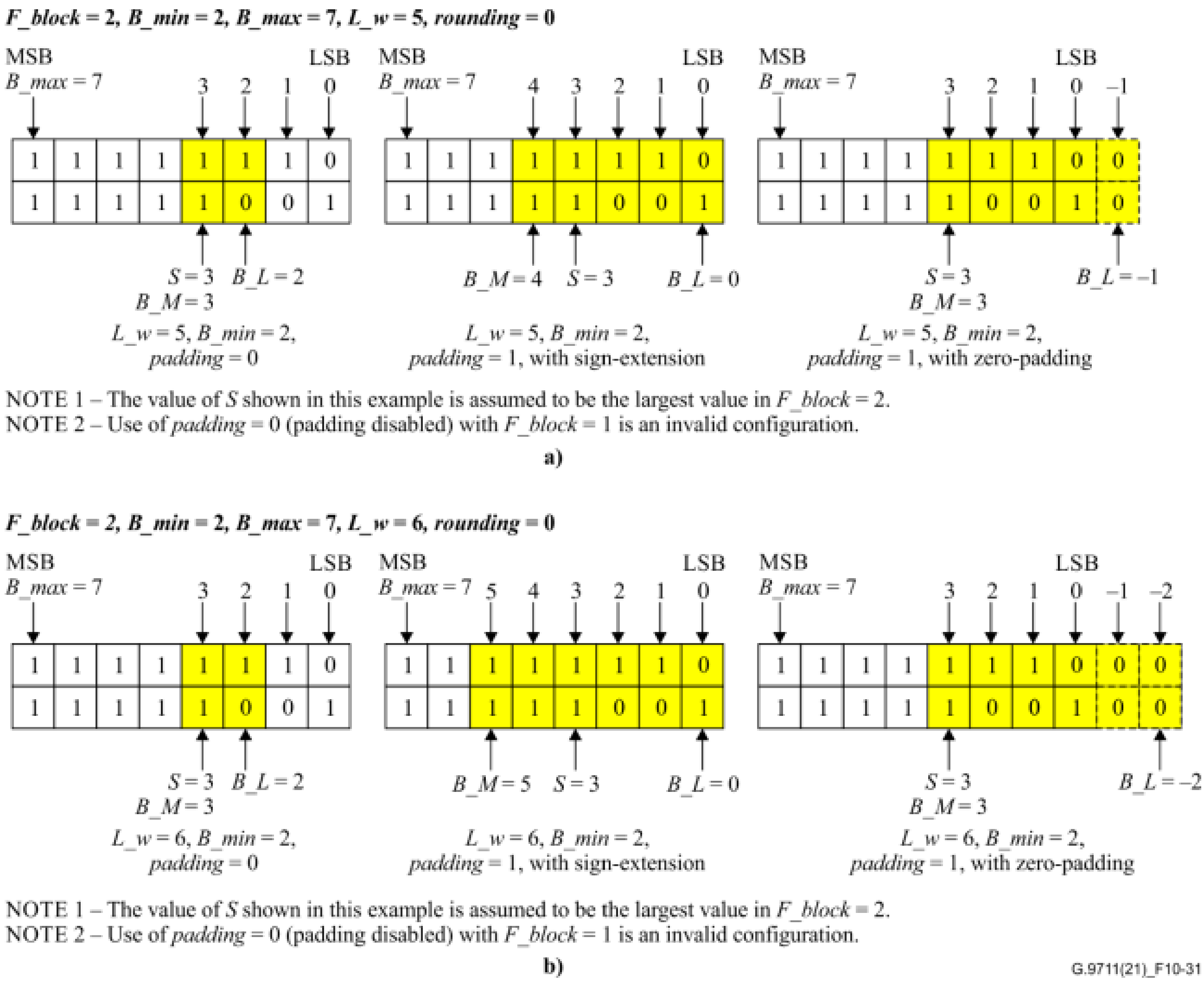


Figure 10-31 – Example of reported bits for a block of VF samples for different padding types without rounding

Figure 10-32(a) depicts an example of the reported bits for a block of VF samples for different padding types, with *F_block*=2, *B_min*=2, *B_max*=7, *L_w*=5, *rounding*=1 and Figure 10-32(*b*) uses *L_w*=6.

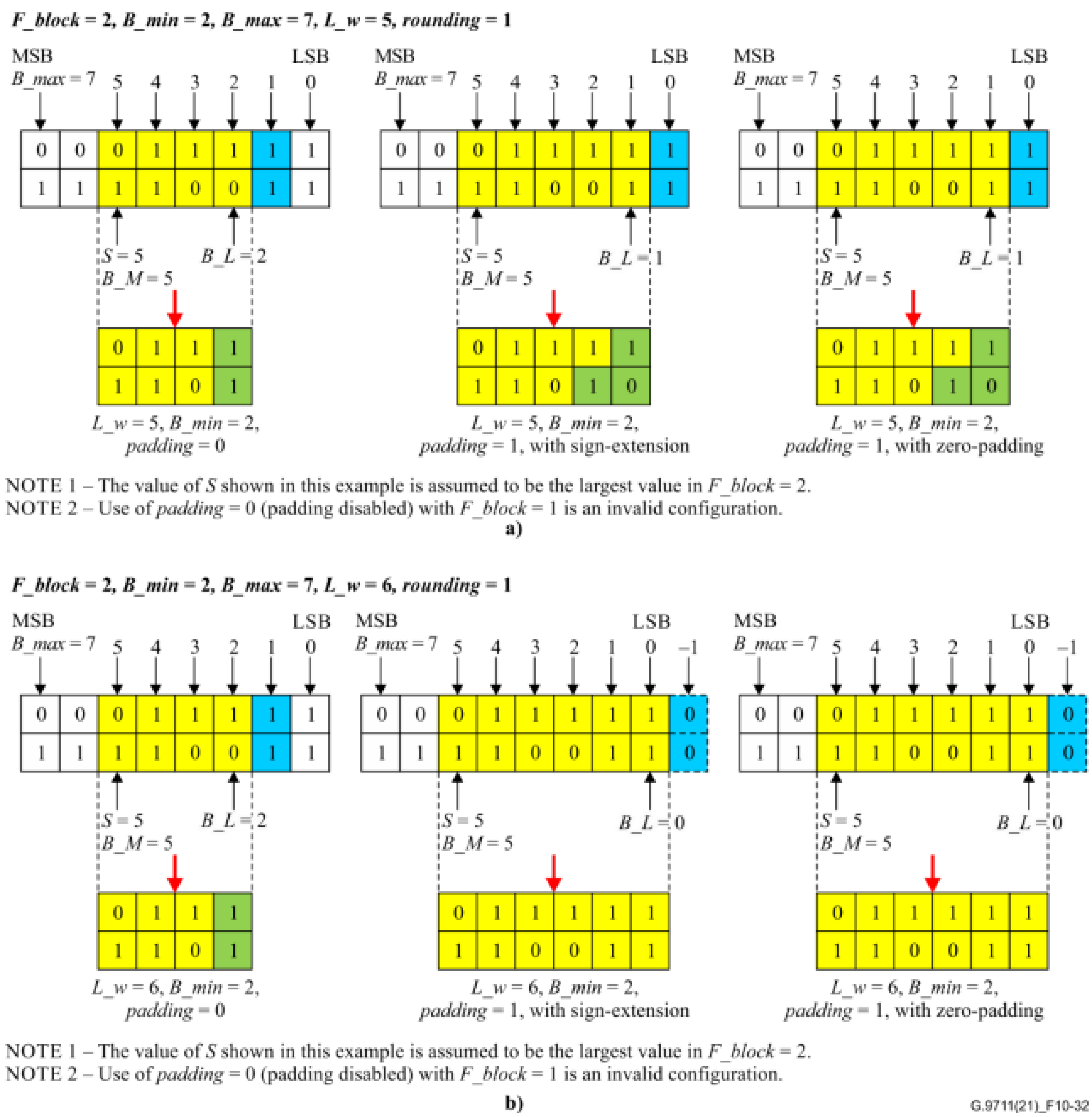


Figure 10-32 – Example of reported bits for a block of VF samples for different padding types with rounding

10.3.2.3.2.2 Grouping of VF samples in case of DFT output sample reporting

The values of the reported VF sample components (f_x, f_y) shall be formatted using the two's-complement representation containing L_w bits. The parameter B_M shall be calculated corresponding to the definition of DFT output samples (see clause 10.3.2.2), and its value shall always satisfy: $0 \leq B\_M \leq 15$.

The value of B_L shall be set as: $B\_L = B\_M - L\_w + 1$.

NOTE – In case of DFT output sample reporting (this clause), the values B_M and B_L have a different meaning than in the case of error samples reporting (clause 10.3.2.3.2.1), although the same name is used.

The MTU-R shall implement padding using sign extension.

10.3.2.3.2.3 Calculation of *N_block*

This clause applies to both reporting of DFT output samples and reporting of error samples.

For the assigned value of *F_block*, the block consists of VF samples reported for *F_block* subsequent subcarriers from those assigned for reporting in the vectored band. The subcarriers shall be assigned to blocks starting from the lowest frequency subcarrier of the vectored band, subsequently, in ascending order, *F_block* subcarriers in each block. The number of blocks in the vectored band *vb* can be computed as:

$$N\_block(vb) = ceiling\left(\frac{ceiling\left(\dfrac{N\_carrier(vb)}{F\_sub(vb)}\right)}{F\_block}\right)$$

The blocks shall be identified by their numbers: $eb = 0$ to $N\_block(vb) - 1$, assigned in the ascending order of subcarrier indices associated with the block. The last components of the last block that do not belong to the subcarriers of the vectored band (if any), shall be set to dummy values that represent the value of zero.

10.3.2.4 Vectoring feedback channel format

The number of bytes per sync symbol needed to report the VF samples depends on the values configured by the VCE for the vectoring feedback control parameters (see clause 10.3.3.2). Blocks of VF samples (VF blocks) of the vectored bands are mapped into the VFRB.

Each VFRB is associated with a particular sync symbol carrying one probe sequence element. The VFRB has a single format defined in clause 10.3.2.4.1 that is further encapsulated into:

- eoc message (for an eoc-based vectoring feedback channel), or
- SOC message (for an SOC-based vectoring feedback channel).

The sync symbol associated with a particular VFRB is identified by the superframe count (CNT_{SF}) communicated together with the VFRB in the eoc message (for the eoc-based vectoring feedback channel during showtime) or in the SOC message (for an SOC-based vectoring feedback channel during initialization).

10.3.2.4.1 Format of the VFRB

The format of the VFRB is presented in Figure 10-33. The VFRB starts from an 8-bit VFRB_ID field, followed by up to eight vectored band blocks (VBB) fields. The MTU-R shall set the MSB of the VFRB_ID field to '1' to indicate that the VF samples in the VFRB are potentially corrupted (e.g., due to impulse noise, or RFI). Otherwise, the MTU-R shall set the MSB of the VFRB_ID field to '0'. The seven LSB of the VFRB_ID field shall be set to 0 and are reserved for ITU-T. The number of bytes in the VFRB (*N_VFRB*) is the sum of the number of bytes in each of the VBBs, plus one byte for the VFRB_ID field. The concatenation of VBBs in a VFRB shall be in the ascending order of the vectored band numbers, i.e., starting from the vectored band associated with lowest subcarrier indices. Some vectored bands may not be reported on request of the VCE (i.e., the VFRB shall not contain a VBB for the vectored bands for which VCE configures *L_w*=0).

The MSB of the VFRB byte and the first bytes of VBB shall be positioned as indicated in Figure 10-33.

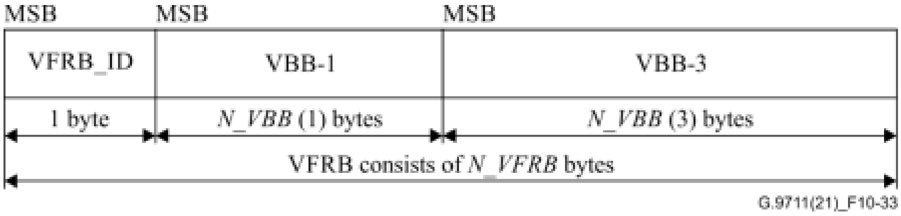


Figure 10-33 – VFRB format (in case only vectored bands 1 and 3 are requested by the VCE)

The format of the VBB is presented in Figure 10-34. Each VBB starts from an 8-bit VBB_ID field, followed by concatenated VF blocks, and ends with a pad of zero, two, four or six bits to fit the length of the VBB to an integer number of bytes (odd number of padding bits is not applicable). The three MSBs of the VBB_ID field shall comprise the number of the vectored band (000 for VBB-0, 001 for VBB-1, …, up to 111 for VBB-7). The five LSBs of the VBB_ID field shall be set to '0' and be reserved for ITU-T. The VF blocks shall be concatenated in a VBB in ascending order: the VF block 0 is the one that contains VF samples for the subcarrier with lowest index and shall be transmitted first. The block of VBB data are mapped to the bytes according to Figure 10-34.

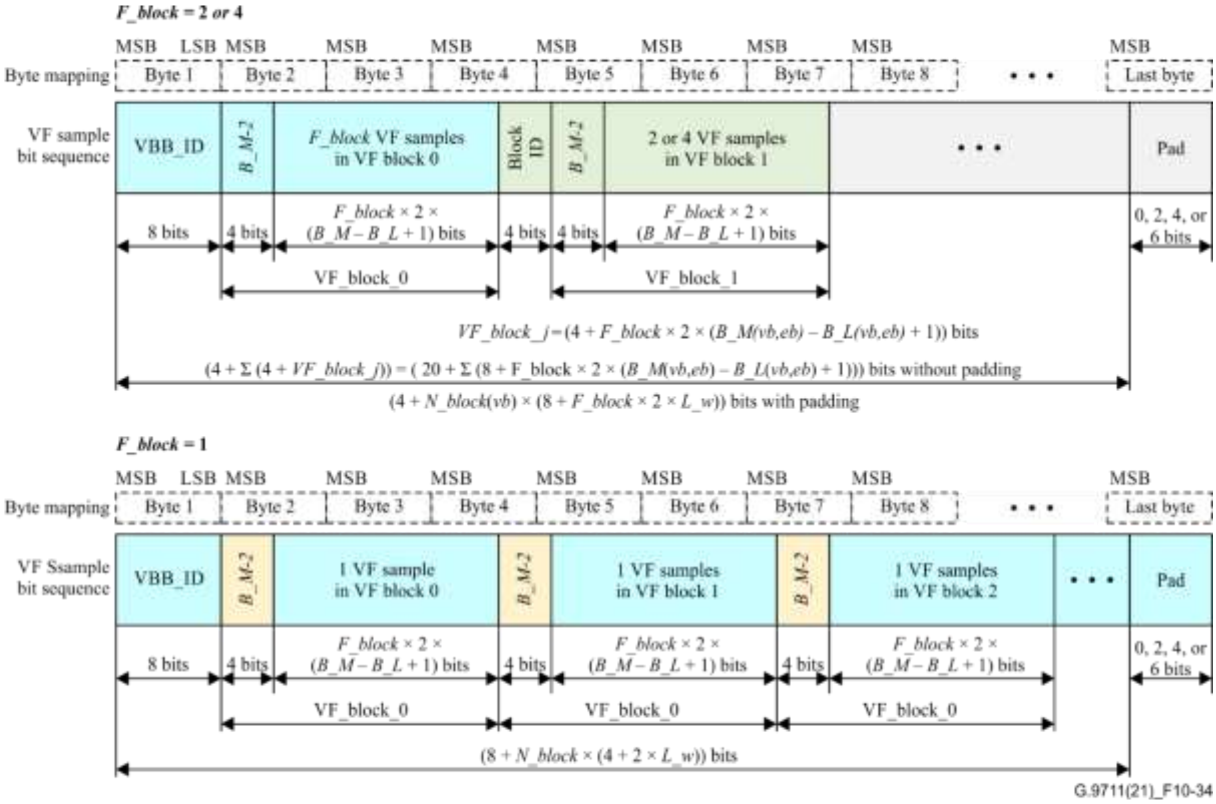


Figure 10-34 – VBB format depending on *F_block*

All fields of the VBB presented in Figure 10-34 shall be transmitted MSB first; the MSB of the VBB_ID shall be the MSB of the first byte of the VBB field, as shown in Figure 10-33.

The format of the VF block is defined in clause 10.3.2.4.2.

In case *F_block* = 2 or 4, a Block_ID shall be pre-pended to each VF block, starting with VF block number 1. A Block_ID shall not be inserted just before VF block 0. The Block_ID shall be four bits long, and shall represent modulo 16 the sequence number of the VF block it precedes as an unsigned integer, in assumption that the first block in the vectored band has the number 0.

In case $F\_block = 1$, a Block_ID shall not be inserted.

NOTE – The VCE can identify VBB in the received VFRB by its VBB_ID and then compute the number of VF blocks, $N\_block(vb)$, in the VBB-*vb* as described in clause 10.3.2.3.2, since all the vectoring feedback control parameters are known to the VCE. The length of the VF block is computed using the parameters (B_M, B_L) of the VF sample and the block size F_block. The first reported sample of the first VF block in the vectored band is for the subcarrier with index X_L (which is always even).

10.3.2.4.2 Format of the VF block

The representation for a VF block containing F_block VF samples ($2\times F\_block$ VF sample components of F_block subcarriers) shall include an *EXP* field (4 bits), and a vectoring feedback field (variable length), see Figure 10-35. The vectoring feedback field includes F_block sub-fields, each carrying a complex VF sample of a subcarrier which is assigned for reporting during the vectoring feedback report configuration (see clause 10.3.3.2).

In case of reporting of error samples, for each VF sample component (r_x, r_y), the compressed representation, as defined in clause 10.3.2.3.2.1, includes only those bits of the VF sample component with indices B_L through B_M, using the convention that the MSB of the compressed representation of the component has index B_max and the LSB of the compressed representation of the component has index B_min. Accordingly, the total number of bits in the vectoring feedback field of a block of VF samples in compressed representation shall be $2\times F\_block\times(B\_M - B\_L + 1)$.

When a VF block contains error samples, the *EXP* fields shall include parameter B_M decreased by 2 and coded as a 4-bit unsigned integer, within the range from 0 to 15 representing B_M values within the range from 2 to 17.

NOTE – The parameter B_L is not reported as it can be calculated by the VCE from the vectoring feedback control parameters (see equations 10-1 and 10-2) and the value of the reported B_M parameter.

In case of reporting of DFT output samples, each VF sample component (f_x, f_y), shall be calculated corresponding to the definition of DFT output samples (see clause 10.3.2.2). The total number of bits in the vectoring feedback field of a block of VF samples in compressed representation shall be $2\times F\_block\times(B\_M - B\_L + 1) = 2\times F\_block\times L\_w$.

When a VF block contains DFT samples, the *EXP* fields shall include parameter B_M coded as a 4-bit unsigned integer, within the range from 0 to 15.

The format of the VF block is presented in Figure 10-35. All parameters and VF samples shall be mapped with the MSB at the left side and LSB to the right side so that the MSB is transmitted first (i.e., the first transmitted bit is the MSB of the *EXP* field). The VF samples in a VF block may not be aligned with byte boundaries as demonstrated in Figure 10-35.

VF samples in the vectoring feedback field shall be mapped in ascending order of subcarrier index from left to right. In case of error samples, for each VF sample, the r_x (real) component shall be mapped left from the r_y (imaginary) component. In case of DFT output samples, the f_x (real) component shall be mapped left from the f_y (imaginary) component.

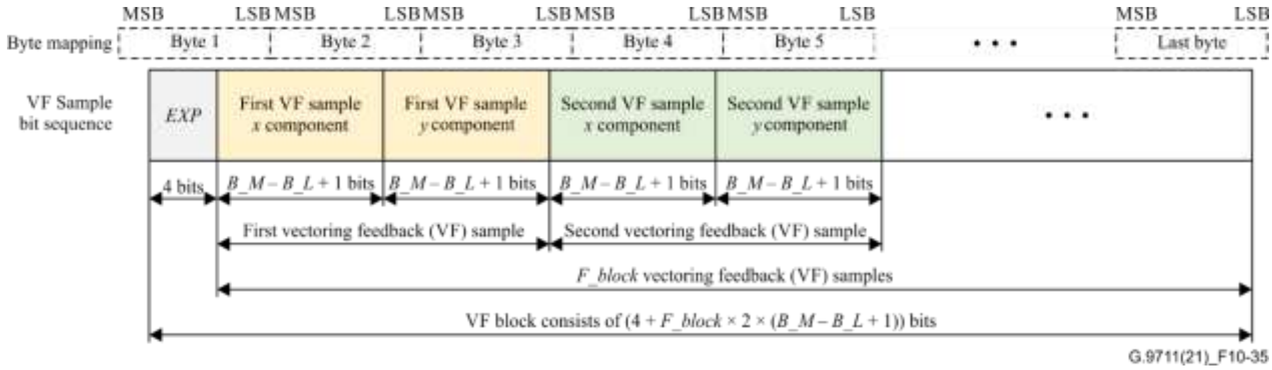


Figure 10-35 – Format of a VF block

10.3.2.4.3 Vectoring feedback channel data rate (informative)

In case *F_block* = 2 or 4, the number of bytes in the VBB-*vb* without padding, following from Figures 10-23, 10-24 and 10-25 is:

$$N\_VBB(vb) = ceiling\left[\left(4 + \sum_{eb=0}^{N\_block(vb)-1} (8 + F\_block \times 2 \times (B\_M(vb,eb) - B\_L(vb,eb) + 1))\right)/8\right]$$

where *B_M(vb,eb)* represents the *B_M* parameter for the VF block number *eb* of vectored band number *vb*, *B_L(vb,eb)* represents the *B_L* parameter for the VF block number *eb* of vectored band *vb*.

In general, this value is not fixed but may be different from one vectoring feedback report to the next, depending on the exact values of the VF samples. If padding (see Table 10-26) is used, the number of bytes in the VBB-*vb* only depends on the vectoring feedback control parameters and not on the values of the VF sample values:

$$N\_VBB(vb) = ceiling\left[(4 + N\_block(vb) \times ((2 \times L\_w \times F\_block) + 8))/8\right]$$

In case *F_block* = 1, padding is used and the number of bytes in the VBB-*vb* only depends on the vectoring feedback control parameters and not on the values of the VF sample values:

$$N\_VBB(vb) = ceiling\left(\frac{8 + N\_block(vb) \times (4 + 2 \times L\_w(vb))}{8}\right)$$

The *N_VFRB* can be calculated as:

$$N\_VFRB = 1 + \sum_{vb=0}^{N\_band-1} report(vb) \times N\_VBB(vb)$$

where *report(vb)* =1 if the VBB-*vb* is included in the VFRB (i.e., *L_w* > 0 for band number *vb*), and *report(vb)* = 0 if the VBB-*vb* is not included in the VFRB (i.e., *L_w* = 0 for band number *vb*).

The vectoring feedback channel data rate (VFCDR) for transmission of the VFRB for each sync symbol is:

$$VFCDR = 8 \times N\_VFRB \times \left(f_{DMT} / (T_F \times M_{SF})\right)$$

where f_{DMT} is the symbol rate (in symbols/s) defined in clause 10.4.4.

The vectoring feedback channel data rate is not constant when padding is not used. In that case, it varies since *N_VFRB* varies from vectoring feedback report to vectoring feedback report.

10.3.2.5 Identification of the VFRB

10.3.2.5.1 Frequency identification control parameters

Frequency identification allows to reduce the size of the VFRB and to fit the corresponding eoc or

SOC message into the desired number of superframe periods (usually one superframe) by reducing the number of reported VF samples. Frequency identification is defined by two parameters:

- the frequency sub-sampling factor (*F_sub*);
- the frequency shift step (*s*).

Frequency identification is enabled by setting $s \neq 0$.

With sub-sampling rate of *F_sub*, VF samples for a particular element X of the probe sequence are reported only for subcarriers of the given vectored band with indices:

$$i = i_{min} + (s \times (n\text{-}1))\text{MOD}(F\_sub) + j \times F\_sub$$

where:

i_{min} is the lowest index of the vectored band;

$j =$ 0, 1, 2…

n is a count of probe sequence cycles covered by the reports; for the first report, n=1.

For example, if $F\_sub = 4$, at the first probe sequence cycle (n=1) all subcarriers with indices $i_{min}+j\times 4$, j = 0, 1, 2… will be reported until the upper index of the vectored band. At the second probe sequence cycle (n=2), the starting subcarrier index is increased by *s*. If $s = 2$, all subcarriers with indices $i_{min}+2+j\times 4$ will be reported at the second probe sequence cycle. These two reports will provide one set of VF samples equivalent to a single report with $F\_sub = 2$ (no more reports are required because in the next probe sequence cycle (n=3) the subcarriers with indices $i_{min}+j\times 4$, j = 0, 1, 2… will be reported again).

The valid values of frequency identification control parameters are presented in Table 10-28.

Table 10-28 – Valid values of frequency identification control parameters

Parameter	Valid values for VCE	Mandatory values for MTU-R to support
F_sub	In accordance with Table 10-27	All valid values.
s	1, 2, 3, 4 provided that $s < F\_sub$ (Note)	All valid values.
NOTE – s = 0 is a special value indicating that frequency identification is disabled.		

For frequency identification reporting:

– To start vectoring feedback reporting, the value of parameter *q* shall be set to 1.

– To stop vectoring feedback reporting, the value of parameter *q* shall be set to 0.

10.3.2.5.2 Time identification control parameters

On each of the sync symbols indicated by the MTU-O by the associated superframe count, the MTU-R shall transmit a single VFRB. In each VFRB, the MTU-R shall also include the superframe count (as defined in clause 12.3.3.2.10) as identification of the downstream sync symbol the VFRB corresponds to. The MTU-O shall indicate such superframe counts using the following time identification control parameters:

- the VFRB update period (*q*);
- the VFRB shift period (*z*).

Time identification is enabled by setting $s = 0$.

The MTU-R shall send the first VFRB on the first sync symbol following the reception of the request to update the VFRB control parameters. Then it shall send a VFRB on every *q*-th subsequent sync symbol position *z*-1 times. After *z* VFRBs are sent (which takes $q\times z$ superframes), the next VFRB shall be reported for the next (q+1)-th sync symbol position, after which the following z-1 VFRBs shall be reported every q-th sync symbol position, etc. until the next request to update VFRB control parameters.

With the rule defined above, the VFRB are sent on the sync symbol positions associated with the superframe count values CNT_{SF_n} computed with the following recursive rule starting from n=0:

$$CNT_{SF_n} = CNT_{SF_0} \text{ if } n = 0$$

$$CNT_{SF_n} = (CNT_{SF_{n-1}} + q) \text{ MOD } 2^{16} \text{ if } n \text{ MOD } z \neq 0$$

$$CNT_{SF_n} = (CNT_{SF_{n-1}} + q + 1) \text{ MOD } 2^{16} \text{ if } n \text{ MOD } z = 0$$

where CNT_{SF_0} is the superframe count value of the first sent VFRB.

Valid values for the time identification control parameters are defined in Table 10-29. For every vectored band of the reported VBB, the starting subcarrier is the one with the smallest index within the vectored band.

The VFRB shift period z equals zero is a special value to indicate that VFRB shall be sent every q sync symbol position starting at CNT_{SF_0} until the next request to update VFRB control parameters. The VFRB period value of $q = 0$ is a special value and shall be used to indicate that the MTU-R shall stop vectoring feedback reporting.

NOTE – The parameters q and z should be selected such that the VF samples are reported at least once for all the elements of the probe sequence after a certain time.

For example, the reports are sent on the following superframe counts with $CNT_{SF_0} = 0$:

q=4 and z=0 then CNT_{SF}=0, 4, 8, 12, 16, 20, 24, 28, …

q=4 and z=4 then CNT_{SF}=0, 4, 8, 12, 17, 21, 25, 29, 34, 38, …

Valid values for the time identification control parameters are defined in Table 10-29.

Table 10-29 – Valid values of time identification control parameters

Parameter	Valid values for VCE	Mandatory values for MTU-R to support
q	0, 1, 2, …, 16	All valid values.
z	If $q > 1$: 0, 2, 3, 4, … z_max (Note) If $q \leq 1$: 0	All valid values.
NOTE – If extended probe sequence length is not selected in the ITU-T G.994.1 MS message, the value of *z_max* is 128. If extended probe sequence length is selected in the ITU-T G.994.1 MS message, the value of *z_max* is 632.		

10.4 Modulation

10.4.1 Data subcarriers

The data subcarriers shall be indexed from $i = LSI$ to $i = MSI$, where LSI, MSI are indices of the lowest and the highest loaded subcarrier, respectively (i.e., LSI is the minimum index and MSI is the maximum index in the MEDLEY set). The values of LSI and MSI may be different for upstream and downstream transmission and are denoted as LSI_{us}, MSI_{us} and LSI_{ds}, MSI_{ds} respectively. The index of the highest loaded subcarrier (MSI_{us} or MSI_{ds}) is restricted by the selected profile. Data bits may be transmitted on NSC_0+NSC_1 subcarriers, with $NSC_{us0}+NSC_{us1} \leq (MSI_{us} - LSI_{us}+1)$ and $NSC_{ds0}+NSC_{ds1} \leq (MSI_{ds} - LSI_{ds}+1)$. The subcarrier with index i=0 shall not be used ($LSI > 0$).

The data subcarriers to be used for transmission in the upstream and downstream directions (MEDLEYus and MEDLEYds sets, respectively) are determined during initialization, as specified in clause 12.3.4, and are intended to carry all types of data (DTU bits, RMC bits, RRC bits) and applicable special signals (in sync symbols, idle symbols, etc.).

NOTE – The subcarriers actually used for data transmission depend on channel characteristics, such as loop attenuation and noise, and on the specific requirements on the PSD of the transmit signal, such as notching of IAR bands, PSD reduction at low frequencies to share the loop with POTS or digital subscriber line (DSL) on other transmission lines.

10.4.2 Subcarrier spacing

Subcarrier spacing is the frequency spacing, f_{SC}, between the subcarriers. The subcarriers shall be centered at frequencies $f = i \times f_{SC}$. The subcarrier index i takes the values $i = 0, 1, 2, ..., N\text{-}1$, where N-1 is the index of the highest subcarrier. The value of subcarrier spacing shall be l×51.75 kHz, with a tolerance of ±50 ppm, where $l = 1$. Other valid values of l are for further study. The support of various subcarrier spacing is defined in profiles, see clause P.5 and Q.5.

10.4.3 Inverse discrete Fourier transform (IDFT)

The IDFT is used to modulate the complex values at the output of the symbol encoder (or those precoded at the MTU-O) onto the DMT subcarriers. It converts the N frequency domain complex values Z_i (as defined in clause 10.2.1.4) generated by the symbol encoder or values Z_i' generated by the precoder into $2N$ real values x_n ($n = 0, 1, ..., 2N - 1$), which is a time domain representation. The conversion shall be performed with a $2N$-point IDFT:

$$x_n = \sum_{i=0}^{2N-1} \exp\left(j \cdot 2 \cdot \pi \cdot \frac{n \cdot i}{2 \cdot N} \right) \cdot Z_i \qquad \text{for } n = 0 \text{ to } 2N - 1$$

The valid values of N are $N = 2^p$, where the valid value of p is 13; other values of p are for further study.

For subcarrier indices i that are not in the MEDLEY set, the corresponding values of Z_i are not generated by the symbol encoder. These values are vendor discretionary, but shall comply with the constraints given in Table 10-22. The value of Z_0 shall always be equal to zero and Z_N shall always be a real value.

In order to generate real values of x_n, the input values Z_i, where $i = 0, 1, ..., N - 1$ and $Z_0 = 0$, shall be further augmented so that the vector Z_i has a Hermitian symmetry:

$$Z_i = \text{conj}(Z_{2N-i}) \qquad \text{for } i = N + 1 \text{ to } 2N - 1$$

10.4.4 Cyclic extension and windowing

The cyclic extension (CE) provides a guard interval between adjacent symbols. This guard interval is intended to protect against inter-symbol interference. The CE also adds windowing that is necessary for spectrum shaping. The transmit symbol shall include CE and shall be constructed from the IDFT $2N$ output samples using the following rules (see Figure 10-36):

1) The IDFT in the current symbol i outputs $2N$ samples labelled x_0 to x_{2N-1} in Figure 10-36. The last L_{CP} samples of the original $2N$ samples in the IDFT output shall be prepended to the $2N$ output IDFT samples as the cyclic prefix (CP).
2) The first $L_{CS} = \beta$ samples of the original 2N samples in the IDFT output shall be appended to the block of $2N + L_{CP}$ samples as the cyclic suffix (CS).

With these two rules, the order of samples in a symbol shall be as follows:

- The first sample of symbol i is IDFT output sample $x_{2N-L_{CP}}$;
- The last sample of the CP is IDFT output sample x_{2N-1}; the next sample is IDFT output sample x_0, which is also the first sample of the cyclic suffix;

The last sample of the symbol is IDFT output sample $x_{\beta-1}$.

The first β samples of the CP and β samples of the cyclic suffix shall be used for shaping the envelope of the transmitted signal (windowing). The values of the window samples are vendor discretionary.

The valid values of β in samples shall be 64 or 128. The windowed parts (β samples) of consecutive symbols shall overlap and shall be added to one another. Therefore, the total number of samples transmitted per each symbol period, after CE and windowing, is $2N + L_{CP}$. The values of β selected for upstream (β_{us}) and downstream (β_{ds}) may be different. The particular value of β is selected by the transmitter of the MTU and shall be communicated to the peer MTU at initialization (β_{ds} is sent in O-SIGNATURE message and β_{us} is sent in R-MSG 1, respectively, see clause 12.3.3.2).

Figure 10-36 summarizes all of the described operations that shall be performed by the transmitter to construct the symbol.

The value of L_{CP} shall be set in order to satisfy the equation $L_{CP} = m \times N/64$, where valid values of *m* are integers 4, 8, 10, 12, 14, 16, 20, 24, 30 and 33, inclusive. The following combinations of *m* and PDX frame length (see clause 10.5) shall be supported:

- m=10 for PDX frame length $M_F = 23$
- m=10 for PDX frame length $M_F = 36$
- m=16 for PDX frame length $M_F = 23$
- m=33 for PDX frame length $M_F = 36$.

In all cases, the following relations shall hold: $L_{CP} > \beta$ and $L_{CS} = \beta$.

The same value of L_{CP} shall be selected for both upstream and downstream.

NOTE – The setting of the L_{CP} (for both upstream and downstream) are exchanged during the ITU-T G.994.1 phase of initialization. The same L_{CP} values are set in all links of the vectored group.

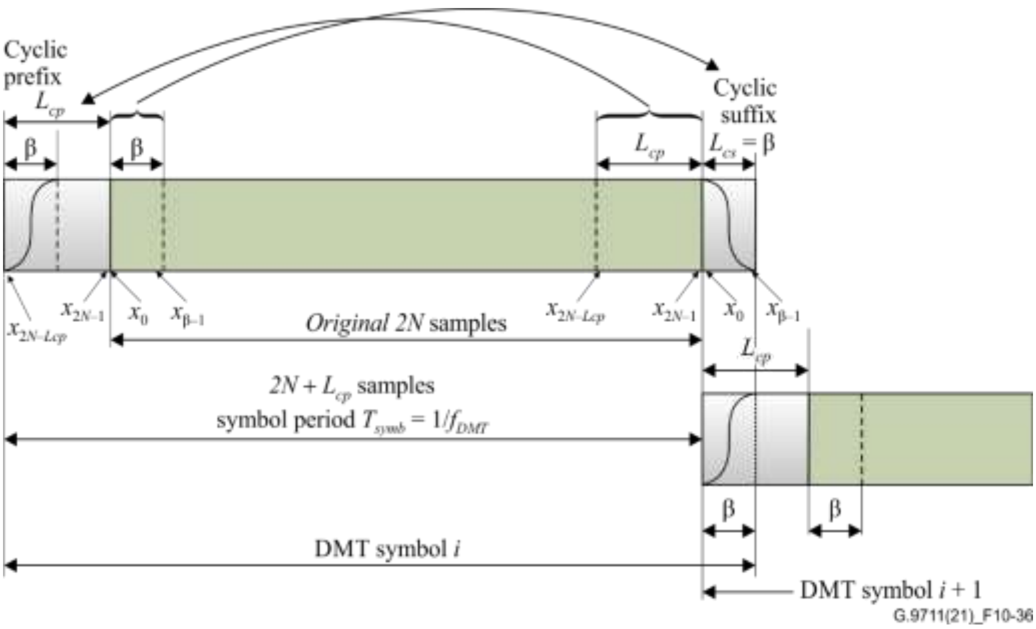


Figure 10-36 – Cyclic extension, windowing and overlap of symbols

For a given setting of the CP length, the symbols will be transmitted at a rate equal to:

$$f_{DMT} = \frac{2N \times f_{SC}}{2N + L_{CP}}$$

The symbol period T_{symb}, accordingly, equals to $1/f_{DMT}$ (see Figure 10-36).If f_{SC} is 51.75kHz and the CP length corresponds to m = 10, this results in a symbol rate of 48000 symbols/s.

10.4.5 Synchronization

The MTU-R shall use loop timing mode, i.e., it shall extract its symbol clock from the received signal. In loop timing mode, the MTU-R operates as a slave; the transmit clock of the MTU-R shall be locked to the transmit clock of the MTU-O. Prior to starting a transmission, the MTU-R shall acquire (or re-acquire) the downstream timing; no transmission is allowed if loop timing is not established.

To facilitate loop timing, the MTU-R may request the MTU-O to assign pilot tones. The number of pilot tones and their subcarrier indices are determined during initialization (see clause 12.3.4.2.8). The MTU-O shall transmit assigned pilot tones during the showtime in Band 0 of all types of data symbols, monitoring symbols, and RMC symbols, and preamble_preamble symbols (see Table 10-31). Pilot tones shall not be transmitted during sync symbols, idle symbols, and quiet symbols.

In case of P2P operation, the maximum number of pilot tones is 16.

In case of P2MP operation, all the pilot tones requested by the MTU-R joining to a P2MP group shall be inside the downstream P2MPOB assigned to this MTU-R. Concerning the number of requested pilot tones, the following rules shall apply:

– not more than 1 pilot tone per 256 downstream subcarriers of the P2MPOB (counting all sub-bands and rounding down the total number of subcarriers to the nearest multiple of 256);

– not more than 4 pilot tones in total.

NOTE 1 – In the P2MPOB of the minimum size (512 subcarriers), two pilot tones can be assigned.

The MTU-O indicates in the O-SIGNATURE message to the joining MTU-R all pilot tone groups of the subcarriers that are blocked within the P2MPOB of the joining MTU-R. These groups are associated with transmission of pilot tones that are used by other MTU-Rs of the P2MP group. Each group consists of G_p = 1, 2, 4, or 8 consecutive subcarriers, at least one of which is used as a pilot tone by one of these MTU-Rs. This subcarrier shall carry the pilot tone for the MTU-R that uses it, while all other G_p -1 subcarriers of this group shall carry the same pilot tone as well, and the whole group shall be counted as one pilot tone in the MTU-R's pilot tone budget.

On all G_p subcarriers of all groups indicated in O-SIGNATURE for the P2MPOB the path of the MTU-O corresponding to the joining MTU-R shall not transmit (Z_i=0). Moreover, the joining MTU-R shall not use those sub-carriers either for data transmission or for synchronization. The G_p subcarriers of pilot tone group can be re-used for data transmission only after being released by the MTU-R that used the pilot tone group, using a DBR procedure. The value of G_p can be different for different pilot tone groups (whether those associated with the same MTU-R or associated with different MTU-Rs).

If, as a result of DBR, one or more pilot tones get outside of the MTU-R downstream P2MPOB, the MTU-O shall still transmit these pilot tones over the same path without interruption and expand each pilot tone to a pilot tone group as defined above, with the size G_p determined by the VCE. The MTU-R shall still be able to use these pilot tones (and may use them, on its own discretion). During this DBR procedure (see clause 13.5.2.2.3):

– the MTU-R shall release the pilot tones that are outside the P2MPOB, except indicated by the MTU-O as allowed to be used, may ask for additional pilot tones inside the new downstream P2MPOB, while releasing one or more of its pilot tones that are inside its P2MPOB or one of more pilot tone groups that are out of its P2MPOB and indicated by the MTU-O as allowed to be used (still keeping up to 4 pilot tones per MTU-R in total);

– the MTU-R indicates to the MTU-O the parameters of the subcarriers of the released pilot tone groups inside P2MPOB to be used for data transmission;
– the MTU-O indicates to the MTU-R the pilot tones groups that are out-of-P2MPOB or will become out-of-P2MPOB immediately after the DBR procedure that the MTU-R is allowed to use. The rest of the out-of-P2MPOB pilot tone groups the MTU-R shall release. Within 500 ms after the completion of this DBR procedure, the MTU-R shall establish synchronization without using the subcarriers that has to be released.

NOTE 2 – Use of pilot tones that are out of P2MPOB reduces the bandwidth available for other MTU-Rs and should be minimized.

After the MTU-R releases the requested out-of-P2MPOB pilot tone groups, the MTU-O may initiate subsequent DBR procedures towards the MTU-Rs in the P2MP group, for which the released pilot tone groups are located inside their respective P2MPOBs. In each of these DBR procedures, the MTU-O indicates to the corresponding beneficiary MTU-R(s) the subcarriers of the released pilot tone groups (see Table 11-72) within its P2MPOB. The beneficiary MTU-R(s), in response, indicates to the MTU-O the proposed bit loadings on the granted subcarriers and adds them to the MEDLEY set.

10.5 PDX frame structure

The PHY duplexing (PDX) frame structure is presented in Figure 10-37 with the following notations describing the frame parameters. The FDS and FUS are transmission regions in which, generally, both the MTU-O and MTU-R can transmit and receive simultaneously in case of FDX and FDXZ framing modes. Value of T_{g1} is the gap time at the U reference point of the MTU-O between the FUS receive frame and FDS transmit frame; and T_{g2} is the gap time at the U reference point of the MTU-O between the FDS transmit frame and the FUS receive frame. T_{g1}' is the gap time at the U reference point of the MTU-R between the FDS receive frame and the FUS transmit frame and T_{g2}' is the gap time at the U reference point of the MTU-R between the FUS transmit frame and the FDS receive frame. The value of T_{g1}' plus one symbol period (T_{symb}) shall be the duration between the sample x_0 (see Figure 10-26) of the last symbol of the FDS receive frame and the sample x_0 of the first symbol of the FUS transmit frame over the U-R reference point. The values of T_{g1}, T_{g2}', T_{g2} are defined similarly. Specifically, value of T_{g1} plus one symbol period (T_{symb}) shall be the duration between the sample x_0 of the last symbol of the FUS receive frame and the sample x_0 of the first symbol of the FDS transmit frame over the U-O reference point. Both the MTU-O and MTU-R shall transmit in respect to downstream and upstream symbol boundaries, respectively.

Value of T_{g1}' determines all other time gap values (see Figure 10-37). The actual value of T_{g1}' is determined during initialization, as described in clause 12.3.3.1. The initial value of T_{g1}' is communicated to the MTU-R in the O-SIGNATURE message. This value is further adjusted to align boundaries of received upstream symbols in all vectored links.

The variable T_F defines the frame period. The PDX frame length shall be an integer multiple of symbol periods. One PDX frame period shall consist of M_{ds} symbol periods dedicated for FDS, M_{us} symbol periods dedicated for FUS, and a total gap time (T_{g1} + T_{g2}) equal to either zero or one symbol period, depending on PDX framing mode; hence $T_F = M_F \times T_{symb}$, where $M_F = M_{ds} + M_{us} + K$, where $K = 0$ or 1, depending on PDX framing mode. The sample x_0 of the first downstream transmit symbol of the FDS determines the PDX frame boundary.

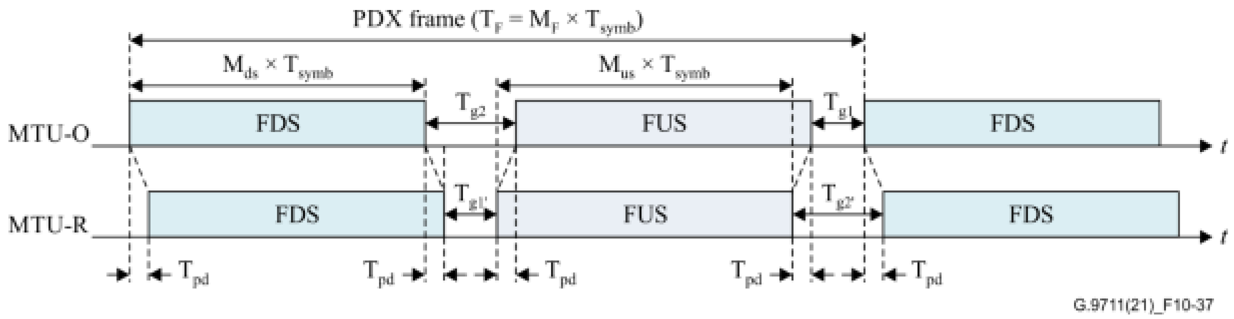


Figure 10-37 – Generic PDX frame structure

The PDX frame lengths of M_F = 36 and M_F = 23 symbol periods shall be supported.

The particular values of M_F and PDX frame parameters M_{ds}, M_{us}, and the PDX framing mode are set during the initialization (ITU-T G.994.1 handshake, see clause 12.3.2), according to the corresponding DPU-MIB parameters. The MTU shall support the ranges of values of M_{ds} as a function of M_F according to Table 10-30. Additional ranges of values of M_{ds} as a function of M_F are for further study.

Table 10-30 – M_{ds} values to support as a function of M_F

M_F	M_{ds} values supported
36	from 10 to 32
23	From 6 to 19

The same PDX frame structure shall be used during both initialization and showtime.

During showtime, symbol periods in a PDX frame are used for transmitting symbols of types defined in Table 10-31.

Table 10-31 – Different symbol types

Symbol type	Data frame type	DTU bytes	Applicable	Note
data (general type)	Normal data frame	B_{DN0} , B_{DN01} , or B_{DD}	NOI, DOI	Any type of data symbol.
Data_quiet	Normal data frame	B_{DN0}	NOI	A data symbol using Band 0 only, encoded as defined in clause 10.2.1
Data_data	Normal data frame	B_{DN01} in NOI, B_{DD} in DOI	NOI, DOI	A data symbol used for DTFO transmission (using both Band 0 and Band 1), encoded as defined in clause 10.2.1. This type is also used for sequential monitoring (DTFO sequential monitoring (DSQM)).
Data_DCM	Normal data frame	B_{DN0}	NOI	A data symbol in which Band 0 is encoded as a data symbol as defined in clause 10.2.1 and in which Band 1 is encoded as a DCM symbol (clause 10.2.2.3).

Table 10-31 – Different symbol types

Symbol type	Data frame type	DTU bytes	Applicable	Note
Data_preamble	Normal data frame	B_{DN0}	NOI	A data symbol in which Band 0 is encoded as a data symbol as defined in clause 10.2.1 and in which Band 1 is encoded as preamble symbol (clause 10.2.2.4).
Data_idle	Normal data frame	B_{D0}	NOI	A data symbol in which Band 0 is encoded as data symbol as defined in clause 10.2.1 and in which Band 1 is encoded as Idle symbol (clauses 10.2.1.7)
RMC (general type)	RMC data frame	B_{DR0} or B_{DR01}	NOI	Any type of RMC symbol.
RMC_idle	RMC data frame	B_{DR0}	NOI	An RMC symbol in which Band 0 is encoded as data symbol as defined in clause 10.2.1 and 10.5.5 and Band 1 is encoded as Idle symbol clause, 10.2.1.7.
RMC_quiet	RMC data frame	B_{DR0}	NOI	An RMC symbol using Band 0 only, clauses 10.2.1, 10.5.5
RMC_data	RMC data frame	B_{DR01}	NOI	An RMC symbol in which Band 0 is encoded as data symbol as defined in clause 10.2.1 and 10.5.5 in which Band 1 is used for DTFO transmission, clauses 10.7.2
RMC_DCM	RMC data frame	B_{DR0}	NOI	An RMC symbol in which Band 0 is encoded as data symbol as defined in clause 10.2.1 and 10.5.5 in which Band 1 is encoded as DCM symbol, clause10.2.2.3
RMC_preamble	RMC data frame	B_{DR0}	NOI	An RMC symbol in which Band 0 is encoded as data symbol as defined in clause 10.2.1 and 10.5.5 in which Band 1 is used for preamble symbol, clause 10.2.2.4.
RRC	Normal data frame	B_D=0	NOI NPSF only	A data symbol carrying RRC bytes only, clause 10.2.1.8
Idle (general type)	Idle data frame	0	NOI	Any type of Idle symbol, clauses 10.2.1.7
Idle_quiet	Idle data frame	0	NOI	Idle symbol with quiet signal in Band 1, clauses 10.2.1.7
Idle_idle	Idle data frame	0	NOI	Idle symbol with idle signal in Band 1, clauses 10.2.1.7
Idle_preamble	Idle data frame	0	NOI	Idle symbol with preamble signal in Band 1. Clauses 10.2.1.7 and

Table 10-31 – Different symbol types

Symbol type	Data frame type	DTU bytes	Applicable	Note
				10.2.2.4
Quiet	Idle data frame	0	DOI	Clauses 10.2.1.6
Sync	Idle data frame	0	NOI, DOI	Clauses 10.6, 10.2.2.1.
monitoring symbol (general type)	Normal data frame or RMC data frame or Idle data frame			A DCM, DSQM or preamble symbol
DCM symbol (general type)	Normal data frame or RMC data frame		NOI	A data_DCM or an RMC_DCM symbol
DSQM symbol (general type)	Normal data frame or RMC data frame		NOI, DOI	A data_data or an RMC_data symbol used for DSQM
preamble (general type)	Normal data frame or RMC data frame or Idle data frame			Any type of symbol using preamble signals in Band 0 and Band 1 or in Band 1 only. Clause 10.2.2.4.
preamble _preamble	Idle data frame	0	DOI	Symbol using preamble signals in both Band 0 and Band 1. Clause 10.2.2.4.

During the initialization, symbol periods in a PDX frame are used for transmission of the sync symbols and the initialization symbols (see clause 10.2.2). The format of initialization symbols is defined in clause 10.2.2.2.

Four modes of PDX framing are defined:

– TDD framing mode

– FDXC with TDD framing mode (FDXC framing mode);

– FDXZ framing mode;

– TDD fallback from FDXZ (TDDZ) framing mode.

The mode of the PDX framing is derived from the profile selected during ITU-T G.994.1handshake and the transmission timing grid shift, *s* (see clause 10.5.4). If the selected profile defines TDD mode only, the TDD framing mode shall be selected. If the selected profile defines FDX mode, the framing mode FDXZ shall be selected if parameter *s* (see clause 10.5.4) is equal to 0, and the FDXC framing mode shall be selected if parameter *s* is different from 0. During initialization, a fallback to TDD framing mode may be requested from FDXC framing mode and fallback to TDDZ framing mode may be requested from FDXZ framing mode.

In case of P2MP operation, a particular framing mode is applied per path (link); the same framing mode or its fallback framing mode shall be used in all paths (all links) of the same transmission line.

10.5.1 TDD framing mode

In TDD framing mode, only downstream transmission is allowed during FDS, and only upstream transmission is allowed during FUS, and the total gap time is of one symbol period, $M_F = M_{ds} + M_{us} + 1$ (i.e., K=1), see Figure 10-38. The valid range of T_{g1}' is from 3 µs to 15 µs. The MTU-R shall support all valid values of T_{g1}'. The MTU-O shall support $T_{g1} \geq 6.5$ µs. The sum $T_{g1}+T_{g2} = T_{g1}'+T_{g2}'$ shall be equal to one symbol period (T_{symb}).

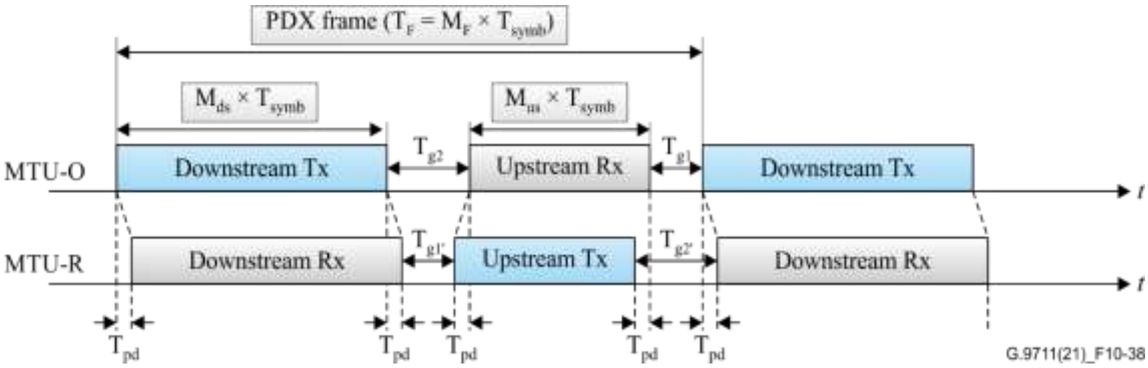


Figure 10-38 – TDD framing mode PDX frame structure

10.5.2 FDXC framing mode

In FDXC framing mode, both downstream and upstream transmission are allowed during both FDS and FUS, and the total gap time is one symbol period, i.e., $M_F = M_{ds} + M_{us} + 1$ (i.e., K=1), see Figure 10-39. Figure 10-39 also shows timing alignment between TDD framing mode (an ITU-T G.9711 link in TDD framing mode or an ITU-T G.9701 line) and MGfast in FDXC framing mode when operated in the same binder.

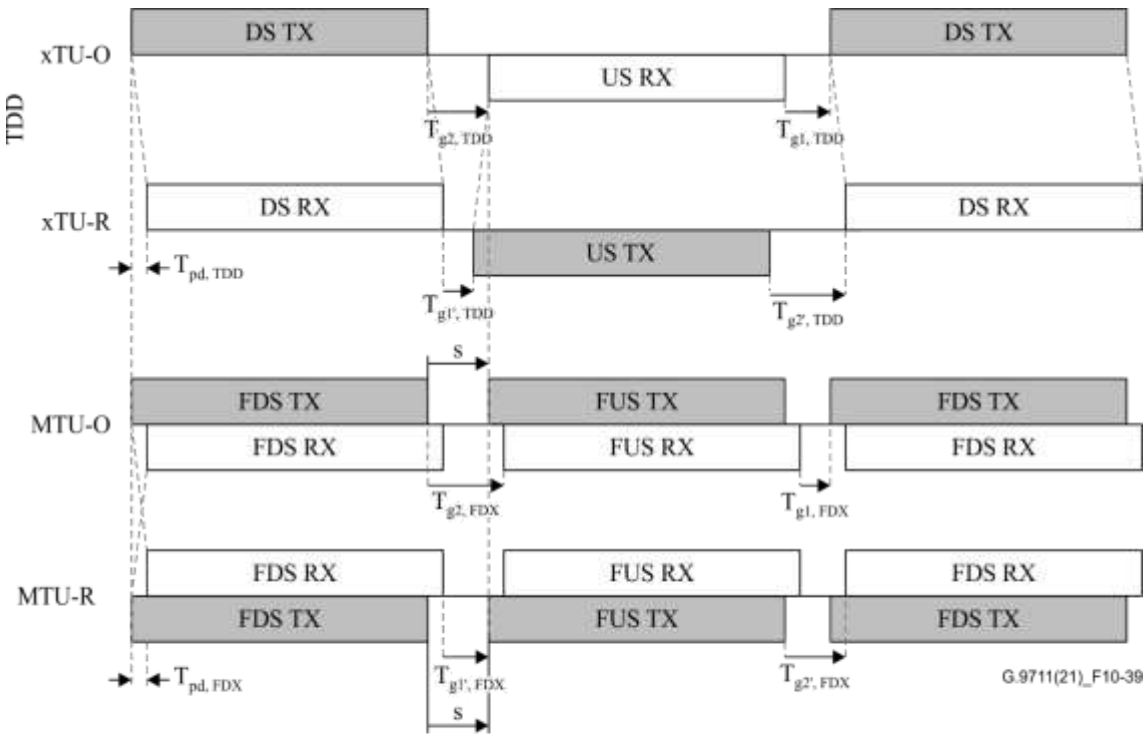


Figure 10-39 – FDXC framing mode PDX frame structure

NOTE 1 – The time shift between the FUS RX and US RX symbol boundaries shown in Figure 10-39 is within the applied value of the cyclic extension.

As shown in Figure 10-39, in FDXC framing mode, both the MTU-O and MTU-R shall transmit with respect to the downstream and upstream symbol boundaries during FDS and FUS, respectively.

The first symbol of the downstream FDS starts at the boundary of the PDX frame. The first symbol of the downstream FUS starts with a time shift from the FDS last symbol that creates a time gap between the downstream FDS and FUS. This time gap is called a transmission grid shift, *s*; the time period between the start (sample x_0) of the last downstream FDS symbol position and the start (sample x_0) of the first downstream FUS symbol position is, accordingly, $Tsymb + s$. The value of *s* is expressed in samples at the Nyquist frequency, $1/(2N\times fsc)$, in the range between 1 and $2N$-1. The same value of the transmission grid shift shall be used in the upstream. The MTU-O indicates the value of *s* to the MTU-R in O-SIGNATURE message.

NOTE 2 – For all FDXC links of a vectored group the value of *s* is intended to be the same.

To enable coexistence with a link or a line using TDD framing mode, the MTU-O shall apply an appropriate time position of both its downstream transmission in FUS and its upstream transmission in FUS with respect to the reception of the upstream sub-frame in the TDD links operating in the same binder (see Figure 10-39). The MTU-O shall select the appropriate time position for FUS transmission, which is controlled by the value of the transmission grid shift *s*. The MTU-R, under control of the MTU-O, shall adopt the indicated value of *s* (by applying a time gap equal to $s+T_{symb}$ from the start (sample x_0) of the last upstream symbol of FDS and the start (sample x_0) of the first upstream symbol of FUS) and also adjust the value of T_{g1}' in the aim to achieve the best performance for the given CE (see clause 10.4.4). This adjustment facilitates the desirable TAD of the upstream transmit symbol and downstream receive symbol in FUS. The valid values of T_{g1}' are from 0 to T_{symb}. The MTU-R shall support all valid values of T_{g1}'. In all cases, the sum $T_{g1}+T_{g2} = T_{g1}'+T_{g2}'$ shall be equal to one symbol period (T_{symb}).

NOTE 3 – For optimal echo cancelling, the value of T_{g1}' should be selected to keep an alignment of the received and transmit symbols at both sides of the loop within the duration of the cyclic extension. For example, this can be achieved by synchronizing the transmission of the downstream symbol over the U-O reference point with the transmission of the upstream symbol over the U-R reference point , i.e., to set $T_{g1}' = s-T_{pd}$. If the alignment cannot be kept inside the duration of the cyclic extension, e.g., the loop is too long or the synchronization with TDD links cannot be maintained, the FDXC link may fall back to TDD framing mode during initialization (see clause 12.3.3.1).

NOTE 4 – If symbol boundaries of the downstream FUS transmission, the upstream FUS transmission, and the US reception in TDD links are aligned as shown in Figure 10-39, then the minimum impact of NEXT from the FDXC link on upstream performance of the TDD link and the best performance of the FDXC link for the given value of CE is achieved. The alignment between downstream FUS transmission and upstream FUS transmission corresponds to the TAD value equal to the propagation delay T_{pd} of the corresponding FDXC link. The FDXC and TDD links are aligned by synchronizing the downstream FUS transmission with the upstream reception (RX US) in TDD links.

10.5.3 FDXZ framing mode

In FDXZ framing mode, both downstream and upstream transmission is allowed during both FDS and FUS, and no time gaps are present between FUS and FDS transmissions (s = 0) in both directions of transmission, $M_F = M_{ds} + M_{us}$ (i.e., K=0), see Figure 10-40a. When in FDXZ framing mode, no coexistence is possible with a TDD link (an ITU-T G.9711 link in TDD framing mode or an ITU-T G.9701 line) when they operate in the same binder.

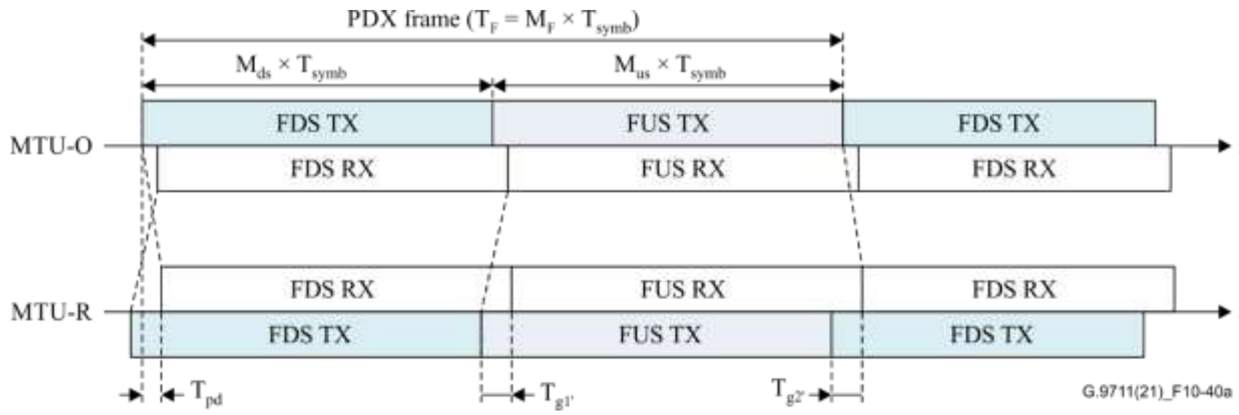


Figure 10-40a – FDXZ framing mode PDX frame structure

In FDXZ framing mode the parameter T_{g1}' is negative and determines the TAD at the MTU-R. The definition of parameters T_{g1}, T_{g2}, T_{g1}' and T_{g2}' remains the same as in TDD and FDXC framing modes, but $T_{g1} + T_{g2} = T_{g1}' + T_{g2}' = 0$, see Figure 10-40a. During the initialization, MTU-O requests the MTU-R to adjust the value of T_{g1}', same as in other modes, to set the desirable value of TAD.

NOTE 1 – This value of TAD is typically smaller than or equal to the propagation delay T_{pd} of the longest physical transmission line in the vectored group. The required CE can be minimized if the T_{g1}' is set so that the transmit symbol boundaries at the MTU-O and MTU-R are aligned in time. If the duration of the cyclic extension is not sufficient, e.g., the loop is too long, the FDXZ transmission line may fall back to TDDZ framing mode during initialization.

NOTE 2 – When FDXZ links are present in the vectored group, no TDD links should be used in the same vectored group. However, TDDZ links can be used in the same vectored group.

10.5.3.1 TDD fallback from FDXZ (TDDZ framing mode)

In TDDZ framing mode, only downstream transmission is allowed during FDS, and only upstream transmission is allowed during FUS, and the total gap time ($T_{g1} + T_{g2} = T_{g1}' + T_{g2}'$) is of one symbol period, $M_F = M_{ds} + M_{us} + 1$ (i.e., K=1). In this mode, the gap between the downstream PSF and upstream PSF shall be such that the upstream FUS is aligned at the U-O reference point with the upstream FUS with the same M_{us} of other links or lines in the vectored group, as shown in Figure 10-40b. This is achieved by keeping the last symbol position in the downstream PSF unoccupied (quiet symbol position).

NOTE 1 – If the last downstream PSF symbol position is used for vectored transmission in the binder, the impedance of both the MTU-O and MTU-R after TDDZ fallback should not change.

The TDDZ mode shall be supported only in profiles supporting FDX and intended exclusively to facilitate a fallback in cases FDXZ operation is not possible or not beneficial (see clause 12.3.3.1). The valid value of T_{g1}' shall be from 0 to T_{symb}.The MTU-R shall support all values of T_{g1}' that are required to support the alignment between TDDZ and FDXZ, as defined in clause 10.5.3.

NOTE 2 – The value of T_{g1}' depends on the propagation delay; the expected values are in the range from T_{symb}-2T_{pd} to T_{symb}-2T_{pd}+CE.

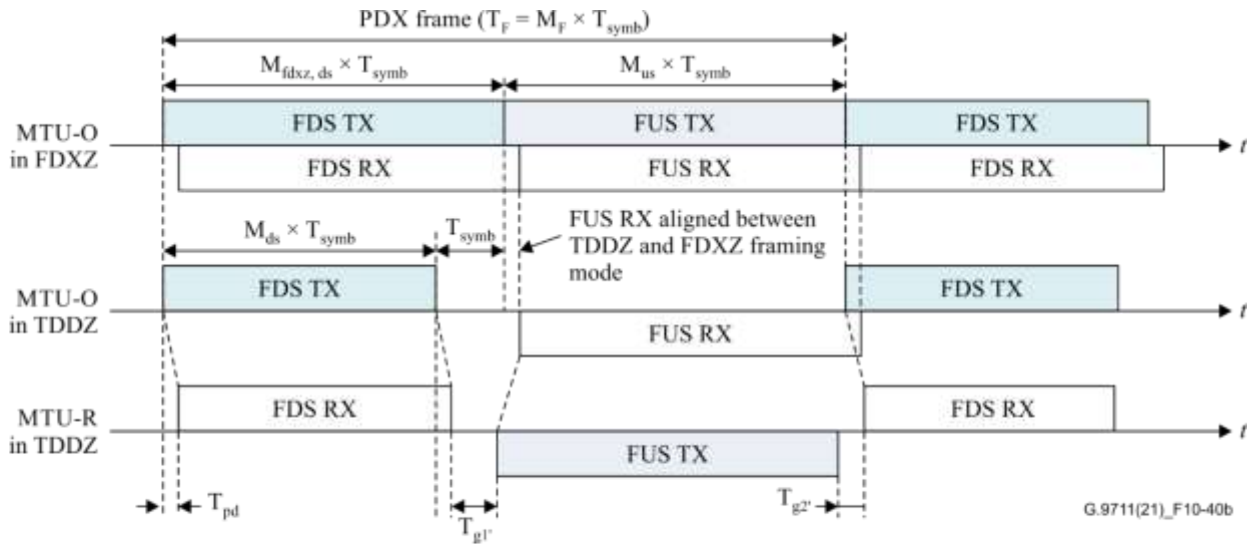


Figure 10-40b – TDDZ framing mode: PDX frame structure and alignment with FDXZ framing

10.5.5 RMC symbol position

The RMC symbol position shall be used to transmit an RMC symbol.

All rules defined in this clause for RMC symbol shall be equally applied to any of its derivatives: RMC_data, RMC_idle, RMC_quiet, RMC_DCM, or RMC_preamble symbols.

An RMC symbol shall be transmitted every PDX frame during the L0 link state.

The format and encoding of RMC symbol are described in clause 9.6.

The position of the downstream RMC symbol and the upstream RMC symbol is offset by D_{RMCds} and D_{RMCus} symbol periods from the start of the first downstream symbol position and from start of the first upstream symbol position in a PDX frame, respectively, as described in Figure 10-41. The value of the offset is assigned by the DP during initialization (see clause 12.3.2). The same value of D_{RMCds} shall be used for downstream RMC symbols in all lines of the vectored group, and the same value of D_{RMCus} shall be used for upstream RMC symbols in all lines of the vectored group. The valid ranges of D_{RMCus} and D_{RMCds} are from 1 to min(M_{us}−1, floor($T_{ack\_max\_R}/T_{symb}$)-2) and 1 to min(M_{ds}−1, floor($T_{ack\_max\_O}/T_{symb}$)), respectively.

Figure 10-41 illustrates RMC and sync symbol positions in PDX frames (notated *R* and *S*, respectively) of a superframe with $CNT_{SF} = P$ for the case of TDD framing mode and FDXC framing mode respectively. Symbol positions notated *D* indicate those can be used for other symbol types, based on the rules defined in clause 10.5, and symbol positions notated *S* are used for sync symbols, as defined in clause 10.6. Figure 10-41 also presents the downstream and the upstream logical frames. A logical frame in a particular transmission direction starts from the RMC symbol and ends on the last symbol position just before the next RMC symbol transmitted in the same direction.

In case of TDD mode, symbol positions in a logical frame assigned for downstream transmission are indexed from 0 to (M_{ds} –1). Symbol positions assigned for upstream transmission in a logical frame are indexed from 0 to (M_{us} –1). The indexing for each transmission direction starts from the RMC symbol, whose position has index zero in both upstream and downstream.

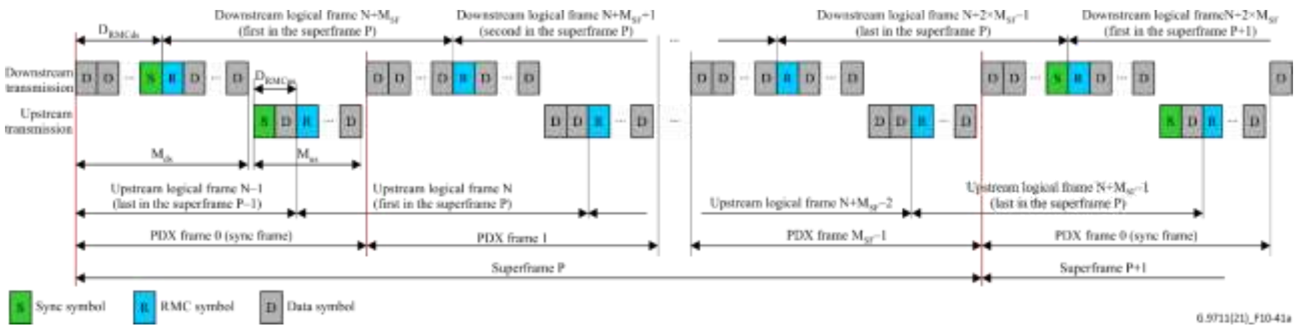


Figure 10-41a – Example of sync symbol and RMC symbol positions in TDD framing mode

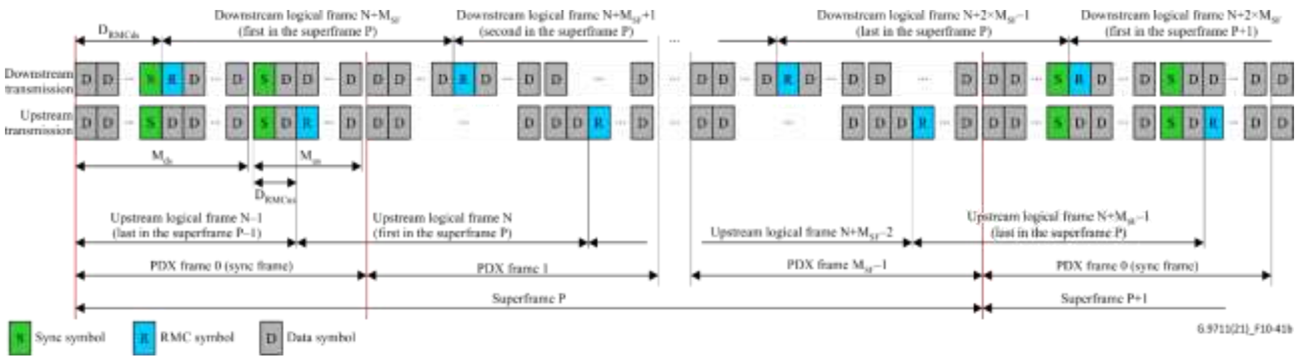


Figure 10-41b – Example of sync symbol and RMC symbol positions in FDXC framing mode

In case of FDX mode, symbol positions in both downstream and upstream logical frames are numbered from 0 to M_F–2 if FDXC framing mode is used and from 0 to M_F–1 if FDXZ framing mode is used.

As shown in Figure 10-41, any logical frame that starts during a PDX frame of a particular superframe shall be considered belonging to this superframe (even though the end of the last logical frame of a superframe is transmitted at the beginning of the next superframe).

Logical frames shall be counted using a modulo 2^{16} logical frame counter. The transmitter shall increment the logical frame count (CNT_{LF}) every time a logical frame is sent. The CNT_{LF} values are defined for upstream ($CNT_{LF\text{-}us}$) and downstream ($CNT_{LF\text{-}ds}$). The $\mathrm{CNT_{LF}}$ shall be reset at the transition into showtime: the $CNT_{LF\text{-}ds}$ shall be reset at the first downstream logical frame transmitted at the showtime and the $CNT_{LF\text{-}us}$ shall be reset at the first upstream logical frame transmitted at the showtime.

10.5.6 Data symbol positions

The data symbol position can be used to transmit a data symbol.

All rules defined in this clause for data symbol shall be equally applied to any of its derivatives: data_data, data_idle, data_quiet, data_DCM, or data_preamble symbols.

Besides, data symbol positions can be used to transmit the following symbol types:

– Preamble symbol in DOI (preamble_preamble symbol type);
– RRC symbol;
– Idle symbol;
– Quiet symbol.

Downstream data symbols shall be transmitted at downstream symbol positions of a logical frame with indices starting from 1 and determined by the parameters TTR_{ds}, TA_{ds}, $TDOI_{ds}$, TTR_{NPSFds} and $TBUDGET_{ds}$ defined in clause 10.7.1 and DTFO rules defined in clause 10.7.2. In TDD mode, the number of data symbols in a downstream logical frame that does not contain a sync symbol may be up to M_{ds}–1, and in those that contain sync symbol may be up to M_{ds}–2. Index 0 is assigned to the downstream RMC symbol.

Upstream data symbols shall be transmitted at upstream symbol positions of a logical frame with indices starting from 1 and determined by the parameters TTR_{us}, TA_{us}, $TDOI_{us}$, TTR_{NPSFus} and $TBUDGET_{us}$ defined in clause 10.7.1 and DTFO rules defined in clause 10.7.2. In TDD mode, the number of data symbols in an upstream logical frame that does not contain a sync symbol may be up to M_{us}-1 and in those that contain sync symbol may be up to M_{us}–2. Index 0 is assigned to the upstream RMC symbol.

In FDX mode, the number of data symbol positions in both downstream and upstream logical frames that do not contain sync symbols can be either up to M_F–1 (in case of FDXC mode) or up to M_F (in case of FDXZ mode). In downstream logical frames containing sync symbols (sync frames), the number of data symbol positions can be up to M_F–2 and M_F–1 for FDXC and FDXZ modes, respectively. The corresponding values in upstream sync frames are M_F–3 and M_F–2. Index 0 is assigned to the downstream RMC symbol in the downstream logical frame and to the upstream RMC symbol in the upstream logical frame.

An idle symbol may be transmitted at any data symbol position that is not used by a data symbol using the rules determined by the selected configuration parameters for discontinuous operation (see clauses 10.7.1 and 10.7.2). This applies to both upstream and downstream.

An RRC symbol may be transmitted at NOI data symbol positions of NPSF when B_D=0 in NOI_{NPSF}. If transmission of RRC symbols is allowed (at initialization, O-MSG 1), and B_D=0 in NOI_{NPSF}, RRC symbols shall be transmitted at all NOI_{NPSF} data symbol positions within the limits determined by TBUDGET.

A preamble_preamble symbol maybe used only during data symbol positions in DOI and are intended for recovering the DTFO DOI block (see clause 10.7.3.2.3).

At data symbol positions that are not used by either a data symbol or an idle symbol, or a monitoring symbol or a preamble_preamble symbol, a quiet symbol shall be transmitted.

10.6 Superframe structure

The ITU-T G.9711 superframe structure is shown in Figure 10-42. The parameter M_{SF} identifies the number of PDX frames that comprise one superframe; the value of M_{SF} depends on the number of symbols in a PDX frame M_F as defined in Table 10-32.

Additional sets of $\{M_F, M_{SF}\}$ are for further study.

Table 10-32 – Mandatory sets of $\{M_F, M_{SF}\}$

M_F	M_{SF}
36	8
23	12

All PDX frames of the superframe shall have the same format as defined in clause 10.5. Superframes shall be transmitted one after another, with no gaps. The PDX frames of each superframe shall be indexed from 0 to $M_{SF} - 1$.

The first PDX frame of the superframe (index 0) is called a PDX sync frame, which is followed by $M_{SF} - 1$ regular PDX frames (indexed from 1 to $M_{SF} - 1$). Each PDX sync frame contains downstream sync symbols and upstream sync symbols. The first symbol of a superframe is D_{RMCds} –

1 symbol positions before the sync symbol transmitted during FDS. Other functions and transmission format of upstream and downstream sync symbols are defined in clause 10.2.2.1.

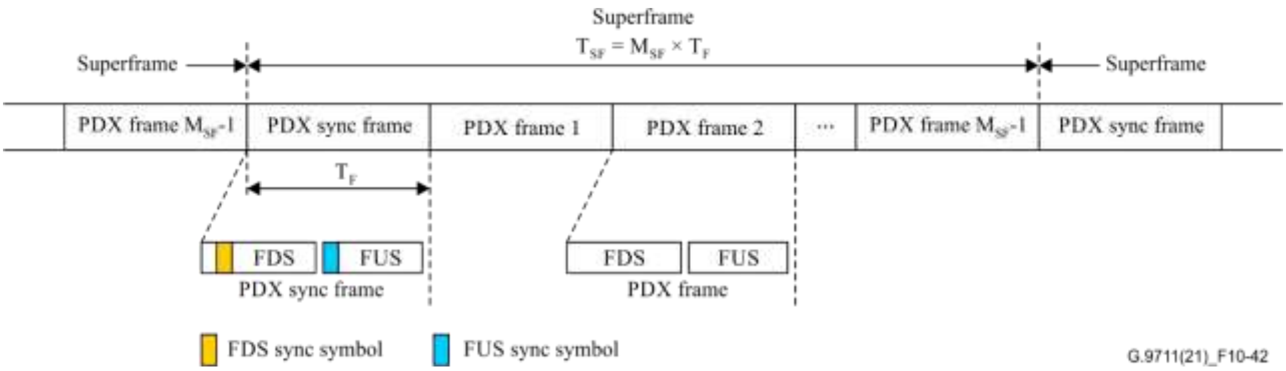


Figure 10-42 – Superframe structure

In TDD and TDDZ framing modes, the downstream sync symbol (downstream FDS sync symbol) shall be transmitted immediately before the downstream RMC symbol position, with the offset of (D_{RMCds} -1) symbols from the start of a PDX sync frame (see Figure 10-42). The downstream FDS sync symbol, accordingly, has index M_{ds}-1 in the last downstream logical frame of the previous superframe. The upstream sync symbol (upstream FUS sync symbol) shall be transmitted on the first symbol position in the upstream part of the PDX sync frame. The upstream FUS sync symbol, accordingly, has index ($M_{us} – D_{RMCus}$) in the last upstream logical frame of the previous superframe.

In FDXC and FDXZ framing modes, the upstream FUS sync symbol and the downstream FDS sync symbol shall be transmitted at the same symbol positions, respectively, as in the TDD framing mode.

In FDXC and FDXZ framing modes sync symbols shall be also transmitted during NPSF (Figure 10-42). Specifically, an upstream sync symbol shall be transmitted also during FDS (upstream FDS sync symbol), at the same symbol position as the downstream FDS sync symbol; and a downstream sync symbol shall be transmitted also during FUS (downstream FUS sync symbol), at the same symbol position as the upstream FUS sync symbol.

The same superframe structure shall be used during both the initialization and the showtime.

Superframes shall be counted using a modulo 2^{16} superframe counter. The transmitter shall increment the superframe count (CNT_{SF}) every time it starts a new superframe. The CNT_{SF} for upstream and downstream shall always be the same for any particular superframe and this value shall be synchronized over all the lines of the vectored group.

The symbol count (CNT_{SYMB}) shall be incremented after each symbol period passed via the U reference point (*MF* periods in total for each downstream logical frame and for each upstream logical frame). Symbol counts are defined in upstream ($CNT_{SYMB,us}$) and downstream ($CNT_{SYMB,ds}$). In a particular direction of transmission, CNT_{SYMB} shall be set to 0 at the symbol position which corresponds to the first RMC symbol transmitted when entering showtime and after reaching the value of CNT_{SYMB} =1022 (modulo 1023) while in showtime.

10.7 Dynamic time frequency operation (DTFO)

10.7.1 Normal and discontinuous operation intervals

10.7.1.1 Operation in TDD mode

In TDD mode each transmitted logical frame is divided into two intervals; a NOI, and a DOI. Both NOI and DOI are configured in every logical frame to facilitate transceiver power savings during link state L0 if not all of the time available for data transmission is needed.

The boundary between NOI and DOI is defined by the parameter *TTR*. In every logical frame the NOI starts from the RMC symbol and has a duration of *TTR* symbol periods. The value of *TTR* may be different from one logical frame to another. The valid range of *TTR* is from 1 to M_{ds} (including the sync symbol, if it resides within the NOI) in the downstream direction and from 1 to M_{us} (including the sync symbol if it resides within the NOI) in the upstream direction. The boundary between NOI and DOI is aligned among all links operating over all of the transmission lines of the vectored group, in both upstream and downstream (the same value of *TTRus* and the same value of *TTRds* in all transmission lines). An example showing division of logical frame into NOI and DOI is shown in Figure 10-43.

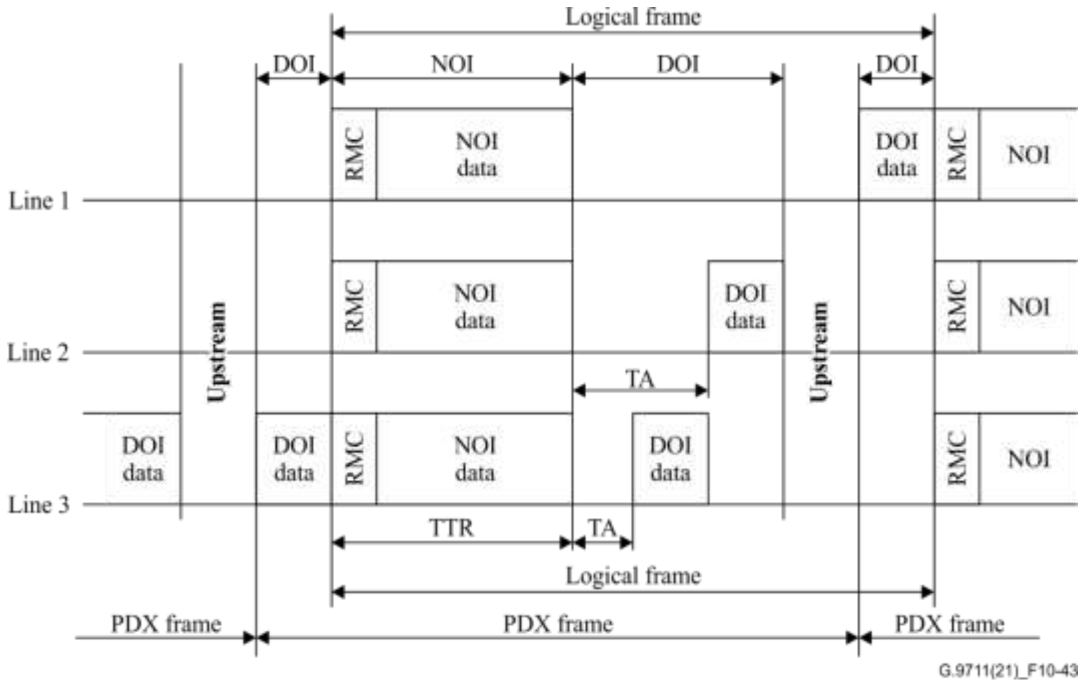


Figure 10-43 – General illustration of NOI and DOI in a logical frame (case of TDD mode, downstream)

Transmission during the NOI can be in Band 0 or in Band 0 and Band 1. DTFO Band 1 is adjacent to the DTFO Band 0. The index of the start sub-carrier of DTFO Band 1 is determined during initialization. The index of the stop sub-carrier of DTFO Band 0 shall be the index of the start sub-carrier of DTFO Band 1 minus one. Band 0 is used for normal operation, while transmission in Band 1 is a part of DTFO, as defined in clause 10.7.2. The start of DTFO Band 1 is aligned among all links operating over all the transmission lines of the vectored group per direction. The value of the Band 1 start subcarrier in upstream and downstream may be different. Band 1 is only used in PSF.

If the transmitting MTU path of a particular link does not have data to send during the NOI, it shall send one or more idle symbols or data symbols filled with dummy DTUs. Selection between transmission of idle symbols and data symbols filled with dummy DTUs is controlled by the DRA and depends on the value of the parameters *IDF* (see Table 9-6, Table 9-7) and the position of active DTFO blocks ($TDOI \neq 0$ or $T\_B1 \neq 0$). At NOI symbol positions located before or inside an active NOI DTFO block, only transmission of data symbols filled with dummy DTU is allowed if there is no data to send. Also, if a DOI DTFO block is active, only transmission of data symbols filled with dummy DTU is allowed in the NOI of the same logical frame, if there is no data to send. If an idle symbol is sent at a particular symbol position of the NOI, all the following symbols of the NOI shall also be idle symbols (except sync symbols, if they reside within the NOI). If the NOI ends with an idle symbol or a data symbol filled with dummy DTUs, no data_data symbols except if used as DSQM symbols (see clause 10.7.3.2) can be sent in the NOI, and all symbols of the DOI of the logical frame shall be quiet symbols, except DSQM symbols, preamble_preamble symbols and sync symbols, if the latter reside within the DOI. If there is no data to send in the DOI, it shall send data symbols filled with dummy DTUs.

Symbol periods within the DOI of a logical frame may be filled with either data_data symbols or with quiet symbols (see clause 10.7.2). Control of symbol positions in the DOI used for transmission of data_data symbols is provided by the DRA of the DPU. The DRA communicates to the MTU-O across the γ reference point the corresponding control parameters for each upstream and downstream logical frame in the associated TXOP primitives (see Table 8-4):

Transmission budget (*TBUDGET*): the total number of symbol positions allocated for the RMC symbol and data symbols in the combined NOI and DOI of a logical frame that does not contain sync symbol. In a logical frame that contains a sync symbol, the number of symbol positions allocated for the RMC symbol and data symbols in the combined NOI and DOI of the logical frame is equal to either *TBUDGET* or (*TBUDGET*-1). It is (*TBUDGET*-1) when the last data symbol position to be allocated for the given *TBUDGET* value has index that is the same as or is larger than the index of the sync symbol position. As a result, the last data symbol position in a logical frame containing sync symbol has the same index as in a logical frame with the same *TBUDGET* value that does not contain a sync symbol.

NOTE – The value of *TBUDGET* determines the index of the last symbol position in the logical frame that is allowed to be used for transmission of a data symbol. This index is equal to (*TBUDGET*-1) if $TBUDGET \leqslant TTR$, otherwise it is equal to (*TBUDGET*+*TA*-1).

TTR: the number of symbol positions in the NOI, including the sync symbol position if it resides within the NOI.

TA: the number of quiet symbol positions inserted before the first data_data symbol transmission in the DOI.

TDOI: the number of contiguous data_data symbol positions inside the DOI. In the TDD mode, the value shall be equal to *TBUDGET-TTR* if *TBUDGET* > *TTR*. Otherwise, it shall be equal to 0.

IDF: indicates that the MTU is allowed to send only data symbols filled with dummy DTUs in the NOI if the MTU does not have data to send over the NOI symbol positions allowed by *TBUDGET*.

The value of $TBUDGET_{ds} + TA_{ds}$ shall not exceed M_{ds} and the value of $TBUDGET_{us} + TA_{us}$ shall not exceed M_{us}.

In case *TBUDGET* is less than *TTR*, on the symbol positions starting from the index *TBUDGET* to the index (*TTR* -1) in the logical frame, the MTU shall transmit idle symbols.

A minimum number of data symbols (containing data or dummy DTUs) *MNDSNOI* (not counting the RMC symbol) shall be transmitted during the NOI in Band 0 of each logical frame. The value of MNDSNOI shall be equal to 2 in both directions. After $MNDSNOI_{ds}$ data symbols have been sent and only dummy DTUs are available until the end of the downstream logical frame, the MTU-O shall send, depending on the value of parameter IDF_{ds}, either idle symbols or data symbols until the end of the NOI (see Table 9-6, Table 9-7) and only quiet symbols in the DOI. After $MNDSNOI_{us}$ data symbols have been sent and only dummy DTUs are available until the end of the upstream logical frame, the MTU-R shall send, depending on the value of parameter IDF_{us}, either quiet symbols or data symbols until the end of the NOI (see Table 9-7) and only quiet symbols until the end of the DOI.

The value of TTR_{ds} shall be $TTR_{ds} \geq MNDSNOI_{ds} + 1$ and the value of TTR_{us} shall be $TTR_{us} \geq MNDSNOI_{us} + 1$.

In P2MP mode, the values of all DTFO control parameters above (*TTR, TA, TA_B1, TB1, TDOI, TBUDGET*) shall be identical in all links operating over the same transmission line, except on some links *T_B1* or *TDOI* or both could be set to 0. The values may be different in upstream and downstream.

The transmit PSD setting for Band 0 used during NOI may be different from those used during the DOI. The PSD settings for Band 1 in NOI and DOI are the same (see clause 12.3.5).

Both MTU-O and MTU-R shall support a separate baseline bit-loading table for each of the intervals (a bit-loading table for NOI and a bit-loading table for the DOI). The NOI and DOI baseline bit-loading tables in both upstream and downstream are established during initialization (see clauses 12.3.4.2.7 and 12.3.4.2.8) and updated after transition into showtime (see clause 10.7.3.1).

The baseline bit-loading tables for both NOI and DOI are updated via eoc-based OLR procedures (SRA and TIGA), as defined in clauses 13.2.1.1 and 13.2.2.1, respectively. The active bit-loading tables for both NOI and DOI are updated through the RMC by the FRA commands defined in Table 9-10 (for the downstream) and Table 9-11 (for the upstream).

10.7.1.2 Operation in FDX mode

In FDX mode, a NOI is defined in both the PSF and NPSF. A DOI is defined only in PSF; in NPSF transmission ends at the end on the NOI. Accordingly, the following framing parameters associated with the DTFO are defined:

– *TTR*: for PSF and NPSF (TTR_{PSF} and TTR_{NPSF});

– *TA*: for PSF only ($TA_{PSF} = TA$);

– *TBUDGET*: the total number of symbol positions allocated for the RMC symbol and data symbols in the NOI_{PSF}, NOI_{NPSF}, and DOI of a logical frame that does not contain sync symbols. In a downstream logical frame that contains a sync symbol, the total number of symbol positions allocated for the RMC symbol and data symbols in the NOI_{PSF}, NOI_{NPSF}, and DOI of a logical frame is equal to either *TBUDGET* or (*TBUDGET*-1). In an upstream logical frame, since it contains two sync symbols (see Figure 10-44c), that number is either *TBUDGET*, (*TBUDGET*-1), or (*TBUDGET*-2).

  NOTE 1 – The index of the last symbol position that is allowed to be used for transmission of a data symbol is determined, besides *TBUDGET*, by the values of *TDOI* and *TTR*, while $TBUDGET \leq TTR_{PSF} + TTR_{NPSF} + TDOI$.

– *IDF*: relates to NOI symbols in both PSF and NPSF (NOI_{PSF} and NOI_{NPSF}, respectively);

– *TDOI*: For PSF only.

The valid values for DTFO parameters in PSF (TTR_{PSF}, TA_{PSF}) and *IDF* are the same in FDX mode as defined for TDD mode in clause 10.7.1.1. The valid values for other parameters are subject for the following conditions:

1) $TTR_{NPSFds} \leq M_{us}$, $TTR_{NPSFus} \leq M_{ds}$

2) $TBUDGET_{ds} + TA_{PSFds} \leq M_{ds} + TTR_{NPSFds}$

3) $TBUDGET_{us} + TA_{PSFus} \leq M_{us} + TTR_{NPSFus}$

Conditions 2 and 3 indicate that no data symbol positions in NPSF are allowed outside the NOI, as shown in Figure 10-44a.

NOTE 2 – The presence of NOI in NPSF, besides increasing the data rate, reduces latency and thus serves for delay-sensitive applications.

In any sub-frame, FDS or FUS, the number of NOI_{NPSF} symbols shall be smaller than or equal to the number of NOI_{PSF} symbols in the opposite transmission direction.

In case $TBUDGET \leq TTR_{PSF} + TTR_{NPSF}$, TDOI shall be set to 0.

NOTE 3 – using DOI is case the required capacity could be accommodated in the NOI reduces efficiency of the vectored group operation and should be avoided.

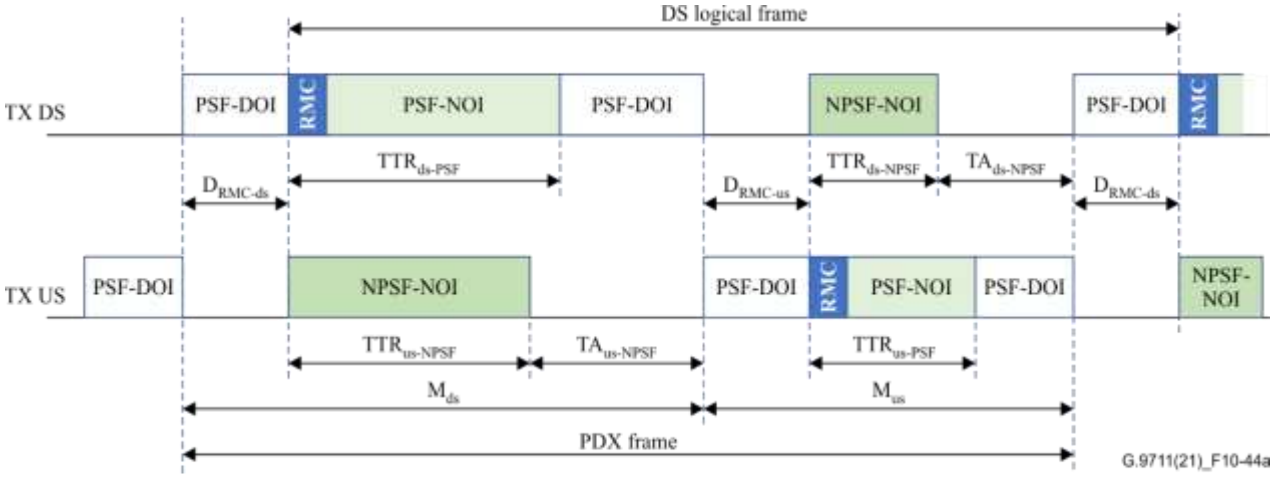


Figure 10-44a – PDX frame using DO

If in a particular sub-frame, FDS or FUS, $TTR_{PSF} \leq M\text{-}D_{RMC}$, the TTR_{NPSF} NOI symbols shall be allocated starting from the RMC symbol position in the opposite direction, as depicted in Figure 10-44a, i.e., the first NOI_{NPSF} symbol is aligned with the RMC symbol in the opposite direction.

If in a particular sub-frame, FDS or FUS, $TTR_{PSF} > M\text{-}D_{RMC}$ and $TTR_{NSPF} > M\text{-}D_{RMC}$, the TTR_{NPSF} NOI symbols shall be allocated in two groups of consecutive symbols, as in the example shown in Figure 10-44b:

– The first group of $TTR_{NPSF} – M + D_{RMC}$ symbols shall be allocated from the start of the NPSF;

– The second group of $M\text{-}D_{RMC}$ symbols shall be allocated starting from the RMC symbol position in the opposite direction, i.e., the first symbol of the second group is aligned with the RMC symbol in the opposite direction.

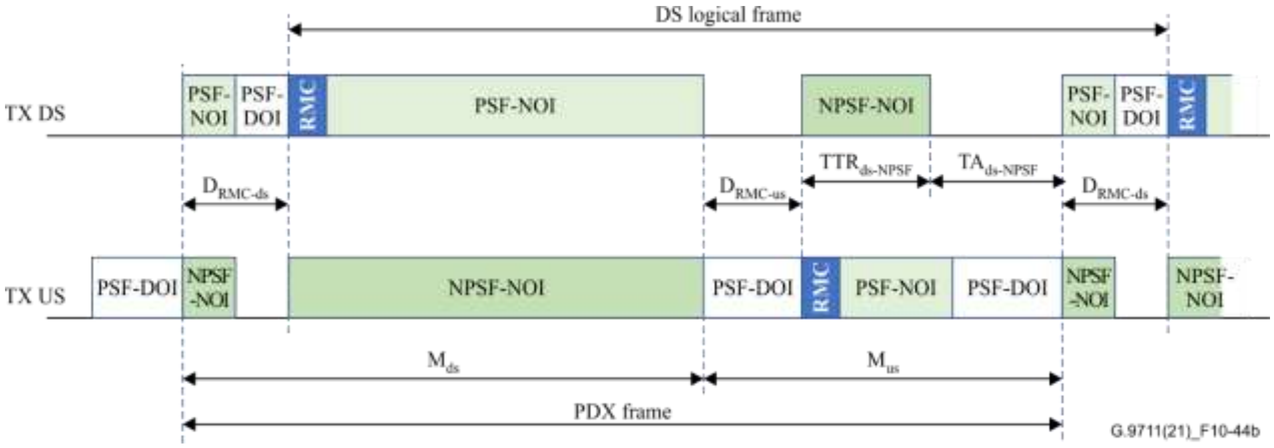


Figure 10-44b – PDX frame using DO in FDX mode (*$TTR_{NPSFus} > M_{ds}\text{-}D_{RMCds}$*)

The case of a sync frame ($TTR_{NPSF} \leq M\text{-}D_{RMC}$) is shown in Figure 10-44c.

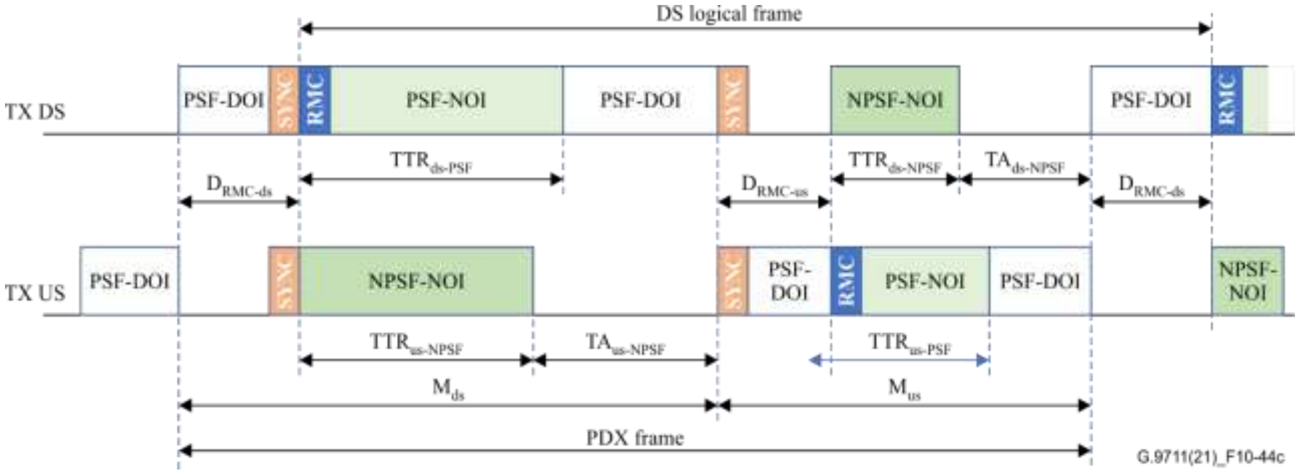


Figure 10-44c – PDX frame using DO in FDX mode (*$TTR_{PSF} \leq M\text{-}D_{RMC}$*)

NOTE 4 – In case of crosstalk-free environment (e.g., coax cable pair, see Annex D and Annex X), when no pre-compensation signals are required, idle symbols and quiet symbols have both zero transmission power. Therefore, setting *IDF*=0 is always appropriate, unless RRC is required or TPS_TESTMODE is activated, and should be used for power savings. With this, no DOI is actually needed for power saving purposes, which corresponds to the following settings:

– $TTR_{PSFds} = TTR_{NPSFus} = M_{ds}$

– $TTR_{PSFus} = TTR_{NPSFds} = M_{us}$

NOTE 5 – The NOI parts of the logical frame are subject for vectoring and thus sensitive to impedance changes. Therefore, it's beneficial if TTR_{NPSF} values, same as TTR_{PSF} values, are aligned across the vectored group. In case durations of PSF and NOI_{NPSF} are not aligned, the impedance of the transmitter should be kept stable till the end of the TTR_{PSF} of the opposite direction. During the DOI in the opposite direction, the transmitter sends quiet symbols (to support crosstalk avoidance).

NOTE 6 – Since transmission of RRC is not possible during the Idle symbols and Quiet symbols, use of Idle and Quiet symbols may result in higher latency of some retransmitted DTUs. This can be avoided by no use of Idle symbols (IDF =1) and no use of DOI. The associated compromise involves a trade-off between latency reduction versus power saving.

In case NPSF has insufficient capacity to transmit data symbols, RRC can still be supported in NPSF using RRC symbols (see clause 9.5).

A minimum number of data symbols (containing data or dummy DTUs) $MNDSNOI_{PSF}$ = *MNDSNOI* = 2 shall be transmitted during the NOI_{PSF} in Band 0 of each logical frame as defined in 10.7.1.2. A minimum number $MNDSNOI_{NPSF}$ = (*MNDSNOI*+1) data symbols (containing data or dummy DTUs) shall be transmitted in the NOI_{NPSF} at the symbol positions where the RMC symbol and the *MNDSNOI* data symbols of the NOI_{PSF} of the same sub-frame are transmitted in the opposite direction. The following conditions shall apply:

– $TTR_{NPSFds} \geq MNDSNOI_{NPSFds} = MNDSNOI_{us}+1$;

– $TTR_{NPSFus} \geq MNDSNOI_{NPSFus} = MNDSNOI_{ds} + 1$.

If the transmitting MTU path of a particular link does not have data to send during the NOI for PSF or NPSF, it shall send one or more idle symbols or data symbols filled with dummy DTUs. Selection between transmission of idle symbols and data symbols filled with dummy DTUs is controlled by the DRA and depends on the value of the parameters *IDF* (see Table 9-6, Table 9-7) and the position of active DTFO blocks (*TDOI*≠0 or *T_B1*≠0). At NOI symbol positions located before or inside an active NOI DTFO block, only transmission of data symbols filled with dummy DTU is allowed if there is no data to send. Also, if a DOI DTFO block is active, only transmission of data symbols filled with dummy DTU is allowed in the NOI of the same logical frame, if there is no data to send. If an idle symbol is sent at a particular symbol position of the NOI_{PSF} or NOI_{NPSF}, all the following symbols of this NOI shall also be idle symbols except sync symbols, if they reside within the NOI, and the data symbols of the NOI_{NPSF} specified by the $MNDSNOI_{NPSF}$ value. If the NOI_{PSF} ends with an idle symbol or a data symbol filled with dummy DTUs, only monitoring symbols (see clause 10.7.3.2) can be sent in Band 1 of this NOI, and all symbols of the DOI of the logical frame shall be quiet symbols, except monitoring symbols and sync symbols (if the latter reside within the DOI). If there is no data to send in the DOI, it shall send data symbols filled with dummy DTUs. Also, the symbol positions of the NOI, in both PSF and NPSF, that are not covered by TBUDGET, shall be filled by idle symbols.

The start frequency of DTFO Band 1 in each transmission direction is aligned among all links operating over all the transmission lines of the vectored group.

The PSD settings in NOI_{NPSF} may be different from those used during the NOI_{PSF} and DOI_{PSF}. Further, both the MTU-O and MTU-R shall support a separate baseline bit-loading table for NOI_{NPSF}. This baseline bit-loading table, for both upstream and downstream, is established during initialization (see clauses 12.3.4.2.7 and 12.3.4.2.8, respectively) and can be updated during the showtime by using eoc-based OLR procedures (SRA and TIGA), as defined in clauses 13.2.1.1, 13.2.1.2 and 13.2.2.1, respectively. The active bit-loading tables are updated by using the FRA, as defined in clause 13.3.1.

10.7.2 DTFO operation

The DTFO operation is intended to reduce power consumption and complexity of the vectoring through frequency and time division access between the transmission lines of the vectored group. For DTFO, the DRA can assign to each link two blocks of symbol positions on which data_data symbols can be transmitted: one block of data_data symbols can be assigned during the NOI_{PSF} (called NOI DTFO block) and another block of data_data symbols can be assigned during the DOI (called DOI DTFO block). No data_data symbols shall be transmitted inside the NOI_{NPSF}.

The assignment of DTFO blocks is configured for each link and for each logical frame in both upstream and downstream using configuration parameters *TA_B1*, *T_B1*, *TA, TTR and TDOI*:

– The parameter *TA_B1* indicates the first symbol position of the NOI DTFO block. The RMC symbol position corresponds to *TA_B1*=0. For *TA_B1*, symbol positions are counted only within the PSF.

– The parameter *T_B1* indicates the number of contiguous symbol positions assigned to the NOI DTFO block. For *T_B1*, symbol positions are counted only within the PSF.

– The parameter *TA* determines the first symbol position of the DOI DTFO block (see 10.7.1).

– The parameters *TDOI* represent number of contiguous symbols in the DOI DTFO block (see 10.7.1).

The value of *TA_B1+T_B1* shall be smaller than or equal to the TTR_{PSF}. The value of *TA* + *TDOI* shall be smaller than or equal to the size of the DOI. In TDD mode, *TDOI* = *TBUDGET-TTR* (assuming $TBUDGET \geq TTR$) and 0 otherwise. In FDX mode, $TDOI \leq TBUDGET - TTR_{PSF} - TTR_{NPSF}$.

Figure 10-45 describes the PSF symbol positions of the DTFO blocks as a function of the logical frame configuration parameters. In FDX mode, a block of NPSF symbol positions (not shown in the Figure) is present inside the logical frame. The NPSF symbol positions are not counted (skipped) when the allocation of DTFO blocks is derived using parameters TTR_{PSF}, *TA_B1*, *T_B1*, *TA* and *TDOI*.

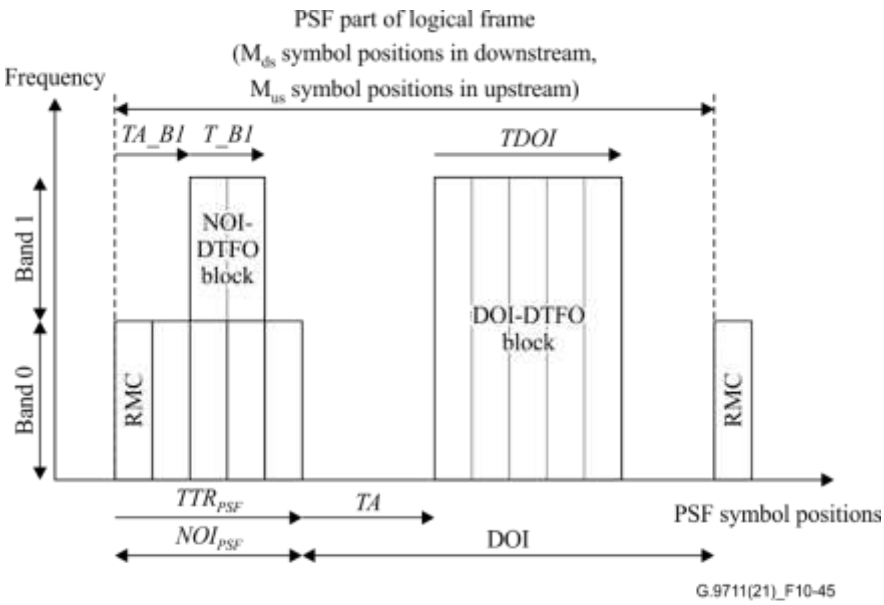


Figure 10-45 – Logical frame configuration for NOI and DOI DTFO blocks

If use of Band 1 is enabled during initialization, the following DTFO blocks may be assigned per logical frame and direction to one transmission line:

– The NOI DTFO block, comprising symbols consisting of all applicable sub-carriers of the Band 0 and Band 1 (the DTFO subcarriers are only those in Band 1) on all symbol positions of the NOI DTFO block.

– The DOI DTFO block, comprising symbols consisting of all applicable sub-carriers of the Band 0 and Band 1 (the DTFO subcarriers are all those in Band 0 and Band 1) on all symbol positions of the DOI DTFO block.

If use of Band 1 is disabled during initialization, only the DOI DTFO block comprising all subcarriers of the Band 0 can be assigned.

In P2MP mode, all links operating over the same transmission line use independently assigned DTFO blocks determined by individual DTFO settings for the following parameters *TTR*, *TA*, *TDOI*, *TA_B1* and *T_B1*. Each link may use, within its SUPPORTEDCARRIERS set, all the subcarriers of Band 1 in the assigned NOI DTFO block and all the subcarriers of both Band 0 and Band 1 in the assigned DOI DTFO block.

The allowed symbol types in the absence of DTFO restoration on all links of the transmission line and in the absence of DCM on all links of all transmission lines of the same vectored group are defined in this clause. The allowed symbol types in the presence of DTFO restoration on at least one link of the transmission line are defined in clause 10.7.3.2.3. The allowed symbol types in the presence of DCM on the current transmission line or on at least one other transmission line are defined in clause 10.7.3.2.1.

DRA shall not assign DTFO blocks overlapping in time to links operating over different transmission lines of the same vectored group. Moreover, the DRA shall not assign DTFO blocks overlapping in time to links of the same P2MP group if SUPPORTEDCARRIERS of those links overlap in the Band 1.

Except for DCM symbols, in each DTFO block, only the assigned links operating over a transmission line shall transmit on their assigned subcarriers ($Z_i \neq 0$), while all other links operating over transmission lines of the same vectored group shall transmit:

– data_idle symbols in case of NOI DTFO block ($Z_i=0$, $Z_i' \neq 0$ on all DTFO subcarriers), or

– data_quiet symbols in case of NOI DTFO block ($Z_i=0$, $Z_i'=0$ on all DTFO subcarriers), or

– quiet symbols in case of DOI DTFO block (Z_i=0, Z_i'=0 on all subcarriers).

On the symbol positions of the assigned NOI DTFO block, both the Band 0 and Band 1 shall be active, i.e., the sub-carriers of the Band 0 and Band 1 assigned to the link shall be loaded as specified in clause 10.2. On those symbol positions the following symbol types are allowed: data_data, RMC_data or sync symbols.

For the symbol positions of the NOI outside the assigned NOI-DTFO block, except the sync symbol positions, only the Band 0 shall be active and the Band 1 shall be inactive, i.e., only the sub-carriers of the Band 0 assigned to the link shall be loaded as specified in clause 10.2 and Z_i shall be set to 0 for all sub-carriers of the Band 1. On those symbol positions, on subcarriers of Band 1 assigned to the link, the MTU-O shall either disable transmission (in which case data_quiet or RMC_quiet symbols are allowed) or enable transmission of pre-compensation signals associated with other links (in which case data_idle or RMC_idle symbols are allowed), while the MTU-R shall disable transmission (in which caseonly data_quiet or RMC_quiet symbols are allowed).

NOTE 1 – Transmission of pre-compensation signals in the Band 1 outside the assigned NOI-DTFO block may improve performance of links on other transmission lines (targeted lines) through beam-forming. However, it increases the complexity of the vectoring.

NOTE 2 – The VCE might also disable transmission of pre-compensation signals in Band 1 if identical baseline bit-loading tables are intended to be used for Band 1 in NOI and DOI.

For symbol positions in the assigned DOI DTFO block, both Band 0 and Band 1 (if enabled) shall be active, i.e., the sub-carriers of the Band 0 and Band 1 assigned to the link shall be loaded as specified in clause 10.2. On those symbol positions the following symbol types are allowed: data_data or sync symbols.

For the DOI symbol positions outside the assigned DOI DTFO block, except the sync symbols, only quiet symbol positions shall be transmitted.

10.7.3 DTFO set-up and maintenance

The DRA may activate DTFO during initialization (see clause 10.7.3.2.1) or during showtime using the DTFO restoration procedure (see clause 10.7.3.2.3).

During showtime, the DRA may do maintenance of DTFO-active links. Since the DTFO block is expected to be used sporadically, depending on the traffic pattern, there might be relatively long periods of no use, which impacts receiver synchronization. Therefore, special monitoring symbols are transmitted over the DTFO blocks (over Band 1 in NOI and over Band 0 and Band 1 in DOI) in showtime to support synchronization. Two types of monitoring are defined: DCM and DSQM, as described in clause 10.7.3.2.

Concerning the use of DTFO, a link can have the following statuses (per direction):

- DTFO-disabled link: A link on which only DTFO-inactive state is allowed. It is not allowed to have restoration procedures or DTFO active state on DTFO-disabled link.
- DTFO-enabled link: A link on which both active and inactive DTFO states are allowed, and restoration procedures are allowed for transitioning the DTFO from inactive to active.
- DTFO-active link: A DTFO-enabled link on which the transmitter and the receiver are ready for data transmission in at least one of DTFO blocks. On a DTFO-active link monitoring symbols are sent to support receiver synchronization.
- DTFO-inactive link: A link in which the transmitter or the receiver or both are not ready for data transmission in DTFO blocks. This may be a DTFO-enabled link under DTFO restoration in NOI or DOI. This may also be a DTFO-disabled link. On a DTFO-inactive link, in the case of DSQM, no monitoring symbols are sent, but in the case of DCM, monitoring symbols are sent (see clause 10.7.3.1).

During showtime, a DTFO-inactive link can be restored back to the DTFO-active status using the DTFO restoration procedure (see clause 10.7.3.2.3).

The MTU-O DTFO RMC command (see clause 9.6) that controls DTFO states shall set the $DTFOEnable_{ds}$ =0 when DTFO is disabled in the downstream and set both *TDOIus*=0 and *T_B1us*=0 when DTFO is disabled in the upstream.

NOTE – When DTFO is disabled in both directions, the MTU-O DTFO RMC command should not be sent.

10.7.3.1 DTFO set-up during initialization

The initial settings of the DTFO for each link are established during initialization (see clauses 12.3.4.2.7, 12.3.4.2.8). These include the baseline bit-loading tables for Band 1 during NOI and DOI and Band 0 during the DOI.

During initialization, the DRA may disable DTFO of a link in a particular direction by selecting no DTFO monitoring in the DTFO descriptor in the O-PMD message or by assigning no symbols with active Band 1 in the "DTFO Band 1 symbol assignment", thus making this link DTFO-disabled in that direction when the transmitting path reaches showtime. In case no DTFO monitoring is indicated in the DTFO descriptor of O-PMD message, DTFO shall stay disabled until a DCMU procedure modifies the DTFO monitoring to either DCM or DSQM. Once DCM or DSQM monitoring is selected, either in initialization or after a DCMU, the DTFO is enabled or disabled at the discretion of the DRA and, for the downstream direction, indicated by setting the $DTFOEnable_{ds}$ bit in the MTU-O DTFO RMC command to 1 or 0, respectively.

During initialization, the DRA may activate DTFO for a specific direction of a link by assigning symbols with active Band 1 in the "DTFO Band 1 symbol assignment", and selecting either DCM or DSQM in the DTFO descriptor, making this link DTFO-enabled and DTFO-active in that direction when the transmitting path reaches showtime. The DTFO RMC command in the first logical frame of showtime shall have $DTFOEnable_{ds}$ =1.

Regardless whether DTFO is activated or not at initialization, for the downstream, the MTU-R receiver indicates to the MTU-O transmitter the DTFO monitoring limits, being the maximum updating periods (i.e., the maximum time gap allowed between consecutive receiver synchronization updates) for both sequential monitoring (updating period *T_upd_seq_max_ds*) and concurrent monitoring (updating period *T_upd_con_max_ds*) that are required for the link, as well as the *N_con_min_ds and T_dcm_min_ds* (see clause 10.7.3.2.1).

NOTE 1 – The value of maximum time gap allowed between consecutive receiver synchronization updates for sequential monitoring in the upstream is not communicated to the MTU-R because time positions of the DSQM symbols are anyway indicated by the MTU-O via the MTU-O DTFO RMC command (see Table 9.16).

Regardless whether DTFO is activated or not at initialization, for both downstream and upstream, the DRA indicates to the MTU-R in the O-PMD message (DTFO descriptor) the actual DTFO monitoring parameters for the link which include the type of monitoring (sequential or concurrent) and the actual values of the DCM monitoring parameters (see DTFO descriptor Table 12-68)), based on the DTFO monitoring limits that are indicated by the receiver during the initialization, taking into account the parameter values of the other active and initializing links.

NOTE 2 – Setting the DTFO monitoring parameters during initialization even in case of DTFO not activated during initialization results in saving time when activating DTFO through a restoration procedure, by avoiding a DCMU procedure.

With the given settings at initialization, transmission of monitoring symbols starts at the transition to showtime using the following rules:

- If DCM is selected to be activated in the DTFO descriptor, the DCM symbols shall be sent, regardless of whether DTFO is enabled or not and regardless whether DTFO is activated or not. The link is DCM-active.

- If DSQM is selected to be activated in the DTFO descriptor, DSQM symbols shall be sent if DTFO is activated and shall not be sent otherwise. The link is DSQM-active.
- If neither DCM nor DSQM is selected to be activated in the DTFO descriptor, DTFO is disabled and no monitoring symbols shall be sent.

10.7.3.2 DTFO maintenance during showtime

During long periods of absence of data symbols in DTFO blocks, the synchronization, the frequency domain equalizer (FEQ) updates, and the SNR updates of the subcarriers in Band 1 assigned to the link during the NOI and DOI are maintained by monitoring symbols.

The DTFO monitoring parameters for a particular direction of the link are derived by the DRA and first set during initialization. These monitoring parameters are applied at the start of showtime.

NOTE 1 – On a DTFO inactive link, DCM symbols may be present depending on the actual DTFO parameters indicated in O-PMD during initialization.

During showtime, the DRA may update the DTFO monitoring parameters by use of a DCMU procedure (see clause 13.6). If DCM is selected in the DTFO descriptor, the DCM symbols are sent regardless of whether DTFO is enabled or not and regardless whether DTFO is activated or not. Therefore, the transmission of DCM symbols continues unmodified during the restoration procedure. Transmission of DCM symbols is modified only by a DCMU procedure.

NOTE 2 – Within the overall group of DTFO-active links handled by the DRA, the particular type of monitoring for a particular direction may be either concurrent or sequential or a mix of both. However, all links of the same transmission line use the same monitoring type.

During showtime, the DRA may disable the DTFO in some active links. The MTU-R is informed of the disabling of the DTFO in the downstream by the $DTFOEnable_{ds}$ bit in the DTFO RMC command. The link enters the DTFO-disabled state in the downstream direction when the $DTFOEnable_{ds}$ bit is set to 0. The DRA shall maintain the $DTFOEnable_{ds}$ bit at 0 until the start of a restoration procedure (see 10.7.3.2.3.1). The MTU-R is not informed if DTFO is enabled or disabled in the upstream direction.

During showtime, the DRA may re-enable and re-activate the DTFO on a link using the DTFO restoration procedure. Restoration of the DTFO, is performed as described in clause 10.7.3.2.3.

After restoration, the DTFO is again further maintained by using monitoring symbols of the type (DCM or DSQM) assigned by the DRA.

Restoration of the DTFO may also be required after loss of receiver synchronization in Band 1 (while Band 0 works normally).

NOTE 3 – In case operation of Band 0 fails, a generic FRA-SRA or fast retrain is used to recover Band 0. It may also be used to recover Band 1.

10.7.3.2.1 DTFO concurrent monitoring

For DCM, the DRA determines a DCM group, which is a group of transmission lines with DCM active links sharing the same DCM active symbol position and the same set of DCM sequences. A particular DCM-active link shall belong to only one DCM group identified by its control parameter TA_dcm. The DRA shall set the DCM settings such that all links over all transmission lines of the same DCM group transmit DCM symbols on the same symbol position (denoted as the DCM active symbol position). On top of identical TA_dcm, this requires identical DCM period T_dcm, and identical position of the DCM active logical frames (i.e., logical frame within the superframe containing the DCM symbol).

The DCM settings are determined by the DRA for each direction separately during initialization and during showtime and send to the MTU-R in the DTFO descriptors during initialization (see clause 12.3.4.2.7 O-PMD) and during showtime (see clause 13.6 DCMU procedure).

The DRA shall determine the DCM settings in the DTFO descriptors for each transmit direction such that all MTU's for all links on transmission lines that are not part of a DCM group (e.g., DTFO inactive links, or DTFO active links with sequential monitoring) shall send only data_idle symbols or data_quiet during all active DCM symbol positions of all DCM groups (see also example in Figure 10-46a).

An MTU on a transmission line that is part of a DCM group shall send only specific symbol types, depending on DCM settings. These specific symbol types are determined by following rules:

For a symbol position within a logical frame corresponding to the TA_dcm value (DCM symbol position) of the current transmission line

- in a DCM active logical frame on links of the current transmission line, a DCM symbol shall be transmitted regardless of whether this symbol position falls inside a NOI DTFO block on the current transmission line or not. This symbol position is denoted as a DCM active symbol position.
- not in a DCM active logical frame (i.e., not a DCM active symbol position) on links of the current transmission line, a data_data, data_idle, data_quiet, RMC_data, RMC_idle or RMC_quiet symbol shall be transmitted (depending on TA_B1 and T_B1 value).

NOTE 1 – Example for first bullet in above list: DTFO block at symbol position index 0 to 4 (TA_B1=0, T_B1=5), DCM symbol on symbol position with index 2. Symbol type data_data only allowed on 0, 1 and 3 and 4.

This is also true in case the DTFO block consists of DSQM symbols.

For a symbol position within a logical frame that is different from the TA_dcm value of the current transmission line:

- and coinciding with a DCM active symbol position on at least one other transmission line, a data_idle, data_quiet, RMC_idle or RMC_quiet symbol shall be transmitted regardless of whether this symbol position falls inside a NOI DTFO block on the current transmission line or not.
- and not coinciding with a DCM active symbol position on any other transmission line, a data_data, data_idle data_quiet, RMC_data, RMC_idle, or RMC_quiet symbol shall be transmitted (depending on TA_B1 and T_B1 value).

NOTE 2 – Example for first bullet in above list: DTFO block at symbol position index 0 to 4 (TA_B1=0, T_B1=5), DCM symbol on another transmission line on symbol position with index 1. Symbol type data_data only allowed on 0 and 2 to 4.

An MTU that is not part of any DCM group shall send only specific symbol types, depending on DCM settings in the DTFO descriptor. These specific symbol types are the same as for a transmission line that is part of a DCM group for the symbol positions different from TA_dcm, i.e., following rules apply:

For a symbol position within a logical frame that is:

- coinciding with a DCM active symbol position on at least one other transmission line, a data_idle or data_quiet symbol shall be transmitted regardless of whether this symbol position falls inside a NOI DTFO block on the current transmission line or not.
- not coinciding with a DCM active symbol position on any other transmission line, a data_data, data_idle, data_quiet, RMC_data, RMC_idle or RMC_quiet symbol shall be transmitted (depending on TA_B1 and T_B1 value).

Symbol types used on DCM symbol positions are summarized in Table 10-33 (see also example in Figure 10-46a)

Table 10-33 – Symbol types during DTFO with DCM

Symbol Position			Symbol Type		
DCM symbol position on current transmission line	**DCM active logical frame on current transmission line**	**DCM active symbol position on other transmission lines**	**DCM symbol**	**data_idle or data_quiet symbol (Note)**	**data_data, data_idle or data_quiet symbol (Note)**
Yes	Yes	N.A.	X		
Yes	No	N.A.			X
No	No	Yes		X	
No	No	No			X
NOTE – On RMC symbol positions, data in Band 0 is replaced by RMC.					

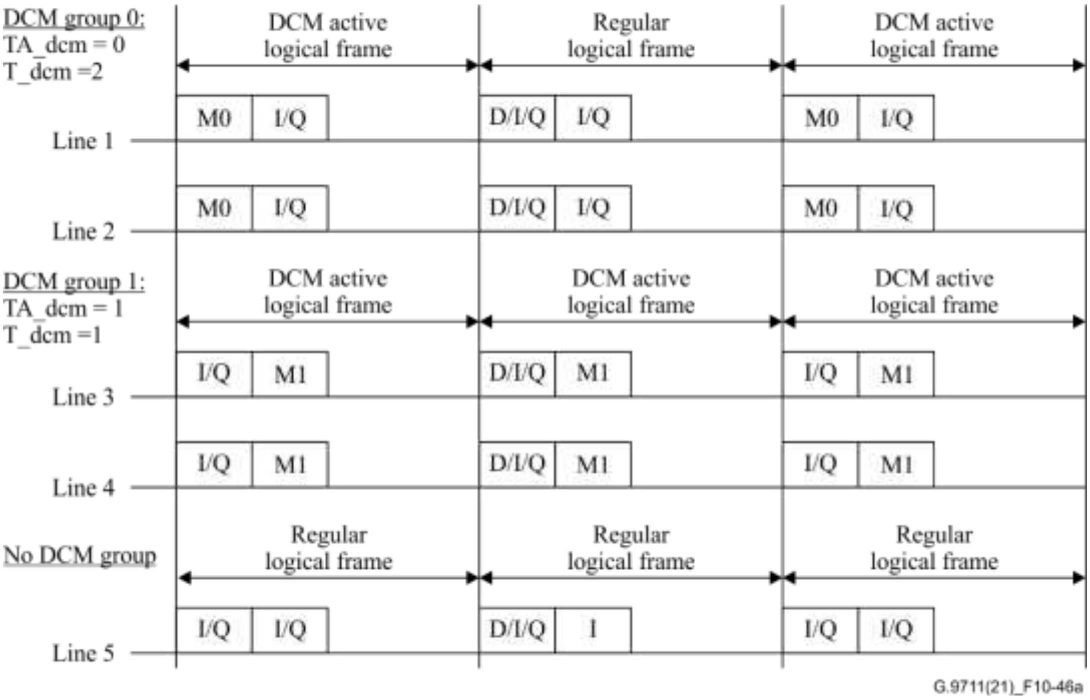


Figure 10-46a – Example of assignment of DCM symbol positions (M0 = DCM symbol position for DCM group 0, M1 = DCM symbol position for DCM group 1, I/Q= data_idle or data_quiet, D/I/Q=data_data, data_idle or data_quiet)

The DCM symbols for each DCM group are transmitted at symbol position with index *TA_dcm* within the DCM active logical frame which is determined by the DRA. The DRA shall assign one DCM symbol position per group. The valid values for *TA_dcm* shall be 0 (RMC symbol position), 1 or 2.

The DCM symbols shall be transmitted at the DCM active symbol position in the NOI part of a logical frame (NOI_{PSF} in FDX mode). DCM symbols shall be transmitted periodically, with a period of *T_dcm* = $k \times M_F$ symbols (i.e., a DCM active logical frame every k logical frames), where k is an integer k = 1, 2, …, 8 (for M_F=36) and k = 1, 2, …, 12 (for M_F =23) (i.e., up to one superframe). The minimum time period required between start of two adjacent DCM symbols is *T_dcm_min* expressed in number of PDX frames. The valid range of *T_dcm_min* is from 1 (one PDX frame) up to 4. The value of T_dcm_min is determined by the receiver at initialization. The value of T_dcm is determined by the DRA and sent to the MTU-R in the DTFO descriptors during initialization (see O-PMD) and during showtime (see DCMU procedure), and its value may be different in upstream and downstream.

NOTE 3 – The superframe length M_{SF} may not be divisible by the value of T_dcm. Hence the position of the DCM active logical frame within the superframe may shift from one superframe to another.

The DCM active logical frame is determined by the DRA and identified using the DCM active logical frame time marker in the DTFO descriptors during initialization and showtime. This time marker indicates the index of the DCM active logical frame within the reference superframe for the DCM group (see figure 10-46b). This reference superframe is also indicated in the DTFO descriptor.

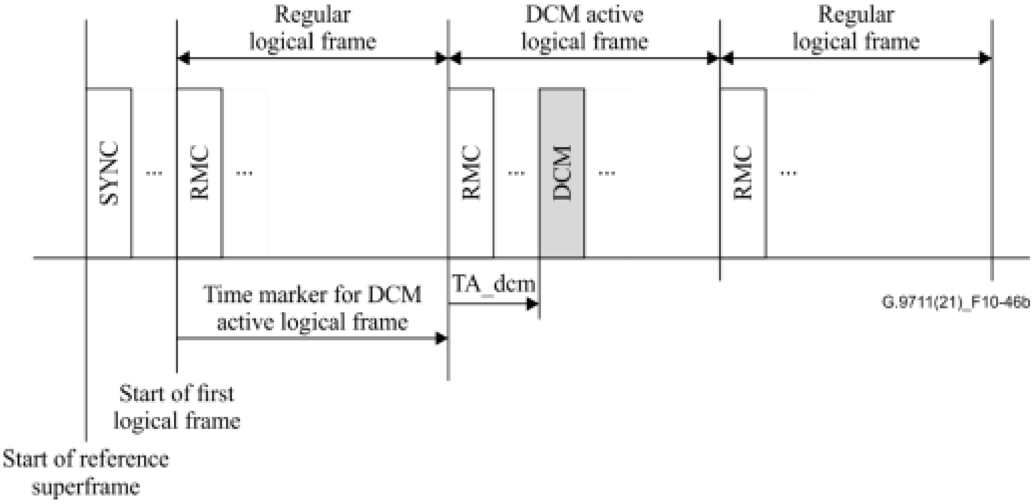


Figure 10-46b – Illustration of time marker to identify the DCM active logical frame

The DRA shall assign for each transmission line of the DCM group a DCM sequence with length of *N_dcm* bits. Each DCM symbol transmits one bit of the assigned sequence. After the entire sequence is transmitted, the next sequence shall be started from the next DCM symbol. The maximum length of the sequence is 64 bits. The valid values of *N_dcm* are 2 and all multiples of 4 from 4 to 64. The value may be different in upstream and downstream.

NOTE 4 – The assigned value of *N_dcm* is greater than or equal to the number of transmission lines at the MTU-O in the assigned DCM group.

At initialization, the receiver indicates to the transmitter the maximum time *T_upd_con_max*, within which at least one entire concurrent sequence (*N_dcm* bits) shall be transmitted, and within which at least the minimum number of non-Z DCM symbols, *N_con_min*, shall be transmitted. The valid values of *N_con_min* are all multiples of two in the range 2 to 512 and the valid values of *T_upd_con_max* are 1, 2, 3, …, 64 superframes, within following constraint using *T_SNR* = 8

$$N\_con\_min \le 4 \times \text{floor}\left(\left[(T\_upd\_con\_max \times M_{SF}) \times \left(\frac{1}{T\_dcm\_min}\right)\right]/4\right) - (T\_upd\_con\_max \times M_{SF}) \times \left(\frac{1}{T\_SNR}\right)$$

NOTE 5 – The value of *N_con_min* provides the necessary noise filtering required for FEQ update and under control of the receiver may span over more than 1 DCM sequence.

NOTE 6 – In case all DCM-active links belong to the same DCM group, there will be only one DCM symbol position per DCM active logical frame, at the RMC symbol position.

The transmitter shall encode the subcarriers assigned to the link in DCM symbols as specified in clause 10.2.2. DCM symbols shall not be precoded, i.e., Z_i=Z_i' for all subcarriers of Band 1.

All DCM sequences transmitted in a particular direction of a DCM group shall start at the same active DCM symbol position in all links of transmission lines of the DCM group. The time marker indicating the start of the DCM sequence is communicated by the MTU-O path to the MTU-R in DTFO descriptors at initialization and updated during showtime. The length of DCM sequences is denoted $Ndcm_{us}$ and $Ndcm_{ds}$ for upstream and downstream, respectively.

NOTE 7 – The receiver, for channel estimation for updating of its FEQ, may use correlation with the DCM sequence, starting at the first element of the DCM sequence and ending it at the last non-Z element of the DCM sequence. The receiver, for measuring *QLN*, see caluse 11.4.1.2.3, during showtime, may use the Z elements of the DCM sequence.

10.7.3.2.2 DTFO sequential monitoring

With sequential monitoring, the DSQM symbols are transmitted at symbol positions determined by the DRA and indicated for the upstream and downstream directions in the corresponding logical frame configuration RMC command (Table 9-6, for the downstream and Table 9-7, Table 9-9 for the upstream). As a consequence, the DSQM symbol positions are identical for all links operating over the same transmission line. The symbol position of the DSQM symbols may be different in different logical frames of a superframe and in different superframes.

The DRA shall assign DSQM symbol positions so that the time, between the start of two DSQM symbols or between the start of a DSQM symbol and the start of a data_data symbol or between the start of a DSQM symbol and the start of an RMC_data symbol, does not exceed the maximum allowed updating period for sequential monitoring (*T_upd_seq_max*) for any link of the transmission line indicated during initialization by the corresponding receiver of the corresponding transmission direction (see clause 12.3.4.2.1, 12.3.4.2.2). The valid values of T_upd_seq_max are from 1 to 64 superframes.

Transmission of DSQM symbols shall follow the rules regarding the allowed symbol types in the presence of DCM on other transmission lines, specified in clause 10.7.3.2.1 for MTUs that are not part of any DCM group: the DSQM symbols shall not be transmitted on the symbol positions used by DCM in other transmission lines, as indicated in the DTFO descriptor.

The format of the DSQM symbol is as of an RMC_data symbol or a regular data_data symbol with all associated rules applied:

– may be transmitted in either NOI or DOI;
– uses current active bit-loading tables established for Band 0 and Band 1, for subcarriers assigned to the link, for NOI and DOI, respectively, if PCS-LCM is used, and uses regular TCM otherwise;
– uses current settings for PCS-LCM parameters established for NOI and DOI, respectively;
– carries normalDTUs or dummy DTUs, in case no data for transmission over DTFO is available.

An example of DSQM timeline is shown in Figure 10-47. When no DTFO data is ordered by the DRA, only DSQM symbols are transmitted to maintain the updating period. As DTFO data is available, data_data symbols are transmitted. When again no DTFO data left is available, transmission of DSQM monitoring continues symbols resumes.

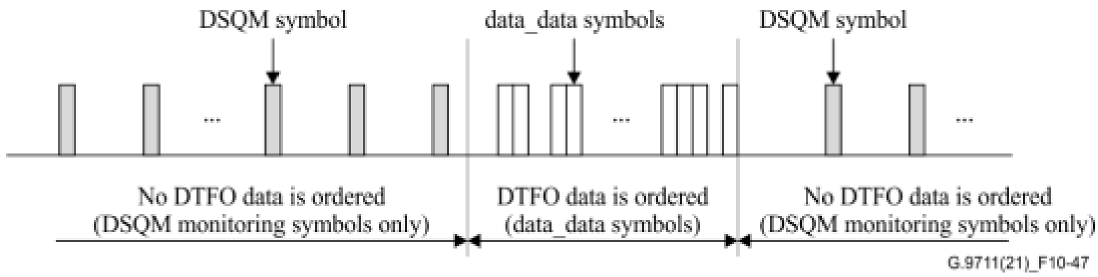


Figure 10-47 – Example of a DSQM timeline (only DTFO symbols shown, DSQM or data_data)

The active bit-loading table for DSQM symbols is either the baseline bit-loading table (for Band 0 and Band 1) or the FRA bit-loading table. The baseline bit-loading tables for the sub-carriers allocated to the link are determined at initialization (see clauses 12.3.4.2.7, 12.3.4.2.8) and updated during the show time using SRA. The FRA bit-loading table for the sub-carriers allocated to the link is determined separately for Band 0 and Band 1 (see clause 13.3.1).

10.7.3.2.3 Restoration of the DTFO

During showtime a DTFO restoration may be initiated, and is performed by transmission of preamble symbols. The transmitter shall encode the preamble symbols as specified in clause 10.2.2.4.

The DTFO restoration procedure takes place if the DRA intends to activate DTFO on a link in a particular direction, after it was temporary deactivate by the DRA or in caseDTFO fails due to loss of receiver synchronization in Band 1 or in case DTFO was not enabled and as a consequence not activated during initialization. The DTFO restoration procedure shall take place before the data transmission over DTFO is resumed.

The preamble symbols can be sent in only one DTFO block, either NOI DTFO block or DOI DTFO block. Preamble symbols shall fill the complete DTFO block under restoration. The DRA shall select all the necessary logical frame configurations to support restoration procedure for the selected DTFO block, such that at least one preamble symbol is sent inthe DTFO block under restoration is active in every logical frame and no symbols are active in the other DTFO block used in the same direction of transmission. The preamble symbols shall not be sent on symbol positions that coincide with DCM active symbol positions on any of the transmission lines.

NOTE 1 – The transmission of DCM symbols continues unmodified during the restoration procedure.

The restoration procedure is performed per link. As a consequence, in P2MP mode, more than one link of a transmission line, in a particular direction, may have restoration procedures ongoing simultaneously (which may or may not be synchronized). The preamble symbols, accordingly, may be sent over some links while other links of a transmission line may send non-preamble symbols on the same symbol positions.

NOTE 2 – In some cases, restoration of one DTFO block allows to send data in both DTFO blocks, because same transmission parameters can be used in both DTFO blocks or transmission parameters of the second DTFO block can be derived from the parameters of the restored one.

10.7.3.2.3.1 Restoration procedure initiated by the DRA

When the DRA concludes that DTFO in the downstream or upstream direction of the link needs to be restored, it requests the MTU-O path to start the DTFO restoration procedure of the appropriate DTFO block of the link.

Upon request by the DRA to start restoration of a downstream DTFO block ($DTFOCtrl_{ds}$ primitive turns on, see Table 8-4), the MTU-O shall set the $DTFOEnable_{ds}$ bit to 1 in the MTU-O DTFO RMC command, in the same logical frame, and transmit the selected DTFO blocks comprising of preamble symbols on the subcarriers assigned to the link and indicate it to the MTU-R by setting the *TxPreamble* bit in the logical frame configuration of the downstream RMC commands. Upon reception of the DTFO RMC command, the MTU-R shall set the *ReqDTFORestoration* bits to 1 for both DTFO blocks upon detection of the transition of the $DTFOEnable_{ds}$ bit from 0 to 1. The DTFO blocks comprising of preamble symbols shall be transmitted in all following logical frames until a downstream FRA on the subcarriers used in that DTFO block (see clause 13.3.1.1) is applied. Once the FRA is applied, the *TxPreamble* bit shall be reset in the downstream RMC command; the corresponding *ReqDTFORestoration* bit in the upstream RMC command shall be reset (see clause 10.7.3.2.3.2); and data symbols using the new active bit loading or monitoring symbols (DSQM) shall be used in the restored DTFO blocks. The MTU-O shall then indicate to the DRA that the restoration procedure is completed.

Upon request by the DRA to start restoration of an upstream DTFO block ($DTFOCtrl_{us}$ primitive turns on, see Table 8-4), the MTU-O shall send a request to the MTU-R by setting the *ReqPreamble* bit in the logical frame configuration of the downstream RMC command. Once the MTU-R detects that the *ReqPreamble* bit is set in the downstream RMC command, it shall transmit the selected DTFO blocks comprising of preamble symbols and indicate it to the MTU-O by setting the *TxPreamble* bit in the upstream RMC command. The DTFO blocks comprising of preamble symbols shall be transmitted in every logical frame until an upstream FRA on the subcarriers used in that DTFO block is applied. Once the FRA is applied, the *TxPreamble* bit shall be reset in the upstream RMC command; the *ReqPreamble* bit shall be reset in the downstream RMC command; and data symbols using the new active bit loading or monitoring symbols (DSQM) shall be used in the restored DTFO blocks. The MTU-O shall then indicate to the DRA that the restoration procedure is completed.

In the case of DCM monitoring type, DCM symbols shall be transmitted on the link before the start of the restoration procedure. If DCM symbols are not yet being transmitted a DCMU procedure (see clause 13.6) is required before the restoration procedure can start.

10.7.3.2.3.2 Restoration procedure initiated by the receiver

If the MTU-O receiver needs the restoration of DTFO, it shall indicate its DTFO restoration request to the DRA. The DRA shall initiate a restoration procedure of the selected upstream DTFO block, as specified in clause 10.7.3.2.3.1.

NOTE 1 – If the upstream DTFO is not restored before data transmission, higher BER could be observed.

If the MTU-R receiver needs the restoration of DTFO, it shall indicate its DTFO restoration request by setting the corresponding *ReqDTFORestoration* bit in the upstream RMC command. The MTU-R can indicate its request for restoration of the NOI DTFO block, DOI DTFO block, or both. Upon detection of the setting of any *ReqDTFORestoration* bit, the MTU-O shall indicate the request of the MTU-R to the DRA. By this request, the DRA shall initiate a restoration procedure of the selected downstream DTFO block, as specified in clause 10.7.3.2.3.1. In case MTU-R requests restoration of both DTFO blocks, the selection of the DTFO block to run the restoration procedure is on discretion of the DRA. The MTU-R shall set the *ReqDTFORestoration* bit to 0 for both DTFO blocks if it detects that the $DTFOEnable_{ds}$ bit in the received MTU-O DTFO RMC command is set to 0.

NOTE 2 – If the downstream DTFO is not restored before data transmission, higher BER could be observed.

NOTE 3 – In the case of DCM monitoring type, DCM symbols are already transmitted before a restoration procedure initiated by the receiver.

10.7.4 Logical frame configuration

For each of the transmission paths, the set of values {*TTR*, *TA*, *TBUDGET*, *IDF*, *T_B1*, *TA_B1*, *TDOI*, *DTFOCtrl*} is the logical frame configuration for TDD mode, including DTFO. The *DTFOCtrl* represents the DTFO enable primitive. In FDX mode, the *TTR* parameter contains two values: TTR_{PSF} and TTR_{NPSF} (see clause 10.7.1). The logical frame configuration may be different for the upstream and the downstream directions and may change from one logical frame to the next.

The MTU-O path indicates in the downstream RMC message of each logical frame the downstream logical frame configuration and the requested upstream logical frame configuration (see Table 9-7). The requested upstream logical frame configuration indicated in the downstream logical frame with $CNT_{LF,ds} = N + M_{SF}$ shall be indicated by the MTU-R as the upstream logical frame configuration in the upstream RMC message of the upstream logical frame with $CNT_{LF,us} = N+1$ (see Table 9-8 and Figure 10-41). The downstream logical frame configuration indicated in the downstream RMC message shall be applied in the next logical frame. The upstream logical frame configuration indicated in the upstream RMC message shall be applied in the in the next logical frame If the RMC message is lost, the receiver shall use the logical frame configuration parameters indicated in the last received RMC message.

NOTE – The MTU-O path is responsible to indicate its request for the new downstream and upstream logical frame configuration in the RMC message of the appropriate logical frame, so that timing requirements for application of TXOPds.indicate and the TXOPus.indicate primitives is compliant with the requirements defined in clause 8.1.1.

10.8 Alignment of transmissions in vectored group

The superframes transmitted by all MTU-Os of a vectored group shall be aligned in time so that the downstream sync symbols in the FDS sub-frames are aligned in time at the U-O reference points of the vectored transmission lines. All other symbols of the superframe transmitted by all MTU-Os of a vectored group shall also be aligned in time between themselves at the U-O reference points of the vectored transmission lines. The misalignment shall be evaluated as the time difference between reference samples of the aligned symbols of the vectored transmission lines (see clause 8.4.1, Figure 8-14) and is vendor discretionary.

NOTE 1 – If ITU-T G.9701 transceivers are part of the vectored group, the downstream FDS sync symbols are expected to be aligned with the downstream sync symbols of the ITU-T G.9701 transceivers.

To avoid performance degradation in a vectored group, the misalignment should be significantly smaller than the assigned value of the CE.

The MTU-O shall facilitate that the upstream symbols transmitted by all MTU-Rs of a vectored group be aligned between themselves at the U-O reference point by adjusting the value of T_{g1}' during the initialization, as described in clause 12.3.3.1.

NOTE 2 – If ITU-T G.9701 transceivers are part of the vectored group, the upstream FUS sync symbols are expected to be aligned with the upstream sync symbols of the ITU-T G.9701 transceivers.

To facilitate alignment in time, symbols in all transmission lines of a vectored group shall be assigned the same CE. Also, the PDX frame parameters M_F, M_{us} and M_{ds} shall be the same in all transmission lines of the vectored group. The CE length used for all transmission lines in a vectored group should be appropriate for the transmission line with the largest propagation delay.

NOTE 3 – If ITU-T G.9701 transceivers are part of the vectored group, the values of CE, M_F, M_{us} and M_{ds} are expected to be the same for both ITU-T G.9711 transceivers and ITU-T G.9701 transceivers in the vectored group.

11 Operation and maintenance (OAM)

11.1 OAM functional model

The OAM reference model of an ITU-T G.9711 link is shown in Figure 11-1 and contains OAM entities intended to manage all the transmission entities of the ITU-T G.9711 transceiver paths: the TPS-TC sub-layer, the PMS-TC sub-layer and the PMD sub-layer. The system-related OAM data refers to all relevant layers above the TPS-TC (which are not in the scope of this Recommendation).

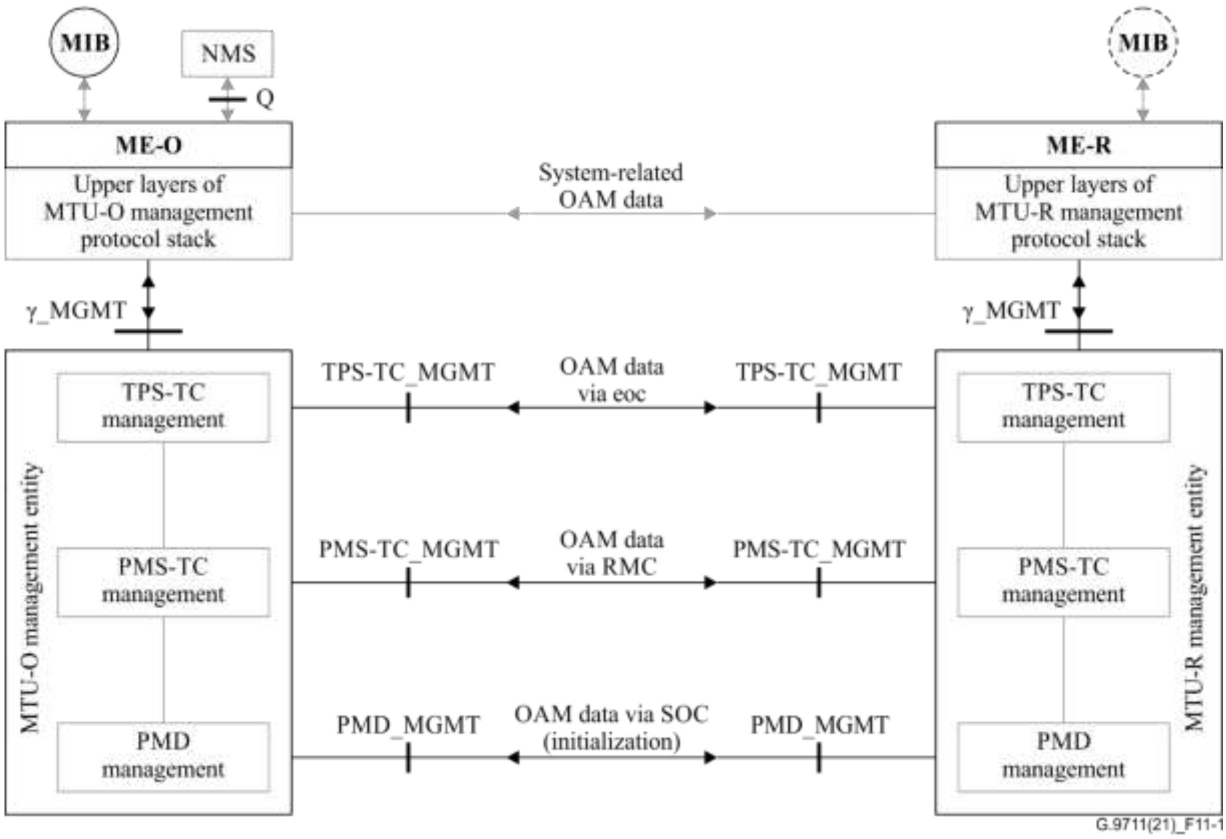


Figure 11-1 – OAM protocol reference model of ITU-T G.9711 link

The OAM data between the peer ITU-T G.9711 transceiver paths at the DPU and the NT is exchanged using the following OAM channels:

– an embedded operation channel (eoc) between respective TPS-TC entities, specified in clause 11.2.2;

– an RMC between respective PMS-TC entities, specified in clause 9.6;

– a special operations channel (SOC) between respective PMD layers during initialization only, specified in clause 12.2.

The system-related OAM data is transported between peer MEs using special eoc commands that provide a transparent channel between peer MEs (see clause 11.2.2.4 and Table 11-1). Time-sensitive data is transported over RMC (e.g., *lpr* – see Table 9-8).

The eoc and RMC are active only during the showtime state and SOC is used to support transceiver paths initialization and is deactivated during the showtime state. The OAM primitives and parameters exchanges via eoc, RMC and SOC are defined at the TPS_MGMT, PMS_MGMT and PMD_MGMT, respectively. Relevant OAM primitives and parameters, both intended for transmission to the peer MTU or received from peer MTU, are exchanges between the MME and its upper-layer ME via γ_MGMT interface.

The NMS, connected to the MTU-O via the Q interface, controls the OAM entities at both MTUs, and collects management data from all relevant OAM entities of both MTU-O and MTU-R. The ME-O provides the interface to the NMS (Q interface), and the interface with the DPU-MIB. The DPU-MIB contains all of the management information related to the ITU-T G.9711 link. It may be implemented to serve an individual link or to be shared between the links served by the DPU. In some implementations a MIB can also be established in the NT and connected to the NMS via the G-interface (see Figure 5-1) and it can be connected to the ME-O via the MME at the MTU-O using the eoc.

The ME-O shall update and store the set of near-end test parameters or far-end test parameters or both (the ones that can be updated during the showtime state) upon the request to do so from the NMS.

11.1.1 γ_MGMT interface

The γ_MGMT_O and γ_MGMT_R reference points describe logical interfaces between the MME and the ME-O (at the MTU-O) and ME-R (at the MTU-R), respectively (see Figure 8-1, Figure 8-2 and Figure 11-1). The interface is defined by a set of control and management parameters (primitives). These parameters are divided into four groups:

– parameters generated by the MME and submitted to the upper-layer ME;

– parameters retrieved by the upper-layer ME from the MME (requested by the ME to be submitted by the MME to upper-layer ME);

– parameters retrieved by the MME from the upper-layer ME. These parameters are used by the MME to control the MTU paths via TPS-TC_MGMT, PMS-TC_MGMT and PMD_MGMT interfaces;

– parameters generated by the upper-layer ME and submitted to the MME to control the local MTU paths or to be transported to the peer MME and submitted to the peer upper-layer ME.

The summary of the γ_MGMT primitives is presented in Table 11-1. The γ_MGMT parameters exchanged with the DPU-MIB are defined in [ITU-T G.997.3].

Table 11-1 – Summary of the γ_MGMT primitives

Primitive	Direction	Description	Reference
Link OAM primitives			
Line-related primitives	MME → ME	Represent anomalies and defects related to PMD and PMS-TC sub-layers.	Clause 11.3.1
Path-related primitives	MME → ME	Represent anomalies and defects of a particular path terminated by peer TPS-TCs.	Clause 11.3.2
Power-related primitives	MME → ME	Represent the status of the MTU power supply.	Clause 11.3.3
Line performance monitoring parameters	MME → ME	Represent parameters defined for line performance monitoring.	Clause 11.4.4
Link OAM parameters			
Status and test parameters	MME → ME-O	Represent various parameters that are computed by the MTU-O and passed to ME-O to indicate the overall performance of the MTU.	Clause 11.4.1
Retransmission configuration parameters	ME-O → MME	Control parameters provided by the DPU-MIB for configuration of the MTU retransmission function (valid at MTU-O only).	Clause 11.4.2
Vectoring configuration parameters	ME-O → MME	Control parameters provided by the DPU-MIB to define the required FEXT cancellation capabilities and characteristics of the line (valid at MTU-O only).	Clause 11.4.3
Data path configuration	ME-O → MME	Control parameters provided by the DPU-MIB for configuration of the MTU data path	Clause 11.4.7

Table 11-1 – Summary of the γ_MGMT primitives

Primitive	Direction	Description	Reference
parameters		function (TPS-TC) (valid at MTU-O only).	
P2MP group OAM parameters	ME-O → MME	Control parameters provided by the DPU-MIB to define a P2MP group on a transmission line (valid at MTU-O only).	Clause 11.5
Link activation and de-activation parameters (Note)			
Control of the MTU state machine	ME → MME	Primitives applied by the ME to control MTU state machine.	Clauses 12.1.2, 12.1.4.3
	MME → ME	Primitives related to the status of the MTU state machine reported by the MME to the ME.	
ITU-T G.994.1 phase	ME → MME	Control parameters provided by the ME to the MTU in support of ITU-T G.994.1 phase of the initialization	Clauses 12.3.2, 7.3
Channel discovery phase	ME-O → MME	Control parameters provided by the ME-O to the MTU-O in support of channel discovery phase of the initialization.	Clauses 12.3.3.2.1, 7.3
	MME → ME	Control parameters reported by the MTU to the ME during the channel discovery phase of the initialization.	
Channel analysis and exchange phase	ME-O → MME	Control parameters provided by the ME-O to the MTU-O in support of channel analysis and exchange phase of the initialization.	Clause 12.3.4.2.1
	MME → ME	Control parameters reported by the MTU to the ME during the channel analysis and exchange phase of the initialization.	
Link OLR parameters			
SRA control parameters	ME → MME	Control parameters provided by the ME to the MTU in support of SRA procedure.	Clause 13.2.1.1.2
RPA control parameters	ME → MME	Control parameters provided by the ME to the MTU in support of RPA procedure.	Clause 13.2.1.3.1
FRA control parameters	ME → MME	Control parameters provided by the ME to the MTU in support of FRA procedure.	Clause 13.3.1.1.1
TIGA control parameters	ME-O → MME	Control parameters provided by the ME-O to the MTU-O in support of TIGA procedure.	Clause 13.2.2.1.1
DBR control parameters	ME-O → MME	Control parameters provided by the ME-O to the MTU-O in support of BDR procedure.	Clause 13.5.1
DCMU control parameters	ME-O → MME	Control parameters provided by the ME-O to the MTU-O in support of DCMU procedure.	Clause 13.6.1
SPA control parameters	ME-O → MME	Control parameters provided by the ME-O to the MTU-O in support of SPA procedure.	Clause 13.2.1.4
SSA control parameters	ME-O → MME	Control parameters provided by the ME-O to the MTU-O in support of SSA procedure.	Clause 13.2.1.6

Table 11-1 – Summary of the γ_MGMT primitives

Primitive	Direction	Description	Reference
Link state transition parameters			
Link state transition request parameters	ME-O → MME	Control parameters provided by the ME-O to the MTU-O in support of the requested link state transition.	Clauses 12.1.1
System-related data transfer parameters			
System-related data and associated parameters to be transferred	ME → MME MME → ME	Data to be transferred to the far-end ME and associated parameters provided by the ME of one MTU to be transferred to the ME of the far-end MTU. The transfer is facilitated by primitives specified in Table 11-2.	Clause 11.2.2.4.1
Link reconfiguration			
Parameters related to link reconfiguration	ME-O → MME	Configuration parameters provided by the ME-O to the MTU-O for showtime reconfiguration of one or more links of a transmission line (SREC).	Clause 13.2.1.5.2.2
NOTE – The VCE or TCE may be involved in generating the ME-O to MTU-O information flow to coordinate timing and control parameters over multiple transmission lines.			

Table 11-2 – System-related primitives at the γ_MGMT reference point

Primitive name	Direction	Description
*.request(parameter)	ME → MTU	Requests the MTU to send the system-related OAM data (represented as a parameter) to the far-end MTU.
*.confirm	MTU → ME	Confirms that the requested data has been scheduled for transmission over eoc or RMC and that the MTU is ready to accept the next request.
*.indicate(parameter)	MTU → ME	Indicates reception of any system-related OAM data (represented as a parameter) from the far-end MTU.
NOTE – The specified set and format of primitives shall be applied to any eoc/RMC command (denoted as *) that provides a transparent channel between the near-end ME and the far-end ME to convey system-related primitives.		

11.2 Management functions and procedures over eoc

11.2.1 eoc transmission method

The eoc is established between the peer TPS-TC management entities and provides exchange of eoc packets between the MTU-O and MTU-R. Each eoc packet is formatted as defined in clause 11.2.2.1 and carries one or more eoc messages formatted as defined in clause 11.2.2.2. The transmission protocol that defines eoc message exchange between peer MTUs is defined in clause 11.2.2.3.

11.2.1.1 eoc packet format

The eoc packet may contain one or more eoc messages. The length of an eoc packet containing m eoc messages with the lengths of $P1$, $P2$, ... Pm bytes is: $P = P1 + P2 + \ldots Pm + 2m + 2$ bytes, where

2*m* corresponds to the 2-byte control field per message, and the final two bytes are for the frame check sequence (FCS). The value of *P* is determined by the MME. The maximum value of *P* is 1024 bytes.

The format of an eoc packet shall be as shown in Figure 11-2. Each message should have a format as defined in clause 11.2.2.2 and could be an eoc message or an eoc message segment. Only one segment of a particular eoc message shall be included in a packet.

Byte	**MSB** **LSB**
1, 2	Control field 1
3	eoc message 1 byte 1
...	....
P1 + 2	eoc message 1 byte *P1*
P1 + 3, *P1* + 4	Control field 2
P1 + 5	eoc message 2 byte 1
...	....
P2 + *P1* + 4	eoc message 2 byte *P2*
	……….
	Control field m
...	eoc message *m* byte 1
...	....
P − 2	eoc message *m* byte *Pm*
P − 1	FCS high byte
P	FCS low byte

Figure 11-2 – eoc packet format containing *m* eoc messages with length *P*1, *P*2, …, *Pm* bytes

The byte 1 of the eoc packet shall be transmitted first and the MSB of each byte shall be transmitted first.

The format of the 16-bit control field is presented in Figure 11-3.

MSB LSB

Control field byte 1								**Control field byte 2**							
15	14	13	12	11	10	09	08	07	06	05	04	03	02	01	00
		Length										C/R	Priority		

Figure 11-3 – Control field format

The 10-bit length field of the control field shall indicate the length of the following eoc message or message segment in bytes, coded as the unsigned integer in the length field plus one. The valid range of the length of the eoc message or message segment is from 2 to 1 020.

The three LSBs of the control field shall indicate the priority of the eoc message sent as specified in Table 11-3. The value of priority shall correspond to the eoc message type, as defined in clause 11.2.2.2.

Bit 03 of the control field shall indicate whether the eoc message contains a command (C/R = 0) or a response (C/R = 1).

The values of bits 15 and 14 of the control field are reserved by ITU-T and shall be set to zero.

The FCS shall be 16 bits in length. The FCS shall be computed as the one's complement of the sum of:

a) the remainder of x^k $(x^{15} + x^{14} + x^{13} + x^{12} + x^{11} + x^{10} + x^9 + x^8 + x^7 + x^6 + x^5 + x^4 + x^3 + x^2 + x + 1)$ divided by the generator polynomial $x^{16} + x^{12} + x^5 + 1$, where *k* is the number of bits in the eoc packet counted from the LSB of the byte 1 of the eoc packet to the MSB of the last byte (byte $P-2$) of the last eoc message in the eoc packet, inclusive; and

b) the remainder of the division by the generator polynomial $x^{16} + x^{12} + x^5 + 1$, of the product of $x^{16}(m_0 \times x^{k-1} + m_1 \times x^{k-2} + \ldots + m_{k-2} \times x^1 + m_{k-1})$, where $m_0 \ldots m_{k-1}$ are the bits of the eoc packet: m_0 is the LSB of the byte 1 of the eoc packet and m_{k-1} is the MSB of the last byte (byte $P-2$) of the last eoc message in the eoc packet, inclusive.

The computed value of the FCS:

$fcs(x) = fcs_0 \times x^{15} + fcs_1 \times x^{14} + \ldots + fcs_{14} \times x + fcs_{15}$ is the FCS polynomial where fcs_0 is the LSB of the high byte of the FCS field and fcs_{15} is the MSB of the low byte of the FCS field, and x is the delay operator.

The arithmetic in this clause shall be performed in the Galois Field GF(2).

NOTE – The FCS is defined in accordance with [b-ISO/IEC 13239].

11.2.1.2 eoc message format

The eoc message format is presented in Figure 11-4.

Byte	MSB LSB
1	OPCODE (message type)
2	Message name
3	Message body byte 1
...	...
S + 2	Message body byte *S*

Figure 11-4 – eoc message format

Each eoc message is a command, a command segment, a response or a response segment. The first byte of a message is the type (command and response type) indicated by an OPCODE. The second byte is the name of the command or the response associated with the given message type. The rest of the bytes carry the management data associated with the command or response.

For message types that can exceed the set maximum value of *P*, the message segmentation protocol shall be applied as defined in clause 11.2.2.3.

11.2.1.3 eoc transmission protocol

An MTU invokes eoc communication with the peer MTU at the other end of the link by sending an eoc command message. The responding MTU, acting as a slave, shall acknowledge a command it has received correctly by sending a response, unless one is not required for the particular command type. Furthermore, it shall perform the requested management function.

Both the MTU-O and the MTU-R shall be capable of sending eoc commands and responding to received eoc commands. The same eoc packet format described in clause 11.2.2.1 and eoc message format described in clause 11.2.2.2 shall be used in both transmission directions. To send commands and responses over the transmission line, the MTU originates eoc messages. For transmission, each eoc message shall be submitted to the TPS-TC_MGMT interface using the eoc message format defined in clause 11.2.2.2. If an eoc packet is received with an FCS error, all messages carried by this packet shall be considered as received in error and discarded.

Each command and the corresponding response are associated with a priority level specified in clause 11.2.2.2. To maintain priorities of eoc commands when sent over the link, the MME shall submit eoc messages to the TPS-TC_MGMT interface in accordance with the priority levels of the commands (responses) carried by these messages, as specified in Table 11-3.

Table 11-3 – eoc message priority levels

Priority level	Control field priority bits (Note 1)	Associated timeout value	eoc command (response)
High	000	50 ms (Note 2)	Table 11-4
Near high	011	100 ms	Table 11-5
Normal	001	200 ms	Table 11-6
Low	010	400 ms	Table 11-7
NOTE 1 – Other values are reserved by ITU-T NOTE 2 – Unless a timeout value indicated in the definition of a specific command is different (see Table 11-4).			

The MTU shall send the eoc command only once and wait for a response, if one is required. No more than one command of each priority level shall be awaiting a response at any time. Upon reception of the response, a new command of the same priority level may be sent. If the command is segmented, all the segments of the command shall be sent, and the response received before the next command of the same priority is sent.

Accordingly, the MTU shall send the message carrying a command or a series of messages containing all segments of a command only once and wait for a response. Upon reception of the response, a new message may be sent. If a response is not received within a specified timeout period (see Table 11-3), or is received incorrectly, a timeout occurs. After a timeout, the MTU may re-send the message within two seconds from the first timeout, after which it shall abandon the message.

In case of an OLR request type 3 (TIGA) command or an OLR request type 1 command in response to TIGA (TIGARESP), the timeout shall be also measured until the reception of the command is acknowledged by setting to ONE of the TIGA-ACK bit or the TIGARESP-ACK bit, respectively, in the following RMC command. After timeout expires, the MTU may resend the command (see clause 13.2.2.1).

From all of the messages available for sending at any time, the MTU shall always send the message with the highest priority first.

Messages or segments of different priorities may be interleaved in the eoc. If in a particular logical frame the remaining eoc capacity is insufficient to send a high priority message or a segment, but there is enough capacity available for a lower priority message or segment, then the lower priority message or segment is allowed to be sent in the remaining eoc capacity of this logical frame. When multiple messages or segments are ready to be sent in the remaining eoc capacity of the logical frame, a message or segment of highest priority shall be sent first. The interleaving of segment/messages of different priorities shall always comply with the rule defined above that only one command of each priority level shall be awaiting a response at any time.

Messages of different priority have different timeout durations, as shown in Table 11-3, except for messages for which a response is not required and hence no timeout period is applicable. Timeouts shall be calculated from the instant the MTU sends the last byte of the message until the instant the MTU receives the first byte of the response message. Both instants shall be referenced to the TPS-TC_MGMT interface. Accordingly, the timeout timer shall be started at the instant the eoc command message is passed via TPS-TC_MGMT interface. If the MTU detects the corresponding eoc response message passing the TPS-TC_MGMT interface before the timeout timer expires, this eoc response message shall be considered to be received; otherwise, the MTU shall consider the response lost (timedout) and may retransmit the command using the rules defined above.

The receiver uses the assigned value specified in clause 11.2.2.2 to determine the type and priority of the received eoc command (response).

11.2.2 eoc commands and responses

11.2.2.1 General

The first byte (OPCODE) of a command (response) specifies the type of command (response). The second byte (message name) specifies the name of the command (response) for the specified command type. Other bytes carry the data associated with the command (response).

The data values to be sent shall be mapped such that the LSB of data is mapped to the LSB of the corresponding byte of the command (response). Data values containing more than one byte shall be mapped with higher order bytes preceding lower order bytes. A vector of data values shall be mapped in order of the index, from the lowest index value to the highest (value with lowest index is transmitted first).

If a specific command (response) is longer than the set values of *P* bytes, the MTU shall segment it as specified in clause 11.2.2.3.

11.2.2.2 Command and response types

The MTU shall support all mandatory eoc command and response types specified in Table 11-4 (high priority commands), Table 11-5 (near high priority commands), Table 11-6 (normal priority commands) and Table 11-7 (low priority commands), and their associated commands and responses. The MTU shall reply with unable to comply (UTC) response on the optional commands that the MTU cannot recognize the assigned value for the command type. The UTC response shall include two bytes: the first byte of the UTC shall be the same as the first byte of the received command, and the second byte shall be FF_{16}. The UTC is a high priority response.

Table 11-4 – High priority commands and responses

Command and response type and assigned OPCODE	Direction of command	Command content	Response content	Support	Reference
Online reconfiguration (OLR) 0000 0001_2	From the receiver of either MTU to the transmitter of the other	All the necessary PMD and PMS-TC control parameter values for the new configuration	Includes a deferral or rejection of the proposed reconfiguration. (Note 1)	See Table 11-11.	See clause 11.2.2.5 and clause 13.
	From MTU-O to MTU-R	Transmitter-initiated gain adjustment (TIGA).	Responded by TIGARESP command (Note 2).	See Table 11-11.	
DBR parameters (DBR-PR) 0000 0010_2	From MTU-O to MTU-R	Requests for downstream DBR parameters and indicates the upstream DBR parameters	Provides the requested downstream DBR parameters (bit-loading and framing parameters) associated with the requested downstream sub-bands; acknowledges for upstream DBR parameters	**Optional (Note 3)**	**See clause 11.2.2.23 and clause 13.5**

Table 11-4 – High priority commands and responses

Command and response type and assigned OPCODE	Direction of command	Command content	Response content	Support	Reference
DCM parameter update 0000 1100_2	From MTU-O to MTU-R	Request to update DCM sequence (upstream or downstream).	Acknowledgement	**Mandatory**	**See clause 11.2.2.25**
NOTE 1 – The positive acknowledgement for an OLR command, which is communicated over the RMC, is an indication marking the instant of reconfiguration. NOTE 2 – The positive acknowledgement to a TIGA is sent over the RMC. NOTE 3 – Support of the DBR parameters command is mandatory if the MTU supports P2MP operation, as described in clause 13.5.					

Table 11-5 – Near high priority commands and responses

Command and response type and assigned OPCODE	Direction of command	Command content	Response content	Support	Reference
NTR frequency synchronization 0101 0000_2	From MTU-O to MTU-R	The phase difference value to run NTR frequency synchronization.	No response needed.	Mandatory	See clause 11.2.2.7
ToD frequency synchronization 0101 0010_2	From MTU-O to MTU-R	The phase difference value to run ToD frequency synchronization.	No response needed.	Mandatory	See clause 11.2.2.8
Vectoring feedback 0001 1000_2	From MTU-O to MTU-R.	Request for VF samples for the given vectored band and with the given format.	eoc encapsulated VF samples and associated parameters, ACK or NACK.	See Table 11-43	See clause 11.2.2.14
Showtime Sync Symbol Adaptation (SSA) 0101 1101_2	From MTU-O to MTU-R	Request to adapt the gains of the sync symbol (upstream only).	Acknowledgement	Mandatory	See clause 11.2.2.24

Table 11-6 – Normal priority commands and responses

Command and response type and assigned OPCODE	Direction of command	Command content	Response content	Support	Reference
Diagnostic 0100 0001_2	From MTU-O to MTU-R	Request to run the self-test, or to update test parameters.	Acknowledgement	Mandatory	See clause 11.2.2.6
	From MTU-R to MTU-O	Request to update test parameters.	Acknowledgement	Mandatory	

Table 11-6 – Normal priority commands and responses

Command and response type and assigned OPCODE	Direction of command	Command content	Response content	Support	Reference
Inventory 0100 0011_2	From either MTU to the other	Identification request, auxiliary inventory information request and self-test results request.	Includes the MTU equipment ID auxiliary inventory information and self-test results.	Mandatory	See clause 11.2.2.10
Management counter read 0000 0101_2	From either MTU to the other	Request to read the counters.	Includes all counter values.	Mandatory	See clause 11.2.2.11
Battery powered status 0000 0011_2	From MTU-R to MTU-O	Indicates whether the MTU-R is being powered by battery.	Acknowledgement	Mandatory	See clause 11.2.2.27, Table 11-83 and Table 11-84
L3 link state transition 0000 1001_2	From either MTU to the other	Indicates request for L0 to L3 link state transition.	An acknowledgement to either reject or grant the new link state	Mandatory	See clause 11.2.2.12
Non-standard facility (NSF) 0011 1111_2	From either MTU to the other	Non-standard identification field followed by vendor proprietary content.	An acknowledgement or a negative acknowledgement indicating that the non-standard identification field is not recognized.	Mandatory	See clause 11.2.2.18
Time synchronization 0101 0001_2	From MTU-O to MTU-R	Includes the time stamps obtained by MTU-O to run time synchronization.	Includes either the corresponding time stamp values of events t_2 and t_3 to accept the time synchronization (ACK) or a reject of the time synchronization command with a reason code.	Mandatory	See clause 11.2.2.9
DRR configuration 0101 0101_2	From MTU-O to MTU-R	DRR configuration request.	DRR configuration confirm.	Mandatory	See clause 11.2.2.16
Clear eoc 0000 1000_2	From either MTU to the other	Includes a management information payload.	Acknowledgement	Mandatory	See clause 11.2.2.4
Probe sequence update 0001 0001_2	From MTU-O to MTU-R	Request to update probe sequence (upstream or downstream).	Acknowledgement	Mandatory	See clause 11.2.2.15
SPA-PREP 0001 0010_2	From MTU-O to MTU-R	Request to adapt MREFPSD_NPus	Includes either the proposed	Mandatory	See clause 11.2.2.21

Table 11-6 – Normal priority commands and responses

Command and response type and assigned OPCODE	Direction of command	Command content	Response content	Support	Reference
			MREFPSD_NPus to accept the command (ACK) or a reject of the command with a reason code.		
Fast start-up training sequence parameters $0000\ 0110_2$	From MTU-O to MTU-R	IDS, number of SOC symbol repetitions (R_S) and number of DS data symbols during initialization (S_{ds}).	Acknowledgement	Mandatory	See clause 11.2.2.17
Update backup RTSBL $0101\ 0111_2$	From either MTU to the other	Request to update the backup *RTSBL*; indicates the time instant from which the update should take place	Acknowledgement	Optional (Note 1)	See clause 11.2.2.20
DBR sub-band description (DBR-SD) $0101\ 0100_2$	From MTU-O to MTU-R	Includes the MTU-R sub-band descriptor to assist the DBR procedure	An acknowledgement of acceptance or reject of the proposed sub-bands after the DBR procedure	Optional (Note 2)	See clause 11.2.2.22 and clause 13
RMC adjustment for DBR (DBR-RMC) $0101\ 0101_2$	From MTU-O to MTU-R	Prompts MTU-R to initiate a downstream RPA to confine RMC tones within the requested band	Acknowledgement	Optional (Note 2)	See clause 13.5.2.2.4
Parameter tracking for DBR (DBR-PT) $0101\ 0111_2$	From either MTU to the other	Reports the expected bit loadings and gain on all MEDLEYG subcarriers	Acknowledgement	Optional at the MTU-O (Note 3)	See clause 13.5.2.2.2
NOTE 1 – Support of the update backup RTSBL command is mandatory if the MTU supports RMCR as described in clause 13.3.1.2. NOTE 2 – Support of the command is mandatory if the MTU supports P2MP operation, as described in clause 13.5. NOTE 3 – Support of the command is mandatory at the MTU-R if the MTU-R supports P2MP operation, as described in clause 13.5.					

Table 11-7 – Low priority commands and responses

Command and response type and assigned OPCODE	Direction of command	Command content	Response content	Support	Reference
PMD test parameter read 1000 0001_2	From either MTU to the other	The identification of test parameters for single read and vector block read.	Includes the requested test parameter values or a negative acknowledgement.	See clause 11.2.2.13	See clause 11.2.2.13
Non-standard facility (NSF) low priority 1011 1111_2	From either MTU to the other	Non-standard identification field followed by vendor proprietary content.	An acknowledgement or a negative acknowledgement indicating that the non-standard identification field is not recognized.	Mandatory	See clause 11.2.2.18
Datagram eoc 0000 1010_2	From either MTU to the other	Includes a management information payload.	No response needed.	Optional (Note 1)	See clause 11.2.2.4.2
INM facility 1000 1001_2	From MTU-O to MTU-R	Set or readout the INM parameters, readout the INM data	An acknowledgement to the INM facility set command, or a response including the INM data	Optional (Note 2)	See clause 11.2.2.19
SREC-R 1000 0110_2	From MTU-O to MTU-R	New configuration parameters	Acknowledgement or rejection	Optional (Note 3)	See clause13.2.1.5.4
NOTE 1 – Support of this command is indicated by the MTU during initialization (see clauses 12.3.4.2.1 and 12.3.4.2.2). Support of this command is mandatory for Annex S (see clause S.4.3). NOTE 2 – Support of this command is indicated by the MTU during initialization (see clauses 12.3.4.2.1 and 12.3.4.2.2). Support of this command is mandatory for clause 11.4.4.7. NOTE 3 – Support of this command is indicated by the MTU during initialization (see clauses 12.3.4.2.1 and 12.3.4.2.2).					

11.2.2.3 Segmentation of eoc messages

The length of the eoc message in bytes shall not exceed the maximum length $P-4$ (see clause 11.2.1.1). If more data has to be sent, the MTU originating the eoc message shall segment it to meet the maximum packet size. The number of segments shall not exceed 64. The multi-segment transmission is supported by the segment code (SC) byte in the command. The two MSBs of the SC shall be set to 00_2 for the first segment and any subsequent intermediate segments, and set to 11_2 for the last segment. The 6 LSBs shall contain the sequence number of the segment starting from 000000_2.

NOTE – Messages that are shorter than $P - 4$ bytes can also be segmented if desired by the vendor. However, use of short segments may reduce efficiency of the eoc and should be used with caution.

The requesting MTU shall send all intermediate segments sequentially. The responding MTU shall send the response (if defined) only after the last segment of the message has been received. If the last segment was received but one or more other segments of the message were not received, the responding MTU shall respond with a reject with the missing segments reason code (as defined in

Table 11-23). If the requesting MTU does not receive the acknowledgement within the timeout specified in Table 11-3 after transmission of the last segment, the command is considered lost. Consequently, in this event the requesting MTU may re-send the entire message or abandon it. The responding MTU shall consider the command abandoned if no more valid segments of the message are received within 2 s after reception of the last segment or if it receives a new message or message segment of the same priority. If a command does not require acknowledgement, the requesting MTU may start transmission of the following command after the last segment of the previous command is transmitted or the previous command is abandoned.

11.2.2.4 Transparent eoc commands and responses

11.2.2.4.1 Clear eoc commands and responses

The clear eoc command may be used to transfer management data between the management entities ME-O and ME-R of the MTU-O and MTU-R. The clear eoc command carries the management data as an information payload. This information payload is generated by the near-end ME and passed to the MME over the γ_MGMT reference point. The size of the information payload generated by the near-end ME shall not exceed 510 bytes. The clear eoc command is shown in Table 11-8 and may be initiated by either MTU; the peer MTU shall then respond. The clear eoc responses shall be as shown in Table 11-9. The first byte of either the command or a response shall be the assigned value for the clear eoc command type shown in Table 11-6. The subsequent bytes of the command shall be as shown in Table 11-8. The subsequent bytes of the responses shall be as shown in Table 11-8. The bytes shall be sent using the format described in clause 11.2.2.1.

Table 11-8 – Clear eoc commands sent by the initiating MTU

Name	Length (bytes)	Byte	Content
Request	Variable	2	01_{16} (Note)
		3	Segment code (SC)
		4 +	The information payload of the clear eoc message to be delivered to the far end.
NOTE – All other values for byte 2 are reserved by ITU-T.			

Table 11-9 – Clear eoc responses sent by the responding MTU

Name	Length (bytes)	Byte	Content
ACK	2	2	80_{16} (Note)
NACK	3	2	81_{16} (Note)
		3	04_{16} – Not supported (Note)
NOTE – All other values for bytes 2 and 3 are reserved by ITU-T.			

Upon reception of a clear eoc information payload (up to 510 bytes in length) over the γ_MGMT reference point from the near-end ME, the MTU shall initiate a clear eoc command (up to 513 bytes in length) based on its priority defined in Table 11-6. The clear eoc command may be segmented. Upon reception of a clear eoc command, the MTU shall respond with an acknowledgement (ACK) and deliver the information payload (up to 510 bytes in length) of the received clear eoc command over the γ_MGMT reference point to the near-end ME transparently, with the original formatting used by the far-end ME of the initiating MTU. The MTU may instead respond with a negative acknowledgment (NACK) including the not supported (value 04_{16}) reason code, indicating that the received information payload of the clear eoc command cannot be delivered to the near-end ME (e.g., because the near-end ME may not support clear eoc messages). Other reason codes are for further study.

11.2.2.4.2 Datagram eoc command

The datagram eoc command is used to transfer management data between the ME-O and ME-R of the MTU-O and MTU-R, respectively. The datagram eoc command carries the management data as an information payload. This information payload is generated by the upper-layer ME and passed to the MME over the γ_MGMT reference point (see clause 11.1). The size of the information payload shall not exceed 1018 bytes. The datagram eoc command is shown in Table 11-10 and may be initiated by either MTU. No response to the datagram eoc command shall be sent by the peer MTU. The first byte of the command shall be the assigned value for the datagram eoc command type shown in Table 11-7. The subsequent bytes of the command shall be as shown in Table 11-10. The bytes shall be sent using the format described in clause 11.2.2.1.

Table 11-10 – Datagram eoc command sent by the initiating MTU

Name	Length (bytes)	Byte	Content
Data	Variable	2	01_{16} (Note)
		3 +	The information payload of the datagram eoc message to be delivered to the far end.
NOTE – All other values for byte 2 are reserved by ITU-T.			

Upon reception of a datagram eoc information payload (up to 1018 bytes in length) over the γ_MGMT reference point from the near-end ME, the MTU shall send a datagram eoc command (up to 1020 bytes in length) based on its priority defined in Table 11-7. Upon reception of a datagram eoc command, the MTU shall deliver the information payload of the received datagram eoc command over the γ_MGMT reference point to the near-end ME transparently, with the original formatting used by the far-end ME of the initiating MTU.

The MTU-O and MTU-R shall be able to transmit and receive datagram eoc commands with a total number of bytes up to the maximum number of eoc bytes per logical frame period (see Table 9-27, Table P.1 and Table Q.1).

11.2.2.5 OLR commands and responses

The MTU shall be capable of sending and receiving the OLR commands and responses listed in Tables 11-11 and 11-12, respectively, for the supported types of OLR (see clause 13.1.1). OLR commands of OLR request types 1 (autonomous SRA, bit swapping or TIGARESP), 2 (in case of autonomous SRA only) and 4 (RPA) specified in Table 11-11 may be initiated by either MTU. The responding MTU, if applicable, may either reject the initiator's request using responses listed in Table 11-19 with reason codes listed in Table 11-23, or positively acknowledge the initiator's request: for OLR request types 1 and 2 – by using the RMC reply to SRA request (SRA-R) command (see Table 9-15) and for RPA – by using the response listed in Table 11-19 and the RMC command (RPA-R) defined in Table 9-16.

Within a TIGA procedure, an OLR command of OLR request type 3 (TIGA) may be initiated by the MTU-O followed by an initiation of an OLR command of OLR request type 1 (TIGARESP) by the MTU-R. Both commands are specified in Table 11-11.

The OLR command of OLR request type 4 (RPA) is sent by the initiating MTU to request to modify the RMC parameters.

Within an SPA-SRA procedure, an OLR command of OLR request type 2 with indication of SPA-SRA may be initiated by the MTU-O only. The MTU-R response is as specified for OLR request type 2.

The first byte of all OLR commands and responses shall be the assigned value for the OLR command type, as shown in Table 11-4. The remaining bytes shall be as shown in Table 11-11 (for commands) and in Table 11-19 and Table 11-23 (for responses). The bytes of the OLR commands and responses shall be sent over the link as described in clause 11.2.2.1.

Table 11-11 – OLR commands sent by the initiating MTU

Name	Length (bytes)	Byte	Content	Support
OLR request type 1 (Autonomous SRA, bit swapping, and TIGARESP) (Note 4)	Variable	2	01_{16} (Note 1)	Mandatory
		3	Segment code (SC)	
		4	[0cbb 00aa] aa = 00: bit swapping aa = 01: autonomous SRA aa = 10: TIGARESP aa = 11: Reserved by ITU-T Sub-frames subject for reconfiguration: bb = 00, None (Note 2) bb = 01, PSF only. bb = 10, NPSF only. bb = 11, PSF and NPSF. Operational interval subject for reconfiguration (Note 9): c = 0 NOI. c = 1 DOI (valid for PSF only)	
		5	One byte for Q	
		6	One byte for K_{FEC}	
		7	One byte for R_{FEC}	
		8	[0000 aaaa] aaaa = PSF SRA configuration change count of the operational interval subject to reconfiguration (SCCC) This field shall not be sent if bb = 10 in byte 4.	
		9	One byte for the PCS-LCM parameters for the operational interval of the PSF subject to reconfiguration with Band 0 and Band 1 active. [bbbb aaaa] aaaa: contains the index of the M_c (NOTE 11). bbbb: contains the value of 4P/Mc. 15 is a special value that indicates P=7×M_c. This field shall not be sent if bb = 10 in byte 4.	

Table 11-11 – OLR commands sent by the initiating MTU

Name	Length (bytes)	Byte	Content	Support
		10	One byte for the PCS-LCM parameters for the operational interval of the PSF subject to reconfiguration with only Band 0 active. [bbbb aaaa] aaaa: contains the index of the M_c (Note 11). bbbb: contains the value of 4P/Mc. 15 is a special value that indicates $P=7\times M_c$. This field shall not be sent if bb = 10 in byte 4. This field shall be set to 0 if c=1 in byte 4.	
		11	One byte for the PCS-LCM parameters for the other operational interval of the PSF with Band 0 and Band 1 active. [bbbb aaaa] aaaa: contains the index of the M_c (Note 11). bbbb: contains the value of 4P/Mc. 15 is a special value that indicates $P=7\times M_c$. This field shall not be sent if bb = 10 in byte 4. (Note 10)	
		12	One byte for PSF *d_SRA or d_TIGARESP* of the operational interval subject to reconfiguration. This field shall not be sent if bb = 10 in byte 4.	
		13 and 14	Two bytes for the PSF start subcarrier index This field shall not be sent if bb = 10 in byte 4.	
		15 and 16	Two bytes for the PSF stop subcarrier index This field shall not be sent if bb = 10 in byte 4.	
		Variable	PSF subcarrier parameter block A variable number of bytes (S_N) describing the subcarrier parameter field for each subcarrier (Note 8) This field shall not be sent if bb = 10.	
		17 + S_N	[0000 aaaa] aaaa = NPSF SRA configuration change count (SCCC) This field shall not be sent if bb = 01 in byte 4.	
		18 + S_N	One byte for the PCS-LCM parameters for the NPSF. [bbbb aaaa] aaaa: contains the index of the M_c (Note 11).	

Table 11-11 – OLR commands sent by the initiating MTU

Name	Length (bytes)	Byte	Content	Support
			bbbb: contains the value of 4P/Mc. 15 is a special value that indicates $P=7\times M_c$. This field shall not be sent if bb = 01 in byte 4.	
		$19 + S_N$	One byte for NPSF *d_SRA or d_TIGARESP* This field shall not be sent if bb = 01 in byte 4.	
		$20 + S_N$ and $21 + S_N$	Two bytes for the NPSF start subcarrier index. This field shall not be sent if bb = 01 in byte 4.	
		$22 + S_N$ and $23 + S_N$	Two bytes for the NPSF stop subcarrier index. This field shall not be sent if bb = 01 in byte 4.	
		Variable	NPSF subcarrier parameter block A variable number of bytes describing the subcarrier parameter field for each subcarrier (Note 8). This field shall not be sent if bb = 01 in byte 4.	
OLR request type 2 (Autonomous SRA, bit swapping and SPA-SRA) (Note 5)	Variable	2	02_{16} (Note 1)	Mandatory
		3	Segment code (SC)	
		4	[0cbb 00aa] aa = 00: bit swapping aa = 01: autonomous SRA aa = 10: SPA-SRA aa = 11: Reserved by ITU-T Sub-frames subject for reconfiguration: bb = 00, Reserved by ITU-T bb = 01, PSF only. bb = 10, NPSF only. bb = 11, PSF and NPSF. Operational interval subject for reconfiguration (Note 9): c = 0 NOI. c = 1 DOI (valid for PSF only)	
		5	One byte for Q	
		6	One byte for K_{FEC}	
		7	One byte for R_{FEC}	
		8	[0000 aaaa] aaaa = PSF SRA configuration change count of the operational interval subject to reconfiguration (SCCC) This field shall not be sent if bb = 10 in byte 4.	
		9	One byte for the PCS-LCM parameters for the operational interval of the PSF subject to	

Table 11-11 – OLR commands sent by the initiating MTU

Name	Length (bytes)	Byte	Content	Support
			reconfiguration with Band 0 and Band 1 active. [bbbb aaaa] aaaa: contains the index of the M_c (Note 11). bbbb: contains the value of 4P/Mc. 15 is a special value that indicates P=7×M_c. This field shall not be sent if bb = 10 in byte 4.	
		10	One byte for the PCS-LCM parameters for the operational interval of the PSF subject to reconfiguration with only Band 0 active. [bbbb aaaa] aaaa: contains the index of the M_c (Note 11). bbbb: contains the value of 4P/Mc. 15 is a special value that indicates P=7×M_c. This field shall not be sent if bb = 10 in byte 4. This field shall be set to 0 if c=1 in byte 4.	
		11	One byte for the PCS-LCM parameters for the other operational interval of the PSF with Band 0 and Band 1 active. [bbbb aaaa] aaaa: contains the index of the M_c (Note 11). bbbb: contains the value of 4P/Mc. 15 is a special value that indicates P=7×M_c. This field shall not be sent if bb = 10 in byte 4. (Note 10)	
		12 and 13	Two bytes for the PSF number of subcarriers N_f to be modified (Note 3). This field shall not be sent if bb = 10 in byte 4.	
		Variable	PSF subcarrier parameter block A variable number of bytes (S_N) describing the subcarrier parameter field for each subcarrier (Note 6). This field shall not be sent if bb = 10 in byte 4 or N_f = 0.	
		14 + S_N	[0000 aaaa] aaaa = NPSF SRA configuration change count (SCCC) This field shall not be sent if bb = 01 in byte 4.	
		15 + S_N	One byte for the PCS-LCM parameters for the NPSF. [bbbb aaaa]	

Table 11-11 – OLR commands sent by the initiating MTU

Name	Length (bytes)	Byte	Content	Support
			aaaa: contains the index of the M_c (Note 11). bbbb: contains the value of 4P/Mc. 15 is a special value that indicates P=7×M_c. This field shall not be sent if bb = 01 in byte 4.	
		16 + S_N and 17 + S_N	Two bytes for the NPSF number of subcarriers N_f to be modified (Note 3). This field shall not be sent if bb = 01 in byte 4.	
		Variable	NPSF subcarrier parameter block A variable number of bytes describing the subcarrier parameter field for each subcarrier. This field shall not be sent if bb = 01 in byte 4 or N_f = 0.	
OLR request type 3 (TIGA)	Variable	2	03_{16} (Note 1)	Mandatory
		3	Segment code (SC)	
		4	[0cbb 000a] a = 0: indicates the real relative gain compensation factor. a = 1: indicates the complex relative gain compensation factor. Sub-frames subject for reconfiguration: bb = 00, Reserved by ITU-T bb = 01, PSF only. bb = 10, NPSF only. bb = 11, PSF and NPSF. Operational interval subject for reconfiguration (Note 9): c = 0, NOI. c = 1, DOI.	
		5 and 6	Two bytes for the PSF start subcarrier index. This field shall not be sent if bb = 10 in byte 4.	
		7 and 8	Two bytes for the PSF stop subcarrier index. This field shall not be sent if bb = 10 in byte 4.	
		Variable	PSF subcarrier parameter block A variable number of bytes (S_N) describing subcarrier parameter field for each subcarrier (Note 6). This field shall not be sent if bb = 10 in byte 4.	
		9 + S_N and 10 + S_N	Two bytes for the NPSF start subcarrier index. This field shall not be sent if bb = 01 in byte 4.	
		11 + S_N and 12	Two bytes for the NPSF stop subcarrier index.	

Table 11-11 – OLR commands sent by the initiating MTU

Name	Length (bytes)	Byte	Content	Support
		+ S_N	This field shall not be sent if bb = 01 in byte 4.	
		Variable	NPSF subcarrier parameter block A variable number of bytes describing subcarrier parameter field for each subcarrier. This field shall not be sent if bb = 01 in byte 4.	
OLR request type 4 (update RMC parameters) (RPA)	8+2 × *NSCR*	2	04_{16} (Note 1)	Mandatory
		3	Segment code (SC)	
		4	[0000 aaaa] aaaa = RPA configuration change count	
		5 and 6	Two bytes for the number of subcarriers of the updated RTS (*NSCR*).	
		7 and 8	CNT_{SF} at which new settings to be applied.	
		9 to 9 + 2 × *NSCR* − 1	2 × *NSCR* bytes describing the subcarrier parameter field for each subcarrier.	

NOTE 1 – All other values for this byte are reserved by ITU-T.
NOTE 2 – Setting bb=00 is only valid for a TIGARESP (see clause 13.2.2.1).
NOTE 3 – Setting N_f = 0 is valid and shall be used if the OLR command of OLR request type 2 is used to modify framing parameters (the subcarrier parameters block is empty).
NOTE 4 – If used in the upstream direction, OLR request type 1 can only be used as an autonomous SRA or bit swapping and *d_SRA* shall be set to 1. It is implied that all gains g_i will remain unchanged.
NOTE 5 – If used in downstream, all gains shall be set to 1. It is implied that *d_SRA =1*.
NOTE 6 –The b_i values indicated in the PSF subcarrier parameter block shall not be applied to RMC subcarriers.
NOTE 7 – The values of K_{FEC}, R_{FEC}, and *Q* shall be applied to both operation intervals (NOI and DOI) and both sub-frame types (PSF and NPSF) (see clause 13.2.1.1.1).
NOTE 8 – In case of OLR request type 1, the subcarrier parameters block always includes at least one subcarrier entry.
NOTE 9 – If the same active bit-loading tables apply to Band 1 in both NOI and DOI, any reconfiguration requested for subcarriers of Band 1 of NOI shall apply to DOI and vice versa.
NOTE 10 – This parameter shall contain the new LDPC setting of the other PSF operational interval if the same bit-loading table for the Band 1 applies to both the NOI_{PSF} and DOI as indicated during initialization (see clause 12.3.4.2). Otherwise, the field shall be filled with 0.
NOTE 11 – Valid indices are 0, 1, 2, 3, 4, 5 and 6 corresponding to M_c values 64, 96, 128, 192, 256, 384 and 512, respectively.

The subcarrier parameter fields for the respective OLR types are different and are specified as follows.

The format descriptor L(i**Q**f) designates a fixed point format with wordlength of *L* bits, with the binary point just to the right of the "*i*"-th most significant bit (including the sign bit if signed integer), and *f* bits are allocated behind the binary point (i.e., *L*=*i*+*f*). Letter Q is a syntax-separator.

The format descriptor L **M** ML(i**Q**f) **E** LE/B designates a floating point format with total wordlength *L*. It has mantissa wordlength of *ML* bits, with the binary point just to the right of the *i*-th most significant bit (including the sign bit if signed integer), and *f* bits are allocated behind the binary point (i.e., *ML*=*i*+*f*). The exponent is always unsigned and has wordlength *LE*. The exponent has unity gain when its value equals *B*. Letters M, Q and E are syntax-separators.

In below fields, the LSB of a parameter shall be mapped to the lowest bit number in the field assigned to that parameter.

For OLR commands of OLR request type 1.

Each subcarrier parameter field shall be formatted as shown in Table 11-12.

Table 11-12 – Subcarrier parameter field format for OLR type 1

Bit	Length (bits)	Parameter	Format
3-0	4	b_i (Notes 1 and 2)	Unsigned integer
NOTE 1 – The values of b_i for subcarriers that are in the specified range but not part of the MEDLEY set shall be included. They shall be set to zero by the transmitter and ignored by the receiver. NOTE 2 – The values of b_i shall follow each other in ascending order of subcarrier index (not re-ordered).			

Two subcarrier parameter fields shall be packed into one byte as shown in Table 11-13.

Table 11-13 – Packing of subcarrier fields into bytes for OLR type 1

Byte	MSB	LSB
k	b_{i+1} [3:0]	b_i [3:0]

If the number of subcarriers is odd, the four MSBs in the last byte is set to 0000.

The scalar gain *d_SRA or d_TIGARESP* shall be formatted as fixed point 5(1Q4) unsigned.

The valid values that are allowed to be used within this format, shall be:

$$(0.5 \leq d\_SRA \leq 1) \text{ and } (0.5 \leq d\_TIGARESP \leq 1)$$

NOTE – Possible values are 8/16, 9/16, … ,16/16 corresponding to backoff levels in dB of –6.02, –5.00, –4.08, –3.25, –2.50, –1.80, –1.16, –0.56, and 0.00.

For OLR commands of OLR request type 2, each subcarrier parameter field shall be formatted as shown in Table 11-14.

Table 11-14 – Subcarrier parameter field format for OLR type 2

Bit	Length (bits)	Parameter	Format
3-0	4	b_i	Unsigned integer
15-4	12	g_i	12(1Q11) unsigned
27-16	12	subcarrier index i	Unsigned integer

Packing of the subcarrier parameter field into bytes shall be as shown in Table 11-15. Bytes of the subcarrier parameter field shall be transmitted in the order of increasing indices, i.e., byte k is the first transmitted byte.

Table 11-15 – Packing of the subcarrier field into bytes for OLR type 2

Byte	MSB … LSB
k	g_i [3:0] b_i [3:0]
k+1	g_i [11:4]
k+2	index_*i* [7:0]
k+3	0000_2 index_*i* [11:8]

Each g_i value shall be represented as an unsigned 12-bit fixed-point quantity with format 12(1Q11). For example, a g_i with binary representation (MSB listed first) 0.01000000000_2 would correspond to a gain of 0.25, so that the power of that subcarrier would be 12.04 dB lower than it was during MEDLEY. Valid values are defined in clause 10.2.1.4.2.

For OLR commands of OLR request type 3 (TIGA) with real relative gain compensation factors, each subcarrier parameter field shall be formatted as shown in Table 11-16.

Table 11-16 – Subcarrier parameter field format for OLR type 3 with real relative gain compensation factors

Bit	**Length (bits)**	**Parameter** (Notes 1 and 2)	**Format**
3-0	4	b_i	Unsigned integer
6-4	3	Exponent of r_i	E3/4
15-7	9	Mantissa of r_i	M9(0Q9) unsigned
NOTE 1 – The values of b_i and r_i for subcarriers that are in the specified range but not part of the MEDLEY set shall be included. They shall be set to zero by the transmitter and ignored by the receiver. NOTE 2 – The values of b_i and r_i shall follow each other in ascending order of subcarrier index (not re-ordered).			

One subcarrier parameter field shall be mapped into two bytes as shown in Table 11-17. Bytes of the subcarrier parameter field shall be transmitted in the order of increasing indices, i.e., byte k is the first transmitted byte.

Table 11-17 – Packing of subcarrier fields into bytes for OLR type 3 with real relative gain compensation factors

Byte	MSB … LSB
k	Mantissa of r_i [0] Exponent of r_i [2:0] b_i [3:0]
k+1	Mantissa of r_i [8:1]

The gain r_i shall be formatted as floating point 12 M9(0Q9) E3/4 unsigned.

The valid range of r_i values expressed in dB is -18 dB < 20 × log10 (r_i) < +18 dB

A special value is r_i = 0, which is coded with a mantissa=0 and exponent=0, and shall be accompanied with b_i = 0.

For OLR commands of OLR request type 3 (TIGA) with complex relative gain compensation factors, each subcarrier parameter field shall be formatted as shown in Table 11-18.

Table 11-18 – Subcarrier parameter field format for OLR type 3 with complex relative gain compensation factors

Bit	Length (bits)	Parameter	Format
3-0	4	b_i (Notes 1 and 2)	Unsigned integer
6-4	3	Exponent of r_i (Notes 1 and 2)	E3/4
16-7	10	Mantissa of imaginary part of r_i (Notes 1 and 2)	M10(1Q9) signed
26-17	10	Mantissa of real part of r_i (Notes 1 and 2)	M10(1Q9) signed
27	1	Reserved by ITU-T	Bit shall be set to 0
NOTE 1 – The values of b_i and r_i for subcarriers that are in the specified range but not part of the MEDLEY set shall be included. They shall be set to zero by the transmitter and ignored by the receiver. NOTE 2 – The values of b_i and r_i shall follow each other in ascending order of subcarrier index (not re-ordered).			

Packing of the subcarrier parameter field into bytes shall be as shown in Table 11-19. Bytes of the subcarrier parameter field shall be transmitted in the order of increasing indices, i.e., byte k is the first transmitted byte.

Table 11-19 – Packing of the subcarrier field into bytes for OLR type 3 with complex relative gain compensation factors

Byte	MSB		LSB
k	Mantissa of imag r_i [0]	Exponent of r_i [2:0]	b_i [3:0]
k+1	Mantissa of imag r_i [8:1]		
k+2	Mantissa of real r_i [6:0]	Mantissa of imag r_i [9]	
k+3	0000_2	0_2	Mantissa of real r_i [9:7]

The valid range of r_i values expressed in dB is –18 dB < 20 × log10(abs(r_i)) < +18 dB,

where abs(x) is the modulus of a complex value x. The real and imaginary part of the gain r_i shall both be formatted as M10(1Q9) E3/4 signed, with a common exponent.

A special value is r_i = 0, which is coded with a mantissa=0 and exponent=0 for both real and imaginary part, and shall be accompanied with b_i = 0.

For OLR request type 4, each subcarrier parameter field shall be formatted as shown in Table 11-20.

Table 11-20 – Subcarrier parameter field format for OLR type 4

Bit numbers	Length (bits)	Parameter	Format
3-0	4	b_i	Unsigned integer
15-4	12	Subcarrier index i	Unsigned integer

Packing of the subcarrier parameter field into bytes shall be as shown in Table 11-21. Bytes of the subcarrier parameter field shall be transmitted in the order of increasing indices, i.e., byte k is the first transmitted byte.

Table 11-21 – Packing of the subcarrier parameter field into bytes for OLR type 4

Byte	MSB LSB
k	index_i [3:0] b_i [3:0]
k+1	index_i [11:4]

A special value b_i =0000_2 signifies that for subcarrier *i* the bit allocation is set to zero, but that the subcarrier remains to be a part of the RTS.

Table 11-22 – Responses sent by the MTU

Name	Length (bytes)	Byte	Content	Support
Reject OLR request type 1	3	2	81_{16} (Note)	Mandatory
		3	One byte for reason code (Table 11-23)	
Reject OLR request type 2	3	2	82_{16} (Note)	Mandatory
		3	One byte for reason code (Table 11-23)	
Reject OLR request type 3	3	2	83_{16} (Note)	Mandatory
		3	One byte for reason code (Table 11-23)	
ACK OLR request type 4	3	2	84_{16} (Note)	Mandatory
		3	[0000 aaaa] aaaa = RPA configuration change count (RCCC)	
Reject OLR request type 4	3	2	85_{16} (Note)	Mandatory
		3	One byte for reason code (Table 11-23)	
NOTE – All other values for byte 2 are reserved by ITU-T.				

Table 11-23 – Reason codes for MTU responses

Reason	Byte value (Note 1)	Applicable to reject OLR request type 1	Applicable to reject OLR request type 2	Applicable to reject OLR request type 3	Applicable to reject OLR request type 4
Busy	01_{16}	Yes	Yes	No	No
Invalid parameters	02_{16}	Yes	Yes	Yes	Yes
Missing segments	03_{16}	Yes	Yes	Yes	Yes
Wait (Note 2)	04_{16}	Yes	Yes	No	No
NOTE 1 – All other reason codes are reserved by ITU-T. NOTE 2 – With this reason code, the MTU shall wait at least 1 second before initiating a new eoc-based OLR procedure.					

11.2.2.6 Diagnostic commands and responses

The diagnostic commands shall be used to control the MTU diagnostic capabilities defined in this clause. The diagnostic commands shown in Table 11-24 may be initiated only by the MTU-O and those that may be initiated only by the MTU-R are shown in Table 11-25. The responses are shown in Table 11-26. All diagnostic commands and responses shall consist of two or three bytes. The first byte shall be the assigned value for the diagnostic command type, as shown in Table 11-6. For commands, the second byte shall be as shown in Table 11-24 and for responses, the second and third bytes shall be as shown in Table 11-26. The bytes shall be sent using the format described in clause 11.2.2.1.

Table 11-24 – Diagnostic commands sent by the MTU-O

Name	Length (bytes)	Byte	Content
Perform self-test	2	2	01_{16} (Note)
Update test parameters	2	2	021_6 (Note)
Start RTX_TESTMODE	2	2	03_{16} (Note)
End RTX_TESTMODE	2	2	04_{16} (Note)
Start TPS_TESTMODE	2	2	05_{16} (Note)
End TPS_TESTMODE	2	2	06_{16} (Note)
NOTE – All other values for byte 2 are reserved by ITU-T.			

Table 11-25 – Diagnostic commands sent by the MTU-R

Name	Length (bytes)	Byte	Content
Update test parameters	2	2	02_{16} (Note)
NOTE – All other values for byte 2 are reserved by ITU-T.			

Table 11-26 – Diagnostic responses sent by the MTU

Name	Length (bytes)	Byte	Content
Self-test acknowledgement (MTU-R only)	3	2	01_{16} (Note)
		3	One byte for the minimum time in seconds the MTU-O shall wait before requesting the self-test result, coded as an unsigned integer.
ACK (MTU-O and MTU-R)	2	2	80_{16} (Note)
NOTE – All other values for byte 2 are reserved by ITU-T.			

A diagnostic command may be sent at any time during showtime, including immediately following the end of the initialization procedure. In all cases, reception of a diagnostic command shall be acknowledged to the initiator (by an ACK or by a self-test acknowledgement response).

NOTE – A negative acknowledgement (NACK) is not used for diagnostic commands.

11.2.2.6.1 Perform self-test

Upon reception of the perform self-test command, the MTU-R shall respond with a self-test acknowledgement, which indicates the minimum amount of time that the MTU-O shall wait before requesting the results of the self-test. Further, the MTU-R shall perform the self-test and generate the self-test result. The self-test procedure is vendor discretionary, but it shall not interfere with the functions of the MTU-R, shall not impact the status of the connection and its duration shall not exceed 255 s. The MTU-R shall obtain and store result of the self-test within the number of seconds indicated in the self-test acknowledgement response. The indicated amount of time shall be an integer between one and 255 s. A coded value of zero is reserved for future use.

The self-test results may be accessed using the inventory command defined in clause 11.2.2.10. The length of the self-test results shall be four bytes. The first byte (including the MSB) shall be 00_{16} if the self-test passed and 01_{16} if it failed. The meaning of failure is vendor discretionary. The contents of the three other bytes are vendor discretionary.

11.2.2.6.2 Update test parameters

Upon reception of the update test parameters command, the requested MTU shall send the ACK response and update the test parameter set defined in clause 11.4.1. All test parameters that can be updated during the showtime shall be updated and stored within 10 s after the request is received. Upon reception of the ACK response, the requesting MTU shall wait at least 10 s before sending the PMD test parameter read commands defined in clause 11.2.2.13 to access the test parameter values defined in clause 11.4.1.

After the update test parameters command has been received, the test parameter values relating to the most recent initialization shall no longer be accessible. They may be discarded by the responding MTU immediately upon reception of the update test parameter command.

11.2.2.6.3 Start/end RTX_TESTMODE

A special test mode is defined for accelerated testing of the MTBE (see clause 9.8.3.1.2). A diagnostic command is defined to enter or leave the mode during the showtime. Upon reception of the enter RTX_TESTMODE command, the MTU-R shall acknowledge it with an ACK response. Afterwards, the MTU-R shall acknowledge all received DTUs in the downstream direction and shall stop retransmitting any DTU upstream. Upon reception of the end RTX_TESTMODE command, the MTU-R shall resume the normal behaviour of retransmission.

11.2.2.6.4 Start/end TPS_TESTMODE

A special test mode is defined for accelerated testing of the MTBE (see clause 9.8.3.1.2). A diagnostic command is defined to enter or leave this mode during the showtime. Upon reception of the enter TPS_TESTMODE command, the MTU-R shall acknowledge it with an ACK response. Afterwards, the MTU-R shall set TPS_TESTMODE enabled. Upon reception of the leave TPS_TESTMODE command, the MTU-R shall set TPS_TESTMODE disabled. The generation of DTUs is as specified in clause 8.3.1.

11.2.2.7 NTR frequency synchronization command

If NTR transport is enabled during the initialization, NTR frequency synchronization eoc commands (presented in Table 11-27) shall be sent by the MTU-O and used by the MTU-R to facilitate NTR frequency synchronization as described in clause 8.4.1. If NTR transport is disabled during the initialization, the MTU-O shall not send NTR synchronization commands during the showtime.

The MTU-R shall not send a response to the NTR synchronization command.

The NTR frequency synchronization command is a near-high priority command. The first byte of the command shall be the command type assigned as shown in Table 11-5 (NTR frequency synchronization command). The remaining bytes of the command shall be as specified in Table 11-27.

The MTU-O shall always send the most recent NTR frequency synchronization command and shall discard all older NTR frequency synchronization commands.

NOTE – Since no response is defined, the MTU-O management entity will not retransmit the lost NTR frequency synchronization command.

Table 11-27 – NTR frequency synchronization command (sent by the MTU-O)

Name	Length (bytes)	Byte	Content
NTR phase offset	6	2	01_{16} (Note 1)
		3 and 4	Two bytes for the count of the superframe associated with the event (Note 2).
		5 and 6	Two bytes, representing the NTR phase offset value (φ) as defined in clause 8.4.1.1.
NOTE 1 – All other values for byte 2 are reserved by ITU-T. NOTE 2 – The value shall be even.			

If the MTU-O indicates during the initialization that its PMD sampling frequency is locked to NTR, as described in clause 8.4.1, the NTR synchronization command shall not be sent by the MTU-O and shall be ignored by the MTU-R.

11.2.2.8 ToD frequency synchronization command

The ToD frequency synchronization command shall only be used in one direction, from MTU-O to MTU-R. The MTU-R shall not send a response to a ToD frequency synchronization command. The ToD frequency synchronization command shall be used if frequency synchronization using ToD phase difference is selected during the initialization; if frequency synchronization through locking the PMD sample clock is selected during the initialization, the ToD frequency synchronization command shall not be used (see clause 8.5.2).

The ToD frequency synchronization command is a near-high priority command. The first byte of the command shall be the command type assigned as shown in Table 11-5 (ToD frequency synchronization command). The remaining bytes of the command shall be as specified in Table 11-28.

The ToD phase difference value and corresponding t_1 event number shall be encapsulated in a ToD frequency synchronization command using the format defined in clause 8.5.2.1 as follows:

Table 11-28 – ToD frequency synchronization command (sent by the MTU-O)

Name	Length (bytes)	Byte	Content
ToD phase difference	5	2	02_{16} (Note)
		3 and 4	Two bytes representing the superframe count of the t_1 event.
		5 and 6	Two bytes representing the ToD phase difference in units of 2 nanoseconds.
NOTE – All other values for byte 2 are reserved by ITU-T.			

The MTU-O shall always send the most recent ToD frequency synchronization command and shall discard all older ToD frequency synchronization commands.

NOTE – Since no response is defined, the MTU-O management entity will not retransmit the lost ToD frequency synchronization command.

11.2.2.9 Time synchronization command and responses

The time synchronization commands and responses are used to establish ToD phase synchronization between the MTU-O and the MTU-R, as defined in clause 8.5. The time synchronization command and responses are listed in Table 11-29 (command sent by MTU-O) and Table 11-30 (response sent by MTU-R), respectively. The command specified in Table 11-29 shall only be sent by the MTU-O. The responses specified in Table 11-30 shall only be sent by the MTU-R.

Upon reception of a time synchronization command, the MTU-R may either reject the request to run the time synchronization procedure using the reject response defined in Table 11-30 with one of the reason codes listed in Table 11-31, or positively acknowledge it by transmitting an ACK response defined in Table 11-30.

The first byte of all time synchronization command and responses shall be the command type assigned, as shown in Table 11-6 (normal priority commands and responses). The remaining bytes for the commands and responses shall be as shown in Table 11-29 and Table 11-30, respectively.

Table 11-29 – Time synchronization commands sent by the MTU-O

Name	Length (bytes)	Byte	Content
ToD(t_1) ToD(t_4) Timestamps	26	2	01_{16} (Note 1)
		3 and 4	Two bytes for the superframe count of time stamps ToD(t_1) and ToD(t_4).
		5 and 6	Two bytes for time synchronization update period expressed in superframes.
		7 to 12	Six bytes describing the integer portion of the timestamp ToD(t_1) in units of seconds.
		13 to 16	Four bytes describing the fractional portion of the timestamp ToD(t_1) in units of nanoseconds. (Note 2)
		17 to 22	Six bytes describing the integer portion of the timestamp ToD(t_4) in units of seconds.
		23 to 26	Four bytes describing the fractional portion of the timestamp ToD(t_4) in units of nanoseconds. (Note 2)
NOTE 1 – All other values for byte 2 are reserved by ITU-T. NOTE 2 – The nanosecond portion is always less than 10^9.			

The bytes for the superframe count of time stamps ToD(t_1) and ToD(t_4) contain the superframe count when ToD(t_1) and ToD(t_4) are taken by the MTU-O (i.e., at the t_1 and t_4 event, see Figure 8-15). This value shall be a multiple of 16. The time synchronization update period indicates to the MTU-R at which superframe count the next set of ToD(t_1), ToD(t_2), ToD(t_3), and ToD(t_4) time stamps shall be recorded. The time synchronization update period (in superframes) shall be a multiple of 16 and shall not exceed the value of TSP that is set during initialization (see Table 12-51).

The ToD(t_1) and ToD(t_4) time stamps shall represent the time offset between the current time of the RTC-O (i.e., the time elapsed since the epoch) at the t_1 and t_4 events respectively. The ToD(t_2) and ToD(t_3) timestamps shall represent the time of the RTC-R (i.e., the time elapsed since the epoch) at the t_2 and t_3 events respectively. The MTU-R shall use the same epoch as the MTU-O, where this common epoch is set by the TCE and passed to the ToD-O over the γ_O reference point (by the *ToD_mc_value*).

NOTE – If at the t_1 event the RTC-O shows +2.000000001 seconds have elapsed since the epoch, this is represented in the ToD(t_1) timestamp by seconds = 0x0000 0000 0002 and nanoseconds = 0x0000 0001. The epoch may be locally set at the DPU or may be an absolute instant in time. For example, if the epoch is the PTP epoch, this means that time-of-day = 1 January 1970 00:00:02.000000001.

Table 11-30 – Time synchronization responses sent by the MTU-R

Name	Length (bytes)	Byte	Content
ACK (ToD(t_2) ToD(t_3) Timestamps)	24	2	81_{16} (Note 1)
		3 and 4	Two bytes for the superframe count of the ToD(t_2) and ToD(t_3) time stamps.
		5 to 10	Six bytes describing the integer portion of the ToD(t_2) timestamp in units of seconds.
		11 to 14	Four bytes describing the fractional portion of the ToD(t_2) timestamp in units of nanoseconds. (Note 2)
		15 to 20	Six bytes describing the integer portion of the ToD(t_3) timestamp in units of seconds.
		21 to 24	Four bytes describing the fractional portion of the ToD(t_3) timestamp in units of nanoseconds. (Note 2)
Reject	3	2	82_{16} (Note 1)
		1	One byte for reason code (see Table 11-31)
NOTE 1 – All other values for byte 2 are reserved by ITU-T. NOTE 2 – The nanosecond portion is always less than 10^9.			

Table 11-31 – Reason codes for time synchronization response

Reason	Byte value
Busy	01_{16}
Invalid parameters	02_{16}
t_2 and t_3 timestamps no longer available at the MTU-R	03_{16}
Still acquiring ToD frequency synchronization	04_{16}
NOTE – All other reason codes are reserved by ITU-T.	

11.2.2.10 Inventory commands and responses

The inventory commands shall be used to determine the identification and capabilities of the MTU at the far end. The inventory commands shown in Table 11-32 may be initiated by either MTU. The inventory responses shall be as shown in Table 11-33. The first byte of all inventory commands and responses shall be the assigned value for the inventory command type, as shown in Table 11-5. The second byte of the inventory commands shall be as specified in Table 11-32. The second byte (ACK) and all following bytes of the inventory responses shall be as specified in Table 11-33. The bytes shall be sent using the format described in clause 11.2.2.1.

Table 11-32 – Inventory commands sent by the requesting MTU

Name	Length (bytes)	Byte	Content
Identification request	2	2	01_{16} (Note)
Auxiliary inventory information request	2	2	02_{16} (Note)
Self-test results request	2	2	03_{16} (Note)
Initialization flags request	2	2	04_{16} (Note)
Initialization flags reset request	2	2	05_{16} (Note)
NT Identification	2	2	06_{16} (Note)
NOTE – All other values for byte2 are reserved by ITU-T.			

Table 11-33 – Inventory responses sent by the responding MTU

Name	Length (bytes)	Byte	Contents
ACK (identification)	58	2	81_{16} (Note)
		3 to 10	Eight bytes of vendor ID.
		11 to 26	Sixteen bytes of version number.
		27 to 58	Thirty two bytes of serial number.
ACK (auxiliary inventory information)	Variable	2	82_{16} (Note)
		3	Segment code (SC)
		4 to 11	Eight bytes of vendor ID.
		12 +	Multiple bytes of auxiliary inventory information.
Self-test results	6	2	83_{16} (Note)
		3 to 6	Four bytes of self-test results.
Initialization flags	3	2	84_{16} (Note)
		3	One byte with the value of the initialization flags.
Initialization flags reset	3	2	85_{16} (Note)
		3	One byte with the value of the initialization flags before the reset.
NT Identification	18	2	86_{16} (Note)
		3 to 18	Sixteen bytes of NT_ID.
NOTE – All other values for byte 2 are reserved by ITU-T.			

Upon reception of one of the inventory commands, the MTU shall send the corresponding response. Any function of either the requesting or the responding MTU shall not be affected by the command.

The vendor ID in the response identifies the system integrator and shall be formatted according to the vendor ID of [ITU-T G.994.1]. In the context of this request, the system integrator usually refers to the vendor of the smallest field-replaceable unit; thus, the vendor ID in the response may not be the same as the vendor ID indicated during the ITU-T G.994.1 handshake phase of the initialization.

The version number sent by the MTU-O is for version control and is MTU-O vendor specific information. It shall contain up to 16 binary bytes.

The version number sent by the MTU-R is for version control. It shall contain the MTU-R firmware version and the MTU-R model. Both shall be encoded in this order and separated by a space character, i.e., "<MTU-R firmware version><space> <MTU-R model>". It shall contain up to 16 American standard code for information interchange (ASCII) characters within the range from code 32 to 126.

The serial number sent by the MTU-O is DPU vendor specific information. The combination of DPU system vendor ID and DPU system serial number creates a unique number for each DPU. It shall contain up to 32 ASCII characters within the range from code 32 to 126.

The serial number sent by the MTU-R shall contain the NT system serial number, the NT model and the NT firmware version. All shall be encoded in this order and separated by space characters, i.e., "<NT serial number><space> <NT model><space> <NT firmware version>". The combination of NT system vendor ID and NT system serial number creates a unique number for each NT. It shall contain up to 32 ASCII characters within the range from code 32 to 126.

The auxiliary inventory information shall be assigned with respect to the same system integrator as contained in the vendor ID. The syntax of this field is beyond the scope of this Recommendation.

The self-test results response shall contain the results from the most recent self-test procedure, initiated either at power-up or by the perform self-test eoc command. The results shall be formatted as defined in clause 11.2.2.6.1.

The initialization flags request and the initialization flags reset request eoc commands shall only be supported from the MTU-O to the MTU-R.

The initialization flags response and the initialization flags reset response shall only be sent from the MTU-R to the MTU-O and shall contain the current value of the initialization flags. The following initialization flags are defined:

– The "previous-loss-of-power" (PLPR) flag: This flag shall be set to 1 after a power-up of the MTU-R due to an interruption in the MTU-R electrical supply (mains) power. The flag shall be set to 0 after sending the initialization flags reset response.

– The "previous host reinit" (PHRI) flag: This flag shall be set to 1 after an exit from showtime of the MTU-R triggered by the NT host (e.g., MTU-R software reboot or L3 request by MTU-R). The flag shall be set to 0 after sending the initialization flags reset response.

  The value of the initialization flags shall be formatted as one byte [0000 00ba] where "a" is the value of the PLPR flag and "b" is the value of the PHRI flag.

NOTE 1 – The MTU-O may first use the 'initialization flags request' eoc command to read the PLPR and PHRI flags, and then, once the MTU-O manages to correctly read these flags, use the 'initialization flags reset request' eoc command (see Table 11-32) to reset the values of these flags.

The NT Identification response shall only be sent from the MTU-R to the MTU-O and shall contain 16 binary bytes representing the 128-bit NT_ID as defined in clause 11.4.6.2.1.

NOTE 2 – For security reasons, the NT_ID can be verified as defined in Annex A.

11.2.2.11 Management counter read commands and responses

The management counter read request command shall be used to retrieve the current value of certain management counters maintained by the far-end MTU. The management counter read request command is shown in Table 11-34 and may be initiated by either MTU and is used to request the values of the counters. The response shall be as shown in Table 11-35. The first byte of the command and response shall be the assigned value for the management counter read command type, as shown in Table 11-6. The second byte of the command shall be as shown in Table 11-34. The second and all following bytes of the response shall be as shown in Table 11-35. The bytes shall be sent using the format described in clause 11.2.2.1.

Table 11-34 – Management counter read commands sent by the requesting MTU

Name	Length (bytes)	Byte	Content
Request	2	2	01_{16} (Note)
NOTE – All other values for byte 2 are reserved by ITU-T.			

Table 11-35 – Management counter read responses sent by the responding MTU

Name	Length (bytes)	Byte	Content
ACK	Variable	2	81_{16} (Note)
		3 to 2 + 4 × (4 + 5 + 2 + 5 + 5)	Bytes for all of the anomaly counters, performance monitoring counters and retransmission and rate reporting status parameter values (see Table 11-36).
NOTE – All other values for byte 2 are reserved by ITU-T.			

Upon reception of the management counter read request command, the MTU shall send the response. Any function of either the requesting or the responding MTU shall not be affected by the command.

Anomalies are only counted at time periods during the transmission of data symbols and RMC symbols.

The management counter values shall be derived from locally generated defects and anomalies defined within clause 11.3. The parameters shall be transferred in the order (top to bottom) defined in Table 11-36. All counter values are defined as 32-bit counters and shall be mapped to the response in order of most significant to least significant byte. No bytes shall be inserted into the response for the TPS-TC functions that are currently disabled.

The counters shall be reset at power-up, and shall not be reset upon a link state transition, and shall not be reset upon read. The time periods when the MTU is powered but not in the showtime state shall be counted as unavailable seconds (see clause 11.4.4.5).

The field EFTR_min contains the *EFTR_min* as derived by the far-end receiver. The field ANDEFTR_min contains the *ANDEFTR_min* as derived by the far-end transmitter. The field ANDEFTR_max contains the *ANDEFTR_max* as derived by the far-end transmitter. The field ANDEFTR_sum contains the *ANDEFTR_sum* as derived by the far-end transmitter. The field ANDEFTR0_min contains the *ANDEFTR0_min* as derived by the far-end transmitter. The field ANDEFTR0_max contains the *ANDEFTR0_max* as derived by the far-end transmitter. The field ANDEFTR0_sum contains the *ANDEFTR0_sum* as derived by the far-end transmitter.

Although the parameters *EFTR_min*, *ANDEFTR_min*, *ANDEFTR0_min*, *ANDEFTR_max* and *ANDEFTR0_max* are reported via the management counter eoc commands, these performance monitoring parameters are not counters (see clauses 11.4.1.1.6, 11.4.1.1.18, 11.4.1.1.18.1, 11.4.1.1.19 and 11.4.1.1.19.1, respectively).

The performance monitoring parameters *EFTR_min*, *ANDEFTR_min*, *ANDEFTR0_min*, *ANDEFTR_max and ANDEFTR0_max* shall be reset at power up, and shall not be reset upon a link state transition, and shall be reset upon read.

Table 11-36 – MTU management counters

Counter of the *fec* anomalies (see clause 11.3.1.1)
Counter of the *crc* anomalies (see clause 11.3.1.1)
Counter of *rtx-uc* anomalies (see clause 11.3.1.1)
Counter of *rtx-tx* anomalies (see clause 11.3.1.1)
Counter of the ESs (see clause 11.4.4.1)
Counter of the SESs (see clause 11.4.4.2)
Counter of the LOSSs (see clause 11.4.4.3)
Counter of the LORSs (see clause 11.4.4.4)
Counter of the UASs (see clause 11.4.4.5)
EFTR_min (see clause 11.4.1.1.6)
Error-free bits counter (see clause 11.4.1.1.9)
ANDEFTR_min (see clause 11.4.1.1.18)
ANDEFTR_max (see clause 11.4.1.1.19)
ANDEFTR_sum counter (see clause 11.4.1.1.20)
Counter of the ANDEFTRDSs (see clause 11.4.1.1.21)
Counter of the LANDEFTRSs (see clause 11.4.4.8)
ANDEFTR0_min (see clause 11.4.1.1.18)
ANDEFTR0_max (see clause 11.4.1.1.19)
ANDEFTR0_sum counter (see clause 11.4.1.1.20)
Counter of the ANDEFTR0DSs (see clause 11.4.1.1.21)
Counter of the LANDEFTR0Ss (see clause 11.4.4.8)
NOTE 1 – Inhibiting of counters is defined in clause 11.4.4.6.

NOTE – The MTU-O should respond to the request from the NMS to read the values of management counters. It is left to the implementations to store and update the counters as necessary for accurate error monitoring and reporting.

11.2.2.12 L3 link state transition commands and responses

The L3 link state transition command shall be used to propose a transition to link state L3. The L3 link state transition command may be initiated by either MTU. The peer MTU shall acknowledge by sending a response.

The first byte of either the command or a response shall be the assigned value for the L3 link state transition command type, as shown in Table 11-6 (normal priority command). The remaining bytes shall be as shown in Table 11-37 and Table 11-38 for commands and responses, respectively.

Table 11-37 – L3 link state transition command (sent by the initiating MTU)

Name	Length (bytes)	Byte	Content
L3 Request	3	2	01_{16} (Note)
		3	03_{16} (Note)
NOTE – All other values for bytes 2 and 3 are reserved by ITU-T.			

Table 11-38 – L3 link state transition responses (sent by the responding MTU)

Name	Length (bytes)	Byte	Content
Grant	2	2	80_{16} (Note)
Reject	3	2	81_{16} (Note)
		3	One byte for reason code.
NOTE – All other values for byte 2 are reserved by ITU-T.			

Reason codes associated with the L3 link state transition commands are shown in Table 11-39.

Table 11-39 – Reason codes for L3 link state transition commands

Reason	Byte value
Busy	01_{16}
Invalid command	02_{16}
Not desired at this time	03_{16}
NOTE – All other reason codes are reserved by ITU-T.	

11.2.2.12.1 L3 Request by MTU-R

Upon receipt of a L3 Request, the responding MTU-O shall send either a Grant or a Reject response. If the format of the command is different than the one presented in Table 11-37, the Reject response shall be sent with the reason code 02_{16}.

The MTU-O may reject a L3 Request using reason code 01_{16} if it is temporarily busy, or reject it using code 03_{16} if it has local knowledge that the L3 state is not desired at this time. Upon receipt of a L3 Request, the MTU-O may reply with a Grant and immediately start transition into the L3 state.

If the MTU-R receives the Grant response, the MTU-R shall stop transmitting. When the MTU-O observes the stopped transmission, it shall transition into O-DEACTIVATING1 state (see clause 12.1.2).

11.2.2.12.2 L3 Request by MTU-O

Upon receipt of a L3 Request, the responding MTU-R shall send either a Grant or a Reject response. If the format of the command is different than one presented in Table 11-37, the Reject response shall be sent with the reason code 02_{16}.

The MTU-R may reject a L3 Request using reason code 01_{16} if it is temporarily busy, or reject it using code 03_{16} if it has local knowledge that the L3 state is not desired at this time. Upon receipt of a L3 Request, the MTU-R may reply with a Grant and immediately start transition into the L3 state.

If the MTU-O receives the Grant response, the MTU-O shall transition into O-DEACTIVATING1 state (see clause 12.1.2). When the MTU-R observes that the MTU-O transitioned to the O-DEACTIVATING1 state, it shall stop transmitting.

11.2.2.13 PMD test parameter read commands and responses

The PMD test parameter read commands shall be used to retrieve the values of the PMD test parameters that are specified in clause 11.4.1 and maintained by the far-end MTU. The PMD test parameter read commands are shown in Table 11-40, and may be initiated by either MTU. The responses shall be as shown in Table 11-41. The first byte of all PMD test parameter read commands and responses shall be the assigned value for the PMD test parameter read command type, as shown in Table 11-6. The subsequent bytes of the commands shall be as shown in Table 11-40. The subsequent bytes of the responses shall be as shown in Table 11-41. The bytes shall be sent using the format described in clause 11.2.2.1.

Table 11-40 – PMD test parameter read commands sent by the requesting MTU

Name	Length (bytes)	Byte	Content	Support
Single read	2	2	01_{16} (Note 1)	Mandatory
Vector block read	7	2	06_{16} (Note 1)	Mandatory
		3	One byte containing the ID of the vector test parameter to be read (Note 2). 04_{16}: *SNR* per subcarrier group (Note 3). 05_{16}: Downstream *ALN* per subcarrier group.	
		4 and 5	Two bytes describing the start subcarrier group index.	
		6 and 7	Two bytes describing the stop subcarrier group index.	
NOTE 1 – All other values for byte 2 are reserved by the ITU-T. NOTE 2 – All other values for byte 3 are reserved by the ITU-T. NOTE 3 – The only valid value of subcarrier group size (*G*) for *SNR* is *G* = 1.				

Table 11-41 – PMD test parameter read responses sent by the responding MTU

Name	Length (bytes)	Byte	Content	Support
Single read ACK	16 (Note 1)	2	81_{16} (Note 2)	Mandatory
		3 to 16	Bytes for the test parameters arranged for the single read format.	
NACK	2	2	80_{16} (Note 2)	Mandatory
Vector block read ACK	Variable (Note 1)	2	86_{16} (Note 2)	Mandatory
		3	Segment code (SC)	
		4 +	Bytes for the test parameters arranged for the vector block read format.	
NOTE 1 – Message length equals three bytes plus the length shown in Table 11-42. NOTE 2 – All other values for byte 2 are reserved by the ITU-T.				

Table 11-42 – PMD test parameter ID values and length of responses

Test parameter ID (Note 1)	**Test parameter name**	**Length for single read (bytes)**	**Length for vector block read (bytes)**	**Support**
04_{16}	SNR per subcarrier	N/A	2 + (stop subcarrier index − start subcarrier index + 1) (Note 2)	Mandatory
05_{16}	Downstream ALN per subcarrier group	N/A	3 + (stop subcarrier group index − start subcarrier group index + 1) (Note 4)	Mandatory
23_{16}	SNRM	2	N/A	Mandatory
24_{16}	ATTNDR	4	N/A	Mandatory
25_{16}	Near-end ACTATP	2	N/A	Mandatory (Note 3)
27_{16}	Far-end *INP_act_shine*	2	N/A	Mandatory
28_{16}	Far-end actual *SNRM_RMC*	2	N/A	Mandatory
29_{16}	RXpower_dBm_DS	2	N/A	Mandatory
30_{16}	TXpower_dBm_US	2	N/A	Mandatory

NOTE 1 – All other test parameter ID values are reserved by the ITU-T.

NOTE 2 –The subcarrier index equals *G* × subcarrier group_index, where the value of *G* is as specified in clause 11.4.1.

NOTE 3 – The near-end actual transmit power (ACTATP) shall be set to zero in the eoc message sent to the MTU-R.

NOTE 4 –The subcarrier index equals *G* × subcarrier group_index, where the value of *G* is included in the response message.

Upon reception of a PMD test parameter read command, the responding MTU shall send the corresponding response. If the format of the test parameter read command is incorrect, the MTU shall respond with the negative acknowledgment (NACK). Any function of either the requesting or the responding MTU shall not be affected.

The single read command shall be used to retrieve all parameters with ID values ≥ 23_{16}. In response to a single read command, the values for the test parameters (one value per parameter) shall be transferred in numerically increasing order of the parameter ID shown in Table 11-42. The format of the bytes for each parameter shall be as specified in clause 11.4.1. Values formatted as multiple bytes shall be mapped to the response in order of most significant to least significant byte. Bytes indicated as reserved shall be set to ZERO in the transmitter and ignored by the receiver.

A vector block read command shall be used to retrieve a single test parameter over a range of subcarrier groups. Support of this read command is mandatory. The ID of the test parameter to retrieve shall be indicated in the third byte of the read command as specified in Table 11-40. In response to a vector block read command, the MTU shall send information for the test parameter associated with the specified block of subcarrier groups. All values for subcarrier groups with indices from start subcarrier group index to stop subcarrier index are transferred in a single response.

If the stop subcarrier group index in the test parameter read command exceeds the round-up of the index of the highest subcarrier in the MEDLEYG set divided by the group size *G*, the response shall be a NACK. The format of the bytes for each parameter value shall be as described in clause 11.4.1.

Values formatted as multiple bytes shall be mapped to the response in order of most significant to least significant byte.

The response to a vector block read command for SNR shall include the measurement time in symbol periods (2 bytes) followed by the *SNR* test parameter value (see clause 11.4.1.2.2).

The response to a vector block read command for ALN shall include the measurement time in symbol periods (2 bytes), followed by the group size (1 byte), followed by the *ALN* test parameter value (see clause 11.4.1.2.4).

Responses to a vector block read command may be segmented.

The values of some test parameters are represented using fewer bits than contained in the corresponding field defined for the response in Table 11-42. In the case that the field has more than one byte, the bits shall be mapped to the LSBs of the multibyte field in the response. Unused MSBs in the multibyte field shall be set to ZERO for unsigned quantities and to the value of the sign bit for signed quantities.

11.2.2.14 Vectoring feedback command and responses

The MTU-O shall use the vectoring feedback command and responses for configuration of the vectoring report parameters and obtaining VF samples, i.e., clipped error samples or DFT output samples, from the MTU-R. The command (containing a request for VF samples) may be initiated only by the MTU-O and shall use the format shown in Table 11-43. The MTU-R shall respond with VF samples for the requested subcarriers in the requested format, or with NACK. The NACK provides a rejection code describing the reason of the request denial. Prior to sending the NACK, the MTU-R shall suspend sending VF samples until it receives a new vectoring feedback command with a valid set of the vectoring feedback report control parameters.

The first byte of the command and the response shall be the assigned value of the vectoring feedback command type, as shown in Table 11-5 (near-high priority command). The second and subsequent bytes shall be as shown in Table 11-43 for the command and in Table 11-46 for responses. The rejection codes shall be as defined in Table 11-47. The data bytes shall be mapped using the generic format described in clause 11.2.2.1.

The MTU-O sends in the vectoring feedback command a set of parameters of the requested vectoring feedback report. The first MTU-R vectoring feedback response data sent in reply serves as an ACK for the vectoring feedback command. More vectoring feedback data may be transmitted, if necessary, in subsequent eoc messages. Transmissions of the following vectoring feedback responses shall be triggered by every VF sample update at superframe counts requested in the vectoring feedback command (update period and shift period). If the update period q is greater than 1, the MTU-R shall update VF samples only at the exact superframe counts indicated by the MTU-O (see clause 10.3.2.5.2).

Vectoring feedback responses shall not be acknowledged. If the vectoring feedback data message exceeds P-4 bytes (see clause 11.2.1.1), it shall be segmented as defined in clause 11.2.2.3 with the maximum number of segments not to exceed 16. The MTU-R shall not retransmit vectoring feedback data messages or their segments. If the MTU-O does not receive a response (ACK), it may send another vectoring feedback command, possibly with different control parameters. The MTU-R shall continue sending vectoring feedback responses until stopped by the MTU-O, including while waiting for a reply to SRA request RMC command. If in the time period allocated to send a particular vectoring feedback response the eoc channel is busy with a currently running high-priority message (e.g., OLR command), the MTU-R shall drop this vectoring feedback response and continue with the next vectoring feedback response.

At the start of showtime, the MTU-R shall not send a vectoring feedback response until it receives a vectoring feedback command with a valid set of vectoring feedback report control parameters. The MTU-O shall send a vectoring feedback command within the first second after entering showtime.

To stop communication of vectoring feedback reports, the MTU-O shall send a vectoring feedback command that carries a special value of VF sample update period $q = 0$ (see Table 11-43). Upon reception of the command containing $q = 0$, the MTU-R shall first stop sending vectoring feedback responses and subsequently respond with NACK.

Table 11-43 – Vectoring feedback command (transmitted by the MTU-O)

Name	Length (bytes)	Byte number	Content
Vectoring feedback request	$9 + 5 \times N\_band$ $+\text{ceiling}(Nprobe_{ds}/8)$ ($N\_band \leq 8$)	2	01_{16} (Note 1)
		3 to 4	First CNT_{SF} (CNT_{SF_0}, see clause10.3.2.5.2) coded as an unsigned integer
		5	Bits [3:0]: VFRB update period (q) (see clause 10.3.2.5.2), coded as an unsigned integer (Note 2, 3) Bit [4]: reporting mode: if set to 0 the VFRB shall carry clipped error samples, if set to 1, the VFRB shall carry both clipped error samples and DFT output samples (see clause 10.3.2.4.1) using the per-element VF reporting mode defined in Table 11-44 Bits [7:5]: VFRB frequency shift step (s) (see clause 10.3.2.5.1), coded as an unsigned integer (Note 4)
		6 to 7	VFRB shift period (z) (see clause 10.3.2.5.2), coded as an unsigned integer
		8 to $9 + 3 \times N\_band$	Vectored bands formatted using the bands descriptor (see Table 12-22)
		$10 + 3 \times N\_band$ to $10 + 5 \times N\_band$ $+2 \times \text{ceiling}(Nprobe_{ds}/8)$	Vectoring feedback report configuration descriptor defined in Table 11-44

NOTE 1 – All other values are reserved by ITU-T.

NOTE 2 – Setting the value of parameter q to 0000_2 stops the report (see clause 10.3.2.5.1 and clause 10.3.2.5.2).

NOTE 3 – For frequency identification, the value of parameter q shall be set to 0001_2.

NOTE 4 – The value of parameter s determines whether frequency identification or time identification shall be used (see clause 10.3.2.5). Setting $s = 000_2$ indicates time identification (see clause 10.3.2.5.2) and setting $s \neq 000_2$ indicates frequency identification (see clause 10.3.2.5.1). In the latter case value of z shall be ignored.

Table 11-44 – Vectoring feedback report configuration descriptor

Parameter	Bit	Byte	Description
N_band	[7:4]	0	The number of configured vectored bands within the range from one to eight coded as an unsigned integer.
Padding	[3]		As defined in clause 10.3.2.3.1.
Rounding	[2]		As defined in clause 10.3.2.3.1.
F_block	[1:0]		Block size, encoded as (Note): 00_2 – *F_block* = 1 01_2 – *F_block* = 2 10_2 – *F_block* = 4 11_2 – Reserved for use by ITU-T
VF Sub-frame type	[1:0]	1	Sub-frame type to be reported encoded as: 01_2 – FDS only 10_2 – FUS only Other values reserved by ITU-T
	[7:2]		reserved by ITU-T
Vectored band 1 control parameters		2-3	See Table 11-45
Vectored band *N_band* control parameters		2 × *N_band* to 2 × *N_band* + 1	See Table 11-45
Per-element VF report	[$Nprobe_{ds}$:0]	2 × *N_band+2 to* 2 × *N_band+1+* ceiling($Nprobe_{ds}/8$)	This field shall not be present if the reporting mode bit in Table 11-43 is set to 0 (applicable during showtime) or if the descriptor is included in the O-VECTOR-FEEDBACK message (applicable during initialization, see Table 12-35). If present, this field represents a bit map indicating reporting mode per probe sequence element. The LSB indicates sample type to be sent on the first element of the downstream probe sequence, the MSB indicates sample type to be sent on the last element. If a bit is set to 0, the corresponding VFRB shall carry clipped error samples, if set to 1, the corresponding VFRB shall carry DFT output samples (see clause 10.3.2.4.1).
NOTE – *F_block* has the same value for all vectored bands.			

Table 11-45 – Vectored band control parameters

Parameter	Bits	Byte	Description
F_sub	[7:4]	0	Sub-sampling rate *F_sub* as defined in clause 10.3.2.3.1, coded as an unsigned integer.
L_w	[3:0]		Length of the VF sample in compressed representation as defined in clause 10.3.2.3.1, with *L_w* coded as an unsigned integer.
B_min	[7:4]	1	Parameter *B_min* as defined in clause 10.3.2.3.1, with (*B_min* – 2) coded as an unsigned integer.
B_max	[3:0]		Parameter *B_max* as defined in clause 10.3.2.3.1, with (*B_max* – 2) coded as an unsigned integer.

Table 11-46 – Vectoring feedback responses (transmitted by the MTU-R)

Name	Length (bytes)	Byte	Content
Vectoring feedback data/ACK	$6 + N_{VFRB}$	2	80_{16} (Note 1)
		3	Segment code (SC), represented as defined in clause 11.2.2.3.
		4 and 5	Superframe count (CNT_{SF}) coded as an unsigned integer within the range as defined in clause 10.6 (Note 2).
		6	Indicate on which type of sub-frame the VF is reported (0: FDS, 1: FUS, other values are reserved by ITU-T).
		7 to 6 + *N_VFRB*	Vectoring feedback data, represented with *N_VFRB* bytes, as defined in clause 10.3.2.4.1 (Note 3).
NACK	3	2	81_{16} (Note 1)
		3	One byte for reason code (see Table 11-47).

NOTE 1 – All other values for this byte are reserved by ITU-T.
NOTE 2 – This field identifies the downstream sync symbol for which vectoring feedback data is reported.
NOTE 3 – This field shall carry the VFRB using the format described in clause 10.3.2.4.1.

Table 11-47 – NACK reason codes

Value	Definition
01_{16}	Invalid set of vectoring feedback control parameters or vectoring feedback report format.
02_{16}	Sending of vectoring feedback reports is stopped on the MTU-Os request (MTU-R received a vectoring feedback command with the value of $q = 0$).

NOTE – All other reason codes are reserved by ITU-T.

11.2.2.15 Probe sequence update commands and responses

Upon instruction of the VCE, the MTU-O shall send the appropriate probe sequence update command to force an update of the upstream probe sequence and communicate the new downstream probe sequence for the line to the MTU-R MME. The commands are shown in Table 11-48 and

Table 11-49, and may be initiated only by the MTU-O. The MTU-R shall respond with either an ACK or NACK, using the format shown in Table 11-50.

The first byte of the commands shall be the assigned value of the upstream and downstream probe sequence update command type, as shown in Table 11-6. The second and subsequent bytes shall be as shown in Table 11-48 and Table 11-49 for commands and in Table 11-50 for responses. The data bytes shall be mapped using the format described in clause 11.2.2.1.

The command length depends on the length of the upstream probe sequence or downstream probe sequence ($Nprobe_{us}$ or $Nprobe_{ds}$, respectively) set during the initialization (see clause 12.3.3.2.1). Only the probe sequence elements may be changed during the showtime. The length of the newly assigned probe sequence shall be the same as the length of the probe sequence that was set during the initialization.

Table 11-48 – Upstream probe sequence update command (transmitted by the MTU-O)

Name	Length (bytes)	Byte	Content
Upstream probe sequence update	3 + ceiling($Nprobe_{us}$/4)	2	01_{16} for change of upstream probe sequence (Note).
		3	01_{16} if interruption of current upstream probe sequence is not allowed; 02_{16} if interruption of current upstream probe sequence is allowed. (Note)
		4 to 3 + ceiling($Nprobe_{us}$/4)	Upstream probe sequence bits, coded as defined for field 13 in Table 12-21.
NOTE – All other values for this byte are reserved by ITU-T.			

Table 11-49 – Downstream probe sequence update command (transmitted by the MTU-O)

Name	Length (bytes)	Byte	Content
Downstream probe sequence update	3 + ceiling($Nprobe_{ds}$/4)	2	02_{16} for change of downstream probe sequence. (Note)
		3	01_{16} if interruption of current downstream probe sequence is not allowed; 02_{16} if interruption of current downstream probe sequence is allowed. (Note)
		4 to 3 + ceiling($Nprobe_{ds}$/4)	Downstream probe sequence bits, coded as defined for field 16 in Table 12-21.
NOTE – All other values for this byte are reserved by ITU-T.			

The third byte of the probe sequence update commands defines the time at which the probe sequence change shall occur:

- If interruption of the current probe sequence is not allowed (value 01_{16}), the probe sequence change shall be applied starting from the next sync symbol position after the end of the current probe sequence, i.e., after the sync symbol modulated by the last element of the old probe sequence, the next sync symbol shall be modulated by the first element of the new probe sequence.

- If interruption of the current probe sequence is allowed (value 02_{16}), the probe sequence change may occur at any sync symbol position, i.e., after the sync symbol modulated by element *i* of old probe sequence, the next sync symbol shall be modulated by element *i* + 1 of the new probe sequence.

The MTU-R shall acknowledge (ACK) the correct reception of the command, as shown in Table 11-50. The MTU-R may only reject (NACK) the request if one or more of the requested parameters is invalid (see Table 11-51).

Table 11-50 – Probe sequence update response transmitted by the MTU-R

Name	Length (bytes)	Byte	Content
ACK	2	2	80_{16} (Note)
NACK	3	2	81_{16} (Note)
		3	One byte for reason code (see Table 11-51)
NOTE – All other values for this byte are reserved by ITU-T.			

Table 11-51 – NACK reason codes

Value (Note)	Definition
01_{16}	Invalid set of parameters.
NOTE – All other reason codes are reserved by ITU-T.	

For the upstream probe sequence update command, the MTU-R shall apply the change only after sending the ACK message. If interruption of the current probe sequence is allowed, the update shall occur within 40 ms after sending the ACK message.

The timing diagram of the upstream probe sequence update eoc command and response is shown in Figure 11-5.

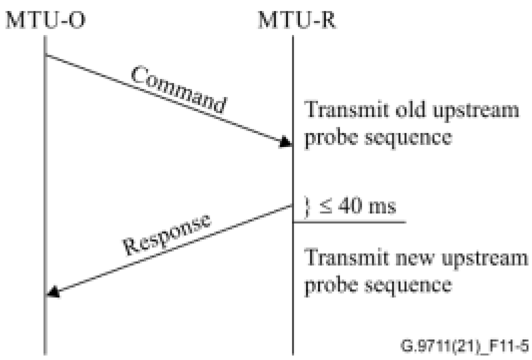


Figure 11-5 – Timing diagram of the upstream probe sequence update command and response

For the downstream probe sequence update command, the MTU-O shall apply the change after receiving the ACK message. If interruption of the current probe sequence is allowed, the update shall occur within 40 ms after receiving the ACK message.

The timing diagram of the downstream probe sequence update eoc command and response is shown in Figure 11-6.

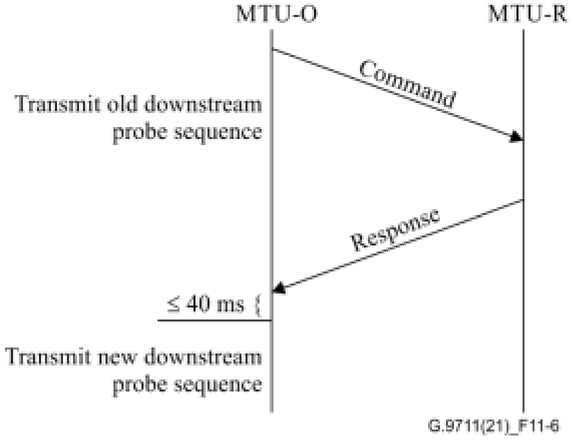


Figure 11-6 – Timing diagram of the downstream probe sequence update command and response

11.2.2.16 DRR configuration commands and responses

The MTU-O shall use the DRR configuration commands to send the value of N_{DRR} and N_{RM} to the MTU-R and to send the DRR configuration request data to the MTU-R (see clause 8.1.1). The command shall be sent by the MTU-O only. The MTU-R shall respond to the DRR request command using DRR.confirm and shall respond to the DRR configuration request command using DRR.config.confirm, respectively.

The first byte of the commands and responses shall be the assigned value DRR configuration command type, as shown in Table 11-6 (normal priority command). The second and subsequent bytes shall be as defined in Table 11-52 (for the commands) and in Table 11-53 (for the responses). The bytes shall be sent using the format described in clause 11.2.2.1.

Table 11-52 – DRR configuration commands (sent by the MTU-O)

Name	Length (bytes)	Byte	Content
DRR request	4	2	01_{16} (Note)
		3	One byte for N_{DRR} coded as an unsigned integer.
		4	One byte for N_{RM} (see Table 8-4) coded as an unsigned integer.
DRR configuration request	Variable	2	02_{16} (Note)
		3+	DRR data as received from the DRA function at the MTU-O (see Table 8-4). The format of the DRR data is defined in Table Y.2.
NOTE – All other values for byte 2 are reserved by ITU-T.			

Table 11-53 – DRR configuration responses (sent by the MTU-R)

Name	Length (bytes)	Byte	Content
DRR.confirm	3	2	81_{16} (Note)
		3	One byte for ACK (00_{16}) or NACK (FF_{16})
DRR.config. confirm	Variable	2	82_{16} (Note)
		3+	DRR data as received from the L2+ function at the MTU-R (see Table 8-4). The format of the DRR data field is defined in Table Y.2.
NOTE – All other values for byte 2 are reserved by ITU-T.			

11.2.2.17 Fast start-up training sequence parameters command and response

The command is to configure the fast start-up training sequence parameters at the MTU-R. The command shall only be sent by the MTU-O. The MTU-R shall acknowledge the command by sending a response.

The first byte of either the command or a response shall be the assigned value for fast start-up training sequence parameters command type, as shown in Table 11-6 (normal priority command). The remaining bytes shall be as shown in Table 11-54 and Table 11-55 for command and response, respectively.

Table 11-54 – Training sequence parameters command (sent by the MTU-O)

Name	Length (bytes)	Byte	Content
Fast start-up training sequence parameters	10	2	01_{16} (Note)
		3	Number of DS SOC data symbols (s_{ds}). The value shall be mapped to the six LSBs of this byte as defined in Table 12-10.
		4	Number of SOC symbol repetitions (Rs). The value shall be mapped to the five LSBs of this byte as defined in Table 12-11.
		5 to 10	Length and elements of IDS The six bytes are represented as a single 48-bit field. The 42 LSBs shall be used for IDS mapping as defined in Table 12-11. The LSB of the field corresponds to bit 0 of byte 5.
NOTE – All other values for byte 2 are reserved by ITU-T.			

The MTU-R shall apply these parameters upon transition from the R-SHOWTIME state to the R-INIT/TRAIN state (fast retrain), as described in Figure 12-3.

The MTU-R shall acknowledge the reception of the command, as shown in Table 11-55. The MTU-R may only reject (NACK) the command if one or more of the requested parameters is invalid.

Table 11-55 – Training sequence parameter responses (sent by the MTU-R)

Name	Length (bytes)	Byte	Content
ACK	2	2	80_{16} (Note)
NACK	2	2	81_{16} (Note)
NOTE – All other values for byte 2 are reserved by ITU-T.			

11.2.2.18 Non-standard facility commands and responses

The non-standard facility (NSF) commands may be used to exchange vendor-discretionary information between the MTUs. The NSF Request command is shown in Table 11-56 and may be initiated by either MTU to request the non-standard information. The responses shall be as shown in Table 11-57. The first byte of either the command or a response shall be the assigned value for the NSF command type, as shown in Table 11-6 for normal priority NSF commands, or in Table 11-7 for low priority NSF commands. The remaining bytes of normal priority and low priority commands shall be as shown in Table 11-56. The second byte of normal priority and low priority responses shall be as shown in Table 11-57. The bytes shall be sent using the format described in clause 11.2.2.1.

Table 11-56 – NSF commands sent by the requesting MTU

Name	Length (bytes)	Byte	Content
Request	Variable	2	01_{16} (Note)
		3 to 8	Six bytes of NSF identifier field.
		9 +	Multiple bytes of NSF message field.
NOTE – All other values for byte 2 are reserved by ITU-T.			

Table 11-57 – NSF responses sent by the responding MTU

Name	Length (bytes)	Byte	Content
ACK	2	2	80_{16} (Note)
NACK	2	2	81_{16} (Note)
NOTE – All other values for byte 2 are reserved by ITU-T.			

Upon reception of the NSF Request command, the MTU shall respond with an acknowledgement (ACK) to indicate that both the NSF identifier field and the message field are recognized, or respond with a negative acknowledgement (NACK) if either the NSF identifier field or NSF message field is not recognized.

The combination of the NSF identifier field and NSF message field corresponds to a non-standard information block as defined in Figure 11 of [ITU-T G.994.1] (without the length-indicator byte). The NSF identifier field shall consist of six bytes. The first two bytes shall be a country code, and the remaining four bytes shall be a provider code as specified by the country. Both values shall be set as defined in [ITU-T T.35]. The NSF message field contains vendor-specific information. The syntax of the NSF message field shall be as defined in Figure 11 of [ITU-T G.994.1] (without the length-indicator byte).

11.2.2.19 INM facility commands and responses

An MTU that supports the INM facility shall maintain INM counters to measure the impulse noise and report the INM performance monitoring parameters defined in [ITU-T G.997.3]. The INM facility commands shall be used to update and read the INM control parameters at the MTU-R and to retrieve the current value of the INM counters maintained by the MTU-R in accordance with [ITU-T G.997.3].

The INM facility commands are described in Table 11-58, and may only be initiated by the MTU-O. The MTU-R shall reply using one of the responses shown in Table 11-56. The first byte of all INM facility commands and responses shall be the assigned value for the INM facility command type, as shown in Table 11-7. The remaining bytes shall be as specified in Table 11-58 and Table 11-56 for commands and responses, respectively. The bytes shall be sent using the format described in clause 11.2.2.1.

Table 11-58 – INM facility commands sent by the MTU-O

Name	Length (bytes)	Byte	Content
Read INM counters	2	2	02_{16} (Note)
Set INM parameters	8	2	03_{16} (Note)
		3 to 8	6 bytes of INM control parameters: see Table 11-61
Read INM parameters	2	2	04_{16} (Note)
NOTE – All other values are reserved by ITU-T.			

Table 11-59 – INM facility responses sent by the MTU-R

Name	Length (bytes)	Byte	Content
ACK	3	2	80_{16} (Note)
		3	Reserved for use by ITU-T, shall be set to zero.
NACK	2	2	81_{16} (Note)
INM counters	111	2	82_{16} (Note)
		3 to 2 + 4 × (17+8+2)	All of the INM counter values in the format defined in Table 11-60
		111	The *INMDF* value coded as an unsigned integer
INM parameters	8	2	84_{16} (Note)
		3 to 8	6 bytes of actual INM control parameters in the format as defined in Table 11-61
NOTE – All other values are reserved by ITU-T.			

Upon reception of any INM facility command, the MTU-R shall send NACK in response if the set INM parameters command includes invalid parameters. Upon reception of an INM facility set INM parameters command that includes a valid set of parameters, the MTU-R shall send the ACK in response if it does support the INM facility.

In case all INM parameter values listed in the set INM parameters command are valid, the MTU-R shall accept all of the INM parameters contained in the command. If, for any of the INM parameters, the value in the command is different from the value that is currently in active use by the INM, the MTU-R shall activate the new INM parameter values and reset the INM counters in less than 1 second after sending the ACK.

Upon reception of the INM facility "read INM parameters" command, the MTU-R shall send the INM parameters response (see Table 11-59) that includes the current value of the MTU-R INM parameters.

Upon reception of the INM facility "read INM counters" command, the MTU-R shall send the INM counters response (see Table 11-59) that includes the INM default flag (*INMDF*). The MTU-R shall set *INMDF* to ONE if all INM control parameters associated with the reported counter values are set to the default values and shall set *INMDF* to ZERO otherwise.

The INM counter values shall be transmitted in the order, top to bottom, as defined in Table 11-60. All counters are 32 bit wrap-around counters, and their values shall be mapped to the response in order of most significant byte transmitted first. The INM counters shall be reset to zero both at power-up and upon activation of the new INM parameter values. The counters shall not be reset upon any link state transition including ones triggered by reinitialization and fast retrain and shall not be reset upon read. The INM counters and the procedure to update these counters shall work continuously and independently of other MTU procedures, e.g., the INM shall not be interrupted by OLR procedures.

NOTE – The values of the INM counters during link state transitions may not be reliable.

Table 11-60 – MTU-R INM counters

INM counters
Counter of the $INMAINPEQ_1$ anomalies
Counter of the $INMAINPEQ_2$ anomalies
Counter of the $INMAINPEQ_{16}$ anomalies
Counter of the $INMAINPEQ_{17}$ anomalies
Counter of the $INMAIAT_0$ anomalies
Counter of the $INMAIAT_1$ anomalies
Counter of the $INMAIAT_6$ anomalies
Counter of the $INMAIAT_7$ anomalies
Counter of the *INMAME* anomalies
Counter of the *INMBLFC* anomalies

The INM control parameter values, both in INM facility command and INM facility response, shall be transmitted in the order defined in Table 11-61.

Table 11-61 – MTU-R INM parameters

Byte	INM parameter (Note)
3 and 4	2 bytes: • The 9 LSBs = *INM_iato* • The 4 MSBs = *INM_iats* Bits [11:9] are reserved by ITU-T and shall be set to zero.
5	1 byte: *INM_cc*
6	1 byte: Reserved by ITU-T, shall be set to zero.

Table 11-61 – MTU-R INM parameters

Byte	INM parameter (Note)
7	1 byte: The 2 LSBs = *INM_INPeq_format* The MSB = *brgn* Bits [6:2] are reserved by ITU-T and shall be set to zero
8	1 byte: histogram scaling: The 4 LSBs = *INPeq_sf* The 4 MSBs = *iat_sf*
NOTE – All values shall be coded as unsigned integers.	

11.2.2.20 Update backup RTSBL

The update backup RTSBL command shall be used to update the backup RMC tone set (*RTS-b*) and bit loading to be used by the transmitter of the peer MTU. The command may be initiated by either MTU. The peer MTU shall acknowledge by sending a response.

The first byte of both the command and the response shall be the assigned value for the update backup RTSBL command type, as shown in Table 11-5 (normal priority command). The remaining bytes shall be as shown in Tables 11-62 and 11-63 for commands and responses, respectively.

Table 11-62 – Update backup RTSBL (sent by the initiating MTU)

Name	Length (bytes)	Byte	Content
Request to update the backup RTSBL	7+4 × ceiling(*NSCR-b*/2)	2	01_{16} (Note 1)
		3	Command SN coded as an unsigned integer within the range from 0 to 15
		4 and 5	CNT_{SF} at which the update shall occur, coded as an unsigned integer
		6 and 7	Number of tones in backup RMC tone set (*NSCR-b*) coded as an unsigned integer (Note 2)
		8 to 7+3 × ceiling(*NSCR-b*/2)	Backup RMC tone set (*RTS-b*) (Note 3)
		8+3 × ceiling(*NSCR-b*/2) to 7+4 × ceiling(*NSCR-b*/2)	Backup bit-loading table for RMC (Note 4)
NOTE 1 – All other values for byte 2 are reserved by ITU-T. NOTE 2 – The number of tones in the upstream backup RMC tone set is $NSCR\text{-}b_{us}$, and the number of tones in the downstream backup RMC tone set is $NSCR\text{-}b_{ds}$. NOTE 3 – The upstream backup RMC tone set is $RTS\text{-}b_{us}$ and the downstream backup RMC tone set is $RTS\text{-}b_{ds}$. The content of this field shall be formatted as defined for field 11 in Table 12-66 for the upstream and Table 12-71 for the downstream. NOTE 4 – The content of this field shall be formatted as defined for field 12 in Table 12-66 for the upstream and Table 12-71 for the downstream.			

The command sequence number (SN) is used for alignment between an "update backup RTSBL" command and its response. The command SN is generated by the initiating MTU, so that each transmitted "update backup RTSBL" command with a content that is different from the preceding one, has its command SN incremented by one, wrapping around to 0 after reaching 15. The command SN shall not be incremented in case a command is resent (e.g., if no response is received for the command).

The command SN in the "update the backup RTSBL" response (see Table 11-63) shall have the same value as in the corresponding "update the backup RTSBL" command.

Table 11-63 – Update backup RTSBL responses (sent by the responding MTU)

Name	Length (bytes)	Byte	Content
ACK	3	2	80_{16} (Note)
		3	Command SN coded as an unsigned integer within the range from 0 to 15
Reject	4	2	81_{16} (Note)
		3	Command SN coded as an unsigned integer within the range from 0 to 15
		4	Rejection code: 01: Busy 02: Invalid parameters (Note)
NOTE – All other values for this byte are reserved by ITU-T.			

The ACK response indicates that the responding MTU received the requested update to the backup *RTSBL* and confirms it will update it at the requested CNT_{SF} (see Table 11-62).

The CNT_{SF} value in the "update backup RTSBL" command shall be set so that the timeout of the command (200ms) is reached at least 100ms before the superframe count associated with CNT_{SF} is reached.

If the "update backup RTSBL" command times out or is rejected, the initiating MTU shall keep the current backup *RTSBL*. In case of timeout, the initiating MTU shall, at its first opportunity, send the "update backup RTSBL" command again and continue to do so until the command is properly acknowledged. In case the command is rejected, the MTU may resend the command.

NOTE – The requirements on CNT_{SF} and retransmission of the command are to prevent a mismatch between the backup RTCBL in the peer MTUs in case the ACK response is lost because the eoc message was corrupted.

11.2.2.21 SPA-PREP command and response

The SPA-PREP command and responses are used for negotiating a new MREFPSD_NPus value between the MTU-O and MTU-R, as well as conveying a new TONEMASK_NPus from the MTU-O to the MTU-R.

The SPA-PREP request command is sent from the MTU-O to the MTU-R. The SPA-PREP response is sent from the MTU-R to the MTU-O.

The first byte of the commands and responses shall be the assigned value of the SPA-PREP command type, as shown in Table 11-5. The second and subsequent bytes shall be as shown in Table 11-64 for the command and in Table 11-65 for the responses. The data bytes shall be mapped using the format described in clause 11.2.2.1.

Table 11-64 – SPA-PREP command sent by the MTU-O

Name	Length (bytes)	Byte	Content
SPA-PREP request	Variable	2	01_{16} (Note)
		Variable	MREFPSDMASK_NPus (PSD descriptor)
		Variable	TONEMASK_NPus (Band descriptor)
NOTE – All other values for this byte are reserved by ITU-T.			

The MREFPSDMASK_NPus format shall be presented using the "PSD descriptor" format defined in Table 12-23 and the number of breakpoints being described shall be either zero or from two to 32. In case the number of breakpoints is zero, the MREFPSDMASK_NPus is not updated in the SPA-PREP request.

The TONEMASK_NPus format shall be presented using the "Band descriptor" format defined in Table 12-22 and the number of bands being described shall be from zero to 32. In case the number of bands is zero, the TONEMASK_NPus is not updated in the SPA-PREP request.

Table 11-65 – SPA-PREP responses sent by the MTU-R

Name	Length (bytes)	Byte	Content
ACK	Variable	2	80_{16} (Note)
		Variable	MREFPSD_NPus (PSD descriptor)
NACK	Variable	2	81_{16} (Note)
		3	One byte for reason code (see Table 11-66)
NOTE – All other values for this byte are reserved by ITU-T.			

The MTU-R shall acknowledge (ACK) upon the correct reception of the command, with a proposed MREFPSD_NPus included in the response, as shown in Table 11-65. The MREFPSD_NPus format shall be presented using the "PSD descriptor" format defined in Table 12-23 and the number of breakpoints being described shall be either zero or from two to 32. In case the number of breakpoints is zero, the MREFPSD_NPus is not updated in the SPA-PREP response.

The MTU-R may reject (NACK) the request only if one or more of the requested parameters are invalid (see Table 11-66).

Table 11-66 – NACK reason codes

Value (Note)	Definition
01_{16}	Invalid set of parameters
NOTE – All other reason codes are reserved by ITU-T.	

11.2.2.22 The DBR-SD request eoc command and response

The DBR-SD request is a normal priority eoc command that is sent by the MTU-O to each MTU-R to update the description (i.e., boundaries) of all sub-bands (active and inactive) used by the P2MP group, to form the sub-band descriptor reflecting the current inactive sub-bands. The command uses a sub-band descriptor (Table 13-19) that may include up to 32 sub-bands. This command is used for both upstream and downstream DBR.

The command contains a DBR-SD configuration change counter (DBR-SD-CCC). Upon reception of the DBR request command, each CPE shall send a DBR response command that acknowledges the DBR request with the corresponding value of the DBR counter. The format of the DBR request command is defined in Table 11-67.

The first byte of the command and of each response shall be the assigned value for the DBR-SD eoc command type shown in Table 11-5. The subsequent bytes of the command shall be as shown in Table 11-67. The subsequent bytes of the responses shall be as shown in Table 11-68. The bytes shall be sent using the format described in clause 11.2.2.1.

Table 11-67 – DBR-SD request command (MTU-O only)

Name	Length (bytes)	Byte	Content
DBR sub-band description (DBR-SD)	Variable	2	01_{16} (Note 1)
		3	Segment code (SC)
		4	Control field: [bc00 aaaa] aaaa – DBR-SD configuration change count (DBR-SD-CCC) (Note 2). b=0 for downstream and b=1 for upstream c = The SDI of the DBR-SD to be updated (Note 3).
		Variable	DBR sub-band descriptor formatted as defined in Table 13-19
NOTE 1 – All other values are reserved by ITU-T. NOTE 2 – This counter shall be set to 0 at the transition to showtime and increased by 1 in every new DBR-SD command. It shall wraparound to 0 after reaching 15. NOTE 3 – The SDI value shall be different from one that is associated with currently used sub-band description.			

Table 11-68 – DBR-SD response (MTU-R only)

Name	Length (bytes)	Byte	Content
ACK DBR-SD	2	2	$8A_{16}$ (Note)
		3	Control field: [bc00 aaaa] The values aaaa, b, and c of this field shall be the same as in the associated DBR-SD command.
Reject DBR-SD	3	2	$8B_{16}$
		3	Control field: [bcdd aaaa] The values aaaa, b, and c of this field shall be the same as in the associated DBR-SD command. dd = reason code with the following valid values: 02 – invalid parameters (Note)
NOTE – All other values are reserved by ITU-T.			

11.2.2.23 The DBR-PR request eoc command and response

The DBR-PR eoc command is a high priority command to request the downstream transmission parameters from an MTU-R or indicate upstream transmission parameters to the MTU-R for the set of subcarriers in the sub-band assignment descriptor (SA). In case of bidirectional DBR, the downstream transmission parameters are requested, and the upstream transmission parameters are indicated in the same DBR-PR command. The DBR-PR request command contains a DBR-PR configuration change counter (DBRCCC).

Upon reception of the DBR-PR request command, the MTU-R shall send a DBR-PR response that acknowledges the DBR-PR request.

In case of downstream DBR, the DBR-PR request command indicates the updated downstream sub-bands assignment (list of active sub-bands), and pilot tone groups used by other MTU-Rs of the P2MP group within downstream band granted to the MTU-R, and the out-of-band pilot tone groups that the MTU-R shall release for data transmission by other MTU-Rs. The MTU-R responds with the requested transmission and framing parameters associated with the requested sub-bands and requested additional pilot tones if its downstream P2MPOB is increased, as defined in clause 10.4.5.

In case of upstream DBR, the DBR-PR request command indicates the updated upstream sub-bands assignment and includes indication of the transmission and framing parameters associated with the requested upstream sub-bands, and MTU-R simply acknowledges.

In case of bidirectional DBR, the DBR-PR request command contains the information associated with both downstream and upstream. The MTU-R responds with the requested downstream information.

The MTU-R may only reject a DBR-PR request command if the request is invalid or if the MTU-R is busy and cannot proceed due to an unfinished high priority eoc command. This last rejection cause is only valid for downstream or bidirectional DBR-PR.

The first byte of the command and of each response shall be the assigned value for the DBR-PR eoc command type shown in Table 11-5. The subsequent bytes of the command shall be as shown in Table 11-69. The subsequent bytes of the responses shall be as shown in Table 11-67. The bytes shall be sent using the format described in clause 11.2.2.1.

Table 11-69 – DBR-PR request command (MTU-O only)

<table>
<tr><th>Name</th><th>Length (bytes)</th><th>Byte</th><th>Content</th></tr>
<tr><td rowspan="8">DBR parameter request (DBR-PR)</td><td rowspan="8">Variable</td><td>2</td><td>01_{16} (Note 1)</td></tr>
<tr><td>3</td><td>Segment code (SC)</td></tr>
<tr><td>4</td><td>Control field: [0n0d bbce]
bb=01: indicates downstream DBR request
bb=10: indicates upstream DBR request
bb=11: indicates bidirectional DBR request
c = downstream SDI; set to 0 in upstream request
e = upstream SDI; set 0 in downstream request

n=0 if downstream subcarrier parameter block is requested, 1 if not (Note 2)
d=0 if upstream subcarrier parameter block is present, 1 if not (Note 3)</td></tr>
<tr><td>5</td><td>One byte formatted as [0000 aaaa] for DBR-PR configuration count
aaaa –DBR-PR configuration change count (DBRCCC)</td></tr>
<tr><td>6-9</td><td>Downstream Sub-Band Assignment (SA) descriptor formatted as defined in Table 13-20.
This field shall not be present in case of an upstream DBR-PR request (bb=10).</td></tr>
<tr><td>10-13</td><td>Upstream Sub-Band Assignment (SA) descriptor formatted as defined in Table 13-20.
This field shall not be present in case of a downstream DBR-PR request (bb=01).</td></tr>
<tr><td>14-(14+S)</td><td>Upstream parameter block (Table 11-70).
This field shall not be present in case of a downstream DBR request (bb=01).</td></tr>
<tr><td>Variable</td><td>Pilot tones descriptor as defined in Table 11-72</td></tr>
<tr><td colspan="4">NOTE 1 – All other values are reserved by ITU-T.
NOTE 2 – Downstream subcarrier parameter blocks may be redundant if downstream bit-loading settings are exchanged by the preceding DBR-PT command (see clause 11.2.2.28).
NOTE 3 – Upstream subcarrier parameter block may be redundant if upstream bit-loading and gain settings are exchanged by the preceding DBR-PT command (see clause 11.2.2.28).</td></tr>
</table>

Table 11-70 – Upstream parameter block

Byte	Content
10	One byte for Q
11	One byte for K_{FEC}
12	One byte for R_{FEC}
13	One byte for PCS-LCM descriptor of PSF when Band 0 and Band 1 are active, formatted as defined in Table 11-71 (Note 2).
14	One byte for PCS-LCM descriptor of NOI PSF when only Band 0 is active, formatted as defined in Table 11-71.
15	One byte for PCS-LCM descriptor of NPSF, formatted as defined in Table 11-71 (Note 3).
16	One byte formatted as [aaaa bbbb] for upstream NOI PSF and NOI NPSF SCCC count (Note 4) aaaa: NOI PSF SCCC count. bbbb: NOI NPSF SCCC count. It shall be set to 0 in TDD framing mode, in TDDZ framing mode or if Annex X is selected.

Table 11-70 – Upstream parameter block

Byte	Content
17	One byte formatted as [0000 aaaa] for upstream DOI SCCC count (Note 4) aaaa: DOI PSF SCCC count. If DOI is disabled, the field shall be set to 0.
Variable	PSF subcarrier parameter block starting from the first subcarrier or the first active sub-band (corresponding to the lowest LSB set to 1 in the SA descriptor of this DBR-PR request command) to the last subcarrier of the last active sub-band (corresponding to the highest MSB set to 1 in the SA descriptor). (Note 2) This field shall be skipped if d=1.
Variable	NPSF subcarrier parameter block starting from the first subcarrier or the first active sub-band (corresponding to the lowest LSB set to 1 in the SA descriptor of this DBR-PR request command) to the last subcarrier of the last active sub-band (corresponding to the highest MSB set to 1 in the SA descriptor). (Note 3) This field shall be skipped if d=1.
NOTE 1 – The number of b_i or m_i and g_i entries of the subcarrier parameter block equals to the sum of the number of subcarriers that belong to MEDLEYGus set in all activated sub-band that corresponds to the indicated DBR-SD index. The format of the field shall be as defined in Table 11-14. Entries of subcarrier outside the MEDLEYGus set shall be ignored by the receiver. NOTE 2 – This field shall be applied to both NOI and DOI. NOTE 3 – If TDD or TDDZ framing mode is used or Annex X is selected, that field shall not be present. NOTE 4 – The SCCC is the same count as the one used for upstream OLR Types 1 and 2. It shall be incremented by 1 for each upstream DBR-PR request.	

Table 11-71 – PCS-LCM descriptor

Byte	Content
1	One byte for the PCS-LCM parameters. [bbbb aaaa] aaaa: contains the index of M_c. Valid indices are 0, 1, 2, 3, 4, 5 and 6 corresponding to M_c values 64, 96, 128, 192, 256, 384 and 512, respectively. bbbb: contains the value of $4P/M_c$. 15 is a special value that indicates $P=7\times M_c$.

Table 11-72 – Pilot tone descriptor

Field	Bytes	Content
Pilot tone groups used by other MTU-Rs	Variable	Subcarriers of pilot tone groups used by other MTU-Rs falling inside the P2MPOB, defined in a format of tone descriptor, as in Table 12-26.
Pilot tone groups out of P2MPOB to be released	Variable	Subcarriers of pilot tone groups out of P2MPOB to be released, as per rules described in clause 10.4.5, defined in a format of a tone descriptor, as shown in Table 12-26 (Notes 2, 3).
NOTE 1 – The minimum size of the field is 2 bytes. NOTE 2 – The MTU-R may require up to 500ms after completion of the DBR procedure to release the indicated pilot tone groups. During this time any DBR procedure on other links of the P2MP group should not request to use the released pilot tone groups for data transmission. NOTE 3 – The MTU-O may also indicate in this field pilot tones that are not out of P2MPOB before the DBR-PR procedure but will be out of P2MPOB immediately after the DBR-PR procedure due to change of P2MPOB.		

Table 11-73 – DBR-PR response (MTU-R only)

Name	Length (bytes)	Byte	Content
Downstream or Bidirectional Response DBR-PR	Variable	2	02_{16} (Note 1)
		3	Segment code (SC)
		4	Control field: [0n00 bbce] The values bb, c, e and n of this field shall be the same as in the the Control field of associated DBR-PR request command.
		5	One byte formatted [0000 aaaa] for DBR-PR configuration change count: aaaa –DBR-PR configuration change count (DBRCCC) as received in the associated DBR-PR request command
		6	One byte formatted as [aaaa bbbb] for downstream NOI PSF and NOI NPSF SCCC count (Note 8) aaaa: NOI PSF SCCC count. bbbb: NOI NPSF SCCC count. It shall be set to 0 in TDD framing mode, in TDDZ framing mode or if Annex X is selected.
		7	One byte for formatted as [0000 aaaa] for downstream DOI SCCC count (Note 8) aaaa: DOI PSF SCCC count. If DOI is disabled, the field shall be set to 0.
		8	One byte for Q
		9	One byte for K_{FEC}
		10	One byte for R_{FEC}
		11	One byte for PCS-LCM descriptor of PSF when Band 0 and Band 1 are active, formatted as defined in Table 11-71 (Note 7).
		12	One byte for PCS-LCM descriptor of NOI PSF when only Band 0 is active, formatted as defined in Table 11-71.
		13	One byte for PCS-LCM descriptor of NPSF, formatted as defined in Table 11-71 (Note 3).
		Variable	Pilot tone descriptor, see Table 11-74
		Variable	PSF subcarrier parameter block starting from the first subcarrier or the first active sub-band (corresponding to the lowest LSB set to 1 in the SA descriptor of this DBR-PR request command) to the last subcarrier of the last active sub-band (corresponding to the highest MSB set to 1 in the SA descriptor). (Note 7) This field shall be skipped if n=1.
		Variable	NPSF subcarrier parameter block starting from the first subcarrier or the first active sub-band (corresponding to the lowest LSB set to 1 in the SA descriptor of this DBR-PR request command) to the last subcarrier of the last active sub-band (corresponding to the highest MSB set to 1 in the SA descriptor). (Note 3) This field shall be skipped if n=1.
Upstream: Response DBR-PR	3	2	$8B_{16}$
		3	Control field: [0000 bbce] The values bb, c and e of this field shall be the same as in the Control field of the associated DBR-PR request command.
		4	One byte formatted as [0000 aaaa] for DBR-PR configuration change count: aaaa –DBR-PR configuration change count (DBRCCC) as received in the associated DBR-PR request command

Table 11-73 – DBR-PR response (MTU-R only)

Name	Length (bytes)	Byte	Content
Reject DBR-PR	3	2	$8A_{16}$
		3	Control field: [00dd aaaa] The values aaaa of this field shall be the same as in the DBRCCC value of the associated DBR-PR request command. dd = reason code with the following valid values: 10 – invalid parameters 11 – missing segments 01 – wait (Note 9) (Note 1)

NOTE 1 – All other values are reserved by ITU-T.
NOTE 2 – The number of b_i or *mi* entries of the subcarrier parameter block equals to the number of the MEDLEYGds subcarriers in the associated sub-band that corresponds to the indicated DBR-SD index. The format of the field shall be as defined in Table 11-12. Entries of subcarrier outside the MEDLEYGds set shall be ignored by the receiver.
NOTE 3 – If TDD or TDDZ framing mode is used or Annex X is selected, that field shall not be present.
NOTE 4 – The format of this field shall be a Tone descriptor as defined in Table 12-26.
NOTE 5 – The format of this field shall be as defined in Table 11-12.
NOTE 6 – The released in-P2MPOB pilot tones are defined using pilot group size of 1 while the released out-of-P2MPOB pilot tones may have the pilot group size larger than 1.
NOTE 7 – This field shall be applied to both NOI and DOI.
NOTE 8 – The SCCC is the same count as the one used for downstream OLR Types 1 and 2. It shall be incremented by 1 for each downstream DBR-PR response.
NOTE 9 – This reason code indicates the MTU-R is busy and cannot process the DBR-PR due to unfinished other high priority command. With this reason code, the MTU-O is supposed to resend the DBR-PR request. This rejection code can only be applied in response to the downstream DBR-PR request.

Table 11-74 – Pilot tone descriptor

Field	Bytes	Content
Pilot tones requested by the MTU-R	Variable	Updated set of pilot tones requested by the MTU-R. It may include the existing or new pilot tones. The format of this field shall be a Tone descriptor as defined in Table 12-26. The pilot tones inside the P2MPOBy, as well as and the requested existing out-of-P2MPOB pilot tones, are defined using pilot group size of 1 (Note 2).

NOTE 1 – The minimum size of the field is 1 byte.
NOTE 2– The new requested pilot tones shall be withing the P2MPOB assigned to the MTU-R, and MTU-R shall not include the out-of-P2MPOB pilot tones indicated in the MTU-O DBR-PR Pilot tone descriptor as to be released. Further, the MTU-R should minimize the number of pilot tones that are out of its P2MPOB not indicated in the MTU-O DBR-PR Pilot tone descriptor as to be released.

11.2.2.24 SSA commands and responses

The SSA command is used to force an adaptation of the upstream sync symbol transmit gains (g_i) on the subcarriers of the MEDLEYGus set, except those belonging to the FDXMASKus

The SSA command is sent from the MTU-O to the MTU-R. The command is shown in Table 11-75, and may be initiated only by the MTU-O. The MTU-R shall respond with either an ACK or a NACK, using the format shown in Table 11-76.

The first byte of the command shall be the assigned value of the SSA command type, as shown in Table 11-4. The second and subsequent bytes shall be as shown in Table 11-75 for the command and in Table 11-76 for the responses. The data bytes shall be mapped using the format described in clause 11.2.2.1.

Table 11-75 – SSA command sent by the MTU-O

Name	Length (bytes)	Byte	Content
Upstream SSA	6	2	01_{16} (Note)
		3	[00000baa] aa = 00: Reserved by ITU-T aa = 01: PSF only aa = 10: NPSF only aa = 11: PSF and NPSF b = 0: request for gi_SYNC = gi_DATA_NOI b = 1: request for gi_SYNC = gi_SSA
		4	[gggg gggg] gggg gggg= gi_SSA [7:0]
		5	[0000 hhhh] hhhh = gi_SSA [11:8]
NOTE – All other values for this byte are reserved by ITU-T.			

The MTU-R shall acknowledge (ACK response) upon the correct reception of the command, as shown in Table 11-76. The MTU-R may reject (NACK response) the request only if one or more of the requested parameters are invalid (see Table 11-77).

Table 11-76 – SSA response sent by the MTU-R

Name	Length (bytes)	Byte	Content
ACK	2	2	80_{16} (Note)
NACK	3	2	81_{16} (Note)
		3	One byte for reason code (see Table 11-77)
NOTE – All other values for this byte are reserved by ITU-T.			

Table 11-77 – NACK reason codes

Value (Note)	Definition
01_{16}	Invalid set of parameters
NOTE – All other reason codes are reserved by ITU-T.	

11.2.2.25 DCM parameter update commands and responses

Upon instruction of the VCE, the MTU-O shall send the appropriate DCM parameter update command to force an update of the parameters for the upstream DCM to be transmitted by the MTU-R or to communicate the new parameters for the downstream DCM to be transmitted by the MTU-O to the MTU-R.

The first byte of the commands shall be the assigned value of the DCMU command type, as shown in Table 11-3. The second and subsequent bytes shall be as shown in Table 11-78 for commands and in Table 11-79 and Table 11-80 for responses.

Table 11-78 – DCM parameter update command (transmitted by the MTU-O)

Name	Length (bytes)	Byte	Content
DCM parameter update	Variable	2	[0000 00aa] *aa* = 01 for change of downstream DCM only *aa* = 10 for change of upstream DCM only *aa* = 11 for change of both upstream and downstream DCM (Note).
		3	DCMU configuration change count (DCMUCCC)
		4 to 15 + ceiling($Ndcm_{ds}$/4)	Downstream DTFO descriptor This field shall not be sent if aa = 10.
		16 + ceiling($Ndcm_{ds}$/4) to 27 + ceiling($Ndcm_{us}$/4)	Upstream DTFO descriptor This field shall not be sent if aa = 01.
NOTE – All other values for this byte are reserved by ITU-T.			

The MTU-R shall acknowledge (ACK) the correct reception of the command, as shown in Table 11-79. The MTU-R may only reject (NACK) the request if one or more of the requested parameters is invalid (see Table 11-80).

Table 11-79 – DCM sequence update response transmitted by the MTU-R

Name	Length (bytes)	Byte	Content
ACK	2	2	80_{16} (Note)
NACK	3	2	81_{16} (Note)
		3	One byte for reason code (see Table 11-DCMNACK)
NOTE – All other values for this byte are reserved by ITU-T.			

Table 11-80 – NACK reason codes

Value (Note)	Definition
01_{16}	Invalid set of parameters.
NOTE – All other reason codes are reserved by ITU-T.	

11.2.2.26 The DBR-RMC command and response

The DBR-RMC eoc command is a normal priority command to request the MTU-R of a particular link to initiate a downstream RPA in the aim to confine the RMC tones within a frequency band suitable for the following downstream DBR procedure.

Upon reception of the DBR-RMC command, the MTU-R shall send a DBR-RMC response that acknowledges the DBR-PR request and initiate the requested RPA procedure on the first opportunity.

The DBR-RMC command indicates the frequency bands within which all RMC tones shall reside upon completion of the following RPA. If the MTU-R is not able to assign the RMC tones as requested, it shall reject the command with the corresponding indication.

The first byte of the command and of each response shall be the assigned value for the DBR-RMC command type shown in Table 11-5. The subsequent bytes of the command shall be as shown in Table 11-81. The subsequent bytes of the response shall be as shown in Table 11-82. The bytes shall be sent using the format described in clause 11.2.2.1.

Table 11-81– DBR-RMC command (MTU-O only)

Name	Length (bytes)	Byte	Content
DBR-RMC	Variable	2	01_{16} (Note)
		Variable	RMC bands represented as a band descriptor (Table 12-22).
NOTE – All other values are reserved by ITU-T.			

Table 11-82 – DBR-RMC response (MTU-R only)

Name	Length (bytes)	Byte	Content
ACK	2	2	81_{16} (Note)
Reject	5	2	$0x82_{16}$ (Note)
		3	Reason code: 00_{16} – NACK, invalid parameters 01_{16} –NACK, impossible to assign all RMC bits.
		4-5	The value indicates the number of remaining unallocated RMC bits in case the message was NACK with a reason code 01_{16}
NOTE – All other values for byte 2 are reserved by ITU-T.			

11.2.2.27 Battery powered status

The battery powered status eoc command is a normal priority command that shall be sent from the MTU-R that has an option to be battery powered (see Table 12-51) to the MTU-O, to indicate the MTU-R battery status.

The first byte of either a command or a response shall be the OPCODE, as shown in Table Table 11-83 for the battery powered status command. The remaining bytes shall be as shown in Table 11-83 for the battery powered status command, and Table 11-84 for the battery powered status response.

The MTU-R sends the command to the MTU-O when battery powering status changes (e.g., when loss of power occurs, or as power is restored at customer premises).

The MTU-O acknowledges the reception of the command.

Table 11-83 – Battery powered status command (MTU-R to MTU-O)

Name	Length (Bytes)	Byte	Content
Battery powered status	3	2	08_{16} (Note 1)
		3	One byte encoding MTU-R battery primitive as follows (Note 1): 01_{16}: MTU-R is not battery powered 02_{16}: MTU-R is battery powered
NOTE – All other values are reserved by ITU-T.			

Table 11-84 – Battery powered status response (MTU-O to MTU-R)

Name	Length (Bytes)	Byte	Content
Acknowledge battery powered status	2	2	84_{16} (Note 1)
NOTE – All other values are reserved by ITU-T.			

11.2.2.28 The DBR-PT command and response

The DBR-PT eoc command is a normal priority command to report the bit-loading values and in upstream also the fine gains, on all the subcarriers of the MEDLEYG set expected to be relevant for the upcoming DBR procedure. The DBR-PT is initiated by the MTU-R in case of downstream DBR-PT and by MTU-O in case of upstream DBR-PT. Upon reception of the DBR-PT command, the MTU shall send a DBR-PT response that acknowledges the command or, in the case the content is invalid, a DBR-PT response that rejects the command.

The first byte of the command and of each response shall be the assigned value for the DBR-PT command type shown in Table 11-6. The subsequent bytes of the command shall be as shown in Table 11-85. The subsequent bytes of the response shall be as shown in Table 11-86. The bytes shall be sent using the format described in clause 11.2.2.1.

Table 11-85 – DBR-PT command (MTU-O or MTU-R)

Name	Length (bytes)	Byte	Content
DBR-PT	Variable	2	01_{16} (Note)
		3	Segment code (SC)
		4	[0000 00bb] Sub-frames subject for reconfiguration: bb = 00, Reserved by ITU-T bb = 01, PSF only. bb = 10, Reserved by ITU-T bb = 11, PSF and NPSF
		5 and 6	Two bytes for the PSF start subcarrier index
		7 and 8	Two bytes for the PSF stop subcarrier index
		Variable	PSF subcarrier parameter block A variable number of bytes (S_N) describing the subcarrier parameter field for each subcarrier using the format defined in Table 11-12 (for the downstream DBR-PT) and Table 11-14 (for the upstream DBR-PT).
		9 + S_N and 10 + S_N	Two bytes for the NPSF start subcarrier index. This field shall not be sent if bb = 01.
		11 + S_N and 12 + S_N	Two bytes for the NPSF stop subcarrier index. This field shall not be sent if bb = 01.
		Variable	NPSF subcarrier parameter block A variable number of bytes describing the subcarrier parameter field for each subcarrier using the format defined in Table 11-12 (for the downstream DBR-PT) and Table 11-14 (for the upstream DBR-PT). This field shall not be sent if bb = 01.
NOTE – All other values are reserved by ITU-T.			

Table 11-86 – DBR-PT response command (MTU-R or MTU-O)

Name	Length (bytes)	Byte	Content
ACK	2	2	81_{16} (Note)
Reject	3	2	82_{16} (Note)
		3	Reason code: 00_{16} invalid parameters
NOTE – All other values for byte 2 are reserved by ITU-T.			

11.3 OAM primitives

Among the standard OAM primitives, this Recommendation specifies only anomalies, defects and loss-of-power primitives.

Both the near-end and the far-end primitives shall be represented at the MTU-O and the MTU-R.

11.3.1 Line-related primitives

Line-related primitives represent anomalies and defects related to PMD and PMS-TC sub-layers. These primitives are exchanged over the PMD_MGMT interface or PMS-TC_MGMT interface (see clause 9.1.2 or clause 10.1.2).

Anomalies and defects are computed only at time periods during transmission of data symbols or RMC symbols by the far-end transceiver.

11.3.1.1 Near-end anomalies

- FEC (*fec*): For further study. As such, this anomaly shall not occur.
- Uncorrected DTU (*rtx-uc*): An *rtx-uc* anomaly occurs at the receiver under any of the following conditions:
  - each time a DTU of the normal DTU type (see clause 8.2.1.3) is not delivered over the alpha reference point by the receiving PMS-TC because the DTU is received in error and has not been corrected by a retransmission within *delay_max_0*;
  - after a time period T_{SF} + *delay_max_0* with no DTU of the normal type delivered over the alpha reference point by the receiving PMS-TC and until the next DTU of the normal type is delivered over the alpha reference point by the receiving PMS-TC, at least at time instants $CNT_{symb} = TS + (T_{SF} + delay\_max\_0 + n \times T_{SF}) / T_{symb}$ (n = 0, 1, 2…), where TS is the timestamp of the last DTU of the normal type delivered over the alpha reference point by the receiving PMS-TC.

NOTE – The declaration of rtx-uc is based on the SID of the DTUs (see clause 8.2.1.1), the *TS* of the DTUs (see clause 8.2.1.2) and on the fact that the transmitter always transmits at least one normal DTU per time interval equal to the duration of one superframe, even if there are no data packets to send (see clause 8.3.1).

- Retransmitted DTU (*rtx-tx*): An *rtx-tx* anomaly occurs at the transmitter each time a DTU of normal type (see clause 8.2.1.3) is retransmitted. Multiple retransmissions of the same DTU are counted as many times as the DTU has been retransmitted.
- Cyclic redundancy check (*crc*): The *crc* anomaly is defined by the detection of at least one *rtx-uc* anomaly per 17ms time interval.
- Loss-of-power interruption (*lpr_intrpt*): Excluding reinitializations triggered by the ME-O (see clause 12.1.2), this anomaly occurs upon entry into showtime when at least one of the following conditions is met:
  - a far-end loss-of-power (flpr) primitive (see clause 11.3.3.2) was declared before the exit from showtime, or
  - the PLPR flag (retrieved from the MTU-R) is set to ONE at the entry into showtime (see clause 11.2.2.10).

  This anomaly is only defined at the MTU-O.
- Host-Reinit interruption (*hri_intrpt*): Excluding reinitializations triggered by the ME-O (see clause 12.1.2), this anomaly occurs upon entry into showtime if the PHRI flag (retrieved from the MTU-R) is set to ONE (see clause 11.2.2.10).

  This anomaly is only defined at the MTU-O.
- Spontaneous interruption (*spont_intrpt*): Excluding reinitializations triggered by the ME-O (see clause 12.1.2), this anomaly occurs upon entry into showtime,
  - after a successful fast initialization,
  - after a successful full initialization, if the following three conditions are met:
    - between the exit from showtime and the first successful reception of an ITU-T G.994.1 message a failed fast initialization occurred, and
    - the time between the exit from showtime of the MTU-O and the first successful reception of an ITU-T G.994.1 message is less than 20 seconds, and
    - neither an *lpr_intrpt* nor an *hri_intrpt* occurs at the entry into showtime.

  This anomaly is only defined at the MTU-O.

11.3.1.2 Far-end anomalies

No far-end anomalies are defined.

11.3.1.3 Near-end defects

- Loss of signal (*los*): A reference power shall be established by averaging the ITU-T G.9711 receive power over the RMC symbol over a 0.1 s interval and over a subset of subcarriers used for showtime, and a threshold shall be set 6 dB below this level. A *los* shall occur when the level of the ITU-T G.9711 receive power averaged over a 50 ms interval (where these 50 ms intervals are contiguous) and over the same subset of subcarriers is lower than the threshold, and shall terminate when this level, measured in the same way, is at or above the threshold. The subset of subcarriers is implementation dependent.
- Loss of margin (*lom*): This defect occurs when the signal-to-noise ratio margin (SNRM, see clause 11.4.1.3) observed by the near-end receiver is below the minimum signal-to-noise ratio margin (MINSNRM, see clause 12.3.4.2) for a bit-rate greater than or equal to *ETR_min_eoc*, and an increase of SNRM is no longer possible within the far-end aggregate transmit power and transmit PSD level constraints. This defect terminates when the SNRM is above the MINSNRM. The SNRM measurement update rate shall be at least once every 0.5 second.
- Loss of RMC (*lor*): This defect occurs when the percentage of errored RMC messages within a 50 ms interval (where these 50 ms intervals are contiguous) exceeds 50%. The *lor* defect terminates when this level is at or below the threshold.
- Low all-NOI and DOI data error-free throughput rate (*landeftr*): This defect is declared if, for the 1-second interval the *ANDEFTR* is calculated over (see clause 11.4.1.1.17), the *ANDEFTR* is below the *low_ANDEFTR_threshold*, excluding the seconds in which *ANDEFTR* is not defined.

  NOTE 1 – If the *low_ANDEFTR_threshold* value is 0 then no *landeftr* defects will be declared.

  The *low_ANDEFTR_threshold* defined for the downstream and upstream are denoted as *low_ANDEFTR_threshold-ds* and *low_ANDEFTR_threshold-us*, respectively.

  The control parameter *low_ANDEFTR_threshold* is equal to the DPU-MIB configuration parameter LOW-ANDEFTR-THRESHOLD.

  NOTE 2 – In case DTFO Band 1 bit loading is unknown, *landeftr* defects are not generated as *ANDEFTR* is not defined.
- Low all-NOI data error-free throughput rate with DTFO disabled (*landeftr0*): This defect is declared if, for the 1-second interval the *ANDEFTR0* is calculated over (see clause 11.4.1.1.17), the *ANDEFTR0* is below the *low_ANDEFTR0_threshold*, excluding the seconds in which *ANDEFTR0* is not defined.

  NOTE 3 – If the *low_ANDEFTR0_threshold* value is 0 then no *landeftr0* defects will be declared.

  The *low_ANDEFTR0_threshold* defined for the downstream and upstream are denoted as *low_ANDEFTR0_threshold-ds* and *low_ANDEFTR0_threshold-us*, respectively.

  The control parameter *low_ANDEFTR0_threshold* is equal to the DPU-MIB configuration parameter LOW-ANDEFTR0-THRESHOLD.

11.3.1.4 Far-end defects

- Far-end loss of signal (*los-fe*): This defect occurs when the far-end *los* indicator bit (Table 9-8) in a correctly received RMC message is zero. A *los-fe* terminates when this far-end *los* indicator bit is one.
- Far-end loss of margin (*lom-fe*): This defect occurs when the far-end *lom* indicator bit (Table 9-8) in a correctly received RMC message is zero. A *lom-fe* terminates when this far-end *lom* indicator bit is one.

- Far-end loss of RMC (*lor-fe*): This defect occurs when the far-end *lor* indicator bit (Table 9-8) in a correctly received RMC message is zero. A *lor-fe* terminates when this far-end *lor* indicator bit is one.

11.3.1.5 Initialization primitives

- Full initialization (*full_init*): This primitive occurs each time the MTU-O transitions from the O-SILENT to the O-INIT/HS state (see Figure 12-2).
- Failed full initialization (*failedfull_init*): This primitive occurs each time the MTU-O transitions from the O-INIT/HS to the O-SILENT state and each time the MTU-O transitions from the O-INIT/TRAIN to the O-DEACTIVATING1 state following a *full_init* primitive (see Figure 12-2).
- Fast initialization (*fast_init*): This primitive occurs each time the MTU-O transitions from the O-DEACTIVATING2 to the O-INIT/TRAIN state (see Figure 12-2).
- Failed fast initialization (*failedfast_init*): This primitive occurs each time the MTU-O transitions from the O-INIT/TRAIN to the O-DEACTIVATING1 state following a *fast_init* primitive (see Figure 12-2).

11.3.1.6 Near-end OLR/FRA/RMCR primitives

- Successful bit swap (*success_BSW*): This primitive occurs each time the bit loading on the data symbols (NOI or DOI) is changed through the near-end initiating an OLR type 1 for bit swapping or an OLR type 2 for bit swapping (see Table 11-11).
- Successful autonomous SRA (*success_SRA*): This primitive occurs each time the bit loading on the data symbols (NOI or DOI) is changed through the near-end initiating an OLR type 1 for autonomous SRA or an OLR type 2 for autonomous SRA (see Table 11-11).
- Successful FRA (*success_FRA*): This primitive occurs each time the bit loading on the data symbols (NOI or DOI) is changed through the near-end initiating an FRA (see clause 13.3.1.1).
- Successful RPA (*success_RPA*): This primitive occurs each time the set of RMC subcarriers or the bit loading of RMC subcarriers is changed through the near-end initiating an OLR type 4 for RPA (see Table 11-11).
- Successful TIGA (*success_TIGA*): This primitive occurs each time the bit loading on the data symbols (NOI or DOI) is changed through the near-end initiating an OLR type 3 for TIGA (see Table 11-11).
- Successful RMCR (*success_RMCR*): This primitive occurs each time the set of RMC subcarriers changed through the near-end initiating an RMCR procedure (see clause 13.3.1.2).

11.3.1.7 Far-end OLR/FRA/RMCR primitives

- Successful bit swap (*success_BSW_FE*): This primitive occurs each time the bit loading on the data symbols (NOI or DOI) is changed through the far-end initiating an OLR type 1 for bit swapping or an OLR type 2 for bit swapping (see Table 11-11).
- Successful autonomous SRA (*success_SRA_FE*): This primitive occurs each time the bit loading on the data symbols (NOI or DOI) is changed through the far-end initiating an OLR type 1 for autonomous SRA or an OLR type 2 for autonomous SRA (see Table 11-11).
- Successful FRA (*success_FRA_FE*): This primitive occurs each time the bit loading on the data symbols (NOI or DOI) is changed through the far-end initiating an FRA (see clause 13.3.1.1).

- Successful RPA (*success_RPA_FE*): This primitive occurs each time the set of RMC subcarriers or the bit loading of RMC subcarriers is changed through the far-end initiating an OLR type 4 for RPA (see Table 11-11).
- Successful RMCR (*success_RMCR*): This primitive occurs each time the set of RMC subcarriers changed through the far-end initiating an RMCR procedure (see clause 13.3.1.2).

11.3.1.8 Synchronous access network transient anomaly (SANTA)

Existence of SANTA clause is for further study.

11.3.2 Path-related primitives

Path-related primitives are defined separately for each path, terminated by the corresponding TPS-TC. The primitives for each TPS-TC type shall be represented by relevant OAM indicators specified for this protocol.

For the TPS-TC of type PTM, path-related primitives are for further study.

11.3.3 Power-related primitives

11.3.3.1 Near-end primitives

Loss of power (*lpr*): This primitive occurs when the MTU power supply (mains) voltage drops below the manufacturer-determined level required for proper MTU operation. An *lpr* terminates when the power level exceeds the manufacturer-determined minimum power level.

11.3.3.2 Far-end primitives

Far-end loss of power (*flpr*): This primitive detected at the far end is reported by the *lpr* indicator, which shall be coded 1 to indicate that no *lpr* is being reported (see Table 9-8) and shall be coded 0 for a minimum of three consecutive *lpr* indicator transmissions from the onset of *lpr* and as long as *lpr* persists, to indicate that an *flpr* (i.e., "dying gasp") is being reported. An *flpr* occurs when two or three out of three consecutively received *lpr* indicators are set to ZERO. An *flpr* terminates when, for a period of 0.5 seconds, the received *lpr* indicator bit is set to ONE and no near-end *los* is present. This far-end primitive is only defined for the MTU-O, and is generated based on the *lpr* indicator received from the MTU-R.

Far-end PSE lost power dying gasp (*fdgl*): This primitive detected at the far end is reported by the *dgl* indicator, which shall be coded 1 to indicate that no PSE-DGL is being reported (see Table 9-8) and shall be coded 0 for a minimum of three consecutive *dgl* indicator transmissions from the onset of *dgl* and as long as PSE-DGL persists, to indicate that a PSE-DGL (see Table A.6-3 of [ITU-T G.997.2]) is being reported. An *fdgl* occurs when 2 or 3 out of 3 consecutively received *dgl* indicators are set to ZERO. An *fdgl* terminates when, for a period of 0.5 seconds, the received *dgl* indicator bit is set to ONE. This far-end primitive is only defined for the MTU-O, and is generated based on the *dgl* indicator received from the MTU-R.

Far-end PSE power fail with off-hook phone during NORMAL OPERATIONS (*fohp*): This primitive (see clause A.7.4.1.2 of [ITU-T G.997.2]) detected at the far end is reported by the *ohp* indicator, which shall be coded 1 to indicate that no PSE-OHP is being reported (see Table 9-8) and shall be coded 0 for a minimum of three consecutive *ohp* indicator transmissions from the onset of *ohp* and as long as PSE-OHP persists, to indicate that a PSE-OHP (see Table A.6-3 of [ITU-T G.997.2]) is being reported. An *fohp* occurs when 2 or 3 out of 3 consecutively received *ohp* indicators are set to ZERO. An *fohp* terminates when, for a period of 0.5 seconds, the received *ohp* indicator bit is set to ONE. This far-end primitive is only defined for the MTU-O, and is generated based on the *ohp* indicator received from the MTU-R.

11.3.4 INM primitives

INM-related primitives represent anomalies related to PMD and PMS-TC sublayers.

11.3.4.1 Near-end primitives

The following near-end INM primitives are defined in clause 11.4.4.7.3:

– $INMAINPEQ_1$ – $INMAINPEQ_{17}$ (clause 11.4.4.7.3.1);
– *INMAME* (clause 11.4.4.7.3.2);
– $INMAIAT_0$ – $INMAIAT_7$ (clause 11.4.4.7.3.3);
– *INMBLFC* (clause 11.4.4.7.3.4).

11.3.4.2 Far-end primitives

The far-end primitives are the near-end primitives defined in clause 11.3.4.1, obtained at the remote end. These primitives are communicated from the remote end by eoc INM facility commands specified in clause 11.2.2.19.

11.3.5 P2MP operation

For P2MP operation, the MTU-O shall instantiate the near-end and the far-end OAM primitives per link.

11.4 P2P OAM parameters

11.4.1 Test and status parameters

For the test parameters in this clause, the condition "undetermined" may be reported by use of a special value. This condition may occur, for example, when no value is available due to the fact that no initialization or no successful initialization has been possible for this transmission line. This condition may also occur in other situations for which the description is beyond the scope of this Recommendation.

11.4.1.1 Status parameters

11.4.1.1.1 Net data rate (*NDR*)

The status parameter net data rate (*NDR*) is defined in Table 9-27 as

$$NDR = DPR - 1\,000 \text{ kbit/s},$$

where the *DPR* represents the DTU payload rate (defined in Table 9-27) and the 1 000 kbit/s is a reference value for the eoc overhead channel rate that shall be used for the purpose of this calculation.

The *NDR* shall be calculated by the receiver during initialization and updated during the L0 link state upon OLRs, e.g., FRA and RPA, using equations for *DPR* presented in Table 9-27. It shall not be updated during L3 link state.

The valid values for *NDR* are all integers from 0 to the configured value of *NDR_max* (see clause 11.4.2.2).

The *NDR* shall be coded as a 32-bit unsigned integer expressing the value of *NDR* in kbit/s. This data format supports a granularity of 1 kbit/s.

A special value 2^{32}-1 indicates that *NDR* is undetermined. All other values are reserved by ITU-T.

The DPU derives the DPU-MIB net data rate reporting parameter NDR from *NDR*. During the L0 link state, downstream and upstream actual *NDR* values are reported in the DPU-MIB. During the L3 link state (see Figure 12-1), the values of the last update are available in the DPU-MIB, until the MTU-O transitions to the O-INIT/HS state, at which time the values may become "undetermined".

11.4.1.1.1.1 Net data rate with DTFO disabled (NDR_0)

The status parameter net data rate with DTFO disabled (NDR_0) is defined in Table 9-27 as

$$NDR_0 = DPR_0 – 1\,000 \text{ kbit/s},$$

where the DPR_0 represents the DTU payload rate with DTFO disabled (defined in Table 9-27) and the 1 000 kbit/s is a reference value for the eoc overhead channel rate that shall be used for the purpose of this calculation.

The NDR_0 shall be calculated by the receiver during initialization and updated during the L0 link state upon OLRs, e.g., FRA and RPA, using equations for DPR_0 presented in Table 9-27. It shall not be updated during L3 link state.

The valid values for NDR_0 are all integers from 0 to the configured value of *NDR_max* (see clause 11.4.2.2).

The NDR_0 shall be coded as a 32-bit unsigned integer expressing the value of NDR_0 in kbit/s. This data format supports a granularity of 1 kbit/s.

A special value 2^{32}-1 indicates that NDR_0 is undetermined. All other values are reserved by ITU-T.

The DPU derives the DPU-MIB net data rate reporting parameter NDR0 from NDR_0. During the L0 link state, downstream and upstream actual NDR_0 values are reported in the DPU-MIB. During the L3 link state (see Figure 12-1), the values of the last update are available in the DPU-MIB, until the MTU-O transitions to the O-INIT/HS state, at which time the values may become "undetermined".

11.4.1.1.2 Attainable net data rate (*ATTNDR*)

The status parameter attainable net data rate (*ATTNDR*) is defined as the *NDR* that would be achieved if control parameter *NDR_max* were configured at the maximum valid value of *NDR_max* (see clause 11.4.2.2), while other control parameters remain at the same value.

The *ATTNDR* shall be calculated by the receiver during initialization and updated during the L0 link state upon OLRs, e.g., FRA and RPA. It shall not be updated during the L3 link state. The downstream *ATTNDR* is communicated from the MTU-R to the MTU-O through the eoc.

The valid values for *ATTNDR* are all integers from 0 to the maximum valid value of *NDR_max* (see clause 11.4.2.2).

The *ATTNDR* shall be coded as a 32-bit unsigned integer expressing the value of *ATTNDR* in kbit/s. This data format supports a granularity of 1 kbit/s.

A special value 2^{32}-1 indicates that the parameter is undetermined. All other values are reserved by ITU-T.

The DPU derives the DPU-MIB attainable net data rate reporting parameter ATTNDR from *ATTNDR*. While the link is in the L0 state, downstream and upstream *ATTNDR* values are reported in the DPU-MIB. During the L3 link state (see Figure 12-1), the values of the last update are available in the DPU-MIB, until the MTU-O transitions to the O-INIT/HS state, at which time the values may become "undetermined".

11.4.1.1.3 Expected throughput (*ETR*)

The status parameter expected throughput (*ETR*) is defined in Table 9-27 as:

$$ETR = (1 - RTxOH) \times NDR$$

The *ETR* shall be calculated by the receiver during initialization and updated during the L0 link state upon OLRs (e.g., FRA and RPA) using equations for *NDR* and *RTxOH* presented in Table 9-27. It shall not be updated during the L3 link state.

The *RTxOH* is the expected rate loss, expressed as a fraction of *NDR*, due to combined effect of:

- INP against worst-case REIN impulses as described by the configuration parameters INPMIN_REIN and IAT_REIN in the DPU-MIB
- INP against worst-case SHINE as described by the configuration parameters INPMIN_SHINE and SHINERATIO in the DPU-MIB
- overhead due to correction of stationary noise errors.

The valid values for *ETR* are all integers from 0 to the configured value of *NDR_max* (see clause 11.4.2.2).

The *ETR* shall be coded as a 32-bit unsigned integer expressing the value of *ETR* in kbit/s. This data format supports a granularity of 1 kbit/s.

A special value 2^{32}-1 indicates that the parameter is undetermined. All other values are reserved by ITU-T.

The DPU derives the DPU-MIB expected throughput reporting parameters ETR from *ETR*. During the L0 link state, downstream and upstream actual *ETR* values are reported in the DPU-MIB. During the L3 link state (see Figure 12-1), the values of the last update are available in the DPU-MIB, until the MTU-O transitions to the O-INIT/HS state, at which time the values may become "undetermined".

11.4.1.1.3.1 Expected throughput with DTFO disabled (ETR_0)

The status parameter expected throughput with DTFO disabled (ETR_0) is defined in Table 9-27 as:

$$ETR_0 = (1 - RTxOH) \times NDR_0$$

The ETR_0 shall be calculated by the receiver during initialization and updated during the L0 link state upon OLRs, e.g., FRA and RPA using equations for NDR_0 and *RTxOH* presented in Table 9-27. It shall not be updated during the L3 link state.

The *RTxOH* is the expected rate loss, expressed as a fraction, due to combined effect of:

- INP against worst-case REIN impulses as described by the configuration parameters INPMIN_REIN and IAT_REIN in the DPU-MIB
- INP against worst-case SHINE as described by the configuration parameters INPMIN_SHINE and SHINERATIO in the DPU-MIB
- overhead due to correction of stationary noise errors.

The valid values for ETR_0 are all integers from 0 to the configured value of *NDR_max* (see clause 11.4.2.2).

The ETR_0 shall be coded as a 32-bit unsigned integer expressing the value of ETR_0 in kbit/s. This data format supports a granularity of 1 kbit/s.

A special value 2^{32}-1 indicates that the parameter is undetermined. All other values are reserved by ITU-T.

The DPU derives the DPU-MIB expected throughput reporting parameters ETR_0 from the status parameter ETR_0. During the L0 link state, downstream and upstream actual ETR_0 values are reported in the DPU-MIB. During the L3 link state (see Figure 12-1), the values of the last update are available in the DPU-MIB, until the MTU-O transitions to the O-INIT/HS state, at which time the values may become "undetermined".

11.4.1.1.4 Attainable expected throughput (*ATTETR*)

The status parameter attainable expected throughput (*ATTETR*) is defined as:

$$ATTETR = (1 - RtxOH) \times ATTNDR$$

The *ATTETR* shall be calculated by the receiver during initialization and updated during the L0 link state upon OLRs, e.g., FRA and RPA. It shall not be updated during the L3 link state.

The valid values for *ATTETR* are all integers from 0 to the maximum valid value of *NDR_max* (see clause 11.4.2.2).

The *ATTETR* shall be coded as a 32-bit unsigned integer expressing the value of *ATTETR* in kbit/s. This data format supports a granularity of 1 kbit/s.

A special value 2^{32}-1 indicates that the parameter is undetermined. All other values are reserved by ITU-T.

The DPU derives the DPU-MIB attainable expected throughput reporting parameters ATTETR from *ATTETR*. During the L0 link state, downstream and upstream *ATTETR* values are reported in the DPU-MIB. During the L3 link state (see Figure 12-1), the values of the last update are available in the DPU-MIB, until the MTU-O transitions to the O-INIT/HS state, at which time the values may become "undetermined".

11.4.1.1.5 Error-free throughput (*EFTR*) parameter

The error-free throughput (*EFTR*) is defined as the average bit-rate, calculated during a one second time window, at the α reference point at the receiver side, of DTU payload bits originating from DTU's of the normal DTU type (see clause 8.2.1.3) that cross the α reference point at the receiver. The one second time windows are consecutive and non-overlapping.

NOTE 1 – As a result of this definition, EFTR ≤ DPR (see Table 9-27).

NOTE 2 – DTUs that have been detected to be in error and DTUs that exceed *delay_max_0* do not cross the α reference point at the receiver side.

The *EFTR* shall be calculated by the receiver in showtime during L0 link state only.

The *EFTR* shall be calculated for every complete second the MTU is in the showtime L0 link state. Only for these seconds, the *EFTR* is defined. For other seconds, the *EFTR* is not defined. The *EFTR* is not a status parameter directly reported to the ME, but is used in the definition of related parameter *EFTR_min*.

NOTE 3 – EFTR is not defined in L3.

11.4.1.1.6 Minimum error-free throughput (*EFTR_min*) parameter

The performance monitoring parameter minimum error-free throughput (*EFTR_min*) is defined as the minimum of the *EFTR* observed in the seconds since the last reading of the *EFTR_min*, excluding the following seconds:

- seconds in which *EFTR* is not defined;

NOTE 1 – *EFTR_min* will be close to the DPR at instances of high data throughput and when TPS_TESTMODE is enabled. At instances of no data throughput, *EFTR_min* will be at the maximum of the eoc data rate and the background normal DTU rate for performance monitoring (see clause 8.3.1).

The *EFTR_min* shall be measured in showtime by the receiver. Reading by the MTU-O of the far-end *EFTR_min* shall be via the management counter read command (see clause 11.2.2.11) over the U interface.

The valid values are all integers from *0* to the maximum of the valid values of the maximum *DPR*.

The performance monitoring parameter *EFTR_min* shall be coded as a 32-bit unsigned integer expressing the value of ceiling(*EFTR_min* in kbit/s). This data format supports a granularity of 1 kbit/s.

A special value 2^{32}-1 indicates that the parameter is undetermined. All other values are reserved by ITU-T.

The previous value of *EFTR_min* shall be reported if no *EFTR* measurement has been done since the last reading of *EFTR_min*.

NOTE 2 – The above requirement covers the case where two retrievals of *EFTR_min* over the eoc take place in less than one second, and in which no new *EFTR* measurement is available, since the *EFTR* is only updated on one second interval.

Although this parameter *EFTR_min* is reported via the management counter read eoc command, this performance monitoring parameter is not a counter.

The parameter reported to the DPU-MIB, MINEFTR, is defined as the minimum of the retrieved *EFTR_min* values observed over the 15 min or 24 hour accumulation periods.

The MME at the MTU-O shall retrieve the far-end *EFTR_min*, to calculate the downstream MINEFTR as defined in the DPU-MIB. The MME at the MTU-O shall retrieve the near-end *EFTR_min* to calculate the upstream MINEFTR, as defined in the DPU-MIB. If the 15 min or 24 hour interval contains only seconds with undefined EFTR, the related MINEFTR shall be set to 0.

NOTE 3 – The frequency of retrieval for both near-end and far-end is left to the implementation, as necessary for accurate monitoring.

The upstream MINEFTR value shall be reported to the DPU-MIB as a near-end value.

The downstream MINEFTR value shall be reported to the DPU-MIB as a far-end value.

11.4.1.1.7 Actual INP against SHINE (*INP_act_shine*)

The status parameter *INP_act_shine* is defined as the actual INP (as defined in clause 9.8.3.3) against SHINE under following specific conditions:

- Assuming INP against REIN equal to *INP_min_rein*
- Assuming $RTXOHact \leq RTX\_OH$ with *RTXOHACT* defined as in the definition of ANDEFTR (see clause 11.4.1.1.17) and *RTX_OH* as defined in Table 9-27.

It shall be calculated by the transmitter during initialization and showtime during the L0 link state and updated upon OLR.

The status parameter *INP_act_shine* shall be coded as a 16-bit unsigned integer expressing the value in symbol periods in steps of 1 symbol period.

The valid range is from 0 to 2 046.

A special value 2 047 indicates a value of 2 047 or higher.

A special value 2^{16}–1 indicates that the parameter is undetermined.

All other values are reserved by ITU-T.

The status parameter *INP_act_shine* shall be mapped on the reporting parameter ACTINP. The downstream and upstream values shall be reported in the DPU-MIB.

During the L3 link state (see Figure 12-1), the values of the last update are available in the DPU-MIB, until the MTU-O transitions to the O-INIT/HS state, at which time the values may become "undetermined".

11.4.1.1.8 Actual INP against REIN (*INP_act_rein*)

The status parameter *INP_act_rein* is defined in the downstream direction as the actual INP (as defined in clause 9.8.3.3) against REIN under the following specific conditions:

- Assuming INP against SHINE equal to *INP_min_shine*,
- Assuming $RTXOHact \leq RTX\_OH$ with *RTXOHACT* defined as in the definition of ANDEFTR (see clause 11.4.1.1.17) and *RTX_OH* as defined in Table 9-27.

It shall be calculated by the MTU-O during initialization and showtime during the L0 link state and updated upon OLR.

In the upstream direction, it shall be set as: *INP_act_reinus* = *INP_min_reinus.*

The status parameter *INP_act_rein* shall be coded as an 8-bit unsigned integer expressing the value in symbol periods in steps of one symbol period.

The valid range is from 0 to 62.

A special value 63 indicates a value of 63 or higher.

A special value 2^8-1 indicates that the parameter is undetermined.

All other values are reserved by ITU-T.

The status parameter *INP_act_rein* shall be mapped on the reporting parameter ACTINP_REIN. The downstream and upstream values shall be reported in the DPU-MIB.

During the L3 link state (see Figure 12-1), the values of the last update are available in the DPU-MIB, until the MTU-O transitions to the O-INIT/HS state, at which time the values may become "undetermined".

11.4.1.1.9 Error-free bits counter

This is a near-end counter counting the number of error-free bits passed over the α reference point at the receiver, divided by 2^{16}. Error-free bits are DTU payload bits originating from DTUs of the normal DTU type (see clause 8.2.1.3) that cross the α reference point at the receiver. If the same DTU crosses multiple times the α reference point (see clause 9.1), the number of payload bits of that DTU shall be counted only once.

It is a 32-bit wrap-around counter. The counter shall be reset at power-on. The counters shall not be reset with a link state transition and shall not be reset when read.

The upstream value shall be reported in the DPU-MIB as a near-end value.

The downstream value shall be reported in the DPU-MIB as a far-end value.

NOTE – DTUs that have been detected to be in error, and DTUs that exceed *delay_max_0* do not cross the α reference point at the receiver side.

11.4.1.1.10 Signal-to-noise ratio margin parameter (*SNRM*)

The signal-to-noise ratio margin (*SNRM*) parameter is a parameter that reports the signal-to-noise ratio margin (as defined in clause 9.8.3.2) for data symbols L0.

The *SNRM* shall be measured by the receiver during the initialization. The measurement may be updated autonomously and shall be updated on request during showtime (L0). The *SNRM* shall be sent to the far-end MTU during the initialization and shall be sent on request to the near-end ME at any time. The near-end ME shall send the *SNRM* to the far-end ME on request during showtime (L0 link state).

The signal-to-noise ratio margin in the downstream direction shall be coded as a 10-bit two's complement signed integer *snrm*, with the value of *SNRMds* defined as

$$SNRMds = snrm/10 \text{ dB}.$$

This data format supports an *SNRMds* granularity of 0.1 dB and an *SNRMds* range from −50.9 to +50.9 dB, corresponding to the set of valid values of *snrm* = −509 to 509.

A special value *snrm* = 510 indicates a value of *SNRM* = 51.0 dB or higher.

A special value *snrm* = –510 indicates a value of *SNRM* = –51.0 dB or lower.

A special value *snrm* = –512 indicates that the parameter is undetermined.

All other values are reserved by ITU-T.

The same definition and representation shall apply to the signal-to-noise ratio margin in the upstream direction, *SNRMus*.

During the L0 link state, downstream and upstream *SNRM* values are reported by the MTU-O as SNRM in the DPU-MIB.

During the L3 link state (see Figure 12-1), the value of *SNRM* at the last update is available in the DPU-MIB, until the MTU-O transitions to the O-INIT/HS state, at which time the values may become "undetermined".

11.4.1.1.11 Signal-to-noise ratio margin for the RMC (*SNRM_RMC*)

The *SNRM_RMC* is the signal-to-noise ratio margin of the RMC. It is defined in clause 9.8.3.4.

The *SNRM_RMC* shall be measured over all subcarriers assigned to the RMC in RMC symbols for which $b_i > 0$ in the transmission direction.

The measurement of *SNRM_RMC* may be updated autonomously and shall be updated on request during the showtime (L0 link state). The *SNRM_RMC* shall be sent to the far-end MTU during the initialization and shall be sent on request to the near-end ME at any time. The near-end ME shall send the *SNRM_RMC* to the far-end ME on request during the showtime (L0 link state).

The *SNRM_RMC* shall use the same representation as defined for SNRM in clause 11.4.1.1.10.

The value during the L0 link state shall be reported as SNRM-RMC in the DPU-MIB.

During the L0 link state, downstream and upstream *SNRM_RMC* values are reported by the MTU-O as SNRM-RMC in the DPU-MIB.

During the L3 link state (see Figure 12-1), the value of SNRM-RMC at the last update is available in the DPU-MIB, until the MTU-O transitions to the O-INIT/HS state, at which time the values may become "undetermined".

11.4.1.1.12 DTU FEC codeword size (N_{FEC})

The status parameter N_{FEC} is the DTU FEC codeword size as defined in clause 9.3.

The N_{FEC} shall be updated during showtime (L0 link state).

The valid values for N_{FEC} are all integers from 32 to 255.

The N_{FEC} shall be coded as an 8-bit unsigned integer.

A special value 0 indicates that the parameter is undetermined.

All other values are reserved by ITU-T.

The N_{FEC} value shall be reported by the MTU-O as DTU-NFEC in the DPU-MIB.

The downstream and upstream values shall be reported in the DPU-MIB.

During the L3 link state (see Figure 12-1), the values of the last update are available in the DPU-MIB, until the MTU-O transitions to the O-INIT/HS state, at which time the values may become "undetermined".

11.4.1.1.13 DTU FEC redundancy (R_{FEC})

The status parameter R_{FEC} is the DTU FEC codeword redundancy as defined in clause 9.3.

The R_{FEC} shall be updated during showtime (L0 link state).

The valid values for R_{FEC} are 2, 4, 6, 8, 10, 12, and 16.

The R_{FEC} shall be coded as an 8-bit unsigned integer.

A special value 255 indicates that the parameter is undetermined.

All other values are reserved by ITU-T.

The R_{FEC} value shall be reported by the MTU-O as DTU-RFEC in the DPU-MIB.

The downstream and upstream values shall be reported in the DPU-MIB.

During the L3 link state (see Figure 12-1), the values of the last update are available in the DPU-MIB, until the MTU-O transitions to the O-INIT/HS state, at which time the values may become "undetermined".

11.4.1.1.14 FEC codewords per DTU (*Q*)

The status parameter *Q* is the number of FEC codewords per DTU as defined in clause 9.3.

The *Q* shall be updated during showtime (L0 link state).

The valid values for *Q* are all integers from 1 to 16.

The *Q* shall be coded as an 8-bit unsigned integer.

A special value 255 indicates that the parameter is undetermined.

All other values are reserved by ITU-T.

The *Q* value shall be reported by the MTU-O as DTU-Q in the DPU-MIB.

The downstream and upstream values shall be reported in the DPU-MIB.

During the L3 link state (see Figure 12-1), the values of the last update are available in the DPU-MIB, until the MTU-O transitions to the O-INIT/HS state, at which time the values may become "undetermined".

11.4.1.1.15 Bit Allocation on data subcarriers

The status parameter, in case of TCM contains the bi values as defined in clause 10.2.1.2.3, and in case of PCS-LCM the modulation index values mi as defined in clause 10.2.1.3.4.1 on data symbols in the NOI in L0. The upstream values as conveyed in O-PMD (clause 12.3.4.2.7), the downstream values as conveyed in R-PMD (clause 12.3.4.2.7).

The b_i (in case of TCM) or m_i (in case of PCS-LCM) shall be updated during showtime (L0 link state). The valid values for b_i are all integers from 0 to 14. The valid values for m_i are all integers from 0 to 15.The b_i and m_i shall be coded as an 8-bit unsigned integer.

A special value 255 indicates that the parameter is undetermined. All other values are reserved by ITU-T.

The b_i or m_i value shall be reported by the MTU-O as BITSps in the DPU-MIB.

The downstream and upstream values shall be reported in the DPU-MIB.

During the L3 link state (see Figure 12-1), the values are "undetermined".

11.4.1.1.16 Bit Allocation on RMC subcarriers

This status parameter, in case of TCM contains the b_i values as defined in clause 10.2.1.2.3, and in case of PCS-LCM the modulation index values m_i as defined in clause 10.2.1.3.4.1 on RMC subcarriers in RMC symbols. The upstream values are conveyed in O-PMD (clause 12.3.4.2.7), the downstream values are conveyed in R-PMD (clause 12.3.4.2.7).

The b_{RMCi} (in case of TCM) or m_{RMCi} (in case of PCS-LCM) shall be updated during showtime (L0 link state).

The valid values for b_{RMCi} are 0 and all integers from 2 to 6. The valid values for m_{RMCi} are all integers from 0 to 4.

The b_{RMCi} and m_{RMCi} shall be coded as an 8-bit unsigned integer.

A special value 255 indicates that the parameter is undetermined. All other values are reserved by ITU-T.

The b_{RMCi} or m_{RMCi} value shall be reported by the MTU-O as BITS-RMCps in the DPU-MIB.

The downstream and upstream values shall be reported in the DPU-MIB.

During the L3 link state (see Figure 12-1), the values are "undetermined".

11.4.1.1.17 All NOI and DOI with Data symbols EFTR with DTFO enabled (*ANDEFTR*) parameter

The All NOI and DOI with Data symbols EFTR with DTFO enabled (ANDEFTR) is defined as

$$ANDEFTR = (DPR - EOCact) \times (1 - RTXOHact)$$

and is calculated over a 1 second time window. The 1 second time windows are consecutive and non-overlapping.

NOTE – As a result of this definition, $ANDEFTR \leq DPR$ (see Table 9-27).

The actual retransmission ratio (RTXOHact) is defined as the ratio

N_DTU_C_NACK / N_DTU_C,

where:

– N_DTU_C is the number of complete dummy or normal DTUs (new ones or retransmitted), contained in RMC and Data symbols, that are transmitted during the 1 second time window; and

– N_DTU_C_NACK is the number of those DTUs contained in RMC and Data symbols, indicated as NACKed in the ACK bit maps, out of the N_DTU_C DTUs. If the ACK bit map is not received, all DTUs of the corresponding ack window are considered as NACKed.

RTXOHact shall be computed by the transmitter.

The actual eoc bit rate (EOCact) is defined at the TPS_TC_MGMT reference point and shall be computed by the transmitter as the actual number of transmitted eoc bits over the same 1 second time window.

The *ANDEFTR* shall be calculated by the transmitter for every complete second the link is in the L0 link state and during which Band 1 bitloading is known in every logical frame of that second. In case Band 1 bitloading is known, but B_{DOI} is unknown, *ANDEFTR* shall be calculated with the value $B_{DOI} = B_{N01}$ in the DPR formula. In case the B_{N01} or B_{DOI} bitloading changes during the second, *ANDEFTR* shall be calculated using the minimum value of the DPR that occured over that second. *ANDEFTR* is not defined for seconds during which Band 1 bit loading is unknown for one or more logical frames of that second (e.g., due to restoration procedure), for seconds during which the link changes state and for seconds during which the link is in link states other than L0. The *ANDEFTR* is not a status parameter directly reported to the ME but is used in the definition of related parameters.

11.4.1.1.17.1 All NOI with Data symbols EFTR with DTFO disabled (ANDEFTR0) parameter

The All NOI with Data symbols EFTR with DTFO disabled (*ANDEFTR0*) is defined as

$$ANDEFTR0 \quad = (DPR_0 - EOCact) \times (1 - RTXOHact)$$

and is calculated over a 1 second time window. The 1 second time windows are consecutive and non-overlapping.

NOTE – As a result of this definition, *ANDEFTR0* ≤ DPR_0 (see Table 9-27).

The actual retransmission ratio (RTXOHact) is defined as the ratio

N_DTU_C_NACK / N_DTU_C,

where:

– N_DTU_C is the number of complete dummy or normal DTUs (new ones or retransmitted), contained in RMC and Data symbols, that are transmitted during the 1 second time window; and

– N_DTU_C_NACK is the number of those DTUs contained in RMC and Data symbols, indicated as NACKed in the ACK bit maps, out of the N_DTU_C DTUs. If the ACK bit map is not received, all DTUs of the corresponding ack window are considered as NACKed.

RTXOHact shall be computed by the transmitter.

The actual eoc bit rate (EOCact) is defined at the TPS_TC_MGMT reference point and shall be computed by the transmitter as the actual number of transmitted eoc bits over the same 1 second time window.

The *ANDEFTR0* shall be calculated by the transmitter for every complete second the link is in the L0 link state. *ANDEFTR0* is not defined for seconds during which the link changes state and is not defined for seconds during which the link is in link states other than L0. The *ANDEFTR0* is not a status parameter directly reported to the ME but is used in the definition of related parameters.

11.4.1.1.18 Minimum All NOI and DOI with Data symbols EFTR with DTFO enabled (*ANDEFTR_min*) parameter

The performance monitoring parameter minimum All NOI and DOI with Data symbols EFTR with DTFO enabled (*ANDEFTR_min*) is defined as the minimum of the *ANDEFTR* observed in the seconds since the last reading of the *ANDEFTR_min*, excluding the seconds in which *ANDEFTR* is not defined.

The *ANDEFTR_min* shall be measured in showtime by the transmitter. Reading by the MTU-O of the far-end *ANDEFTR_min* shall be via the management counter read command (see clause 11.2.2.11) over the U interface.

The valid values are all integers from 0 to 2^{24}-1. A special value 2^{32}-1 indicates that the parameter is undetermined. All other values are reserved by ITU-T.

The performance monitoring parameter *ANDEFTR_min* shall be coded as a 32-bit unsigned integer expressing the value of $floor(\frac{ANDEFTR\_min \text{ in bit/s}}{1000\text{bit/s}})$. This data format supports a granularity of 1 kbit/s.

The previous value of *ANDEFTR_min* shall be used if no *ANDEFTR* measurement has been done since the last reading of *ANDEFTR_min*.

NOTE 1 – The above requirement covers the case where two retrievals of *ANDEFTR_min* over the eoc take place in less than 1 second, and in which no new *ANDEFTR* measurement is available, since the *ANDEFTR* is only updated on 1 second intervals.

NOTE 2 – The above requirement covers the case when not in L0 mode.

Although this parameter *ANDEFTR_min* is obtained via the management counter read response (see clause 11.2.2.11), this performance monitoring parameter is not a counter.

The parameter reported to the DPU-MIB, MINANDEFTR, is defined as the minimum of the retrieved *ANDEFTR_min* values observed over the 15 min or 24 hour accumulation periods.

The MME at the MTU-O shall retrieve the far-end *ANDEFTR_min*, to calculate the upstream MINANDEFTR. The MME at the MTU-O shall retrieve the near-end *ANDEFTR_min* to calculate the downstream MINANDEFTR. If the 15 min or 24 hour interval contains only seconds with undefined ANDEFTR, the related MINANDEFTR shall be set to 0.

NOTE 3 – The frequency of retrieval for both near-end and far-end is left to the implementation, as necessary for accurate monitoring.

The upstream MINANDEFTR value shall be reported to the DPU-MIB as a near-end value even though it is calculated from the far-end *ANDEFTR_min* values retrieved from the MTU-R.

The downstream MINANDEFTR value shall be reported to the DPU-MIB as a far-end value even though it is calculated from the near-end *ANDEFTR_min* values retrieved from the MTU-O.

11.4.1.1.18.1 Minimum All NOI with Data symbols EFTR with DTFO disabled (ANDEFTR0_min) parameter

The performance monitoring parameter minimum All NOI with Data symbols EFTR with DTFO disabled (*ANDEFTR0_min*) is defined as the minimum of the *ANDEFTR0* observed in the seconds since the last reading of the *ANDEFTR0_min*, excluding the seconds in which *ANDEFTR0* is not defined.

The *ANDEFTR0_min* shall be measured in showtime by the transmitter. Reading by the MTU-O of the far-end *ANDEFTR0_min* shall be via the management counter read command (see clause 11.2.2.11) over the U interface.

The valid values are all integers from 0 to 2^{24}-1. A special value 2^{32}-1 indicates that the parameter is undetermined. All other values are reserved by ITU-T.

The performance monitoring parameter *ANDEFTR0_min* shall be coded as a 32-bit unsigned integer expressing the value of $floor(\frac{ANDEFTR0\_min \text{ in bit/s}}{1000\text{bit/s}})$. This data format supports a granularity of 1 kbit/s.

The previous value of *ANDEFTR0_min* shall be used if no *ANDEFTR0* measurement has been done since the last reading of *ANDEFTR0_min*.

NOTE 1 – The above requirement covers the case where two retrievals of *ANDEFTR0_min* over the eoc take place in less than 1 second, and in which no new *ANDEFTR0* measurement is available, since the *ANDEFTR0* is only updated on 1 second intervals.

NOTE 2 – The above requirement covers the case when not in L0 mode.

Although this parameter *ANDEFTR0_min* is obtained via the management counter read response (see clause 11.2.2.11), this performance monitoring parameter is not a counter.

The parameter reported to the DPU-MIB, MINANDEFTR0, is defined as the minimum of the retrieved *ANDEFTR0_min* values observed over the 15 min or 24 hour accumulation periods.

The MME at the MTU-O shall retrieve the far-end *ANDEFTR0_min*, to calculate the upstream MINANDEFTR0. The MME at the MTU-O shall retrieve the near-end *ANDEFTR0_min* to calculate the downstream MINANDEFTR0. If the 15 min or 24 hour interval contains only seconds with undefined ANDEFTR0, the related MINANDEFTR0 shall be set to 0.

NOTE 3 – The frequency of retrieval for both near-end and far-end is left to the implementation, as necessary for accurate monitoring.

The upstream MINANDEFTR0 value shall be reported to the DPU-MIB as a near-end value even though it is calculated from the far-end *ANDEFTR0_min* values retrieved from the MTU-R.

The downstream MINANDEFTR0 value shall be reported to the DPU-MIB as a far-end value even though it is calculated from the near-end *ANDEFTR0_min* values retrieved from the MTU-O.

11.4.1.1.19 Maximum All NOI and DOI with Data symbols EFTR with DTFO enabled (*ANDEFTR_max*) parameter

The performance monitoring parameter maximum All NOI and DOI with Data symbols EFTR with DTFO enabled (*ANDEFTR_max*) is defined as the maximum of the *ANDEFTR* observed in the seconds since the last reading of the *ANDEFTR_max*, excluding the seconds in which *ANDEFTR* is not defined:

The *ANDEFTR_max* shall be measured in showtime by the transmitter. Reading by the MTU-O of the far-end *ANDEFTR_max* shall be via the management counter read command (see clause 11.2.2.11) over the U interface.

The valid values are all integers from 0 to 2^{24}-1. A special value 2^{32}-1 indicates that the parameter is undetermined. All other values are reserved by ITU-T.

The performance monitoring parameter *ANDEFTR_max* shall be coded as a 32-bit unsigned integer expressing the value of $ceiling\left(\frac{ANDEFTR\_max \text{ in bit/s}}{1000 \text{ bit/s}}\right)$. This data format supports a granularity of 1 kbit/s.

The previous value of *ANDEFTR_max* shall be reported if no *ANDEFTR* measurement has been done since the last reading of *ANDEFTR_max*.

NOTE 1 – The above requirement covers the case where two retrievals of *ANDEFTR_max* over the eoc take place in less than 1 second, and in which no new *ANDEFTR* measurement is available, since the *ANDEFTR* is only updated on 1 second intervals.

NOTE 2 – The above requirement covers the case when not in L0 mode.

Although this parameter *ANDEFTR_max* is reported via the management counter read response (see clause 11.2.2.11), this performance monitoring parameter is not a counter.

The parameter reported to the DPU-MIB, MAXANDEFTR, is defined as the maximum of the retrieved *ANDEFTR_max* values observed over the 15 min or 24 hour accumulation periods.

The MME at the MTU-O shall retrieve the far-end *ANDEFTR_max*, to calculate the upstream MAXANDEFTR. The MME at the MTU-O shall retrieve the near-end *ANDEFTR_max* to calculate the downstream MAXANDEFTR. If the 15 min or 24 hour interval contains only seconds with undefined ANDEFTR, the related MAXANDEFTR shall be set to 0.

NOTE 3 – The frequency of retrieval for both near-end and far-end is left to the implementation, as necessary for accurate monitoring.

The upstream MAXANDEFTR value shall be reported to the DPU-MIB as a near-end value even though it is calculated from the far-end *ANDEFTR_max* values retrieved from the MTU-R.

The downstream MAXANDEFTR value shall be reported to the DPU-MIB as a far-end value even though it is calculated from the near-end *ANDEFTR_max* values retrieved from the MTU-O.

11.4.1.1.19.1 Maximum All NOI with Data symbols EFTR with DTFO disabled (ANDEFTR0_max) parameter

The performance monitoring parameter maximum All NOI with Data symbols EFTR with DTFO disabled (*ANDEFTR0_max*) is defined as the maximum of the *ANDEFTR0* observed in the seconds since the last reading of the *ANDEFTR0_max*, excluding the seconds in which *ANDEFTR0* is not defined:

The *ANDEFTR0_max* shall be measured in showtime by the transmitter. Reading by the MTU-O of the far-end *ANDEFTR0_max* shall be via the management counter read command (see clause 11.2.2.11) over the U interface.

The valid values are all integers from 0 to 2^{24}-1. A special value 2^{32}-1 indicates that the parameter is undetermined. All other values are reserved by ITU-T.

The performance monitoring parameter *ANDEFTR0_max* shall be coded as a 32-bit unsigned integer expressing the value of $ceiling\left(\frac{ANDEFTR0\_max \text{ in bit/s}}{1000 \text{ bit/s}}\right)$. This data format supports a granularity of 1 kbit/s.

The previous value of *ANDEFTR0_max* shall be reported if no *ANDEFTR0* measurement has been done since the last reading of *ANDEFTR0_max*.

NOTE 1 – The above requirement covers the case where two retrievals of *ANDEFTR0_max* over the eoc take place in less than 1 second, and in which no new *ANDEFTR0* measurement is available, since the *ANDEFTR0* is only updated on 1 second intervals.

NOTE 2 – The above requirement covers the case when not in L0 mode.

Although this parameter *ANDEFTR0_max* is reported via the management counter read response (see clause 11.2.2.11), this performance monitoring parameter is not a counter.

The parameter reported to the DPU-MIB, MAXANDEFTR0, is defined as the maximum of the retrieved *ANDEFTR0_max* values observed over the 15 min or 24 hour accumulation periods.

The MME at the MTU-O shall retrieve the far-end *ANDEFTR0_max*, to calculate the upstream MAXANDEFTR0. The MME at the MTU-O shall retrieve the near-end *ANDEFTR0_max* to calculate the downstream MAXANDEFTR0. If the 15 min or 24 hour interval contains only seconds with undefined ANDEFTR0, the related MAXANDEFTR0 shall be set to 0.

NOTE 3 – The frequency of retrieval for both near-end and far-end is left to the implementation, as necessary for accurate monitoring.

The upstream MAXANDEFTR0 value shall be reported to the DPU-MIB as a near-end value even though it is calculated from the far-end *ANDEFTR0_max* values retrieved from the MTU-R.

The downstream MAXANDEFTR0 value shall be reported to the DPU-MIB as a far-end value even though it is calculated from the near-end *ANDEFTR0_max* values retrieved from the MTU-O.

11.4.1.1.20 Sum All NOI and DOI with Data symbols EFTR with DTFO enabled (*ANDEFTR_sum*) parameter

The performance monitoring parameter sum All NOI and DOI with Data symbols EFTR with DTFO enabled (*ANDEFTR_sum*) is a counter. The transceiver shall establish an internal *ANDEFTR_acc* counter of bits and shall increment it every second by a value of floor(*ANDEFTR* in bit/s × 1 s), excluding the seconds in which *ANDEFTR* is not defined. *ANDEFTR_acc* is a 48-bit wrap-around counter.

The *ANDEFTR_sum* shall be measured in showtime by the transmitter. Reading by the MTU-O of the far-end *ANDEFTR_sum* shall be via the management counter read command (see clause 11.2.2.11) over the U interface.

The *ANDEFTR_sum* shall be a wrap around counter coded as a 32-bit unsigned integer expressing the value of $ceiling\left(\frac{ANDEFTR\_acc}{2^{16} \text{ bits}}\right)$. This data format supports a granularity of 2^{16} bits.

NOTE 1 – The format of the ANDEFTR_sum counter is the same as for the error free bits counter.

The parameter reported to the DPU-MIB, SUMANDEFTR, is defined as the increment of the retrieved *ANDEFTR_sum* values observed over the 15 min or 24 hour accumulation periods.

The MME at the MTU-O shall retrieve the far-end *ANDEFTR_sum* to calculate the upstream SUMANDEFTR. The MME at the MTU-O shall retrieve the near-end *ANDEFTR_sum* to calculate the downstream SUMANDEFTR.

NOTE 2 – If the 15 min or 24 hour interval contains only seconds with undefined ANDEFTR, the related SUMANDEFTR is 0.

NOTE 3 – The frequency of retrieval for both near-end and far-end is left to the implementation, as necessary for accurate monitoring.

The upstream SUMANDEFTR value shall be reported to the DPU-MIB as a near-end value even though it is calculated from the far-end *ANDEFTR_sum* values retrieved from the MTU-R.

The downstream SUMANDEFTR value shall be reported to the DPU-MIB as a far-end value even though it is calculated from the near-end *ANDEFTR_sum* values retrieved from the MTU-O.

NOTE 4 – SUMANDEFTR and ANDEFTRDS can be used to calculate the mean ANDEFTR in bit/s as $ceiling(\frac{SUMANDEFTR \text{ in bits}}{ANDEFTRDS \text{ in sec}})$. There is a low probability that the mean ANDEFTR will be greater than the reported MAXANDEFTR.

11.4.1.1.20.1 Sum All NOI with Data symbols EFTR with DTFO disabled (ANDEFTR0_sum) parameter

The performance monitoring parameter sum All NOI with Data symbols EFTR with DTFO disabled (*ANDEFTR0_sum*) is a counter. The transceiver shall establish an internal *ANDEFTR0_acc* counter of bits and shall increment it every second by a value of floor(*ANDEFTR0* in bit/s × 1 s), excluding the seconds in which *ANDEFTR0* is not defined. *ANDEFTR0_acc* is a 48-bit wrap-around counter.

The *ANDEFTR0_sum* shall be measured in showtime by the transmitter. Reading by the MTU-O of the far-end *ANDEFTR0_sum* shall be via the management counter read command (see clause 11.2.2.11) over the U interface.

The *ANDEFTR0_sum* shall be a wrap around counter coded as a 32-bit unsigned integer expressing the value of $ceiling\,(\frac{ANDEFTR0\_acc}{2^{16} \text{ bits}})$. This data format supports a granularity of 2^{16} bits.

NOTE 1 – The format of the ANDEFTR0_sum counter is the same as for the error free bits counter.

The parameter reported to the DPU-MIB, SUMANDEFTR0, is defined as the increment of the retrieved *ANDEFTR0_sum* values observed over the 15 min or 24 hour accumulation periods.

The MME at the MTU-O shall retrieve the far-end *ANDEFTR0_sum* to calculate the upstream SUMANDEFTR0. The MME at the MTU-O shall retrieve the near-end *ANDEFTR0_sum* to calculate the downstream SUMANDEFTR0.

NOTE 2 – If the 15 min or 24 hour interval contains only seconds with undefined ANDEFTR0, the related SUMANDEFTR is 0.

NOTE 3 – The frequency of retrieval for both near-end and far-end is left to the implementation, as necessary for accurate monitoring.

The upstream SUMANDEFTR0 value shall be reported to the DPU-MIB as a near-end value even though it is calculated from the far-end *ANDEFTR0_sum* values retrieved from the MTU-R.

The downstream SUMANDEFTR0 value shall be reported to the DPU-MIB as a far-end value even though it is calculated from the near-end *ANDEFTR0_sum* values retrieved from the MTU-O.

NOTE 4 – SUMANDEFTR0 and ANDEFTR0DS can be used to calculate the mean ANDEFTR0 in bit/s as $ceiling(\frac{SUMANDEFTR \text{ in bits}}{ANDEFTRDS \text{ in sec}})$. There is a low probability that the mean ANDEFTR0 will be greater than the reported MAXANDEFTR0.

11.4.1.1.21 All NOI and DOI with Data symbols EFTR with DTFO enabled defined second (*ANDEFTRDS*)

The performance monitoring parameter All NOI and DOI with Data symbols EFTR with DTFO enabled defined second (*ANDEFTRDS*) is a counter, incrementing by one every second, excluding the seconds in which *ANDEFTR* is not defined.

The *ANDEFTRDS* shall be measured in showtime by the transmitter. Reading by the MTU-O of the far-end *ANDEFTRDS* shall be via the management counter read command (see clause 11.2.2.11) over the U interface.

The performance monitoring parameter *ANDEFTRDS* shall be a wrap-around counter coded as a 32-bit unsigned integer.

The parameter reported to the DPU-MIB, ANDEFTRDS, is defined as the increase of the retrieved *ANDEFTRDS* values observed over the 15 min or 24 hour accumulation periods.

The MME at the MTU-O shall retrieve the far-end *ANDEFTRDS* to calculate the upstream ANDEFTRDS. The MME at the MTU-O shall retrieve the near-end *ANDEFTRDS* to calculate the downstream ANDEFTRDS.

NOTE 1 – If the 15 min or 24 hour interval contains only seconds with undefined *ANDEFTR*, the related ANDEFTRDS is 0.

NOTE 2 – The frequency of retrieval for both near-end and far-end is left to the implementation, as necessary for accurate monitoring.

The upstream ANDEFTRDS value shall be reported to the DPU-MIB as a near-end value even though it is calculated from the far-end *ANDEFTRDS* values retrieved from the MTU-R.

The downstream ANDEFTRDS value shall be reported to the DPU-MIB as a far-end value even though it is calculated from the near-end *ANDEFTRDS* values retrieved from the MTU-R.

11.4.1.1.21.1 All NOI with Data symbols EFTR with DTFO disabled defined second (ANDEFTR0DS)

The performance monitoring parameter All NOI with Data symbols EFTR with DTFO disabled defined second (*ANDEFTR0DS*) is a counter, incrementing by one every second, excluding the seconds in which *ANDEFTR0* is not defined.

The *ANDEFTR0DS* shall be measured in showtime by the transmitter. Reading by the MTU-O of the far-end *ANDEFTR0DS* shall be via the management counter read command (see clause 11.2.2.11) over the U interface.

The performance monitoring parameter *ANDEFTR0DS* shall be a wrap-around counter coded as a 32-bit unsigned integer.

The parameter reported to the DPU-MIB, ANDEFTR0DS, is defined as the increase of the retrieved *ANDEFTR0DS* values observed over the 15 min or 24 hour accumulation periods.

The MME at the MTU-O shall retrieve the far-end *ANDEFTR0DS* to calculate the upstream ANDEFTR0DS. The MME at the MTU-O shall retrieve the near-end *ANDEFTR0DS* to calculate the downstream ANDEFTR0DS.

NOTE 1 – If the 15 min or 24 hour interval contains only seconds with undefined *ANDEFTR0*, the related ANDEFTRDS is 0.

NOTE 2 – The frequency of retrieval for both near-end and far-end is left to the implementation, as necessary for accurate monitoring.

The upstream ANDEFTR0DS value shall be reported to the DPU-MIB as a near-end value even though it is calculated from the far-end *ANDEFTR0DS* values retrieved from the MTU-R.

The downstream ANDEFTR0DS value shall be reported to the DPU-MIB as a far-end value even though it is calculated from the near-end *ANDEFTR0DS* values retrieved from the MTU-R.

11.4.1.2 Test parameters

In all subclauses, the applicable termination impedance of the metallic wire is as specified in [ITU-T G.9710] Annex P and Annex Q. For the definition of test parameters, the value of the termination impedance shall depend on the profile (see Tables P.1 and Q.1, respectively) selected during the ITU-T G.994.1 phase of initialization.

11.4.1.2.1 Hlog per subcarrier (*Hlog*)

Hlog provides an estimate of the insertion loss of the wireline channel.

The definition of the insertion loss is $-20 \times \log_{10}(|U2(f)/U1(f)|)$ dB. *U1*(*f*) is the voltage as a function of frequency measured across the load impedance R_L in the absence of the wireline channel as shown in Figure 11-7 for the downstream direction. *U2*(*f*) is the voltage as a function of frequency measured across the load impedance R_L in the presence of the wireline channel as shown in Figure 11-8 for the downstream direction.

R_S is a reference impedance, corresponding to the source impedance. R_L is a reference impedance, corresponding to the load impedance.

For the purpose of *Hlog* definition, R_S and R_L shall both be resistive and equal to the termination impedance of the the metallic wire, see [ITU-T G.9710] Annex P and Annex Q, based on the profile (see Tables P.1 and Q.1) selected during the ITU-T G.994.1 phase of initialization.

NOTE 1 – The values of R_S and R_L used for the *Hlog* definition do not imply specific values for MTU implementations.

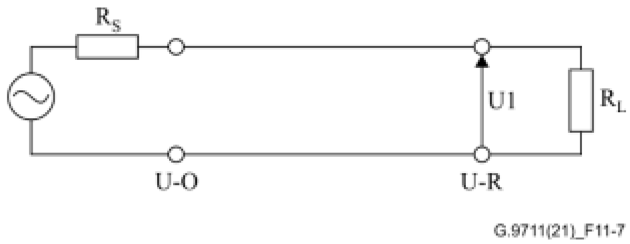


Figure 11-7 – Voltage across the load without access cabling

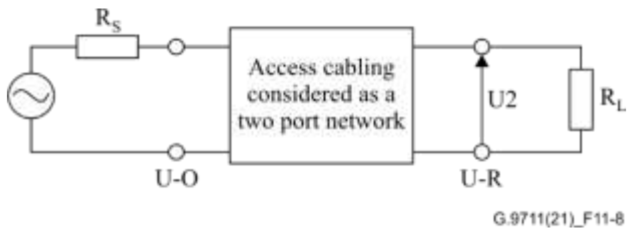


Figure 11-8 – Voltage across the load with access cabling inserted

The same can be applied to the upstream direction (swapping U-O and U-R in Figure 11-7 and Figure 11-8).

The calculation of *Hlog* shall take into account that the signal path is the result of the cascade of four functions:

- the precoder in the downstream and post-processing in the upstream (see clause 10.3);
- the transmitter filter characteristics function;
- the channel characteristics function; and
- the receiver filter characteristics function.

The objective is to provide means by which the insertion loss between the U-O and U-R reference points (see Figure 11-7 and Figure 11-8) can be accurately identified, estimated, and reported to the ME by the VCE in the form of *Hlog*(f) at discrete frequencies $f = i \times f_{SC}$.

The following definition allows the *Hlog* referred to the U-O and U-R reference points to be calculated using equivalents of *U1* and *U2* in Figure 11-7 and Figure 11-8.

Hlog(*f*) shall be computed by the VCE. *Hlog*(*f*) shall be computed in both directions.

With the definition above, for frequency $f = i \times f_{SC}$, *Hlog*(*f*) shall be calculated as:

$$\text{Hlog}(f) = 10 \times \log_{10}\left(\frac{\text{Direct\_Received\_subcarrier\_power\_mW}(i)}{\text{Direct\_Transmit\_subcarrier\_power\_mW}(i)}\right),$$

where Direct_Received_subcarrier_power_mW (*i*) is the average power of the received direct signal component on subcarrier *i* at the U reference point of the receiving MTU, assuming the receiving MTU presents a load impedance R_L to the network of is resistive and equal to the termination impedance of the the metallic wire, see [ITU-T G.9710] Annex P and Annex Q (see Note 3), and Direct_Transmit_subcarrier_power_mW(*i*) is the average power of the transmit direct signal component on subcarrier *i* at the U reference point of the transmitting MTU, assuming the network input impedance is resistive and equal to the termination impedance of the the metallic wire, see [ITU-T G.9710] Annex P and Annex Q (see Note 4 and Note 5).

Direct_Received_subcarrier_power_mW(*i*) and Direct_Transmit_subcarrier_power_mW(*i*) should not include FEXT contributions from other transmission lines of the vectored group. The exact methods used by the VCE to estimate Direct_Received_subcarrier_power_mW (*i*) and Direct_Transmit_subcarrier_power_mW(*i*) are vendor discretionary.

NOTE 2 – One way of avoiding impact of crosstalk in estimation of the Direct_Received_subcarrier_power for both upstream and downstream is by applying particular probe sequences, e.g., probe sequences containing 0-elements on sync symbol positions associated with the estimation on all transmission lines except the transmission line under estimation (similar to estimation of *QLN* defined in clause 11.4.1.2.3).

NOTE 3 – In actual implementations, the receiving MTU load impedance may deviate from the termination impedance defined in [ITU-T G.9710] Annex P and Annex Q.

For downstream *Hlog*, the Direct_Received_subcarrier_power_mW(*i*) can be obtained from the MTU-R reported DFT output samples as specified in clause 10.3.3.2 (DFT samples are referenced to a termination impedance (i.e., load impedance of the MTU receiver to the network) of defined in [ITU-T G.9710] Annex P and Annex Q).

For upstream *Hlog*, the MTU-O's internal measurements are used to obtain Direct_Received_subcarrier_power_mW(*i*).

NOTE 4 – Transmit PSD in G.9710 clause 7.3 is also defined on the termination impedance, purely resistive, of the the metallic wire, see [ITU-T G.9710] Annex P and Annex Q. Remark that in this case termination impedance is to be interpreted as the network/loop input impedance.

NOTE 5 – In actual deployments, the network/loop input impedance may deviate from the termination impedance defined in [ITU-T G.9710] Annex P and Annex Q.

The VCE shall average the measurements over *Navg* of at least 256 symbols (consecutive or non-consecutive), and shall indicate the value of *Navg* coded as a 16-bit unsigned value.

The Direct_Received_subcarrier_power_mW (*i*) and the Direct_Transmit_subcarrier_power_mW(*i*) shall be estimated only during transmission of sync symbols during showtime L0 link state only. *Hlog*(*f*) shall be updated during L0 link state only, on request of the ME-O, in response to an update request for test parameters (see clause 7.1.9.1 of [ITU-T G.997.3]).

The reported *Hlog* values (upstream and downstream) shall be represented by subcarrier groups. The number of subcarriers, *G*, in one subcarrier group shall be equal to:

$$G = \max(2^{\text{ceiling}(\log_2((\Theta+1)/512))}, 1),$$

where Θ is the highest subcarrier index of the MEDLEYGds set, and 512 is the maximum number of subcarrier groups. Valid values of *G* are 1, 2, 4 and 8.

For the given group size *G*, the channel characteristics function $Hlog(k \times G \times f_{SC})$ is the value of *Hlog* at subcarrier with index $i = k \times G$. It shall be represented by an integer number *m(k)*, where the valid values of *k* are from $k = 0$ to k =ceiling(Θ/*G*). The values of *m(k)* shall be coded as 10-bit unsigned integers so that:

$$Hlog(k \times G \times f_{SC}) = 6 - (m(k)/10).$$

This format supports an *Hlog*(*f*) granularity of 0.1 dB with a valid range of values from +5.9 dB to −95.9 dB, corresponding to the set of valid values of *m* = 1 to 1019.

A special value *m* = 0 indicates a value of *Hlog* = 6 dB or higher

A special value *m* =1020 indicates a value of *Hlog* = −96 dB or lower.

A special value *m* =1022 indicates that no measurement could be done for this subcarrier group because the subcarrier with index $i = k \times G$ is out of the MEDLEYds set or its $g_i = 0$.

A special value *m* =1023 indicates that the parameter is undetermined.

All other values are reserved by ITU-T.

Support for reporting of both upstream and downstream HLog is mandatory.

11.4.1.2.2 Signal-to-noise ratio per subcarrier (*SNR*)

The signal-to-noise ratio *SNR* for a particular subcarrier group is a real value that shall represent the ratio between the received signal power and the received noise power for that subcarrier.

The signal-to-noise ratio *SNR* per subcarrier group shall be measured during initialization. The measurement may be updated autonomously during the showtime L0 link state, and shall be updated on request during showtime L0 link state.

During the showtime, *SNR* shall be measured only at time periods during the reception of RMC symbols or the data symbols in the NOI_{PSF} at the symbol positions specified in the downstream by the *MNDSNOIds* value, and in upstream by the *MNDSNOIus* value. *SNR* shall not be computed in the upstream direction during downstream transmissions, and shall not be computed in the downstream direction during the upstream transmissions.

NOTE – With the requirements above, *SNR* is not computed during transmission of quiet or idle symbols.

The near-end MME shall send the *SNR* to the far-end MME on request during showtime L0 link state (see clause 11.2.2.6.2).

The MTU shall measure the signal-to-noise ratio *SNR* during the initialization while receiving O/R-P-MEDLEY signals and shall measure the *SNR* during showtime. For L0 link state, the measurement shall be made over at least 256 symbol periods and shall take at most one second. The MTU shall indicate the number of symbol periods used for the measurement (coded as a 16-bit unsigned integer) to the far-end ME.

The only valid value of subcarrier group size, *G*, for *SNR* is *G* = 1.

The signal-to-noise ratio $SNR(k \times G \times f_{SC})$ shall be the average of the base 10 logarithmic value of the signal-to-noise ratio on the subcarriers $k \times G$ to $((k+1) \times G) - 1$. It shall be coded as an 8-bit unsigned integer *snr*(*k*), where $k = 0$ to (index of the highest supported data bearing subcarrier + 1)/*G* – 1. The value of $SNR(k \times G \times f_{SC})$ shall be defined as

$$SNR(k \times G \times f_{SC}) = -32 + (snr(k)/2) \text{ dB}.$$

This data format supports an $SNR(k \times G \times f_{SC})$ granularity of 0.5 dB and an $SNR(k \times G \times f_{SC})$ range from 0 to 95 dB, corresponding to the set of valid values of *snr* = 64 to 254.

A special value *snr* = 63 indicates a value of *SNR* = –0.5 dB or lower.

A special value *snr* = 255 indicates a value of *SNR* = 95.5 dB or higher.

A special value *snr* = 0 indicates that the parameter is undetermined.

A special value *snr* = 1 indicates that no measurement could be done for this subcarrier group because it is out of the transmitter MEDLEY set or its $g_i = 0$.

To be consistent with Recommendation [ITU-T G.997.3], the defined special values shall be represented in the following way:

- The special value *snr* = 63 shall be represented as valid value 63;
- The special value *snr* = 255 shall be represented as valid value 254;
- The special value *snr* = 0 shall be represented as special value 255;
- The special value *snr* = 1 shall be represented as special value 255.

11.4.1.2.3 Quiet line noise PSD per subcarrier group (*QLN*)

The quiet line noise PSD *QLN*(*f*) for a particular subcarrier group is the rms level of the noise expressed in dBm/Hz present on the loop when no G.fast signals are transmitted on this transmission line and no G.fast signals are transmitted on any other transmission line in the vector group that this transmission line belongs to. This means that *QLN*(*f*) is measured only when all transmission lines of a vectored group are either transmitting quiet symbols or are turned off. *QLN*(*f*) is measured during sync symbol positions, when sync symbols that have all subcarriers masked are transmitted on this transmission line and on all other transmission lines in the vector group that this transmission line belongs to. Sync symbols that have all subcarriers masked correspond to elements in the probe sequence with value 0 as defined in clause 10.2.2.1.

The *QLN*(*f*) per subcarrier group shall be measured by the VCE during showtime L0 link state only, and shall be updated during showtime L0 link state only, on request of the ME-O in response to an update test parameters request (see clause 7.1.9.1 of [ITU-T G.997.3]).

The objective is to provide means by which the quiet line noise PSD at the U-O reference point (referred to as upstream *QLN*) and at the U-R reference point (referred to as downstream *QLN*) can be accurately identified. Upstream *QLN* is referred to the U-O reference point and downstream *QLN* is referred to the U-R reference point by removing the effects of the corresponding receiver filter characteristics function, assuming the receiving MTU presents a load impedance to the network of is resistive and equal to the termination impedance of the the metallic wire, see [ITU-T G.9710] Annex P and Annex Q (see Note).

NOTE – In actual implementations, the receiving MTU load impedance may deviate from the termination impedance defined in [ITU-T G.9710] Annex P and Annex Q.

For downstream *QLN*, the MTU-R reported DFT output samples as specified in clause 10.3.3.2 can be used (DFT samples are referenced to a termination impedance (i.e., load impedance of the MTU transmitter to the network) definied in [ITU-T G.9710] Annex P and Annex Q).

For upstream *QLN*, the MTU-O's internal measurements are used.

The VCE shall average the measurements over *Navg* of at least = 256 symbols (consecutive or non-consecutive), and shall indicate the measurement value of *Navg*, coded as a 16-bit unsigned integer.

The reported *QLN* values shall be represented by subcarrier groups. The number of subcarriers, *G*, in one subcarrier group shall be equal to:

$$G \leq \max(2^{\text{ceiling}(\log_2((\Theta+1)/512))}, 1)$$

where Θ is the highest subcarrier index of the MEDLEY set (either MEDLEYGds set or MEDLEYGus set), and 512 is the maximum number of subcarrier groups. Valid values of *G* are 1, 2, 4 and 8.

For the given group size G, $QLN(k \times G \times f_{SC})$ shall be the average of the linear power values of quiet line noise on the subcarriers with indices from $k \times G$ to $((k+1) \times G) - 1$. *QLN* shall be expressed in dBm/Hz. It shall be coded as an 8-bit unsigned integer n(k), where the valid values of k are from $k = 0$ to ceiling(Θ/G). The value of *n(k)* shall be coded so that:

$$QLN(k \times G \times f_{SC}) = -35 - (n(k)/2) \text{ dBm/Hz}.$$

This format supports a *QLN*(*f*) granularity of 0.5 dB with a range of values for *QLN*(*f*) from −35.5 dBm/Hz to −160.0 dBm/Hz , corresponding to the set of valid values of n = 1 to 250.

A special value n = 0 indicates a value of *QLN* = –35 dBm/Hz or higher

A special value n = 251 indicates a value of *QLN* = –160.5 dBm/Hz or lower. A special value n = 254 indicates that no measurement could be done for this subcarrier group because none of its subcarriers is in the MEDLEY set with $g_i > 0$.

A special value n = 255 indicates that the parameter is undetermined.

All other values are reserved by ITU-T.

11.4.1.2.4 Active line noise PSD per subcarrier group (*ALN*)

The active line noise PSD *ALN*(*f*) for a particular subcarrier group is the rms level of the total noise measured by the receiver at the constellation de-mapper referred to the U reference point. This total noise includes the extrinsic noise present on the loop, all MTU receiver internal noises, and residual crosstalk. The level shall be expressed in dBm/Hz. It is defined for downstream only.

In referring back to the U-R reference point, the objective is that the receive PMD function accounts for the receiver transfer function between the U-R reference point and the constellation de-mapper. The MTU-R shall take into account the gain it has applied to the received signal and do a best effort attempt to remove the impact of the near-end receiver filter characteristics to achieve an accurate estimate of *ALN*(*f*), assuming the receiving MTU presents a load impedance to the network of is resistive and equal to termination impedance [ITU-T G.9710] Annex P and Annex Q (see Note 1).

NOTE 1 – In actual implementations, the receiving MTU load impedance may deviate from the termination impedance defined in [ITU-T G.9710] Annex P and Annex Q.

NOTE 2 – The *ALN* is equivalent to the noise component used in calculation of the SNR test parameter referred back to the U-reference point.

NOTE 3 – If FEXT cancellation is disabled on the transmission line under test, the *ALN* includes the full crosstalk level from all the other transmission lines into the transmission line under test.

NOTE 4 – *ALN* for upstream is not defined because of the presence of the post-canceller in the upstream receiver. A post-canceller combines signals conveyed across multiple U-reference points.

The active line noise PSD *ALN*(*f*) per subcarrier group shall be measured by the MTU-R during showtime L0 link state only, and shall be updated during showtime L0 link state only on request in response to an update test parameters request (see clause 7.1.9.1 of [ITU-T G.997.3]). The MTU-R MME shall send the *ALN* to the MTU-O MME via eoc on request (see clause 11.2.2.6.2).

The *ALN* shall be measured only at time periods during reception of downstream RMC symbols or downstream data symbols in the NOI_{PSF} at the symbol positions specified in the downstream by the *MNDSNOIds* value and in the upstream by the *MNDSNOIus* value.

NOTE 5 – *ALN*(*f*) is measured on a transmission line that is in the L0 link state, whilst the transmission line state of other transmission lines served by the same DPU may stay in whatever line state they are in. Therefore, the *ALN* measurement results may be affected by the line state of the other transmission lines, e.g., the measured *ALN* could be lower due to the transmission of decimated RMC symbols in low power link states.

The MTU-R shall average the measurements over *Navg* of at least 256 symbols (consecutive or non-consecutive) and shall take at most 1 second. The MTU-R shall indicate the number of symbol periods used for the measurement (coded as a 16-bit unsigned integer) together with the *ALN* update.

The *ALN* shall be represented by subcarrier groups. The number of subcarriers, *G*, in one subcarrier group shall be equal to:

$$G \leq \max(2^{\text{ceiling}(\log_2((\Theta ds+1)/512)}, 1)$$

where Θds is the highest subcarrier index of the MEDLEYGds set, and 512 is the maximum number of subcarrier groups. Valid values of *G* are 1, 2, 4 and 8. The MTU shall indicate the group size G used for the measurement (coded as an 8-bit unsigned integer) together with the *ALN* update.

The active line noise PSD $ALN(k \times G \times f_{SC})$ shall be the average of the linear power values of active line noise on the subcarriers $k \times G$ to $((k+1) \times G) - 1$, where f_{SC} is the subcarrier spacing in Hz defined in clause 10.4.2. *ALN* shall be expressed in dBm/Hz. It shall be coded as an 8-bit unsigned integer n(*k*), where $k = 0$ to ceiling$(\Theta ds/G)$. The value of $ALN(k \times G \times f_{SC})$ shall be coded as:

$$ALN(k \times G \times f_{SC}) = -35 - (n(k)/2) \text{ dBm/Hz.}$$

This data format supports an *ALN*(*f*) granularity of 0.5 dB with a range of values for *ALN*(*f*) from −35.5 to −160 dBm/Hz , corresponding to the set of valid values of $n = 1$ to 250.

A special value $n = 0$ indicates a value of *ALN* = –35 dBm/Hz or higher.

A special value $n = 251$ indicates a value of *ALN* = –160.5 dBm/Hz or lower. A special value $n = 254$ indicates that no measurement could be done for this subcarrier group because none of its subcarriers is in the transmitter MEDLEY set with $g_i > 0$.

A special value $n = 255$ indicates that the parameter is undetermined.

All other values are reserved by ITU-T.

11.4.1.2.5 Actual transmit PSD reference per subcarrier (*ACTPSDREF*)

In the downstream direction, the actual transmit PSD reference *ACTPSDREF* for a particular subcarrier shall report the V2PSD (in dBm/Hz). The V2PSD values shall not deviate from the actual PSD during O-P-VECTOR2, as calculated into the termination impedance (see clause 7.3 of [ITU-T G.9710]) at the U-O reference point, by more than 1 dB.

NOTE 1 – The reporting of the *ACTPSDREFpsds* allows a VCE to calculate an actual PSD in NOI_{PSF} at the U-O reference point that includes power from the precoder signals, reported in the DPU-MIB as ACTPSDpsds.

NOTE 2 – V2PSD is not communicated in an initialization message.

In the upstream direction, the actual transmit PSD reference *ACTPSDREF* for a particular subcarrier shall report interpolated values (in dBm/Hz) obtained from MREFPSDus as reported by the MTU-R in R-PRM message. The MREFPSDus values shall not deviate from the actual PSD in NOI_{PSF} during channel analysis and exchange phase, as calculated into the termination impedance (see clause 7.3 of [ITU-T G.9710]) at the U-R reference point, by more than 1 dB.

NOTE 3 – The reporting of the *ACTPSDREFpsus* allows a VCE to calculate an actual PSD in NOI_{PSF} at the U-R reference point that includes the upstream gain adjustments g_i, reported in the DPU-MIB as ACTPSDpsus.

Spectrum shaping caused by time-domain filters and analogue filters included in the transmission path between the output of the modulator and U reference point, shall be taken into consideration.

The *ACTPSDREF* per subcarrier shall be calculated during the initialization.

The valid range of values is from –65 to –100 dBm/Hz in steps of 0.1 dBm/Hz.

A special value shall indicate that the subcarrier is not transmitted.

NOTE 4 – Examples of subcarriers that are not transmitted are subcarriers in RFI bands or IAR bands, subcarriers outside of LPM and subcarriers outside the MEDLEY set.

11.4.1.2.6 Actual aggregate transmit power (*ACTATP*)

The actual aggregate transmit power (*ACTATP*) is the maximum over NOI and DOI in the PSF sub-frame, including DTFO Band 0 and Band 1, of the total amount of output power delivered by the transmit PMD function at the U reference point at tip-and-ring (in dBm into a termination impedance, see [ITU-T G.9710] Annex P and Annex Q), at the instant of measurement, assuming a continuous transmission (either completely in the NOI or completely in the DOI) of data_data symbols over the whole PDX frame duration (100% duty cycle) by all active transmission lines of the vectored group.

NOTE – *ACTATP* includes the direct signal as well as the precoder compensation signals.

At the DPU side, the near-end *ACTATP* shall be calculated during the initialization. It may be updated autonomously and shall be updated on request during the showtime L0 link state (see clause 11.2.2.6.2). The near-end *ACTATP* value may be computed by the VCE.

At the NT side, the near-end *ACTATP* shall be calculated by the MTU-R during initialization using the assigned values of g_i. It may be updated autonomously and shall be updated on request during showtime L0 link state (see clause 11.2.2.6.2). The near-end *ACTATP* shall be sent on request to the ME-O during showtime.

The actual aggregate transmit power shall be coded as a 10-bit two's complement signed integer *actatp*, with the value of *ACTATP* defined as

$$ACTATP = actatp/10 \text{ dBm}.$$

This data format supports an *ACTATP* granularity of 0.1 dB, with an *ACTATP* range from −31.0 to + 31.0 dBm, corresponding to the set of valid values of *actatp* = –310 to 310.

A special value *actatp* = –311 indicates a value of *ACTATP* = –31.1 dBm or lower.

A special value *actatp* = 311 indicates a value of *ACTATP* = 31.1 dBm or higher.

A special value *actatp* = –512 indicates that the parameter is undetermined.

All other values for *actatp* are reserved by ITU-T.

11.4.1.2.7 Signal attenuation (*SATN*)

11.4.1.2.7.1 Downstream signal attenuation ($SATN_{ds}$)

The downstream signal attenuation is denoted as $SATN_{ds}$. SATN is defined as the difference in dB between the total power of the direct signal transmitted by the MTU-O, and the total power of the signal received by the MTU-R. These signals are referred to the U-O and U-R reference points, respectively. *SATN* shall be computed so as to remove the power of the crosstalk compensating precoder signals downstream.

The $SATN_{ds}$, shall be computed by the VCE using the following reference formula:

$SATN_{ds}$ = Direct_TXpower_dBm_DS – RXpower_dBm_DS

The MTU-R shall measure and report the received signal total power defined as:

$$\text{RXpower\_dBm\_DS} = 10 \times \log_{10}\left(\sum_{i \in \{MEDLEYds,\, gi \neq 0\}} \left(\text{Received\_subcarrier\_power\_mW\_DS}(i) \right) \right)$$

where {*MEDLEYds, gi≠0*} denotes all subcarriers of the MEDLEYds set that have gi≠0, and Received_subcarrier_power_mW_DS(*i*) is the received signal total power at the U-R reference point on subcarrier *i* expressed in milliWatts, assuming the receiving MTU presents a load impedance to the network of is resistive and equal to termination impedance [ITU-T G.9710]

Annex P and Annex Q (see Note 1).

NOTE 1 – In actual implementations, the receiving MTU load impedance may deviate from the termination impedance defined in [ITU-T G.9710] Annex P and Annex Q.

The MTU-R shall average the received signal total power over at least 256 symbols (consecutive or non-consecutive). The received signal total power shall only be measured in time periods during reception of RMC symbols or data symbols in the NOI_{PSF} in DTFO Band 0 at the symbol positions specified by the *MNDSNOIds* value.

The VCE, in cooperation with the MTU-O, shall refer the Direct_TXpower_dBm_DS to the U-O reference point, assuming the network input impedance is resistive and equal to the termination impedance of the the metallic wire, see [ITU-T G.9710] Annex P and Annex Q (see Note 2).

NOTE 2 – In actual deployments, the network/loop input impedance may deviate from the termination impedance defined in [ITU-T G.9710] Annex P and Annex Q.

Direct_TXPower_dBm_DS shall be computed as:

$$\text{Direct\_TX\_power\_dBm\_DS} = 10 \times \log_{10}\left(\sum_{i \in \{MEDLEYds, gi \neq 0\}} \text{f}_{SC} \times 10^{(MREFPSD_i/10)} \left(\frac{Pdirect\_Z_i'}{Ptotal\_Z_i'} \right) \right)$$

Where f_{SC} is the subcarrier spacing in Hz defined in clause 10.4.2, $MREFPSD_i$ is the value of MREFPSD in dBm/Hz, $Pdirect\_Z_i'$ is the power of the direct signal at the output of the precoder in milliWatts, and $Ptotal\_Z_i'$ is the power of the full signal (direct signal + crosstalk pre-compensation signals) at the output of the precoder in milliWatts; for subcarrier *i*. The Direct_TX_power_dBm_DS shall be computed only during RMC symbols or data symbols in the NOI_{PSF} in DTFO Band 0 at the symbol positions specified by the MNDSNOIds value.

NOTE 3 – With the requirements above, the received signal total power is not measured during reception of sync, quiet, idle and data symbols in DOI. For $SATN_{ds}$ the transmitted signal power in dBm, TXpower_dBm_DS, is calculated by the VCE for the direct signal only, after scaling to remove any change in power caused by the precoder, and by the transmit filtering.

The $SATN_{ds}$ shall be updated during showtime, during L0 link state only, on request of the ME-O in response to an update request for near-end test parameters (see clause 7.1.9.1 of [ITU-T G.997.3]). The MTU-R, accordingly, shall send on request the updates of the RXpower_dBm_DS via eoc (see clause 11.2.2.13). The RXpower_dBm_DS shall be calculated during L0 link state only.

The received signal total power RXpower_dBm_DS, shall be coded as a 10-bit unsigned integer *p*. The value of RXpower_dBm_DS shall be coded as:

RXpower_dBm_DS = 20 – (*p*/10) dBm.

This data format supports an RXpower_dBm_DS granularity of 0.1 dB. The set of valid values ranges from +8 dBm to −80 dBm, corresponding to the set of valid values of *p* =120 to 1000.

A special value *p* = 119 indicates a value of *RXpower_dBm_DS* = 8.0 dBm or higher.

A special value *p* = 1001 indicates a value of *RXpower_dBm_DS* = –80.1 dBm or lower.

A special value *p* = 1023 indicates that the parameter is undetermined.

All other values for p are reserved by ITU-T.

Towards the DPU-MIB, the signal attenuation, $SATN_{ds}$, shall be coded as a 10-bit unsigned integer $satn_{ds}$, with the value of $satn_{ds}$ coded as:

$$SATN_{ds} = satn_{ds}/10 \text{ (dB)}$$

This data format supports a $SATN_{ds}$ granularity of 0.1 dB and a $SATN_{ds}$ range from 0.1 dB to 100.0 dB, corresponding to the set of valid values of $satn_{ds}$ = 1 to 1000.

A special value $satn_{ds}$ = 0 indicates a value of $SATN_{ds}$ = 0 dB or lower.

A special value $satn_{ds}$ = 1001 indicates a value of $SATN_{ds}$ = 100.1 dB or higher.

A special value $satn_{ds}$ = 1023 indicates that the parameter is undetermined. All other values for $satn_{ds}$ are reserved by ITU-T.

Test parameter $SATN_{ds}$ is reported in the DPU-MIB as SATNds.

11.4.1.2.7.2 Upstream signal attenuation ($SATN_{us}$)

The upstream signal attenuation, $SATN_{us}$, shall be computed by the VCE using the following reference formula:

$$SATN_{us} = \text{TXpower\_dBm\_US} - \text{Direct\_RXpower\_dBm\_US}$$

For upstream, the transmitted signal power in dBm, TXpower_dBm_US, is the value of the amount of output power, measured over only DTFO Band 0 in NOI of the PSF sub-frame, delivered in upstream by the MTU-R transmit PMD function at the U reference point at tip-and-ring (in dBm into a termination impedance, see [ITU-T G.9710] Annex P and Annex Q), at the instant of measurement, assuming a continuous transmission in NOI_{PSF} of data symbols over the whole PDX frame duration (100% duty cycle). (see Note 1 and Note 2).

NOTE 1 – The *ACTATPus* (see clause 11.4.1.2.6) reported by the MTU-R is defined on is the termination impedance of the the metallic wire, see [ITU-T G.9710] Annex P and Annex Q. Remark that in this case termination impedance is to be interpreted as the network/loop input impedance. In actual deployments, the network/loop input impedance may deviate from the termination impedance defined in [ITU-T G.9710] Annex P and Annex Q.

NOTE 2 – The TXpower_dBm_US is a version of *ACTATPus* but measured only in NOI_{PSF} and only in DTFO Band 0.

The MTU-O measures the power of the received subcarriers after post-cancellation and then sums over those subcarriers with $g_i>0$ that are in the MEDLEYus set to estimate the direct received power.

The MTU-O first computes the power of each direct received subcarrier signal by averaging the power of the direct received signal on subcarrier *i* of the post-canceller output samples as follows:

$$\text{Direct\_Received\_subcarrier\_power\_mW\_US(i)} = \frac{1}{Navg}\sum_{k=1}^{Navg}\left|G_k(i)\right|^2$$

where *Navg* is the number of post-canceller output samples that are used to estimate the average power and $G_k(i)$ is the result of taking the output sample of the post-canceller and removing the impact of the receive filter and dividing by the magnitude of the post-canceller matrix diagonal element.

The computed powers for each subcarrier are then summed over all subcarriers to determine the direct received signal power as:

$$\text{Direct\_RXpower\_dBm\_US} = 10 \times \log_{10}\left(\sum_{i \in \{MEDLEYus, gi>0\}} \left(\text{Direct\_Received\_subcarrier\_power\_mW\_US}(i)\right)\right)$$

The MTU-O and VCE shall refer Direct_RXpower_dBm_US back to the U-O reference point, assuming the receiving MTU presents a load impedance to the network of is resistive and equal to the termination impedance of the the metallic wire, see [ITU-T G.9710] Annex P and Annex Q (see Note 2).

NOTE 3 – In actual implementations, the receiving MTU load impedance may deviate from the termination impedance defined in [ITU-T G.9710] Annex P and Annex Q.

For $SATN_{us}$, the MTU-O's internal measurements are used.

The MTU-O shall average the received total power over at least 256 symbols (consecutive or non-consecutive). The received total power shall only be measured in time periods during reception of RMC symbols or data symbols in the NOI_{PSF} in DTFO Band 0 at the symbol positions specified by the *MNDSNOI* value.

The $SATN_{us}$ shall be calculated by the MTU-O during showtime, and shall be updated during showtime, on request of the ME-O in response to an update request for near-end test parameters (see clause 7.1.9.1 of [ITU-T G.997.3]).

The MTU-R shall send on request the updates of the TXpower_dBm_US via eoc (see clause 11.2.2.13). The TXpower_dBm_US shall be calculated during L0 link state only.

The transmit signal power TXpower_dBm_US, shall be coded as a 10-bit unsigned integer *p*. The value of TXpower_dBm_US shall be coded as:

TXpower_dBm_US = 20 – (*p*/10) dBm.

This data format supports a TXpower_dBm_US granularity of 0.1 dB. The set of valid values ranges from +8 dBm to −80 dBm, corresponding to the set of valid values of *p* =120 to 1000.

A special value *p* = 119 indicates a value of *TXpower_dBm_US* = 8.0 dBm or higher.

A special value *p* = 1001 indicates a value of *TXpower_dBm_US* = –80.1 dBm or lower.

A special value *p* = 1023 indicates that the parameter is undetermined.

All other values for p are reserved by ITU-T.

The signal attenuation, $SATN_{us}$, shall be coded as a 10-bit unsigned integer $satn_{us}$, with the value of $satn_{us}$ coded as:

$$SATN_{us} = satn_{us}/10 \text{ (dB)}.$$

This data format supports a $SATN_{us}$ granularity of 0.1 dB and an $SATN_{us}$ range from 0.1 dB to 100.0 dB, corresponding to the set of valid values of $satn_{us}$ = 1 to 1000.

A special value $satn_{us}$ = 0 indicates a value of $SATN_{us}$ = 0 dB or lower.

A special value $satn_{us}$ = 1001 indicates a value of $SATN_{us}$ = 100.1 dB or higher.

A special value $satn_{us}$ = 1023 indicates that the parameter is undetermined. All other values for $satn_{us}$ are reserved by ITU-T.

Test parameter $SATN_{us}$ is reported in the DPU-MIB as SATNus.

11.4.1.2.8 Actual transmit PSD per subcarrier (*ACTPSD*)

The test parameter *ACTPSDps* is the maximum of the actual transmit PSD over the NOI and DOI in the PSF sub-frame, including DTFO Band 0 and Band 1, for a particular subcarrier at the U reference point, as calculated into the termination impedance (see clause 7.3 of [ITU-T G.9710]).

NOTE – *ACTPSDpsds* includes the direct signal as well as the precoder compensation signals.

The test parameter *ACTPSDps* values are computed by the VCE, and reporting is according to the description in this clause. The exact method used by the VCE to calculate the values of *ACTPSDps* is vendor discretionary.

The *ACTPSDps* is updated on request during showtime L0 link state.

The *ACTPSDps* value is reported as ACTPSDps in the DPU-MIB.

The downstream and upstream values are reported in the DPU-MIB.

Each reported *ACTPSDps* value shall be represented by an integer number *p*. The values of *p* shall be coded as 8-bit unsigned integers so that:

$$ACTPSDps = -(p/2) \text{ dBm/Hz}$$

This format supports an *ACTPSDps* granularity of 0.5 dB with a valid range from −0.5 to −125.5 dBm/Hz, corresponding to the set of valid values of p=1 to 251.

A special value p = 0 indicates a value of *ACTPSD*= 0 dBm/Hz or higher.

A special value p = 252 indicates a value of *ACTPSD*= −126.0 dBm/Hz or lower.

A special value p = 253 is reserved by ITU-T.

A special value p = 254 indicates that the subcarrier is not transmitted.

A special value p = 255 indicates that the parameter is undetermined.

11.4.1.2.9 FEXT downstream coupling coefficients (*Xlogpsds*)

11.4.1.2.9.1 Definition

11.4.1.2.9.1.1 FEXT coupling coefficient from line L_2 into line L_1

The downstream FEXT coupling coefficient from line L_2 into line L_1 over the frequency f is defined as the ratio of the FEXT insertion gain transfer function from line L_2 into line L_1 to the direct channel insertion gain transfer function of line L_1 as follows:

$$Xlogds_{12}(f) = 20 \times \log_{10}\left(\left|\frac{FEXT\_IG\_DS_{12}(f)}{IG\_DS_{11}(f)}\right|\right)$$

where:

$FEXT\_IG\_DS_{12}(f)$	is the FEXT insertion gain transfer function from line L_2 into line L_1 in the downstream direction over frequency f, and
$IG\_DS_{11}(f)$	is the direct channel insertion gain transfer function of line L_1 in the downstream direction over frequency f

11.4.1.2.9.1.2 Direct channel insertion gain transfer function of line L_1

The direct channel insertion gain transfer function of line L_1 in the downstream direction over frequency f is defined as:

$$IG\_DS_{11}(f) = \frac{V_{RX1}^{L11}(f)}{V_{RX1}^{N11}(f)}$$

where:

$V_{RX1}^{N11}(f)$	is the voltage as a function of frequency across the load impedance R_{L1} in the absence of the wireline channel as shown in Figure 11-9 for the downstream direction
$V_{RX1}^{L11}(f)$	is the voltage as a function of frequency across the load impedance R_{L1} in the presence of the wireline channel L1 and L2 as shown in Figure 11-10 for the downstream direction.

R_{S1} and R_{S2} are reference impedances, corresponding to the source impedances. R_{L1} and R_{L2} are reference impedances, corresponding to the load impedances.

For determining the reference value IG_DS_{11}, all reference impedances (R_{S1}, R_{S2}, R_{L1} and R_{L2}) shall be esistive and equal to the termination impedance of the the metallic wire, see [ITU-T G.9710]

Annex P and Annex Q. In case the cable consists of more pairs than those used for lines 1 and 2, all other pairs shall also be terminated by that termination impedance at both ends.

NOTE 1 – Terminating the other pairs is intended for avoid reflections that will further lead to wrong measurement of the reference value for the direct channel insertion gain transfer function due to crosstalk coupling.

NOTE 2 – The values of R_{S1}, R_{S2}, R_{L1} and R_{L2} used for the definition of the reference value do not imply specific values for MTU implementations connected to lines 1 and 2 and to the other lines in the binder.

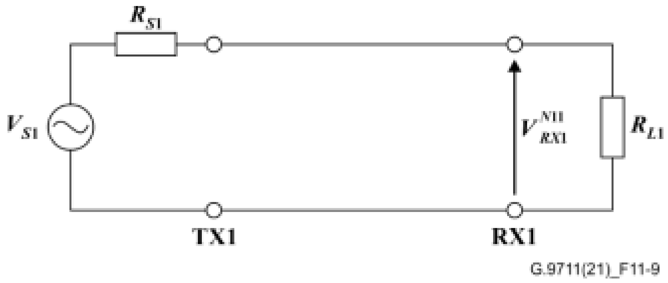


Figure 11-9 – Voltage across the load without access cabling

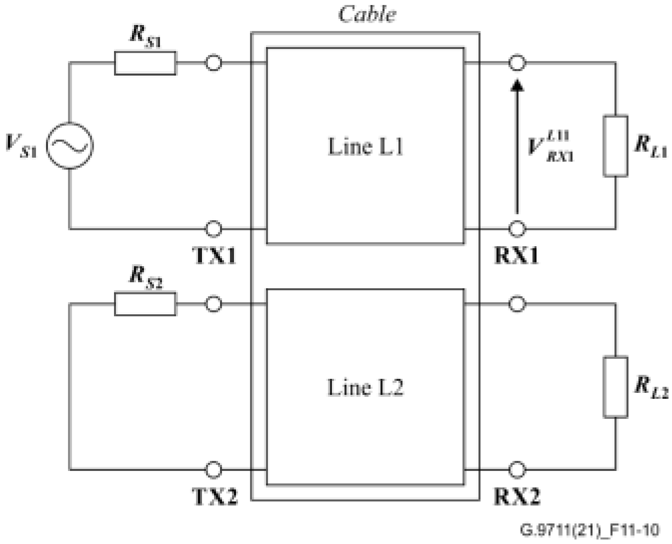


Figure 11-10 – Voltage across the load with access cabling inserted

11.4.1.2.9.1.3 FEXT insertion gain transfer function from line L_2 into line L_1

The FEXT insertion gain transfer function from line L_2 into line L_1 in the downstream direction over frequency *f*, is defined as

$$FEXT\_IG\_DS_{12}(f) = \frac{V_{RX1}^{L12}(f)}{V_{RX1}^{N12}(f)}$$

where:

– $V_{RX1}^{N12}(f)$ is the voltage as a function of frequency across the load impedance R_{L1} in the absence of the wireline channel as shown in Figure 11-11 for the downstream direction

– $V_{RX1}^{L12}(f)$ is the voltage as a function of frequency across the load impedance R_{L1} in the presence of the wireline channel L1 and L2 as shown in Figure 11-12 for the downstream direction.

R_{S1} and R_{S2} are reference impedances, corresponding to the source impedances. R_{L1} and R_{L2} are reference impedances, corresponding to the load impedances.

For determining the reference value $FEXT\_IG\_DS_{12}$, all reference impedances (R_{S1}, R_{S2}, R_{L1} and R_{L2}) shall be resistive and equal to the termination impedance of the the metallic wire, see [ITU-T G.9710] Annex P and Annex Q. In case the cable consists of more pairs than those used for lines 1 and 2, all other pairs shall also be terminated by that termination impedance at both ends.

NOTE 1 – Terminating the other pairs is intended for avoid reflections that will further lead to wrong measurement of the reference value for the FEXT insertion gain transfer function due to crosstalk coupling.

NOTE 2 – The values of R_{S1}, R_{S2}, R_{L1} and R_{L2} used for the definition of the reference value do not imply specific values for MTU implementations connected to lines 1 and 2 and to the other lines in the binder.

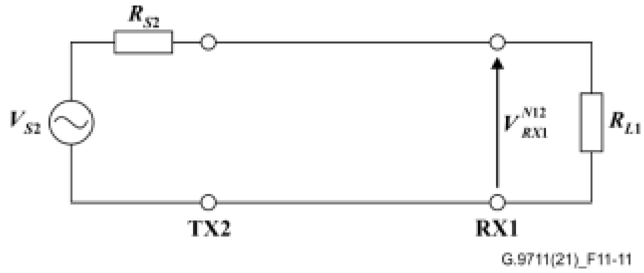


Figure 11-11 – Voltage across the load without access cabling

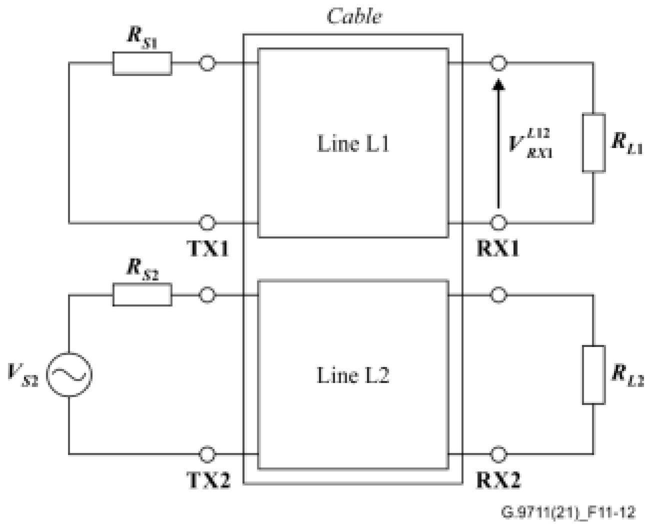


Figure 11-12 – Voltage across the load with access cabling inserted

11.4.1.2.9.2 Reporting of *Xlogpsds*

Xlogpsds values are computed by the VCE, and reporting shall be according to the description in this clause. The exact method used by the VCE to estimate the values of *Xlogpsds* is vendor discretionary.

The downstream FEXT coupling coefficients $Xlogds_{i,k}$ ($n \times \Delta f$) for current line i, shall be reported to the management entity upon request at least for all lines k in the vectored group and subcarrier indices n for which FEXT from line k into line i is estimated or cancelled in the downstream direction with the subcarrier index n specified by:

$$n \in \bigcup_{bands} \{start\_subcarrier\_index + m \times XLOGGds : m = 0 \ldots floor((stop\_subcarrier\_index - start\_subcarrier\_index) / XLOGGds)\}$$

In this description,

– disturber line k is identified by its VCE_port_index (see clause 11.4.6.1.2) within the same vectored group as the current line i,

– each frequency band shall be represented by a pair of (start_subcarrier_index, stop_subcarrier_index),

NOTE 1 – The start_subcarrier_index and stop_subcarrier_index may not coincide with the edges of the bands in which FEXT is estimated or cancelled. The reported start_subcarrier_index corresponds with the first reported subcarrier for the band. The reported stop_subcarrier_index corresponds with the last reported subcarrier for the band.

– for each frequency band *XLOGGds* is the subcarrier group size used.

The reported parameter XLOGDISTds shall represent the VCE_port_index (see clause 11.4.6.1.2) of the disturber line *k* to which the reported *Xlogpsds* values apply. A special value ZERO shall indicate that the requested VCE_port_index (*XTALKDREQ* value, see clause 11.4.3.3) is invalid.

The reported parameter *XLOGBANDSds* shall represent an array of triplets (start_subcarrier_index, stop_subcarrier_index, group size) in increasing frequency order. The reported bands shall not intersect. The values of *XLOGBANDSds* are vendor discretionary.

XLOGGds is restricted to powers of two, and shall be the smallest supported value that is equal to or greater than the *XLOGGREQds* value (see clause 11.4.3.2). Valid values for *XLOGGds* are 1, 2, 4, 8, 16, 32 and 64. Mandatory values for *XLOGGds* are 8, 16, 32 and 64.

NOTE 2 – The value of XLOGGds may be different from *F_sub* (see clause 10.3.2.3.1).

The total number of subcarriers being reported over all frequency bands shall be restricted to a maximum of 512.

Each reported *Xlogpsds* value shall be represented by an integer number *p*. The values of *p* shall be coded as 8-bit unsigned integers so that:

$$Xlogpsds = 40 - (p/2)$$

This format supports an *Xlogpsds*(*f*) granularity of 0.5 dB with a valid range from +39.5 dB to −85 dB, corresponding to the set of valid values of p = 1 to 250.

A special value *p* = 0 indicates a value of *Xlogpsds* = 40 dB or higher

A special value *p* = 251 indicates a value of *Xlogpsds* = −85.5 dB or lower.

Special values *p* = 252 and 253 are reserved by ITU-T.

A special value *p* = 254 indicates that no measurement could be done from line k into line *i* for subcarrier *n*.

A special value *p* = 255 indicates that the parameter is undetermined.

Accuracy requirements are for further study.

11.4.1.2.10 Average NEXT coupling (*ANEXT*)

11.4.1.2.10.1 Definition of NEXT insertion gain transfer function from line L2 into line L1

The NEXT insertion gain transfer function from line L2 into line L1 over frequency *f*, is defined as:

$$NEXT\_IG_{12}(f) = \frac{V_{RX1}^{S12}(f)}{V_{RX1}^{N12}(f)}$$

where:

– $V_{RX1}^{N12}(f)$ is the voltage as a function of frequency across the load impedance R_{L1} in the absence of the wireline channel as shown in Figure 11-13.

– $V_{RX1}^{S12}(f)$ is the voltage as a function of frequency across the load impedance R_{L1} in the presence of the wireline channel L1 and L2 as shown in Figure 11-14.

Also, $V_{S2}(f)$ is the source voltage. $V_{RX1}^{N12}(f)$, $V_{RX1}^{S12}(f)$ and $V_{S2}(f)$ are all at same end of the cable containing the lines.

R_{S1} and R_{S2} are reference impedances, corresponding to the source impedances. R_{L1} and R_{L2} are reference impedances, corresponding to the load impedances.

For determining the reference value $NEXT\_IG_{12}(f)$, all reference impedances (R_{S1}, R_{S2}, R_{L1} and R_{L2}) shall be resistive and equal to the termination impedance of the the metallic wire, see [ITU-T G.9710] Annex P and Annex Q. In case the cable consists of more pairs than those used for lines 1 and 2, all other pairs shall also be terminated by that termination impedance at both ends.

NOTE 1 – Terminating the other pairs is intended for avoid reflections that will further lead to wrong measurement of the reference value for the NEXT insertion gain transfer function due to crosstalk coupling.

NOTE 2 – The values of R_{S1}, R_{S2}, R_{L1} and R_{L2} used for the definition of the reference value do not imply specific values for MTU implementations connected to lines 1 and 2 and to the other lines in the binder.

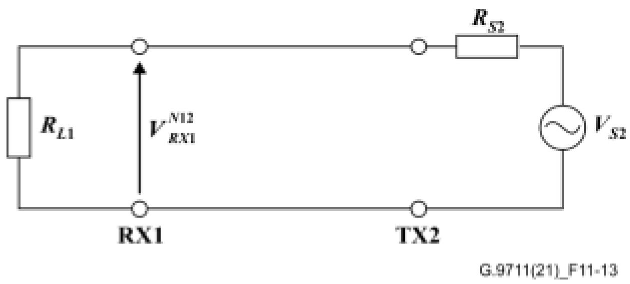


Figure 11-13 – Voltage across the load without access cabling.

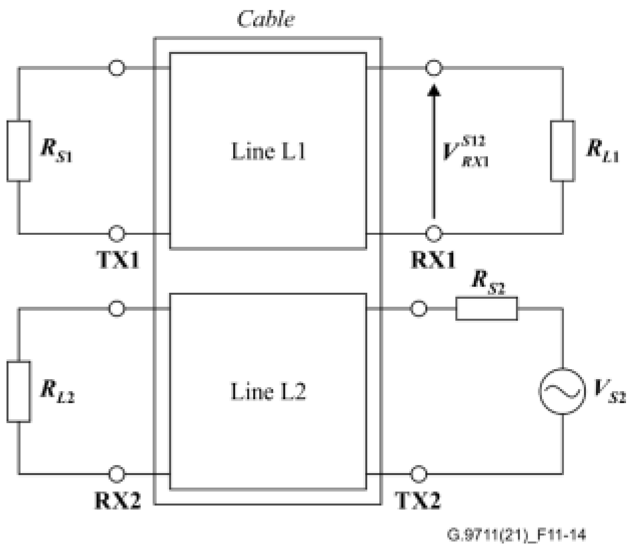


Figure 11-14 – Voltage across the load with access cabling inserted.

11.4.1.2.10.2 Definition of Average NEXT coupling from line L2 into line L1

The NEXT coupling from line L2 into line L1 at frequency *f* is defined as the magnitude of the NEXT insertion gain transfer function in dB:

$$NEXT_{12}(f) = 20 \times \log_{10}\left(\left|NEXT\_IG_{12}(f)\right|\right).$$

The average NEXT coupling **(***ANEXT***)** at the MTU-O end of the line is defined as the average across subcarriers over which the NEXT coupling in dB is calculated at the U-O reference point of another line L2 and the U-O reference point of the current line L1. The *ANEXT* at the MTU-R end of the line is defined as the average across subcarriers over which the NEXT coupling in dB is calculated at the U-R reference point of another line L2 and the U-R reference point of the current line L1.

Define *MEAS_SET_R* for the *ANEXT* at the MTU-R, as the set of subcarriers that are in both the downstream SUPPORTEDCARRIERS set of line L1 and upstream SUPPORTEDCARRIERS set of line L2, are not in either the downstream BLACKOUT set of line L1 or the upstream BLACKOUT set of line L2, are not subcarriers in the downstream PSF with gi(n) = 0 on line L1, and are not subcarriers in the upstream NPSF with gi(n) = 0 on line L2. The gi values in this definition relate to gi values used in the PSF sub-frame during NOI.

Mathematically, if subcarrier with index $n \in MEAS\_SET\_R$, then $n \in \mathrm{SUPPORTEDCARRIERSdsL1} \bigcap \mathrm{SUPPORTEDCARRIERSusL2}$, and $n \notin \mathrm{BLACKOUTdsL1} \bigcup \mathrm{BLACKOUTusL2}$ and

$n \notin \{\mathrm{n} \mid \mathrm{downstream\ gi(n)=0\ L1}\} \cup \{\mathrm{n} \mid \mathrm{upstream\ gi(n)=0\ L2}\}$.

where SUPPORTEDCARRIERSdsL1 is the SUPPORTEDCARRIERSds set of line L1, SUPPORTEDCARRIERSusL2 is the SUPPORTEDCARRIERSus set of line L2, BLACKOUTdsL1 is the downstream BLACKOUT set of line L1, BLACKOUTusL2 is the upstream BLACKOUT set of line L2, {n | downstream gi(n)=0 L1} is the set of subcarriers in the downstream PSF with gi(n) = 0 on line L1, and {n | upstream gi(n)=0 L2} is the set of subcarriers in the upstream NPSF with gi(n) = 0 on line L2.

Define *MEAS_SET_*O for the *ANEXT* at the MTU-O, as the set of subcarriers that are in both the upstream SUPPORTEDCARRIERS set of line L1 and downstream SUPPORTEDCARRIERS set of line L2, and are not in either the upstream BLACKOUT set of line L1 or the downstream BLACKOUT set of line L2, are not subcarriers in the upstream PSF with gi(n) = 0 on line L1, and are not subcarriers in the downstream NPSF with gi(n) = 0 on line L2. The gi values this definition relate to gi values used in the PSF sub-frame during NOI.

Mathematically, if subcarrier with index $n \in MEAS\_SET\_O$, then $n \in \mathrm{SUPPORTEDCARRIERSusL1} \bigcap \mathrm{SUPPORTEDCARRIERSdsL2}$, and $n \notin \mathrm{BLACKOUTusL1} \bigcup \mathrm{BLACKOUTdsL2}$ and

$n \notin \{\mathrm{n} \mid \mathrm{upstream\ gi(n)=0\ L1}\} \cup \{\mathrm{n} \mid \mathrm{downstream\ gi(n)=0\ L2}\}$.

where SUPPORTEDCARRIERSusL1 is the SUPPORTEDCARRIERSus set of line L1, and SUPPORTEDCARRIERSdsL2 is the SUPPORTEDCARRIERSds set of line L2, BLACKOUTusL1 is the upstream BLACKOUT set of line L1, BLACKOUTdsL2 is the downstream BLACKOUT set of line L2, {n | upstream gi(n)=0 L1} is the set of subcarriers in the upstream PSF with gi(n) = 0 on line L1, and {n | downstream gi(n)=0 L2} is the set of subcarriers in the downstream NPSF with gi(n) = 0 on line L2.

ANEXT is calculated using only every 16th subcarrier.

The *ANEXT* shall be calculated using every 16th subcarrier of the intersection of the *MEAS_SET* and the *ANEXTBANDS*, designated as *CALC_SET*. Mathematically this corresponds with subcarriers with the subcarrier index *n* specified by:

$$CALC\_SET = n \in \bigcup_{NEXTbands} \{start\_subcarrier\_index + m \times 16 \mid m = 0 \ldots floor((stop\_subcarrier\_index - start\_subcarrier\_index)/16)\} \cap MEAS\_SET$$

In this description, each of the *ANEXTBANDS* shall be represented by a pair of (start_subcarrier_index, stop_subcarrier_index). The values of *ANEXTBANDS* are vendor discretionary.

NOTE – The start_subcarrier_index and stop_subcarrier_index may not coincide with the edges of the bands in which NEXT is cancelled. The reported start_subcarrier_index corresponds with the first subcarrier in that band used for calculating *ANEXT*. The reported stop_subcarrier_index may be up to 15 higher than the last subcarrier in that band used for calculating *ANEXT*.

ANEXT is averaged in dB

$$ANEXT = \frac{\sum_{n \in \{CALC\_SET\}} NEXT_{12}(n \times f_{SC})}{ANEXT\_N\_CALC\_SET}$$

where *ANEXT_N_CALC_SET* is defined as the number of subcarriers in *CALC_SET*.

11.4.1.2.10.3 Reporting of *ANEXT*

ANEXT values are computed by the VCE, and reporting shall be according to the description in this clause. ANEXT shall be reported from both the MTU_O and the MTU_R ends of the line for all lines that are in FDX mode. The exact method used by the VCE to estimate the values of *ANEXT* is vendor discretionary.

The average NEXT coupling at the MTU **(***ANEXT)* for the current line shall be reported to the management entity upon request for all lines in the vectored group that are in FDX mode. The reported parameter NEXTDIST shall represent the VCE_port_index (see clause 11.4.6.1.2) of the disturber line L2 to which the reported *ANEXT* value applies. A special value ZERO shall indicate that the requested VCE_port_index (*XTALKDREQ* value, see clause 11.4.3.3) is invalid.

The reported parameter *ANEXTBANDSds/us* shall represent an array of triplets (start_subcarrier_index, stop_subcarrier_index, group size) of frequencies used to compute *ANEXT* in increasing frequency order. The only allowed value for group size equals 16. The reported bands shall not intersect. The number of bands shall be between 1 and 8 if NEXTDIST≠0. The array shall be empty if NEXTDIST=0.The parameter *N_CALC_SET* shall also be reported as NCALCSET. Valid values are 0 to 512.

The reported *ANEXT* value shall be represented by an integer number *p*. The values of *p* shall be coded as 8-bit unsigned integers so that:

$$ANEXT = 40 - (p/2)$$

This format supports an *ANEXT* granularity of 0.5 dB with a valid range from +39.5 dB to −85 dB, corresponding to the set of valid values of p = 1 to 250.

A special value *p* = 0 indicates a value of *ANEXT* = 40 dB or higher

A special value *p* = 251 indicates a value of *ANEXT* = −85.5 dB or lower.

Special values *p* = 252 and 253 are reserved by ITU-T.

A special value *p* = 254 indicates that no measurement could be done from the disturber line identified with *XTALKDREQ* into the current line.

A special value *p* = 255 indicates that the parameter is undetermined.

The parameters are updated only in L0 link state.

Accuracy requirements are for further study.

11.4.2 Retransmission control parameters

11.4.2.1 Minimum expected throughput (*ETR_min*)

The *ETR_min* is a control parameter that specifies the minimum allowed value for the expected throughput rate with DTFO disabled ETR_0 (see clause 9.8).

The *ETR_min* is used in the channel-initialization policy (*CIpolicy* – see clause 12.3.7) and in the fast-retrain policy (*FRpolicy* – see clause 12.1.4.2).

The valid values for *ETR_min* range from 0 to $(2^{16}-1) \times 96$ kbit/s, in steps of 96 kbit/s (see Table 9-19).

The control parameter *ETR_min* is derived by the DRA from the DPU-MIB minimum data rate configuration parameters.

11.4.2.2 Maximum net data rate (*NDR_max*)

The *NDR_max* is a control parameter that specifies the maximum allowed value for the net data rate *NDR* (see clause 9.8).

It is used in the channel-initialization policy (*CIpolicy*) and in the online reconfiguration (OLR), FRA and RPA procedures.

The valid values for *NDR_max* range from 0 to $(2^{16}-1) \times 96\,000$ bit/s, in steps of 96 000 bit/s.

The control parameter *NDR_max* is derived by the DRA from the DPU-MIB maximum data rate configuration parameters.

11.4.2.3 Maximum delay (*delay_max*)

The control parameter *delay_max* is derived by the transmitting TPS-TC from the value of MAXDELAY in an MTU vendor discretionary way for internal usage.

The MAXDELAYis a configuration parameter that specifies the maximum allowed delay for retransmission (see clause 9.8).

It is used in the channel-initialization policy (*CIpolicy*) and in the online reconfiguration (OLR) procedures.

The downstream and upstream values of MAXDELAYshall be configured in the DPU-MIB.

The valid MAXDELAYvalues range from 1 to 16 ms in steps of 0.25 ms.

11.4.2.4 Minimum impulse noise protection against SHINE (*INP_min_shine*)

The control parameter *INP_min_shine* shall be set to the same value as the configuration parameter INPMIN_SHINE.

The INPMIN_SHINE is a configuration parameter that specifies the minimum INP against SHINE (see clause 9.8).

It is used in the channel-initialization policy (*CIpolicy*) and in the online reconfiguration (OLR) procedures.

The downstream and upstream values of INPMIN_SHINE shall be configured in the DPU-MIB.

The valid INPMIN_SHINE values range from 0 to 520 symbol periods in steps of one symbol period.

11.4.2.5 *SHINEratio*

The control parameter *SHINEratio* shall be set to the same value as the configuration parameter SHINERATIO.

The SHINERATIO is a configuration parameter that is used in the definition of the expected throughput rate (*ETR*) (see clause 9.8).

It is used in the channel-initialization policy (*CIpolicy*) and in the online reconfiguration (OLR) procedures.

The downstream and upstream values shall be configured in the DPU-MIB.

The valid SHINERATIO values range from 0 to 0.1 in increments of 0.001.

NOTE – Typically, the detailed characteristics of the SHINE impulse noise environment are not known in advance by the operator. Therefore, it is expected that this parameter will be set by the operator using empirical methods.

11.4.2.6 Minimum impulse noise protection against REIN (*INP_min_rein*)

The control parameter *INP_min_rein* shall be set to the same value as the configuration parameter INPMIN_REIN.

The INPMIN_REIN is a configuration parameter that specifies the minimum INP against REIN (see clause 9.8).

It is used in the channel-initialization policy (*CIpolicy*) and in the online reconfiguration (OLR) procedures.

The downstream and upstream values of INPMIN_REIN shall be configured in the DPU-MIB.

The valid INPMIN_REIN values range from 0 to 63 symbol periods in steps of 1 symbol period.

11.4.2.7 REIN Inter-arrival time for retransmission (*iat_rein_flag*)

The control parameter *iat_rein_flag* shall be set to the same value as the configuration parameter IAT_REIN.

The IAT_REIN is a configuration parameter that specifies the REIN inter-arrival time (see clause 9.8).

It is used in the channel-initialization policy (*CIpolicy*) and in the online reconfiguration (OLR) procedures.

The downstream and upstream values of IAT_REIN shall be configured in the DPU-MIB.

The valid IAT_REIN values are 0 (100 Hz), 1 (120 Hz), 2 (300 Hz) and 3 (360 Hz).

11.4.2.8 Minimum R_{FEC}/N_{FEC} ratio (*rnratio_min*)

The control parameter *rnratio_min* shall be set to the same value as the configuration parameter MINRNRATIO.

The MINRNRATIO is a configuration parameter that indicates the minimum required ratio, R_{FEC}/N_{FEC}, of FEC code parameters. The ratio is computed as the number of redundancy bytes (R_{FEC}) divided by the total number of bytes (N_{FEC}) in each FEC codeword.

It is used in the channel-initialization policy (*CIpolicy*) and in the online reconfiguration (OLR) procedures.

The valid MINRNRATIO values are from 0 to 8/32 in steps of 1/32.

11.4.3 Vectoring control parameters

11.4.3.1 FEXT cancellation enable/disable (*FEXT_TO_CANCEL_ENABLE*)

The control parameter *FEXT_TO_CANCEL_ENABLE* shall be set to the same value as the configuration parameter FEXT_TO_CANCEL_ENABLE.

This FEXT_TO_CANCEL_ENABLE is a configuration parameter in the DPU-MIB that enables (if set to ONE) or disables (if set to ZERO) FEXT cancellation from all the other vectored transmission lines into a transmission line in the vectored group. If FEXT cancellation is disabled for a transmission line in a particular direction, no FEXT cancellation shall occur from any other transmission line in the vectored group into that transmission line for the given direction. If FEXT cancellation is disabled for a transmission line in a particular direction, the probe sequence shall still be sent on that transmission line for estimation of the FEXT from that transmission line into other transmission lines.

If downstream FEXT cancellation is disabled on transmission line *n*, then the precoder output for this transmission line shall be equal to the precoder input (i.e., $Z'_n = Z_n$, see Figure 10-1).

This configuration parameter shall be defined independently for the upstream and downstream directions.

11.4.3.2 Downstream requested Xlog subcarrier group size (*XLOGGREQds*)

This parameter represents the lower bound for the value *XLOGGds* in the reporting of *Xlogpsds* (see clause 11.4.1.2.9.2).

Valid values for *XLOGGREQds* are 1, 2, 4, 8, 16, 32 and 64.

This configuration parameter is defined only for the downstream direction.

11.4.3.3 Requested Xlog disturber line (*XTALKDREQ*)

This parameter represents the requested value of the VCE_port_index for the disturber line *k* in the reporting of *Xlogpsds*(*i*) (see clause 11.4.1.2.9.2).

Valid values for *XTALKDREQ*ds are 1 to the maximum number of lines supported by the VCE, and different from the VCE_port_index of current line *i*.

This configuration parameter is defined only for the downstream direction.

11.4.4 Line performance monitoring parameters

11.4.4.1 Errored second (ES)

An errored second (ES) is declared if, during a 1-second interval, there are one or more *crc* anomalies, or one or more *los* defects, or one or more *lor* defects, or one or more *lpr* primitives.

11.4.4.2 Severely errored second (SES)

A severely errored second (SES) is declared if, during a 1-second interval, there are 18 or more *crc* anomalies, or one or more *los* defects, or one or more *lor* defects, or one or more *lpr* primitives.

11.4.4.3 Los second (LOSS)

A los second (LOSS) is declared if, during a 1-second interval, there are one or more *los* defects.

11.4.4.4 Lor second (LORS)

A lor second (LORS) is declared if, during a 1-second interval, there are one or more *lor* defects.

11.4.4.5 Unavailable second (UAS)

An unavailable second (UAS) is declared if, during a complete 1-second interval, the link is "unavailable".

A link in the L3 link state is "unavailable". A link in the L0 link state is "available".

Upon a link state transition to the L3 link state, all contiguous SESs until this transition time instant shall be included in the unavailable time.

NOTE – At the onset of *reinit_time_threshold* contiguous SESs, the near-end transceiver path leaves the SHOWTIME state (see clause 12.1.4.3), the link becomes "unavailable", and these *reinit_time_threshold* SESs are included in unavailable time.

11.4.4.6 Inhibiting performance monitoring parameters

The accumulation of certain performance monitoring parameters shall be inhibited during periods of unavailability or during SESs. The inhibiting rules are as follows:

- Counter of UASs shall not be inhibited.
- Counter of *landeftr* defect seconds, *landeftr0* defect seconds and MINEFTR shall not be inhibited.
- Counters of SESs, ESs, LORSs, and LOSSs shall be inhibited only during unavailable time even if the unavailable time is declared retroactively.

NOTE – An implementation may count the SESs, ESs, LORSs, and LOSSs during the contiguous SESs leading to the declaration of UAS and subtract them at the onset of the declaration of UAS.

- Counters of *fec*, and *crc* anomalies shall be inhibited during UAS and during SES. Inhibiting shall be retroactive to the onset of unavailable time.
- Counters of *INM* anomalies shall be inhibited during any 1-second interval that contains one or more *los* defects or one or more *lpr* defects.

11.4.4.7 Impulse noise monitoring facility procedure and parameters

This clause describes the procedure and associated configuration and reporting parameters for the impulse noise monitoring (INM) facility. Support of the INM facility is indicated by both MTUs during initialization (see clauses 12.3.4.2.1 and 12.3.4.2.2). Use of the INM facility is enabled via the DPU-MIB (configuration parameter INM_ENABLE).

11.4.4.7.1 INM procedure

Figure 11-15 shows the functional block diagram for the INM facility.

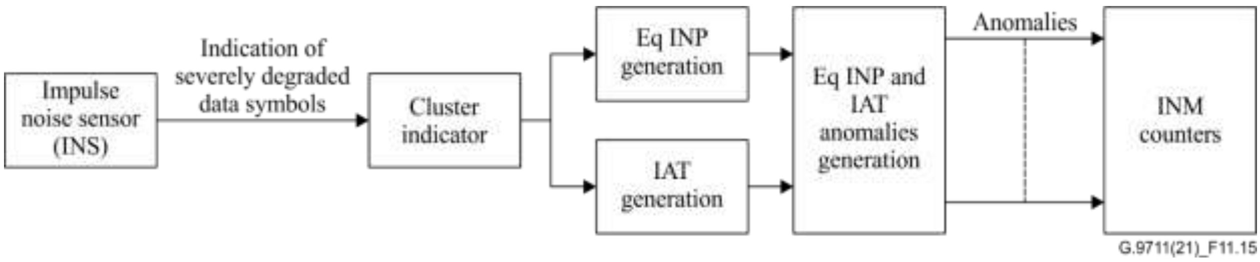


Figure 11-15 – Impulse noise monitor functional block diagram

The impulse noise sensor (INS) indicates whether, among the received data symbols and RMC symbols, there are severely degraded symbols or clusters of severely degraded symbols, presumably subject of erasure by impulse noise. The detection of severely degraded symbols could be implemented at the PMD layer or at the PMS-TC layer. If the detection is done at the PMD layer, the criteria of severely degraded symbol detection is vendor discretionary. If the detection is done at the PMS-TC layer, the detection of severely degraded symbols or a cluster of severely degraded symbols shall be done through searches of a cluster of corrupted DTUs using the rules defined in this clause. The selection of the detection method is vendor discretionary. The following rules shall apply for INS using either detection method:

1) INS shall disregard (skip) the time used for transmission in the opposite direction (in TDD mode) and symbol positions occupied by sync symbols, by idle symbols, or by quiet symbols. The exact number of data and RMC symbols transmitted in a given logical frame is indicated by the parameter "actual transmission time in the previous logical frame"

communicated in the RMC symbol of the next logical frame (see Table 9-5 and Table 9-8). If the corresponding RMC message is received in error, the MTU shall use the *ETT* from the RMC message of the previous logical frame as the value of "actual transmission time in the previous logical frame" if the RMC message of the previous logical frame was received. If the RMC message of the previous logical frame was also received in error, the MTU shall use the latest value of TBUDGET in the corresponding transmission direction as the value of "actual transmission time in the previous logical frame". All other logical frame parameters to be used by INS shall be from the latest received RMC symbol.

2) If bridging is enabled (control parameter *brgn* is set), INS shall bridge the impulse noise event over idle symbols, quiet symbols (within TA and beyond TBUDGET), sync symbol, and over transmission time for opposite direction (in TDD mode) of every logical frame for which bridging conditions apply. Otherwise, the mentioned time intervals shall be counted as gaps. Bridging conditions imply that the last symbol of the logical frame and the first symbol of the following logical frame that carry new DTU(s) are both severely degraded.

If the detection of severely degraded symbols is done at the PMS-TC, the following additional rules shall apply:

3) A symbol shall be considered as severely degraded if all DTUs (complete and partial) carried by this symbol are corrupted.

4) If at least one of the DTUs carried by a symbol is corrupted and at least one is not corrupted, the symbol shall not be considered as severely degraded (just a corrupted symbol) unless the symbol immediately preceding and the symbol immediately following are both severely degraded.

These rules and principles for detection of severely degraded symbols are illustrated in ITU-T G.9701 Appendix VIII for detection at the PMS-TC.

The impulse noise event identifier (INEI) indicates short groups of severely degraded symbols as clusters, each cluster forming a single impulse noise event. The cluster can contain a single severely degraded symbol, a group of consecutive severely degraded symbols, or several groups of one or more consecutive severely degraded symbols with gaps between the groups. A gap is defined as a group of non-severely degraded symbols, or symbol positions disregarded by the INS in-between two severely degraded symbols. A cluster is defined as the largest group of consecutive symbols, starting and ending with a severely degraded symbol, containing severely degraded symbols, separated by gaps smaller than or equal to *INM_cc* symbols (the cluster continuation parameter, see clause 11.4.2.2.4, *INM_cc* ≥ 1).

NOTE – Since *INM_cc* is equal to or greater than 1, a corrupted symbol that is amid two severely degraded symbols is a part of a cluster of severely corrupted symbols (i.e., for INM purposes it shall also be considered as severely degraded). This also relates to sync symbols.

As a consequence of the above definition of a cluster, each cluster starts with a severely degraded symbol preceded by a gap larger than *INM_cc* and ends with a severely degraded symbol followed by a gap larger than *INM_cc*, while gaps inside the cluster are all smaller than or equal to *INM_cc*.

In the Eq INP generation block, the "equivalent INP" of a cluster is generated. For each cluster, the impulse noise cluster length (INCL), defined as the number of symbols from the first to the last severely degraded symbol in the cluster, shall be determined.

The equivalent INP is generated as $INP\_eq = INCL$ using the configured INMCC value (see clause 11.4.4.7.2.3).

Anomalies are generated for several values of equivalent INP (INPEQ primitive), as defined in clause 11.4.4.7.3.1. The counters of these anomalies represent the INPEQ histogram.

In the IAT generation block, the inter-arrival time (IAT) is generated as the total number of symbol positions from the start of a cluster to the start of the next cluster (including sync symbols, idle and quiet symbols, and time occupied by transmission in opposite direction). Anomalies are generated for several ranges of IAT (INMAIAT primitive), as defined in clause 11.4.4.7.3.3. The counters of these anomalies represent the IAT histogram.

For every logical frame processed by INM, the total measurement count INMAME (see clause 11.4.4.7.3.2) is increased by 1.

For every blank logical frame (i.e., a logical frame that does carry any complete DTUs) processed by INM, the total measurement count INMBLFC (see clause 11.4.4.7.3.4) is increased by 1. Blank frame shall be declared only if detection of severely degraded symbols is done at the PMS-TC level.

11.4.4.7.2 INM configuration parameters

11.4.4.7.2.1 Definition of parameter INMIATO

Configuration parameter INMIATO defines the INM inter-arrival time offset for the IAT anomaly generation in order to determine in which bin of the IAT histogram the particular IAT sample is to be reported (see clause 11.4.4.7.3.3).

The control parameter *INM_iato* shall be set to the same value as the configuration parameter INMIATO in the DPU-MIB. The control parameter in the downstream direction is *INM_iato-ds*, and the control parameter in the upstream direction is *INM_iato-us*.

The valid values for *INM_iato* in both directions range from 3 × *iat_sf* to 511 × *iat_sf* DMT symbols in steps of *iat_sf* DMT symbol (see clause 11.4.4.7.2.7). If the MTU supports the INM facility, it shall support all valid values.

Upon entering the first showtime after power-up, the MTU-R shall use a default value of *INM_iato-ds* = 36. During showtime, this value may be overwritten by the MTU-O using an INM facility command defined in clause 11.2.2.19. A link state transition shall not affect the current *INM_iato-ds* value (e.g., not reset the value to the default value).

The MTU-O shall use the current values of INMIATO stored in the DPU-MIB.

11.4.4.7.2.2 Definition of parameter INMIATS

Configuration parameter INMIATS defines the INM inter-arrival time step for the IAT anomaly generation in order to determine in which bin of the IAT histogram the particular IAT sample is to be reported (see clause 11.4.4.7.3.3).

The control parameter *INM_iats* shall be set to the same value as the configuration parameter INMIATS in the DPU-MIB. The control parameter in the downstream direction is *INM_iats-ds*, and the control parameter in the upstream direction is *INM_iats-us*.

The valid values for *INM_iats* range from 1 × *iat_sf* to 7 × *iat_sf* in steps of *iat_sf* DMT symbols. If the MTU supports the INM facility, it shall support all valid values.

Upon entering the first showtime after power-up, the MTU-R shall use a default value of *INM_iats-ds* = 1. During showtime, this value may be overwritten by the MTU-O using an INM facility command defined in clause 11.2.2.19. A link state transition shall not affect the current *INM_iats-ds* value (e.g., not reset the value to the default value).

The MTU-O shall use the current values of INMIATS stored in the DPU-MIB.

11.4.4.7.2.3 Definition of parameter INMCC

Configuration parameter INMCC defines the INM cluster continuation value to be used in the cluster indication process described in clause 11.4.4.7.1. The value for the INMCC parameter shall be as set in the DPU-MIB.

The control parameter *INM_cc* shall be set to the same value as the configuration parameter INMCC in the DPU-MIB. The control parameter in the downstream direction is *INM_cc-ds*, and the control parameter in the upstream direction is *INM_cc-us*.

The valid values for *INM_cc* range from 1 to 255 DMT symbols in steps of 1 DMT symbol. If the MTU supports the INM facility, it shall support all valid values.

Upon entering the first showtime after power-up, the MTU-R shall use a default value of *INM_cc-ds* = 1. During showtime, this value may be overwritten by the MTU-O using an INM facility command defined in clause 11.2.2.19.

A link state transition shall not affect the current *INM_cc-ds* value (e.g., not reset the value to the default value).

The MTU-O shall use the current values of INMCC stored in the DPU-MIB.

11.4.4.7.2.4 Definition of parameter INM_INPEQ_FORMAT

Configuration parameter INM_INPEQ_FORMAT defines the way the scale is configured for the INM_INPEQ histogram, as defined in clause 11.4.4.7.3.1.

The control parameter *INM_INPeq_format* shall be set to the same value as the configuration parameter INM_INPEQ_FORMAT in the DPU-MIB. The control parameter in the downstream direction is *INM_INPeq_format-ds*, and the parameter in the upstream direction is *INM_INPeq_format-us*.

The valid values for *INM_INPeq_format* are 0 and 1. If the MTU supports the INM facility, it shall support both *INM_INPeq_format* = 0 and *INM_INPeq_format* = 1.

Upon entering the first showtime after power-up, the MTU-R shall use a default value of *INM_INPeq_format* = 0. During showtime, this value may be overwritten by the MTU-O using an INM facility command defined in clause 11.2.2.19.

A link state transition shall not affect the current *INM_INPeq_format* value (e.g., not reset the value to the default value).

The MTU-O shall use the current values of INM_INPEQ_FORMAT stored in the DPU-MIB.

11.4.4.7.2.5 Definition of parameter BRGN

Configuration parameter BRGN indicates whether bridging should be applied by the INS in determination of clusters of severely degraded symbols.

The control parameter *brgn* shall be set to 1 if the corresponding DPU-MIB configuration parameter BRGN is true, and set to 0 otherwise. The control parameter in the downstream direction is *brgn-ds*, and the control parameter in the upstream direction is *brgn-us*.

The valid values are 1 (bridging to be applied) and 0 (no bridging to be applied) (see clause 11.4.4.7.1). The default value that shall be applied at the entrance into showtime is 0. During showtime, this value may be overwritten by the MTU-O using an INM facility command defined in clause 11.2.2.19.

A link state transition shall not affect the *brgn* value (e.g., not reset the value to the default value).

The value of *brgn-ds* is communicated to the MTU-R via the eoc (see Table 11-61).

11.4.4.7.2.6 Definition of parameter INPEQ scaling factor (INPEQ_SF)

Configuration parameter INPEQ_SF indicates the value of the scaling factor to be used for reporting INM INPEQ histogram primitive, as defined in clause 11.4.4.7.3.1.

The control parameter *INPeq_sf* shall be set to the same value as the configuration parameter INPEQ time unit scaling factor (INPEQ_SF) in the DPU-MIB. The same scaling factor is used in both the downstream direction and the upstream direction.

The valid values for *INPeq_sf* are 4, 8, and 12. If the MTU supports the INM facility, it shall support all valid values. The default value that shall be applied at the entrance into showtime is 12. During showtime, this value may be overwritten by the MTU-O using an INM facility command defined in clause 11.2.2.19.

A link state transition shall not affect the *INPeq_sf* value (e.g., not reset the value to the default value).

The MTU-O shall use the current values of INPEQ_SF stored in the DPU-MIB.

11.4.4.7.2.7 Definition of parameter IAT scaling factor (IAT_SF)

Configuration parameter *iat_sf* indicates the value of the scaling factor to be used for reporting INM IAT histogram primitive, as defined in clause 11.4.4.7.3.3.

The control parameter *iat_sf* shall be set to the same value as the configuration parameter IAT time unit scaling factor (IAT_SF) in the DPU-MIB. The same scaling factor is used in both the downstream direction and the upstream direction.

The valid values for *iat_sf* are 4, 8, and 12. If the MTU supports the INM facility, it shall support all valid values. The default value that shall be applied at the entrance into showtime is 12. During showtime, this value may be overwritten by the MTU-O using an INM facility command defined in clause 11.2.2.19.

A link state transition shall not affect the *iat_sf* value (e.g., not reset the value to the default value).

The MTU-O shall use the current values of IAT_SF stored in the DPU-MIB.

11.4.4.7.3 INM reporting parameters and primitives

INM-related reporting parameters are INPEQ histogram, IAT histogram, and INM total measurement base. The primitives of these reporting parameters represent anomalies related to PMD and PMS-TC sublayers.

11.4.4.7.3.1 INM INPEQ histogram primitives

If *INM_INPeq_format* = 0, then the INM INPEQ histogram shall be configured with a linear scale as follows:

– $INMAINPEQ_1$ … $INMAINPEQ_{16}$: every $INMAINPEQ_i$ is a primitive detected at the near end only. This anomaly occurs when the equivalent INP (as defined in clause 11.4.4.7.1) is between $((i - 1) \times INPeq\_sf + 1)$ and $(i \times INPeq\_sf)$ DMT symbols, where *INPeq_sf* is a scaling factor (see clause 11.4.4.7.2.6).

– $INMAINPEQ_{17}$ is a primitive detected at the near end only. This anomaly occurs when the equivalent INP (as defined in clause 11.4.4.7.1) is strictly more than $(16 \times INPeq\_sf)$ DMT symbols.

If *INM_INPeq_format* = 1 then the INM INPEQ histogram shall be configured with a logarithmic scale as follows ($\lfloor x \rfloor$ denotes rounding to the lower integer):

– $INMAINPEQ_1$ … $INMAINPEQ_{16}$: every $INMAINPEQ_i$ is a primitive detected at the near end only. This anomaly occurs when the equivalent INP (as defined in clause 11.4.4.7.1) falls within the range from $\lfloor 1.33^{i+1} \rfloor \times INPeq\_sf$ to $\lfloor 1.33^{i+2} \rfloor \times INPeq\_sf - 1$ DMT symbols, both boundaries inclusive.

– *INMAINPEQ*$_{17}$ is a primitive detected at the near end only. This anomaly occurs when the equivalent INP (as defined in clause 11.4.4.7.1) is at least $\lfloor 1.33^{17+1} \rfloor$ × *INPeq_sf* = 169 × *INPeq_sf* DMT symbols.

NOTE – The logarithmic scale gives the possible *INMAINPEQ* histogram ranges (in DMT symbols). It gives a finer granularity for the higher probability short duration impulses, whilst still capturing some information about the longer duration events. The ranges of duration of an impulse noise events corresponding to each bar of the logarithmic scale histogram are shown below for *INPeq_sf* = 1.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1 – 1	2 – 2	3 – 3	4 – 4	5 – 6	7 – 8	9 – 12	13 – 16	17 – 22	23 – 29	30 – 39	40 – 53	54 – 71	72 – 94	95 – 126	127 – 168	≥ 169

11.4.4.7.3.2 INM total measurement count primitive

INMAME is a primitive detected at the near end only. This indication occurs every time a logical frame is processed by the impulse noise sensor.

11.4.4.7.3.3 INM inter-arrival time histogram primitives

The IAT histogram shall be represented using linear scale as follows:

– *INMAIAT*$_0$ is a primitive detected at the near end only. This anomaly occurs when the reported value of IAT falls within the range from 2×*iat_sf* to (*INM_iato* × *iat_sf*) −1, both boundaries inclusive.

– *INMAIAT*$_1$ … *INMAIAT*$_6$: every *INMAIAT*$_i$ is a primitive detected at the near end only. This anomaly occurs when the reported value of IAT falls within the range from (*INM_iato* + (i − 1) × (2^{INM_iats})) × *iat_sf* to ((*INM_iato* + i ×(2^{INM_iats})) × *iat_sf*) −1 DMT symbols, both boundaries inclusive.

– *INMAIAT*$_7$ is a primitive detected at the near end only. This anomaly occurs when the reported value of IAT falls within the range from (*INM_iato* + 6 × (2^{INM_iats})) × *iat_sf* DMT symbols to infinity.

11.4.4.7.3.4 INM blank logical frame count primitive

INMBLFC is a primitive detected at the near end only. This indication occurs every time a blank logical frame is processed by the impulse noise sensor.

11.4.4.8 Low ANDEFTR second (LANDEFTRS)

A low ANDEFTR second (LANDEFTRS) is declared if, during a 1-second interval, there is a *landeftr* defect.
The upstream LANDEFTRS value shall be reported to the DPU-MIB as a near-end value even though it results from a *landeftr* defect declared at the MTU-R.

The downstream LANDEFTRS value shall be reported to the DPU-MIB as a far-end value even though it results from a *landeftr* defect declared at the MTU-O.

11.4.4.8.1 Low ANDEFTR0 second (LANDEFTR0S)

A low ANDEFTR0 second (LANDEFTR0S) is declared if, during a 1-second interval, there is a *landeftr0* defect.
The upstream LANDEFTR0S value shall be reported to the DPU-MIB as a near-end value even though it results from a *landeftr0* defect declared at the MTU-R.

The downstream LANDEFTR0S value shall be reported to the DPU-MIB as a far-end value even though it results from a *landeftr0* defect declared at the MTU-O.

11.4.5 Low power operation parameters

No low power operation parameters are specified in G.9711.

11.4.6 Inventory parameters

11.4.6.1 Vectoring specific inventory parameters

11.4.6.1.1 VCE ID (VCE_ID)

For a transmission line in a vectored group, the VCE ID uniquely identifies the VCE that manages and controls the vectored group to which the transmission line belongs. It is an integer with a valid range of values from 1 to 255. The special value of zero means the transmission line is not in a vectored group.

11.4.6.1.2 VCE port index (VCE_port_index)

For a transmission line in a vectored group, the VCE port index uniquely identifies the VCE port to which the transmission line is connected. It is an integer from 1 to the maximum number of transmission lines supported by the VCE. The combination of VCE ID and VCE port index creates a unique identifier for each vectored MTU-O/-R.

11.4.6.2 Inventory parameters for NT identification

11.4.6.2.1 NT Identity (NT_ID)

The NT_ID shall be 128-bits long and shall uniquely identify the NT. The NT_ID is determined by the NT vendor and hardcoded in the NT at production time. The NT_ID shall not change with NT software updates (e.g., as defined in Annex S).

The NT_ID shall be sent by the MTU-R during the ITU-T G.994.1 handshake (see clause 12.4) and shall reported in the DPU-MIB by the ME-O. The NT_ID shall be readable by the DPU from the NT over an inventory command and response eoc message (see clause 11.2.2.10).

NOTE – Methods for generation of a unique NT_ID are described in [b-IETF RFC 4122]. These allow for the NT_ID to be based on (combinations or hash of) the MAC address, the serial number, the timestamp, random numbers, etc. The NT_ID may also be based on the certificate fingerprint.

11.4.7 Data path configuration parameters

This clause defines the configuration of the mapping of Layer 2 queues to QoS channels (as relevant for the ME-O and ME-R) and the QoS class parameters for each QoS channel (as relevant for the TPS-TC at the MTU-O and MTU-R).

11.4.7.1 Mapping of Layer 2 queue to QoS channel

At the DPU, up to 8 Layer 2 QoS queues may be supported per NT. At the NT, up to 8 Layer 2 QoS queues may be supported. At the MTU-O and MTU-R TPS-TC, up to 4 QoS channels may be supported (see clause 5.5). The mapping of Layer 2 queues (queue-id) to QoS channels (channel-id) is configured in the DPU-MIB, separately for downstream (as relevant for the ME-O) and upstream (as relevant for the ME-R). More than one Layer 2 queue may be mapped to a particular QoS channel. The number of downstream QoS channels shall equal the number of upstream QoS channels.

A queue-id (QID) shall be represented as an unsigned integer in the range [0, 7].

A channel-id (CID) shall be represented as an unsigned integer in the range [0, 3].

NOTE – These management objects are only for the DPU and NT system, not for the transceiver.

11.4.7.2 QoS class

Through configuration in the DPU-MIB, with each downstream QoS channel, a particular downstream QoS class is associated, and with each upstream QoS channel, a particular upstream QoS class is associated. A QoS class is determined through the combination of the parameters defined in this clause.

NOTE – This management object is for the transceiver (i.e., for the TPS-TC). The TPS-TC inputs are packets, while each packet is labelled with a QoS channel-id. The TPS-TC outputs are DTUs, while each DTU is labelled with a QoS grade. For each QoS channel in transmit direction, the TPS-TC translates the config parameters of the associated QoS class into a QoS grade. The QoS grade is then used by the PMS-TC to handle the retransmission of DTUs, see clause 9.8. which contains whatever α reference point rtx class control parameters are needed for the PMS-TC to handle the DTUs correctly.

11.4.7.2.1.Priority (PRIORITY)

The PRIORITY is represented by an unsigned integer in the range [0, 3], where 0 represents the lowest and 3 represents the highest priority.

Each of the downstream QoS classes associated with the downstream QoS channels shall have a different PRIORITY value. Each of the upstream QoS classes associated with the upstream QoS channels shall have a different PRIORITY value.

11.4.7.2.2.Target Maximum Delay (MAXDELAY)

The target maximum delay shall be in the range [0ms, 16ms]. It shall be represented as an unsigned integer in the range [0, 64] and in steps of 0.25 ms.

11.4.7.2.3.Proactive Retransmission (PROACTIVE_RTX)

The PROACTIVE_RTX is configured through an enumeration type that may take one of the following values (as defined in clause 9.8):

0. not-required: DTUs carrying DTU frames of this QoS class are not required to but may be retransmitted proactively;

1) forced1: DTUs carrying DTU frames of this QoS class shall be retransmitted at least once;

2) forced2: DTUs carrying DTU frames of this QoS class shall be retransmitted at least twice.

11.4.8 FDX mask parameter

The control parameter *fdxmask* shall be set to the same value as the DPU-MIB configuration parameter FDXMASK. FDX masking applies separately to upstream and downstream, so there are separate control parameters for $fdxmask_{ds}$ *and* $fdxmask_{us}$ with corresponding DPU-MIB configuration parameters, respectively, for FDXMASKds and FDXMASKus.

11.5 P2MP OAM parameters

For P2MP operation, the MTU-O shall instantiate the P2P OAM parameters per link. Each instance includes the configuration and reporting parameters defined in clause 11.4. Each instance identified by the NT_ID of the NT. The maximum number of instances supported by the ME-O is DPU vendor discretionary. The maximum number of instances may also be configured in the DPU-MIB through the MAXP2MPGROUPSIZE configuration parameter (see clause 11.5.1.1).

Next to the per link instances of the P2P OAM parameters, the MTU-O shall also support the P2MP configuration and reporting parameters defined in clauses 11.5.1 and 11.5.2 respectively.

11.5.1 P2MP group control parameters

The P2MP group control parameters are defined only if the MTU-O supports P2MP operation and apply to the MTU-O only in P2MP operation.

11.5.1.1 Maximum P2MP groupsize (*p2mpgroupsize_max*)

The *p2mpgroupsize_max* is a control parameter that specifies the maximum number of active links in the P2MP group that the link belongs to.

The valid values for *p2mpgroupsize_max* range from 1 to 16.

The control parameter *p2mpgroupsize_max* shall be equal to the DPU-MIB MAXP2MPGROUPSIZE configuration parameter.

11.5.1.2 Maximum P2MP group aggregate transmit power (*p2mpgroupatp_max*)

The *p2mpgroupatp_max* is a control parameter that specifies the maximum value allowed for the sum over all active links in the P2MP group of the aggregate transmit powers (*ACTATP*). This control parameter is defined for downstream and upstream separately.

The valid values for *p2mpgroupatp_max* range from -31 dBm to +31 dBm in steps of 0.1 dBm.

The control parameter *p2mpgroupatp_max* shall be equal to the DPU-MIB MAXP2MPGROUPATP configuration parameter.

11.5.1.3 Maximum P2MP group net data rate (*p2mpgroupNDR_max*)

The *p2mpgroupNDR_max* is a control parameter that specifies the maximum value allowed for the sum over all active links in the P2MP group of the net data rates (NDR). This control parameter is defined for downstream and upstream separately.

The valid values for *p2mpgroupNDR_max* range from 0 to $(2^{16}-1) \times 96\,000$ bit/s, in steps of 96 000 bit/s.

The control parameter *p2mpgroupNDR_max* is derived by the DRA from the DPU-MIB maximum data rate configuration parameters.

11.5.2 P2MP group status objects

11.5.2.1 Actual P2MP groupsize (*p2mpgroupsize_act*)

The *p2mpgroupsize_act* is a status parameter that reports the actual number of active links in the P2MP group that the link belongs to.

The valid values for *p2mpgroupsize_act* range from 1 to 16.

The status parameter *p2mpgroupsize_max* shall be reported in the DPU-MIB ACTP2MPGROUPSIZE status parameter.

11.5.2.2 Actual P2MP group aggregate transmit power (*p2mpgroupatp_act*)

The *p2mpgroupatp_act* is a status parameter that reports the actual value of the sum over all active links in the P2MP group of the aggregate transmit powers (*atp_act*). This status parameter is defined for downstream and upstream separately.

The status parameter *p2mpgroupatp_act* shall be reported in the DPU-MIB ACTP2MPGROUPATP status parameter.

11.5.2.3 Actual P2MP group net data rate (*p2mpgroupNDR_act*)

The *p2mpgroupNDR_act* is a status parameter that specifies the actual value of the sum over all active links in the P2MP group of the net data rates (NDR). This control parameter is defined for downstream and upstream separately.

The status parameter *p2mpgroupNDR_act* is reported in the DPU-MIB ACTP2MPGROUPNDR status parameter.

12 Link activation methods and procedures

12.1 Overview

12.1.1 Link states and link-state diagram

12.1.1.1 Link-state diagram

Figure 12-1 shows the link states (L0 and L3), the references to the procedures that, upon successful completion, make the link transition from one link state to another. In the L0 link state, both transceiver paths are in the SHOWTIME state. The link state transitions are shown in Figure 12-1 as arrows, and occur at a defined time instant.

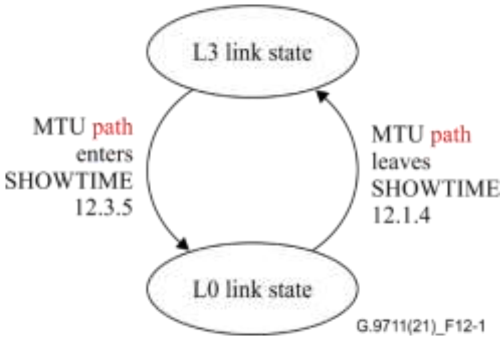


Figure 12-1 – Link states and link-state transition diagram

The procedures for transition from the L0 state to the L3 link state are:

- Deactivation as defined in clause 12.1.4.1;
- Fast retrain as defined in clause 12.1.4.2, triggered by the fast retrain policy (*FRpolicy*).

In either case, the link state transition shall occur at the time instant the MTU path leaves the SHOWTIME state (see Figures 12-4 and 12-5). If the MTU path does not leave the SHOWTIME state because the L3 request was rejected, then no link state transition shall occur.

The procedure for transition from the L3 link state to the L0 link state is defined in clauses 12.3.2 to 12.3.5 for initialization and in clauses 12.3.3 to 12.3.5 for a fast retrain. In either case, the link state transition shall occur at the time instant that both MTU paths enter the SHOWTIME state ("pass", see Figures 12-2 and 12-3). If the procedure is not completed successfully ("fail", see Figures 12-2 and 12-3), then no link state transition shall occur.

12.1.1.2 L3 – Idle state

L3 is the link state in which the MTU-O path is provisioned through a management interface for the service desired by the operator. In this link state, both the MTU-O path and the MTU-R path do not transmit any signal. During a fast retrain or full initialization, the link state is L3 until both transceiver paths are in the SHOWTIME state, at which time the link state becomes L0. The only signals that are allowed to be transmitted during the L3 link state are those associated with the initialization procedure (see clause 12.3).

12.1.1.3 L0 – Normal operation state

L0 is the full power state used during normal operation. This mode allows for bit rates over all links up to the maximum values determined by the configured M_F and M_{ds} with no compromise on QoS, including one-way latency.

When all the links operate at their maximum bit rates, the power consumption and dissipation reach their maximum level.

Discontinuous operation is efficiently used in this state to reduce power consumption, providing that symbols are not transmitted if no data is available. The details of discontinuous operation method are described in clause 10.7.

The L0 state also facilitates power reduction by controlling the maximum transmission time during a PDX frame. A PCE (see clause 5.1, which is beyond the scope of the ITU-T G.9711 transceiver), in cooperation with the DRA, determines and updates from time to time the maximum allowed transmission time for each link using corresponding control parameters at the γ reference point. This allows the ME-O to control the actual power dissipation of a DP, keeping it under the desired limit.

The transmission time limit may vary from link to link and in some links may reach the demarcation point between US and DS. Discontinuous operation is efficiently used in this state to further reduce power consumption.

No compromise on QoS is allowed in this state, except for the implied limit on the maximum bit rate due to the reduced transmission time during PDX frame.

NOTE – Limit on the actual transmission time may be implemented by limiting the duration of the transmission opportunities or by limiting the total number of symbols transmitted over all links during a superframe, or both. The configuration may be determined by the DRA.

12.1.1.4 Transitions between link states

The MTU-O path shall initiate a transition to the L0 or L3 link state if and only if requested by the DRA. The DRA requests a link state by sending a LinkState.request (*LinkState*) primitive to the MTU-O, with the value of *LinkState* indicating the requested link state (see Table 8-4).

The DRA may request a link state transition based on the following indications:

- The ME-O indicates to the DRA that the link state is forced through the DPU-MIB (AdminStatus);
- The MTU-O path indicates to the DRA the MTU-R battery state;
- The ME-O may indicate to the DRA the PSE battery state received from the PSE by the ME-O path by means beyond the scope of this Recommendation;
- The VCE indicates to the DRA that a link state transition is required for coordination of link states over the vectored group;
- The MTU-O path indicates to the DRA that a link state transition is required because the requirements defined for the current link state (e.g., data rate and *SNRM* boundaries) cannot be maintained under the current line conditions;
- The MTU-O path indicates to the DRA that an L3 request has been received from the MTU-R path.

The MTU-O path shall initiate a transition to the L3 link state (L3 request by the MTU-O path) or grant/reject a transition to the L3 link state (L3 request by the MTU-R) using the L3 link state transition commands and responses defined in clause 11.2.2.12.

The MTU-O path shall support transitions between L0 and L3 link states. Those transitions of link state shall be seamless, i.e., shall not cause any errored seconds (ES).

Upon receiving a LinkState.request (*LinkState*) primitive over the γ_O reference point, the MTU-O path shall respond with a LinkState.confirm (*LinkStateResult*) primitive.

- If the *LinkState* equals the actual link state, the MTU-O path shall not initiate any link state transition ("NOOP"), and shall respond within 100 msec with *LinkStateResult* equal to *LinkState*.
- If the *LinkState* requires a valid link state transition, the MTU-O path shall initiate the transition. If the transition is completed within the allowed time, the MTU-O path shall

respond with a *LinkStateResult* that equals the *LinkState*. If the transition cannot be completed within the allowed time, the MTU-O path shall abort the link state transition, shall respond with a *LinkStateResult* that equals "FAIL", the link state shall remain unchanged, and the DRA may resend the LinkState.request (*LinkState*) primitive.

- If the *LinkState* requires an invalid link state transition, the MTU-O path shall not initiate any link state transition, and shall respond within 100 msec with a *LinkStateResult* that equals "FAIL".

Only one LinkState.request primitive shall be outstanding at any time. The MTU-O path shall ignore any LinkState.request primitive received before the MTU-O path has responded with a LinkState.confirm primitive to the last previously received LinkState.request primitive.

12.1.1.5 Configuration and status reporting of the link state

The actual link state shall be reported in the DPU-MIB through the Link State (LINK-STATE).

12.1.1.5.1 Configuration of the Link state

The desired link state shall be configured in the DPU-MIB through the Administrative State

When AdminStatus="up", the allowed link state transitions shown in Figure 12.1 shall be followed to bring the link to the L0 link state.

When AdminStatus="down", the allowed link state transitions shown in Figure 12.1 shall be followed to bring the link to the L3 state.

12.1.1.5.2 Link state status reporting

The actual link state shall be reported in the DPU-MIB through the Operational State (OperStatus="up" or OperStatus="down").

12.1.2 Transceiver states and transceiver state diagram

State diagrams are given in Figure 12-2 for the MTU-O and in Figure 12-3 for the MTU-R. States are indicated by ovals, with the name of the state given within the oval. The states are defined in Table 12-4 and Table 12-5 for the MTU-O and in Table 12-6 for the MTU-R. Transitions between states are indicated by arrows, with the primitives or the events associated with them causing the transition listed next to the arrow. All states are mandatory.

The primitives exchanged between the MME and ME (host controller) (preceded by "o:_" for the MTU-O or MTU-O path and "r:_", for the MTU-R) and events associated with them are shown in Table 12-1, Table 12-2, and Table 12-3 respectively. The way in which these events are implemented is vendor discretionary.

NOTE 1 – The MTU-R contains only a single MTU-R path. Therefore, no distinction regarding primitives and states is made between the "MTU-R" and the "MTU-R path".

Once the MTU-O has returned to the O-IDLE state, the ME shall request the MTU-O to transition to the O-SILENT state (represented by the o:_L0_request primitive, see Table 12-3) in order for an MTU-O path to be instantiated and the link (i.e., an active ITU-T G.9711 session) with the related MTU-R path to enter the L0 state.

Table 12-1 – MTU-O state machine primitives

Primitive name	Direction	Valid state	Description
o:_power on	ME-O → MTU-O	O-SELFTEST	MTU-O power on.
o:_selftest	ME-O → MME	O-IDLE O-UNIT-FAIL	Request to start selftest.
o:_selftest_result	MME → ME-O	O-SELFTEST	Report of selftest result: – pass; – fail.
o:_idle_ignore	ME-O → MME	Any state	Request to move back to O-IDLE state.
o:_L0_request	ME-O → MME	O-IDLE O-SILENT	Request to move from O-IDLE state to O-SILENT state or from O-SILENT state to O-INIT/HS state with continuation to O-INIT/TRAIN state.

Table 12-2 – MTU-O path state machine primitives

Primitive name	Direction	Valid state	Description
o:_init result	MME → ME-O	O-INIT/HS	Report on result of the ITU-T G.994.1 session: – pass with mode selected; – silent or no mode selected; – fail.
o:_training_result	MME → ME-O	O-INIT/TRAIN	Reports the result of initialization (channel discovery and channel analysis and exchange phases): – pass; – fail.
o:_end_showtime	ME-O → MME	O-SHOWTIME	Request for transition from O-SHOWTIME state to O-DEACTIVATING 2 state upon conditions defined by fast-retrain policy (see clause 12.1.4).
o:_fast-retrain	ME-O → MME	O-DEACTIVATING2	Request to transition to O-INIT/TRAIN state (start of fast retrain).
o:_reinitialization	ME-O → MME	O-DEACTIVATING1	Request to transition to O-SILENT state (normal restart after power off or training failure).
o:_L3_request	MME → ME-O	O-SHOWTIME	Request to transition to O-DEACTIVATING1 state through L3 request/grant eoc message exchange.
o:_L3_reject	MME → ME-O	O-SHOWTIME	Reject of the MTU-R request for transition to O-DEACTIVATING1 state.

Table 12-3 – MTU-R state machine primitives

Primitive name	Direction	Valid state	Description
r:_power on	ME-R → MTU-R	R-SELFTEST	MTU-R power on.
auto_init	ME-R → MME	R-SELFTEST	Requests to automatically start initialization (ITU-T G.994.1 following ITU-T G.9711 initialization) when transceiver is in the valid state.
r:_selftest	ME-R → MME	R-IDLE R-UNIT-FAIL	Request to start selftest.
r:_selftest_result	MME → ME-R	R-SELFTEST	Report of selftest result: – pass; – fail.
r:_idle_ignore	ME-R → MME	Any state	Request to move back to O-IDLE state.
r:_L0_request	ME-R → MME	R-IDLE R-SILENT	Request to move from O-IDLE state to O-SILENT state or from O-SILENT state to O-INIT/HS state with continuation to R-INIT/TRAIN state.
r:_init result	MME → ME-R	R-INIT/HS	Report on result of the ITU-T G.994.1 session: – pass with mode selected; – silent or no mode selected; – fail.
r:_training_result	MME → ME-R	R-INIT/TRAIN	Reports the result of initialization (channel discovery and channel analysis and exchange phases): – pass; – fail.
r:_end_showtime	ME-R → MME	R-SHOWTIME	Request to transition from R-SHOWTIME state to R-INIT/TRAIN state upon conditions defined by fast-retrain policy (see clause 12.1.4).
r:_L3_request	MME → ME-R	R-SHOWTIME	Request to transition to R-SILENT state through L3 request/grant eoc message exchange.
r:_L3_reject	MME → ME-R	R-SHOWTIME	Reject of the MTU-O request for transition to R-SILENT state.

In the state diagrams for the MTU-O and MTU-R, O-IDLE and R-IDLE states, respectively, are defined. This provides a quiet period, which may be useful for test purposes.

In the state diagrams for both the MTU-O and the MTU-R, a self-test function is mandatory, but its content is vendor discretionary. It is also a vendor discretionary option to define when self-test occurs (e.g., always at power-up or only under MTU-O control), and which transition for an MTU-R to take after successfully completing self-test (i.e., enter R-IDLE or enter R-SILENT state).

IDLE is the state where the MTU is provisioned through a management interface for the service desired by the operator. In this state, the MTU does not transmit any signal. An MTU that receives a primitive from the ME enabling it to activate (o:_L0_request for MTU-O or r:_L0_request for MTU-R) shall use the initialization procedure defined in clause 12.3 to instantiate an MTU-O path and transition with the related MTU-R path the link from the L3 state to the L0 state. An MTU enabled for activation that detects initialization signals at the U reference point shall respond by using the initialization procedure. If disabled, the MTU shall remain in the IDLE state.

A link transitions to the L0 state once the initialization procedure has completed successfully and both the MTU-O path and MTU-R path are in the SHOWTIME state. Upon a guided power management (o:_L3_request, see clause 11.2.2.12), the MTU-O path shall enter the O-DEACTIVATING1 state, the MTU-O path instance shall end, and then, in case of P2P operation, the MTU-O shall return to the O-SILENT state. Upon a fast retrain triggered by fast-retrain policy (see clause 12.1.4), the MTU-O path shall enter O-DEACTIVATING2 state. In both the O-DEACTIVATING1 state and the O-DEACTIVATING2 state, the MTU-O path shall transmit quiet or idle symbols at sync symbol positions and idle symbols (defined in clause 3.2.13) in all logical frames at RMC symbol positions, at all NOI data symbol positions, and at all DOI symbol positions except symbol positions that are beyond *TBUDGET* and those assigned for quiet symbols by parameters *TIQ* and *TA* (see clause 10.7). The selection of the type of symbols during sync symbol positions is under VCE control.

Upon a guided power management (r:_L3_request, see clause 11.2.2.12), the MTU-R shall transition back to the R-SILENT state. Upon a fast retrain triggered by fast-retrain policy (see clause 12.1.4), the MTU-R shall transition to the R-INIT/TRAIN state.

When the MTU-O path transitions from the O-SHOWTIME state to the O-DEACTIVATING2 state, the MTU-R detects a fast-retrain policy trigger (see clause 12.1.4.2). Upon detecting a fast-retrain policy trigger, the MTU-R shall transition immediately to the R-INIT/TRAIN state.

When the MTU-O path transitions from the O-INIT/TRAIN state to the O-DEACTIVATING1 state, the MTU-R detects a failure in the training. Upon detecting a failure in the training, the MTU-R shall transition immediately to the R-SILENT state, followed by the R-INIT/HS state and shall start transmission of R-TONES-REQ or R-P2MP-REQ (see [ITU-T G.994.1]) within one second.

When the MTU-R transitions from the R-SHOWTIME state to the R-INIT/TRAIN state, the MTU-O path detects a fast-retrain policy trigger (see clause 12.1.4.2). Upon detecting a fast-retrain policy trigger, the MTU-O path shall transition immediately to the O-DEACTIVATING2 state, followed by the O-INIT/TRAIN state. The MTU-O path shall further transition from the O-DEACTIVATING2 state to the O-INIT/TRAIN state after the VCE updates the FEXT cancellation coefficients among the transmission lines in the O-DEACTIVATING2 state. The ME-O indicates the readiness by o:_fast-retrain primitive.

When the MTU-R transitions from the R-INIT/TRAIN state to the R-SILENT state, the MTU-O path detects a failure in the training. Upon detecting a failure in the training, the MTU-O path shall transition immediately to the O-DEACTIVATING1 state. When the MTU-O path receives the o:_reinitialization primitive from the ME-O, the MTU-O path instance shall end and, in case of P2P operation, the MTU-O shall return to the O-SILENT state.

NOTE 2 – While the MTU-O path is in the O-DEACTIVATING1 state, the VCE updates the coefficients among the showtime lines. The ME-O indicates its readiness to continue with the reinitialization (to re-instantiate the MTU-O path and to re-establish the link with the related MTU-R path) by issuing an o:_reinitialization primitive.

In the O-SILENT state, the MTU-O shall monitor for R-TONES-REQ (MTU-R initiated P2P handshake, see [ITU-T G.994.1]) or R-P2MP-REQ (MTU-R initiated P2MP handshake, see Annex D of [ITU-T G.994.1]). Upon detection of R-TONES-REQ or R-P2MP-REQ, the MTU-O shall transition to O-INIT/HS state. If the MTU-O receives an o:_L0_request from the ME-O while in the O-SILENT state (MTU-O initiated handshake, see [ITU-T G.994.1]), it shall transition to the O-INIT/HS state. The MTU-O shall transmit C-TONES within one second after transitioning to the O-INIT/HS state.

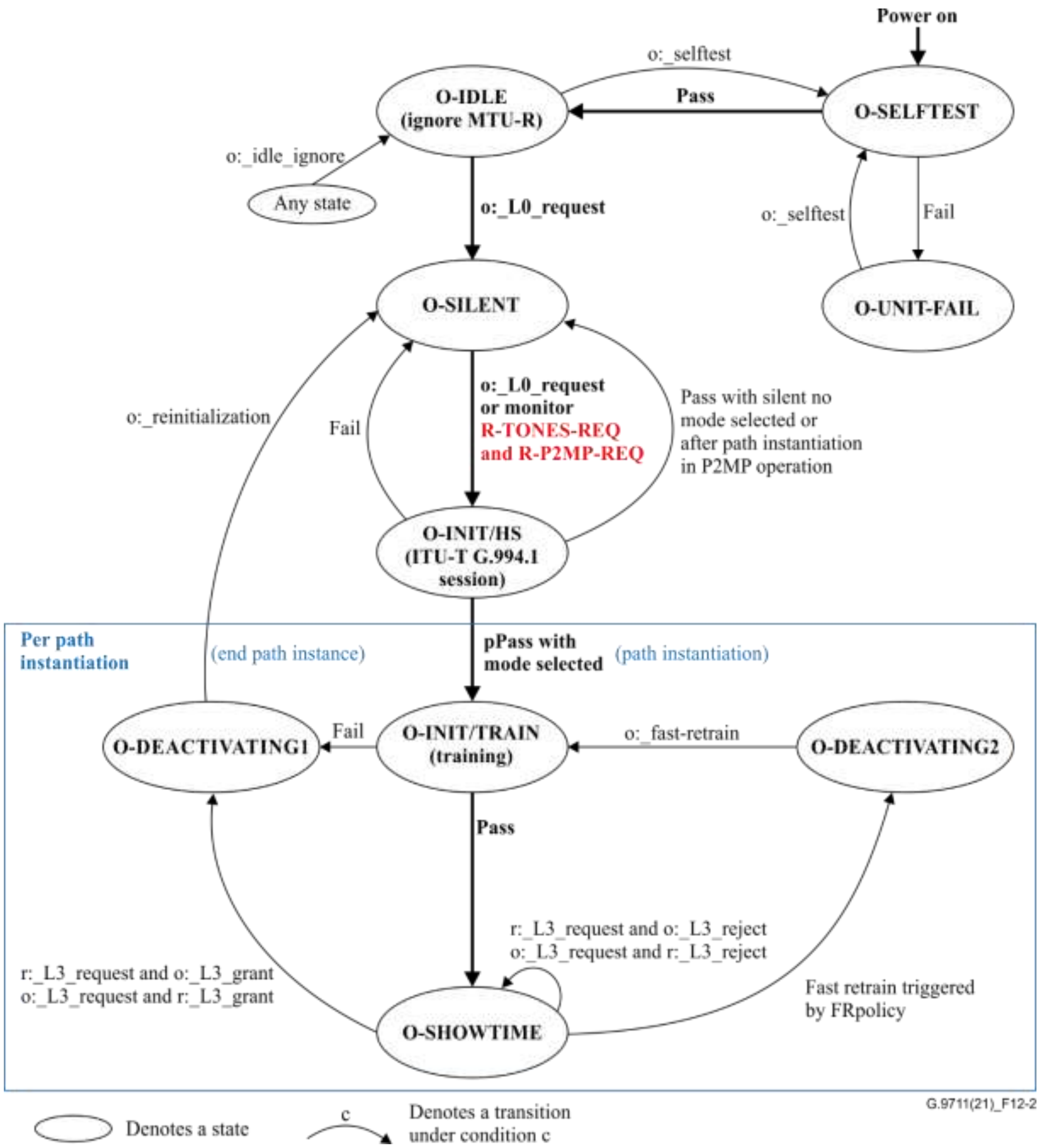


Figure 12-2 – State diagram for the MTU-O

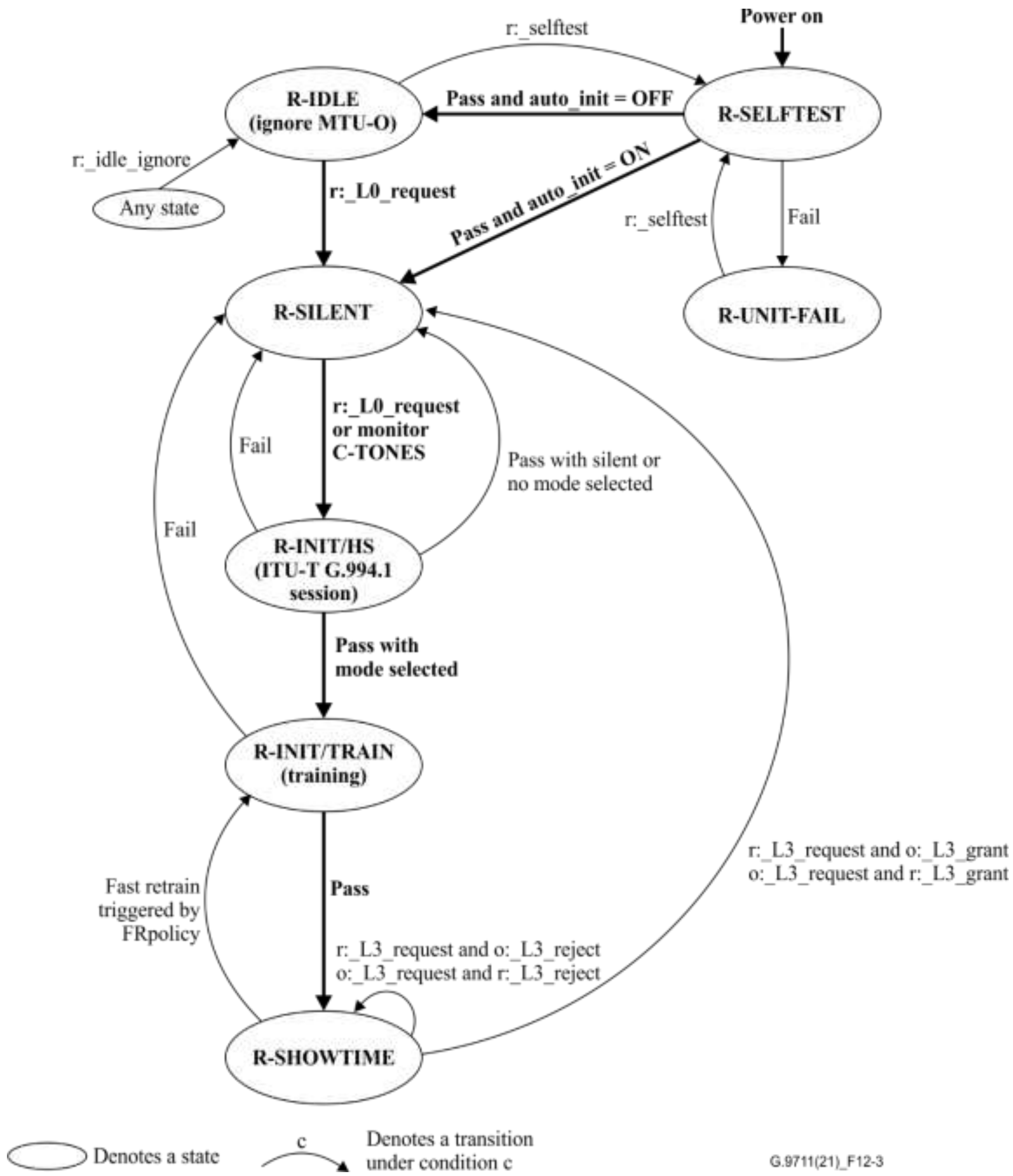


Figure 12-3 – State diagram for the MTU-R

Table 12-4 – MTU-O state definitions

State name	Description
O-SELFTEST (mandatory)	Temporary state entered after power-up in which the MTU performs a self test; Transmitter is off (QUIET signal at U-O reference point); Receiver is off (no response to R-TONES-REQ or R-P2MP-REQ signal signal – see [ITU-T G.994.1]); If self-test passes, the MTU-O transitions to the O-IDLE state; If self-test fails, the MTU-O transitions to the O-UNIT-FAIL state.
O-UNIT-FAIL (mandatory)	Steady state entered after an unsuccessful MTU-O self-test; Transmitter is off (QUIET signal at U-O reference point); Receiver is off (no response to R-TONES-REQ signal or R-P2MP-REQ signal); The ME-O retrieves the self-test results from the MME.
O-IDLE (mandatory)	Steady state entered after successful self-test; Transmitter is off (QUIET signal at U-O reference point); Receiver is off (no response to R-TONES-REQ signal or R-P2MP-REQ signal); The MME waits for an initialization request from the ME-O.
O-SILENT (mandatory)	Steady state defined in [ITU-T G.994.1], entered upon initialization request from the ME-O; Transmitter is off (QUIET signal at U-O reference point) if no path instances exist; Receiver is on in case of MTU-R initiated HS (monitors for R-TONES-REQ signal or R-P2MP-REQ signal, if detected, transitions to the O-INIT/HS state); MME waits for initialization request from ME-O to transition to the O-INIT/HS state in case MTU-O initiated HS.
O-INIT/HS (mandatory)	Temporary state entered to perform the ITU-T G.994.1 phase of initialization; Transmitter is on (starts by transmitting C-TONES signal, in the presence of other signals if one or more path instances exist); Receiver is on (starts by monitoring for R-SILENT0 signal in the presence of other signals if one or more path instances exist); If silent period or no mode selected, transitions back to the O-SILENT1 state; If operating mode selected then a path is instantiated, with the path in the O-INIT/TRAIN state. If P2MP operation is selected, the MTU-O transitions back to the O-SILENT state, to continue monitoring for HS signals, in the presence of other signals of one or more path instances. If P2P operation is selected, the MTU-O state equals the MTU-O path state.

Table 12-5 – MTU-O path state definitions

State name	Description
O-INIT/TRAIN (mandatory)	Temporary state entered to perform other phases of initialization; Transmitter is on (starts with O-P-QUIET1); Receiver is on (starts by monitoring for R-P-QUIET1); If initialization passes, transitions to the O-SHOWTIME state; If initialization fails, transitions to the O-DEACTIVATING1 state.
O-SHOWTIME (mandatory)	Steady state entered to transmit user data; Online reconfigurations occurs within this state; Upon conditions satisfying the fast-retrain policy (*FRpolicy*), transitions to the O-DEACTIVATING2 state; When link transition to L3 state is granted, the MTU-O path transitions to the O-DEACTIVATING1 state; The MME reports the MTU-O path performance parameters to the ME-O.
O-DEACTIVATING1 (mandatory)	Temporary state entered upon the link transition to L3 state; Transmitter is on (transmits idle symbols at the required positions of all logical frames: values Z_i at the precoder input are set to zero but pre-compensation signals are transmitted to support downstream FEXT cancellation); Receiver is on (to support upstream FEXT cancellation and detect the status of the MTU-R); The VCE updates the downstream and upstream FEXT cancellation coefficients; after the update is complete, the precoder output Z_i' is set to zero, the MTU-O path instance ends and, in case of P2P operation, the MTU-O transitions to the O-SILENT state.
O-DEACTIVATING2 (mandatory)	Temporary state entered upon fast retrain request; Transmitter is on (transmits idle symbols at the required positions of all logical frames: values Z_i at the precoder input are set to zero but pre-compensation signals are transmitted to support downstream FEXT cancellation); Receiver is on (to support upstream FEXT cancellation and detect the status of the MTU-R); The VCE updates the downstream and upstream FEXT cancellation coefficients; after update is complete, the precoder output Z_i' is set to zero, and MTU-O path transitions to the O-INIT/TRAIN state (start with O-P-QUIET1).

Table 12-6 – MTU-R state definitions

State name	Description
R-SELFTEST (mandatory)	Temporary state entered after power-up in which the MTU performs a self-test; Transmitter is off (QUIET signal at U-R reference point); Receiver is off (no response to C-TONES signal); If self-test passes, the MTU-R transitions to the R-IDLE state if it is under ME-R control or transitions to the R-SILENT state if it is in automatic training mode; If self-test fails, the MTU-R transitions to the R-UNIT-FAIL state.
R-UNIT-FAIL (mandatory)	Steady state entered after an unsuccessful MTU-R self-test; Transmitter is off (QUIET signal at U-R reference point); Receiver is off (no response to C-TONES signal); The ME-R retrieves the self-test results.

Table 12-6 – MTU-R state definitions

State name	Description
R-IDLE (mandatory)	Steady state entered after successful self-test if MTU-R is under ME-R control; Transmitter is off (QUIET signal at U-R reference point); Receiver is off (no response to C-TONES signal); The MME waits for initialization request from the ME-R.
R-SILENT (mandatory)	Temporary state defined in [ITU-T G.994.1]. Entered after self-test passes if the MTU-R is in automatic training mode or from the R-IDLE state with ME-R command; Transmitter is off (transmits R-SILENT0 signal); Receiver is on in case of MTU-O initiated HS (monitors for C-TONES signal, if detected, transitions to the R-INIT/HS state).
R-INIT/HS (mandatory)	Temporary state entered to perform the ITU-T G.994.1 phase of initialization; Transmitter is on (starts by transmitting R-TONES-REQ signal or R-P2MP-REQ signal); Receiver is on (starts by monitoring for C-TONES signal); If silent period or no mode selected, transitions back to the R-SILENT state; If operating mode selected, transitions to the R-INIT/TRAIN state.
R-INIT/TRAIN (mandatory)	Temporary state entered to perform other phases of initialization; Transmitter is on (starts with R-P-QUIET1); Receiver is on (starts by monitoring for O-P-QUIET1 in the frequency band indicated during the G.994.1 phase); If initialization passes, transitions to the R-SHOWTIME state; If initialization fails, transitions to the R-SILENT state.
R-SHOWTIME (mandatory)	Steady state entered to transmit user data; Online reconfigurations occurs within this state; Upon conditions satisfying the fast-retrain policy (*FRpolicy*), transitions to the R-INIT/TRAIN state; When link transition to L3 state is granted, the MTU-R transitions to the R-SILENT state; The MME reports the MTU-R performance parameters to the ME-R and to the MTU-O (via indicator bits).

12.1.3 Initialization procedures

The ITU-T G.9711 initialization procedures comprise 3 phases:

– ITU-T G.994.1 handshake phase,

– Channel discovery phase, and

– Channel analysis and exchange phase.

During the ITU-T G.994.1 handshake phase of the initialization procedure, the MTUs exchange capability lists and agree on a common mode for training and operation using the ITU-T G.994.1 protocol. A successful completion of the ITU-T G.994.1 handshake phase will lead to establishing a link, starting with the channel discovery phase of initialization. Failure of the ITU-T G.994.1 handshake phase leads the MTU back to the SILENT state and leaves the link in the L3 state. The handshake procedure is described in clause 12.3.2 and [ITU-T G.994.1].

A successful completion of the ITU-T G.994.1 handshake phase holds one of the following:

- P2P operation is selected, i.e., a P2P profile is selected in the MS message. The NT_ID may not be present in the G.994.1 Identification Field, may be known to the MTU-O or may be unknown to the MTU-O.
- P2MP operation is selected, i.e., a P2MP profile is selected in the MS message. The P2MP operation shall be selected only if the NT_ID is present in the G.994.1 Identification Field. The NT_ID may be known to the MTU-O or may be unknown to the MTU-O.

During the channel discovery and channel analysis and exchange phases of initialization, the MTUs train their respective transceiver path after identifying the common mode of operation. During these phases, the transceiver path identifies channel conditions, exchanges and optimizes parameters for showtime operation using the applied *CIpolicy*, etc. After successful completion of the initialization procedure, the MTU path transitions to the SHOWTIME state (showtime).

Upon unsuccessful completion of the initialization procedure, the MTU-O path transitions to the O-DEACTIVATE1 state, then the MTU-O path instance ends and, in case of P2P operation, the MTU-O returns to the O-SILENT state. The MTU-R returns to the R-SILENT state. The link rermains in the L3 state. The initialization phases are described in clauses 12.3.3 and 12.3.4.

12.1.4 Deactivation, reinitialization, persistent link defects and high_BER events

12.1.4.1 Deactivation

The deactivation procedure allows an orderly shutdown of the link. The MTU paths shall follow the procedures described in clause 12.1.2 to transition the link from the L0 state to the L3 state.

The link enters the L3 state when the MTU path leaves the SHOWTIME state. The MTU-O path transitions from the O-SHOWTIME state to the O-SILENT state via the O-DEACTIVATING1 state. The MTU-R path transitions from the R-SHOWTIME state to the R-SILENT state directly. The transition can be initiated by either the local or the remote MTU path (see clauses 11.2.2.12 and 12.1.2). The deactivation criterion is vendor discretionary.

12.1.4.2 Fast retrain

When the fast retrain policy (*FRpolicy*) triggers a fast retrain at the MTU-O path (see Figure 12-4), the MTU-O path shall transition from the O-SHOWTIME state via the O-DEACTIVATING2 state to the O-INIT/TRAIN state.

In the O-INIT/TRAIN state, the MTU-O path executes the part of the initialization sequence, starting from the QUIET 1 stage (clauses 12.3.3 and 12.3.4) with all G.994.1 parameters set to their values selected during the last previous ITU-T G.994.1 handshake phase of initialization. When the initialization sequence is completed, the MTU-O path transitions back to the O-SHOWTIME state. If the initialization sequence is aborted (per conditions defined in clause 12.1.1), then the MTU-O path transitions to the O-SILENT state (see Figure 12-4).

When a fast retrain is triggered at the MTU-R path (see Figure 12-5) according to the fast retrain policy, the MTU-R path shall transition from the R-SHOWTIME state to the R-INIT/TRAIN state.

In the R-INIT/TRAIN state, the MTU-R path executes the part of the initialization sequence starting from QUIET 1 stage (clauses 12.3.3 and 12.3.4). When the initialization sequence is completed, then the MTU-R path transitions back to the R-SHOWTIME state. If the initialization sequence is aborted (per conditions defined in clause 12.1.1), then the MTU-R path transitions to the R-SILENT state.

The following fast retrain policy is defined for the L0 link state:

- Policy ZERO

If *FRpolicy* = 0, then:

Fast retrain shall be triggered when at least one of the following fast retrain policy triggers is declared:

1) persistent near-end los defect; or
2) persistent near-end lom defect; or
3) persistent near-end lor defect ; or
4) a high_BER event.

12.1.4.3 Persistent link defects and high_BER events

12.1.4.3.1 Persistent near-end *los* defect

A persistent near-end *los* defect shall be declared for the link after *los_persistency* milliseconds of continuous near-end *los* defect (see clause 11.3.1.3). The link control parameter *los_persistency* has valid values from 100 to 2000 in steps of 100, with a default value of 200.

The *los_persistency* defined for the downstream and upstream are denoted as *los_persistency-ds* and *los_persistency-us*, respectively.

The link control parameter *los_persistency* is configured through the DPU-MIB link configuration parameter LOS_PERSISTENCY.

NOTE – The persistency allows the transmitting MTU path to detect the *los* defect condition through the indicator bits, before the receiving MTU path leaves the SHOWTIME state.

12.1.4.3.2 Persistent near-end lom defect

A persistent near-end *lom* defect shall be declared for the link after *lom_persistency* seconds of continuous near-end *lom* defect (see clause 11.3.1.3). The link control parameter *lom_persistency* has valid values from 1 to 20 in steps of 1, with a default value of 2.

The *lom_persistency* defined for the downstream and upstream are denoted as *lom_persistency-ds* and *lom_persistency-us*, respectively.

The link control parameter *lom_persistency* is equal to the DPU-MIB link configuration parameter LOM_PERSISTENCY.

NOTE – The persistency allows the transmitting MTU path to detect the *lom* defect condition through the indicator bits, before the receiving MTU path leaves the SHOWTIME state.

12.1.4.3.3 Persistent near-end *lor* defect

A persistent near-end *lor* defect shall be declared after *lor_persistency* milliseconds of continuous near-end *lor* defect (see clause 11.3.1.3). The link control parameter *lor_persistency* has valid values from 100 to 2000 in steps of 100, with a default value of 200.

The *lor_persistency* defined for the downstream and upstream are denoted as *lor_persistency-ds* and *lor_persistency-us*, respectively.

The link control parameter *lor_persistency* is equal to the DPU-MIB link configuration parameter LOR_PERSISTENCY.

NOTE – The persistency allows the transmitting MTU path to detect the *lor* defect condition through the indicator bits, before the receiving MTU path leaves the SHOWTIME state.

12.1.4.3.4 High_BER event

A high_BER event shall be declared for the link whenever any of the parameters listed in Table 12-7 crosses the listed threshold. These thresholds are configured for the link through the DPU-MIB.

The link control parameter *reinit_time_threshold* has valid values from 5 to 31 seconds in steps of 1 second, with a default value of 10.

The *reinit-time_threshold* defined for the downstream and upstream are denoted as *reinit_time_threshold-ds* and *reinit_time_threshold-us*, respectively.

The link control parameter *reinit_time_threshold* is equal to the DPU-MIB link configuration parameter REINIT_TIME_THRESHOLD.

The link control parameter *low_ETR_threshold* has non-zero valid values from 1 to 30 seconds in steps of 1 second, with a default value of 20 seconds. The valid value 0 indicates that no High_BER event shall be declared based on *ETR0* being below the *ETR_min_eoc*.

The *low_ETR_threshold* defined for the downstream and upstream are denoted as *low_ETR_threshold-ds* and *low_ETR_threshold-us*, respectively.

The link control parameter low*_ETR_threshold* is equal to the DPU-MIB link configuration parameter LOW_ETR_THRESHOLD.

Table 12-7 – Conditions for declaring a high_BER event

Parameter	Threshold
Number of contiguous near-end SES (see clause 11.4.4.2)	*reinit_time_threshold*
Number of consecutive seconds the *ETR0* is below the minimum ETR (*ETR_min_eoc*) after a successful OLR procedure	*low_ETR_theshold* (only if *low_ETR_threshold* ≥ 1)
Duration of time interval in seconds with consecutive eoc command time-outs without a single successful response (through either eoc or RMC)	*reinit_time_threshold*
NOTE – At the MTU-R path, no other conditions shall declare a high_BER event. At the MTU-O path, no other near-end conditions shall declare a near-end high_BER event. Declaration by the MTU-O path of a far-end high_BER event (e.g., as indicated by the FTU-R in the upstream indicator bits) is vendor discretionary.	

12.2 Special operations channel (SOC)

An SOC is established for message exchange between the MTU-O and MTU-R during initialization.

The SOC provides a bidirectional communication of messages between the MTU-O and the MTU-R to support initialization.

The SOC has two states; active and inactive. In the active state, the MTU transmits SOC messages separated by one or more high-level data link control (HDLC) flags. In the inactive state, no SOC messages and no HDLC flags are transmitted.

The state of SOC is determined by the initialization procedure and is indicated in the timing diagrams in Figures 12-8, 12-9 and 12-12. The list of messages used for each phase of initialization is shown in Table 12-8.

12.2.1 Message format

The SOC shall use an HDLC-like format with byte stuffing, as specified in clause 12.2.1.1, and an FCS to monitor errors as specified in clause 11.2.1.1.

The structure of a HDLC frame carrying an SOC message shall be as shown in Figure 12-4.

Size in bytes	Meaning	Value
1	Flag	$7E_{16}$
1	Address field	Message index
1	Control field	Segmentation index
Up to 1 024	Information payload	Message payload
1	Frame check sequence	FCS
1	Frame check sequence	FCS
1	Flag	$7E_{16}$

Figure 12-4 – Structure of SOC message transmitted using HDLC-like frame

The message index is determined by the acknowledgement mode (i.e., automatic repeat (AR), repeat request (RQ) or non-repeat (NR)) and whether a message is being repeated, as defined in clause 12.2.2.

The segmentation index facilitates the message segmentation as described in clause 12.2.4.6. If no segmentation is used, the segmentation index shall be set to 11_{16}.

The number of SOC bytes (before byte stuffing) transmitted in a single HDLC frame shall not exceed 2048.

12.2.1.1 Byte stuffing

With byte stuffing, any data byte that is equal to $7E_{16}$ (flag) shall be replaced, as described below. This is necessary to avoid detection of false flags.

After the FCS computation, the transmitter examines the entire SOC message between the opening and closing flags. Any data byte that is equal to $7E_{16}$ or to $7D_{16}$ shall be replaced by a two-byte sequence as following:

- a data byte $7E_{16}$ shall be replaced by $7D_{16}$ $5E_{16}$;
- a data byte $7D_{16}$ shall be replaced by $7D_{16}$ $5D_{16}$.

On reception, prior to FCS computation, the following substitutions shall be made:

- a sequence of $7D_{16}$ $5E_{16}$ shall be replaced by $7E_{16}$;
- a sequence of $7D_{16}$ $5D_{16}$ shall be replaced by $7D_{16}$;
- a sequence of $7D_{16}$ $7E_{16}$ shall abort the received message.

NOTE – The byte stuffing mechanism might expand the size of the SOC message.

12.2.2 Communication protocol

The SOC shall use either automatic repeat (AR) mode, repeat request (RQ) mode or non-repeat (NR) mode.

12.2.2.1 Automatic repeat (AR) mode

In AR mode, messages encapsulated in HDLC frames shall be automatically repeated. At least four idle flags ($7E_{16}$) shall be inserted between messages (between the last FCS byte of a message and the message index byte of a subsequent message). The MTU shall stop transmission of a particular message in AR mode upon reception of an acknowledgement. The acknowledgement may be sent at any time and could be either an SOC message or an O-P-SYNCHRO signal (see clauses 12.3.3 and 12.3.4).

If message is segmented (see clause 12.2.4.6), segments shall be sent in sequential order and at least four idle flags ($7E_{16}$) shall be inserted between subsequent segments. All segments shall be sent before the message is repeated.

The message index shall always be set to 01_{16} in AR mode. The segmentation index shall be set to 11_{16} if the message is not segmented, or as specified in clause 12.2.4.6 if the message is segmented.

12.2.2.2 Repeat request (RQ) mode

In RQ mode, each message (or message segment) shall initially be sent only once. The MTU expecting the message may request the remote side to repeat the message (segment) by sending an O/R-REPEAT_REQUEST message if the expected message (segment) has timed out or has been received in error (wrong FCS). After two unsuccessful O/R-REPEAT_REQUEST attempts, the reception of a message shall be considered unsuccessful. The value of the timeout shall be 0.5 s.

The MTU shall start the timeout counter as it transmits the last byte of the message (segment) to be replied, and shall stop the counter as it receives the control field of the expected reply-message (segment). For the first message (segment) following the activation or re-activation of the SOC, the MTU shall count the timeout from the start of activation time to the reception of the control field of the message (segment) determined by the message exchange protocol.

In RQ mode, an MTU shall never send a message (segment) prior to receiving an acknowledgement of the previously sent message (segment). A message is acknowledged by either a reply-message in accordance with the message exchange protocol of the particular initialization phase, or an O-P-SYNCHRO signal, as described in clauses 12.3.3 and 12.3.4. Once acknowledged, messages (segments) shall not be re-sent and re-transmission shall not be requested.

If a message is segmented, reception of the first segment and each intermediate segment shall be acknowledged by O/R-ACK-SEG message. The last segment signals the end of the message and thus is acknowledged by a reply-message or by an O-P-SYNCHRO signal.

The MTU shall keep only one unacknowledged message or one unacknowledged segment at a time.

Upon entering the RQ mode, the message index shall initially be set to 01_{16} and shall be incremented by one in every subsequent message. The index shall wrap around and set to 01_{16} after reaching the value of FF_{16}. The value 00_{16} has a special meaning, as described below, and shall be skipped. The index shall not be incremented if an O/R-REPEAT_REQUEST message is received, i.e., if message is re-sent. The message index of an O/R-ACK-SEG message shall be increased by one when a new segment is received.

The segmentation index shall be set to 11_{16} if the message is not segmented, and as specified in clause 12.2.4.6 if the message is segmented. The segmentation index shall not be changed if the message (segment) is re-sent.

The message index and segmentation index of the O/R-REPEAT_REQUEST message shall be set to 00_{16}. These fields shall be ignored by the receiver.

12.2.2.3 Non-repeat (NR) mode

In NR mode, SOC messages or segments are transmitted one after another, separated by four or more $7E_{16}$ flags (IDLE). Neither messages nor message segments are acknowledged or repeated.

Transmission of messages is terminated upon reception of an appropriate termination message (e.g., ACK or another regular SOC message) or by reception of an O-P-SYNCHRO signal.

The message index and segmentation index shall be as specified for repeat request (RQ) mode.

12.2.3 SOC IDLE (O-IDLE, R-IDLE)

When the SOC is in the active state but has no message to send, it shall send IDLE (the MTU-O shall send O-IDLE and MTU-R shall send R-IDLE).

Both O-IDLE and R-IDLE states shall consist of HDLC flags $7E_{16}$ that shall be sent repeatedly instead of HDLC frames.

12.2.4 SOC messages

12.2.4.1 Message codes

The message payload of any SOC message shall contain an integer number of bytes. The payload shall start with a one-byte field containing a unique code to identify the type of message. For one-byte messages the message code is the entire content of the message. The message codes for all defined messages are shown in Table 12-8.

NOTE – All messages sent by the MTU-O have the MSB of the message code equal to ZERO. Except R-REPEAT_REQUEST and R-ACK-SEG, all messages sent by the MTU-R have the MSB of the message code equal to ONE.

Table 12-8 – Message codes for the SOC messages

SOC message	Message code	The rest of the payload
O/R-REPEAT_REQUEST	55_{16}	(Note)
O/R-ACK-SEG	$0F_{16}$	(Note)
MTU-O messages		
O-SIGNATURE	00_{16}	see clause 12.3.3.2.1
O-TG-UPDATE	01_{16}	see clause 12.3.3.2.2
O-EC-PRM	61_{16}	see clause 12.3.3.2.3
O-UPDATE	02_{16}	see clause 12.3.3.2.6
O-EC-PRM 1	62_{16}	see clause 12.3.3.2.8
O-VECTOR-FEEDBACK	03_{16}	see clause 12.3.3.2.10
O-SNR	04_{16}	see clause 12.3.3.2.13
O-PRM	05_{16}	see clause 12.3.3.2.15
O-MSG 1	07_{16}	see clause 12.3.4.2.1
O-TPS	08_{16}	see clause 12.3.4.2.3
O-PMS	09_{16}	see clause 12.3.4.2.5
O-PMD-PSF-1	$0A_{16}$	see clause 12.3.4.2.7
O-PMD-PSF-2	$6A_{16}$	see clause 12.3.4.2.7
O-PMD-NPSF-1	$6B_{16}$	see clause 12.3.4.2.7
MTU-R messages		
R-EC-PRM	90_{16}	see clause 12.3.3.2.4
R-MSG 1	80_{16}	see clause 12.3.3.2.5
R-UPDATE	81_{16}	see clause 12.3.3.2.7
R-EC-PRM 1	91_{16}	see clause 12.3.3.2.9
R-ACK (Note)	82_{16}	see clause 12.3.3.2.11
R-VECTOR-FEEDBACK	83_{16}	see clause 12.3.3.2.12
R-SNR	84_{16}	see clause 12.3.3.2.14
R-PRM	85_{16}	see clause 12.3.3.2.16
R-MSG 2	86_{16}	see clause 12.3.4.2.2
R-ACK 1 (Note)	87_{16}	See clause 12.3.4.2.4
R-PMS	88_{16}	see clause 12.3.4.2.6
R-PMD-PSF-1	89_{16}	see clause 12.3.4.2.8

Table 12-8 – Message codes for the SOC messages

SOC message	Message code	The rest of the payload
R-PMD-NPSF-1	99_{16}	see clause 12.3.4.2.8
R-ACK 2 (Note)	$8A_{16}$	See clause 12.3.4.2.9
NOTE – This is a one-byte message.		

12.2.4.2 O/R-REPEAT_REQUEST

This message shall be used in RQ mode to request the remote side to resend the last unacknowledged message (segment), as described in clause 12.2.2.2. The format of the message shall be as specified in clause 12.2.1, and the payload shall be as specified in Table 12-8.

In AR and NR modes, O/R-REPEAT_REQUEST messages shall be ignored.

12.2.4.3 O/R-ACK-SEG

This message shall be used in RQ mode to acknowledge the reception of intermediate segments of a segmented message, as described in clause 12.2.2.2. The format of the message shall be as specified in clause 12.2.1 and the payload shall be as specified in Table 12-8.

In AR and NR modes, and when no segmentation is used in RQ mode, any O/R-ACK-SEG messages shall be ignored.

12.2.4.4 MTU-O and MTU-R messages

The format of the MTU-O and MTU-R message shall be as specified in clause 12.2.1; the content of the messages are described in detail in clauses 12.3.3 and 12.3.4.

12.2.4.5 Mapping of SOC data

All bytes of the SOC message shall be sent LSB first. An SOC message may be subdivided into fields. A field can contain parameter values expressed in more than one byte. In this case, the field shall be split into bytes with the byte containing the MSBs of the parameter value shall be sent first. For example, a field carrying a 16-bit value $m_{15}...m_0$ shall be split into a first byte $B_0=m_{15}...m_8$ and a second byte $B_1=m_7...m_0$.

Some SOC messages may contain several fields. Some fields can be merged together to form a logical entity called a macro-field, such as "PSD descriptor", which is described in clause 12.3.3.2.1.

The description of fields for specific messages is given in detail in clauses 12.3.3 and 12.3.4. All bytes of a message that follow the currently defined bytes shall be ignored.

NOTE – If future versions of this Recommendation add extra fields to the ones already defined, for reasons of backward compatibility, these fields will be appended to the currently defined ones.

12.2.4.6 Segmentation of SOC messages

Messages that are larger than the maximum allowed size of 2048 bytes shall be segmented before transmission; messages shorter than 2048 bytes may also be segmented to improve robustness. Each segment shall include an integer number of bytes.

Segmentation is facilitated by the segmentation index of SOC message (see Figure 12-4). The four MSBs of this field shall indicate the number of segments, up to a maximum of 15, into which the message has been segmented. The four LSBs of this field shall indicate the index of the current segment, starting from 01_{16}. For example, a segmentation index value of 93_{16} indicates the third segment of a total of nine. In case the message is not segmented, the value of the field shall be 11_{16}.

12.3 Initialization procedure

12.3.1 Overview

Initialization of an MTU-O/MTU-R pair includes the following main tasks:

- Definition of a common mode of operation (profile, PDX framing mode and parameters, initial values of basic modulation parameters);
- Synchronization (sample clock alignment and symbol alignment);
- Channel identification and crosstalk cancellation between the joining lines and active lines;
- Transfer from the MTU-O to the MTU-R of transmission parameters, including information on the probe sequences, PSD masks, RFI and IAR bands to be notched and target data rates in both transmission directions;
- Noise identification;
- Negotiation of DTU size, RS encoder, interleaver parameters and LDPC settings, as well as the bit-loading and gain adjustment tables.

The common mode of operation shall be negotiated during the ITU-T G.994.1 handshake phase. Information such as PDX framing parameters, LPM, locations of RFI and IAR bands to be notched, and target data rates shall be initially available at the MTU-O through the DPU-MIB.

Figure 12-5 shows the timeline of the initialization procedure in the upstream and downstream directions, which contains three phases:

– ITU-T G.994.1 handshake phase

– Channel discovery phase

– Channel analysis and exchange phase

After completion of the channel analysis and exchange phase, the transceiver shall proceed to showtime.

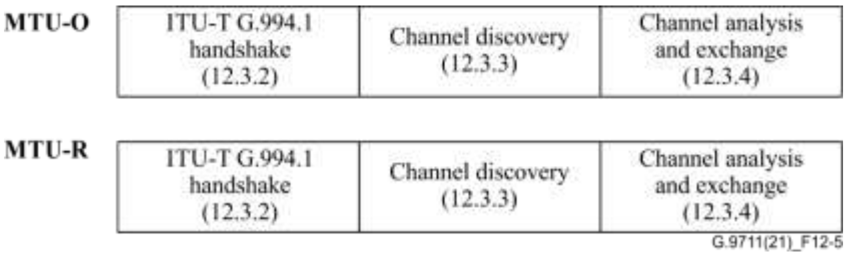


Figure 12-5 – Timeline of the initialization procedure

Each phase of initialization contains a number of tasks. The transition to the next phase of initialization shall occur only after all tasks of the previous phase have been completed. A timeout period is defined for completion of each phase to avoid suspension of the initialization procedure. Violation of the timeout or an inability to complete any task of any phase results in aborting the activation process (unsuccessful activation). The initialization procedure shall be aborted immediately after any of the following events is discovered:

– Timeout of any phase;

– Missing or incomplete task during any phase;

– Violation of the task sequence or in communication protocol during any phase;

– Detection of more than 250 ms of unscheduled silence.

Each phase of initialization has an associated timeout counter. In all phases, the associated timeout counter shall be started as the MTU enters the specific phase and shall be reset upon completion of the phase. The following values for the timeouts shall be used:

– ITU-T G.994.1 handshake phase: As defined in [ITU-T G.994.1];

– Channel discovery phase:

  – *CD_time_out_1* seconds from the start of the channel discovery phase to the reception of O-P-CHANNEL-DISCOVERY 1-1. The valid values for *CD_time_out_1* during an initialization starting with an ITU-T G.994.1 session are from five seconds to forty seconds in steps of five seconds. The MTU-R shall support all valid values. The value to be used during initialization starting with an ITU-T G.994.1 session is indicated in the CL message during the ITU-T G.994.1 phase. During a fast retrain, the valid values for CD_time_out_1 are from 1 to 40 seconds in steps of 1 second. The value to be used during a fast retrain shall be indicated in O-MSG 1. All values shall be supported by the MTU-R;

  – *CD_time_out_2* seconds from the reception of O-P-CHANNEL-DISCOVERY 1-1 to the end of the channel discovery phase. The valid values for *CD_time_out_2* during an initialization starting with an ITU-T G.994.1 session are from ten seconds to eighty seconds in steps of ten seconds. The MTU-R shall support all valid values. The value to be used during initialization is indicated in the CL message during the ITU-T G.994.1 phase. During a fast retrain, the valid values for CD_time_out_2 are from 1 to 80 seconds in steps of 1 second. The value to be used during a fast retrain shall be indicated in O-MSG 1. All valid values shall be supported by the MTU-R.

– Channel analysis and exchange phase: Five seconds.

Exchange of information between the MTU-O and MTU-R during all phases of the initialization, excluding the ITU-T G.994.1 handshake phase, shall be performed using the messaging protocol over the SOC defined in clause 12.2.

For each initialization procedure, the MTU-O shall report in the DPU-MIB the downstream signal count of the last transmitted initialization signal and upstream signal count of the last received initialization signal. The downstream signal count is defined in the range from 0 to 31 (0 = ITU-T G.994.1; 1 = O–P–QUIET1; ... 30 = O–P–SYNCHRO 6; 31 = SHOWTIME). The upstream signal count is defined in the range 0 to 16 (0 = ITU-T G.994.1; 1 = R−P−QUIET1; … 15 = R-P-MEDLEY; 16 = SHOWTIME).

12.3.1.1 Initialization procedure in a P2MP scenario

Initialization in P2MP scenario shall use the initialization procedure defined in clauses 12.3.2 (Handshake phase), 12.3.3 (Channel Discovery phase), and 12.3.4 (CA&E phase), with the $SUPPORTEDCARRIERS_n$ set that includes only subcarriers within the frequency band assigned for the joining $MTU\text{-}R_n$. This $SUPPORTEDCARRIERS_n$ set is communicated to the MTU-R during the G.994.1 handshake in the CL message (see clause 12.3.2.1.1).

If at the time when a MTU-R requests to join the P2MP group (at the start of G.994.1 handshake, see G.994.1 Annex D) there is no frequency band available for this MTU-R, the DRA, under control of the VCE, initiates a DBR procedure (see clause 13.5), which releases the necessary sub-bands for the joining MTU-R. The DRA shall schedule this DBR procedure so that the description of the frequency band for the joining MTU-R is ready prior to transmission of the CL message of the G.994.1 handshake and the frequency band is available for use by the MTU-R prior to the beginning of the Channel Discovery phase of initialization.

If by some (unexpected) reason the DBR is not complete prior to beginning of Channel Discovery phase, the MTU-O may apply longer O-P-QUIET 1 signal (see clause 12.3.3.3.1) to let the DBR completion or may restart the initialization of the MTU-R (by termination the G.994.1 handshake or abandoning the Channel Discovery phase).

Examples of timelines of an MTU-R joining to the P2MP group are shown in Figure 12-6, for one joining MTU-R and multiple joining MTU-Rs. In the latter case, MTU-Rs join one after another, following the P2MP G.994.1 collision control protocol defined in G.994.1 Annex D.

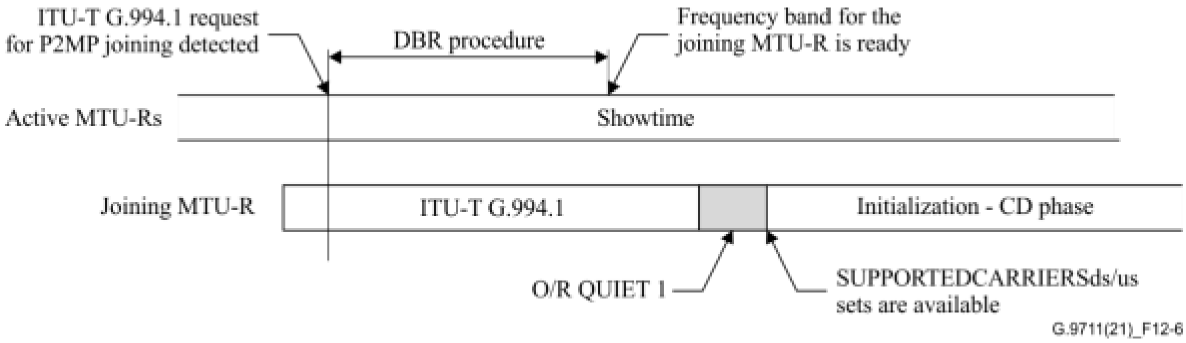


Figure 12-6 – Timeline of an MTU-R joining to P2MP group (all active MTU-Rs are in showtime)

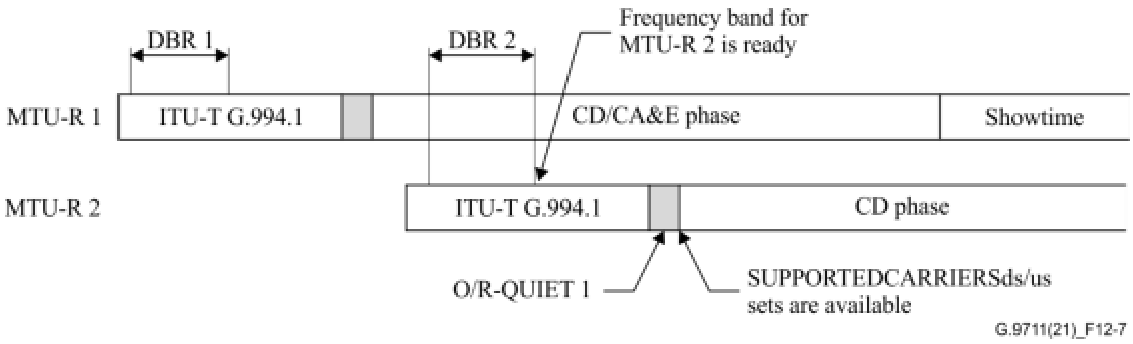


Figure 12-7 – Timeline of simultaneous joining of two MTU-Rs to P2MP group

NOTE – The O-P-QUIET1 of MTU-R 2 (i.e., the later joining MTU-R) should be after the VECTOR 2 stage of MTU-R 1 is completed.

12.3.2 ITU-T G.994.1 handshake phase

MTU-R sends a request for joining using the ITU-T G.994.1 handshake. After common operation mode between the MTU-O and MTU-R is found, the MTU-O starts the joining procedure.

The detailed procedures for the ITU-T G.994.1 handshake phase are defined in [ITU-T G.994.1].

12.3.2.1 Handshake – MTU-O

An MTU-O, after power-up, loss of signal, or recovery from errors during the initialization procedure, shall enter the initial ITU-T G.994.1 state, C-SILENT1. The MTU-O responds to detection of R-TONES-REQ signal from the MTU-R (MTU-R initiated P2P activation) by transitioning to the transmission of C-TONES. Operation shall then proceed according to the procedures defined in [ITU-T G.994.1]. In case the P2MP operation is enabled in the DPU-MIB and supported by the MTU-O, and the MTU-O detects the R-P2MP-REQ signals from the MTU-R (MTU-R initiated P2MP activation), it responds by transmission of C-P2MP signal and proceeds with the collision control protocol defined in Annex D of [ITU-T G.994.1].

If ITU-T G.994.1 procedures select this Recommendation as the mode of operation, the MTU-O shall continue the initialization at the completion of the ITU-T G.994.1 handshake phase, as defined in clauses 12.3.3 and 12.3.4.

12.3.2.1.1 CL messages

An MTU-O indicates its ITU-T G.9711 capabilities in an ITU-T G.994.1 capabilities list (CL) message by setting to ONE the ITU-T G.9711 SPar(1) bit as defined in Table 11.0.5 of [ITU-T G.994.1]. The NPar(2) (Table 11.71 of [ITU-T G.994.1]) and SPar(2) (Table 11.72 of [ITU-T G.994.1]) fields corresponding to the ITU-T G.9711 SPar(1) bit are defined in Table 12-9 and Table 12-10, respectively. For each ITU-T G.9711 SPar(2) bit set to ONE, a corresponding NPar(3) field shall also be present (beginning with Table 11.72.1 in clause 9.4 of [ITU-T G.994.1]). Table 12-11 shows the definitions and coding for the MTU-O CL NPar(3) fields.

The MTU-O shall indicate support for a capability in the CL message if and only if the capability is supported by the MTU-O and the capability is not disabled by the upper layer management over its γ_MGMT interface (e.g., through the DPU-MIB, or by the DRA/VCE functionality).

Table 12-9 – MTU-O CL message NPar(2) bit definitions

ITU-T G.994.1 NPar(2) bit	Definition of NPar(2) bit
Default CE length	If set to ZERO, indicates that the MTU-O is not configured to use the default CE length $L_{CP} = m \times N/64$, where $m = 10$. If set to ONE, indicates that the MTU-O is configured to use of the default CE length.
Default number of symbol periods in PDX frame	If set to ZERO, indicates that the MTU-O is not configured to use the default M_F value 36. If set to ONE, indicates that the MTU-O is configured to use the default M_F value 36.

Table 12-10 – MTU-O CL message SPar(2) bit definitions

ITU-T G.994.1 SPar(2) bit	Definition of SPar(2) bit
Profiles	Always set to ONE.
DS transmission band	Always set to ONE.
Number of symbol positions in downstream PSF	Always set to ONE
RFIBANDS	If set to ONE, indicates that transmit PSD reduction in RFI bands is enabled. If set to ZERO, indicates that transmit PSD reduction in RFI bands is disabled (Note 1).
Duration of Channel Discovery 1-1	Always set to ZERO (Note 2).
CE length	If set to ZERO, indicates that the MTU-O supports only the default CE length $L_{CP} = m \times N/64$, where $m = 10$. If set to ONE, indicates that the MTU-O supports valid CE lengths in addition to the default value, as indicated in the corresponding CE length multiplier NPar(3) field.
Number of symbol periods in the PDX frame	If set to ZERO, indicates that the MTU-O supports only the default M_F value of 36. If set to ONE, indicates that the MTU-O supports other valid M_F values (mandatory or optional) in addition to the default value of 36, as indicated in the related NPar(3).
IARBANDS	If set to ONE, indicates that transmit PSD reduction in at least one of the IAR bands is enabled. If set to ZERO, indicates that transmit PSD reduction in all IAR bands is disabled (Note 1).
Scrambler seed	Always set to ONE.
IDS	Always set to ONE.

Table 12-10 – MTU-O CL message SPar(2) bit definitions

ITU-T G.994.1 SPar(2) bit	Definition of SPar(2) bit
Number of SOC symbol repetitions (R_S)	Always set to ONE.
Number of initialization data symbols in downstream PSF (s_{ds})	Always set to ONE.
Downstream RMC offset	Always set to ONE.
CD time out	If set to ZERO, indicates that the MTU-O supports the *CD_time_out_1* value of ten seconds and the *CD_time_out_2* value of twenty seconds. If set to ONE, indicates that the MTU-O supports the *CD_time_out_1* value and the *CD_time_out_2* value as indicated in the corresponding CD time out 1 and CD time out 2 NPar(3) fields.
DTFO downstream Band 1 start sub-carrier	If set to ZERO, DTFO Band 1 is disabled. If set to ONE DTFO Band 1 is enabled.
MTU-R downstream operation bands	If set to ZERO, indicates that the MTU-R shall use the whole downstream band (P2P mode or the first MTU-R joining to P2MP group). If set to ONE, indicates that MTU-R joins to P2MP group using a part of the downstream band.
NOTE 1 – The RFI bands and IAR bands shall apply in the same way to both directions of transmission. The list of RFI bands shall not include IAR bands. NOTE 2 – The parameter is determined by request from the MTU-R; the MTU-O is capable to implement all values inside the valid range.	

Table 12-11 – MTU-O CL message Npar(3) bit definitions

ITU-T G.994.1 SPar(2) Bit	Definition of Npar(3) bits
Profiles	Each valid profile is represented by one bit in a field of 8 bits. The valid profiles are: P424a, P424amp, P424d, P424dmp, Q424c, Q424cmp, Q424d and Q424dmp. Each profile supported by the MTU-O is indicated by setting its corresponding bit to ONE (Note 5).
DS transmission band	This field shall include the lower frequency ($f_{tr1\text{-}DS}$) and the upper frequency ($f_{tr2\text{-}DS}$) of the frequency band assigned for transmission in the downstream direction represented by the start subcarrier index and stop subcarrier index, respectively, using 14 bits per index value. The band shall include the Band 0 and the Band1, if enabled.
Number of symbol positions in downstream PSF	This 6-bit field represents the enabled value of M_{ds}. The number of symbol positions in upstream PSF, Mus, of the PDX frame shall be as defined in clause 10.5 for the selected framing mode.
RFIBANDS	Indicates in ascending order the pairs of start subcarrier index and stop subcarrier index for each RFI band in which the transmit PSD shall be reduced. Each index is represented by 13 bits. Up to 32 RFI bands may be defined.
CE length multiplier (Note 1)	Each bit of this 9-bit field represents a CE length multiplier *m*, excluding the default value 10 (see clause 10.4.4). For each CE length multiplier that the MTU-O supports, the corresponding bit shall be set to ONE.
Number of symbol	Each bit of this 6-bit field represents an M_F value other than 36; specifically bit 1

Table 12-11 – MTU-O CL message Npar(3) bit definitions

ITU-T G.994.1 SPar(2) Bit	Definition of Npar(3) bits
periods in PDX frame (Note 1)	shall be set to ONE if the MTU-O is configured to use the M_F value of 23 and shall be set to ZERO otherwise. Other bits in this 6-bit field are reserved by ITU-T and shall be set to ZERO.
IARBANDS	This 15-bit field indicates by ONE each IAR band in which transmit PSD reduction is enabled and by ZERO each IAR band in which transmit PSD reduction is disabled (Note 2).
Scrambler seed	This 11-bit field indicates the seed to be used for quadrant scrambler initiation, as described in clause 10.2.2.5. The MSB indicates the initial setting of the d_{11} bit and the LSB indicates the initial setting of d_1 bit of the quadrant scrambler.
IDS	This variable length bit field indicates the length and the elements of the IDS. The 6 MSB indicate the length of the IDS and shall be mapped onto the first octet. The remaining bits indicate the elements of the IDS, which shall be mapped as specified in [ITU-T G.994.1]. The valid length of the IDS is 2 and k×4, where k = 1, 2, ..., 8. A special value 0 indicates that no IDS is applied.
Number of initialization data symbols in downstream PSF (s_{ds})	This 6-bit field indicates the number of downstream data symbols in downstream PSF coded as $s_{ds} – 1$ in a logical frame to be used during initialization. The valid range of s_{ds} is from 4 to 32 (Note 3).
Downstream RMC offset	This 5-bit field indicates the downstream RMC offset expressed in symbols coded as $D_{RMC,ds}$ –1. The valid range and settings shall comply with the condition defined in clause 10.5.1 with the indicated value of M_{ds}.
CD time out 1	This 3-bit field shall be coded as an unsigned integer n=0 to 7, indicating that the *CD_time_out_1* value supported by the MTU-O equals (n+1) times five seconds.
CD time out 2	This 3-bit field shall be coded as an unsigned integer n=0 to 7, indicating that the *CD_time_out_2* value supported by the MTU-O equals (n+1) times ten seconds.
Number of SOC symbol repetitions (R_S)	This 5-bit field indicates the number of repetitions of each SOC symbol during Channel Discovery 1 stage. The valid values are 0 (no repetitions), 1, and (k×4-1), where k=1, 2, …, floor(s_{ds}/4), (Note 4).
DTFO downstream Band 1 start sub-carrier	This field shall include the start frequency ($f_{tr3\text{-}DS}$) of the frequency Band 1 assigned for transmission in the downstream direction represented by the start subcarrier index, using 14 bits per index value.
MTU-R downstream operation bands	Indicates in ascending order the pairs of start subcarrier index and stop subcarrier index for each frequency band that shall be assigned to the MTU-R in the downstream direction during initialization. Each index is represented by 13 bits. Up to 2 bands may be defined.

NOTE 1 – If MTU-O is part of the vectored group, only the value currently used by the active lines of the vectored group shall be indicated. In case no vectored group is established, the MTU-O shall indicate all supported values.

NOTE 2 – The list of IAR bands is compliant with [ITU-T G.9700], the mapping of particular IAR bands to the bits of the field shall be as defined in [ITU-T G.994.1].

NOTE 3 – Except O-P-CHANNEL-DISCOVERY 1-1, for which additional limitations defined in clause 12.3.3.3.3.1 shall apply.

NOTE 4 – The parameter value is set based on internal decision of the VCE and may consider requests from the MTU-Rs from the previous initializations (Field #5 of R-MSG 1).

NOTE 5 – A list of the profiles supported by the MTU-O is available in the DPU-MIB (through the MTUO_PROFILES inventory object). Depending on the profiles enabled in the DPU-MIB (through the PROFILES configuration object), the CL message may indicate support for all or a subset of the profiles supported by the MTU-O.

12.3.2.1.1.1 Short CL messages

For operating modes defined in this Recommendation for which the SPAR(1) bit is set to ONE in a CL message, the MTU-O is allowed to include only the NPAR(2) information, and not include the SPAR(2) and NPAR(3) information. If MTU-O does not include SPAR(2) and NPAR(3) information for at least one operating mode, it shall not include it for all operating modes defined in this Recommendation (i.e., no partial SPAR(2)/NPAR(3)).

In order to assure that the necessary capabilities information is exchanged prior to an MS message transaction, the MTU-O transmitting a short CL message shall (in a subsequent transaction and prior to the MS message transaction) send an additional CL message containing the complete NPAR(2), SPAR(2) and NPAR(3) information for all operating modes defined in this Recommendation (see Clause 12.3.2.1.1).

NOTE – It is expected that the MTU-O replies to a short capabilities list request (CLR) with a short CL.

12.3.2.1.2 MS messages

An MTU-O selecting the ITU-T G.9711 mode of operation in an ITU-T G.994.1 mode select (MS) message shall set to ONE the ITU-T G.9711 SPar(1) bit as defined in Table 11.0.5 of [ITU-T G.994.1]. The NPar(2) (Table 11.71 of [ITU-T G.994.1]) and SPar(2) (Table 11.72 of [ITU-T G.994.1]) fields corresponding to this bit are defined in Table 12-12 and Table 12-13, respectively. For each ITU-T G.9711 SPar(2) bit set to ONE, a corresponding NPar(3) field shall also be present (beginning with Table 11.72.1 in clause 9.4 of [ITU-T G.994.1]). Table 12-14 shows the definitions and coding for the MTU-O MS NPar(3) fields.

Table 12-12 – MTU-O MS message NPar(2) bit definitions

ITU-T G.994.1 NPar(2) bit	Definition of NPar(2) bit
Default CE length	Set to ONE if and only if this bit is set to ONE in both the last previous CLR message and the last previous CL message. If set to ONE, both the MTU-O and the MTU-R shall use the default CE length $L_{CP} = m \times N/64$, where $m = 10$ and the CE length SPar(2) bit shall be set to ZERO.
Default number of symbol periods in PDX frame	Set to ONE if and only if this bit is set to ONE in both the last previous CLR message and the last previous CL message. If set to ONE, both the MTU-O and the MTU-R shall use the default M_F value 36 and the number of symbol periods in PDX frame SPar(2) bit shall be set to ZERO.

Table 12-13 – MTU-O MS message SPar(2) bit definitions

ITU-T G.994.1 SPar(2) bit	Definition of SPar(2) bit
Profiles	Always set to ONE.
DS transmission band	Always set to ZERO.
Number of symbol positions in downstream PSF	Always set to ZERO.
RFIBANDS	Always set to ZERO.
Duration of Channel Discovery 1-1	Always set to ZERO.
CE length	Shall be set to ONE if and only if this bit is set to ONE in both the last previous CLR message and the last previous CL message, and the

Table 12-13 – MTU-O MS message SPar(2) bit definitions

ITU-T G.994.1 SPar(2) bit	Definition of SPar(2) bit
	default CE length NPar(2) bit is set to ZERO in this MS message. If set to ONE, indicates that the CE length multiplier to be used by both the MTU-O and the MTU-R shall be communicated in the corresponding CE length multiplier NPar(3) field. If set to ZERO, the default CE length $L_{CP} = m \times N/64$, where $m = 10$ shall be used.
Number of symbol periods in PDX frame	Shall be set to ONE if and only if this bit is set to ONE in both the last previous CLR message and the last previous CL message and the default number of symbol periods in PDX Frame NPar(2) bit is set to ZERO in this MS message. If set to ONE, indicates that the number of symbol periods in a PDX frame to be used by both the MTU-O and the MTU-R shall be communicated in the corresponding NPar(3) field. If set to ZERO, the default M_F value 36 shall be used.
IARBANDS	Always set to ZERO.
Scrambler seed	Always set to ZERO.
IDS	Always set to ZERO.
Number of SOC symbol repetitions (R_S)	Always set to ZERO.
Number of initialization data symbols in downstream PSF (s_{ds})	Always set to ZERO.
Downstream RMC offset	Always set to ZERO.
CD time out	Always set to ZERO
DTFO downstream Band 1 start sub-carrier	Always set to ZERO
MTU-R downstream operation bands	Always set to ZERO

Table 12-14 – MTU-O MS message NPar(3) bit definitions

ITU-T G.994.1 SPar(2) bit	Definition of NPar(3) bits
Profiles	Each valid profile is represented by one bit in a field of 8 bits. The valid profiles are: P424a, P424amp, P424d, P424dmp, Q424c, Q424cmp, Q424d and Q424dmp. The profile selected by the MTU-O is indicated by setting its corresponding bit to ONE.
CE length multiplier	Each bit of this 9-bit field represents a CE length multiplier *m*, excluding the default value 10 (see clause 10.4.4). The MTU-O shall indicate the selected CE length multiplier by setting the corresponding bit to ONE. All other bits in this 9-bit field shall be set to ZERO. The selected CE length multiplier shall be a CE length multiplier that was indicated as a supported value in both the last previous CLR message and the last previous CL message.
Number of symbol	Each bit of this 6-bit field represents an MF value other than 36. The MTU-O shall indicate the selected M_F value by setting the corresponding bit to ONE. All

Table 12-14 – MTU-O MS message NPar(3) bit definitions

ITU-T G.994.1 SPar(2) bit	Definition of NPar(3) bits
periods in PDX frame	other bits of this 6-bit field shall be set to ZERO. The selected M_F value shall be an MF value that was indicated as a supported value in both the last previous CLR message and the last previous CL message.

12.3.2.2 Handshake – MTU-R

An MTU-R, after power-up, loss of signal or recovery from errors during the initialization procedure, shall enter the initial ITU-T G.994.1 handshake state, R-SILENT0 (see [ITU-T G.994.1]). The MTU-R may activate the link by transitioning to transmission of R-TONES-REQ. Operation shall then continue in accordance with the procedures defined in [ITU-T G.994.1]. In case MTU-R is joining in P2MP mode, it shall apply the collision control protocol defined in Annex D of [ITU-T G.994.1].

If the ITU-T G.994.1 procedures select this Recommendation as the mode of operation, the MTU-R shall continue with the initialization at the completion of the ITU-T G.994.1 handshake phase, as defined in clause 12.3.3 and clause 12.3.4.

12.3.2.2.1 CLR messages

An MTU-R indicates its ITU-T G.9711 capabilities in an ITU-T G.994.1 CLR message by setting to ONE the ITU-T G.9711 SPar(1) bit as defined in Table 11.0.5 of [ITU-T G.994.1]. The NPar(2) (Table 11.71 of [ITU-T G.994.1]) and SPar(2) (Table 11.72 of [ITU-T G.994.1]) fields corresponding to the ITU-T G.9711 SPar(1) bit are defined in Table 12-15 and Table 12-16, respectively. For each ITU-T G.9711 SPar(2) bit set to ONE, a corresponding NPar(3) field shall also be present (beginning with Table 11.72.1 in clause 9.4 of [ITU-T G.994.1]). Table 12-17 shows the definitions and coding for the MTU-R CLR NPar(3) fields.

The MTU-R shall indicate a capability in the CLR message if and only if the capability is supported by the MTU-R.

Table 12-15 – MTU-R CLR message NPar(2) bit definitions

ITU-T G.994.1 NPar(2) bit	Definition of NPar(2) bit
Default CE length	Always set to ONE. Indicates that the MTU-R supports the use of the default CE length $L_{CP} = m \times N/64$, where $m = 10$.
Default number of symbol periods in PDX frame	Always set to ONE. Indicates that the MTU-R supports the use of the default M_F value of 36.

Table 12-16 – MTU-R CLR message SPar(2) bit definitions

ITU-T G.994.1 SPar(2) bit	Definition of SPar(2) bit
Profiles	Always set to ONE.
DS transmission band	Always set to ZERO.
Number of symbol positions in the downstream PSF	Always set to ZERO.
RFIBANDS	Always set to ZERO.
Duration of Channel Discovery 1-1	Always set to ONE.
CE length	If set to ZERO, indicates that the MTU-R supports only the default CE length $L_{CP} = m \times N/64$, where $m = 10$. If set to ONE, indicates that the MTU-R supports valid CE lengths in addition to the default value, as indicated in the corresponding CE length multiplier NPar(3) field.
Number of symbol periods in PDX frame	Always set to ONE. Indicates that the MTU-R supports other valid M_F values (mandatory or optional) in addition to the default value of 36, as indicated in the related NPar(3).
IARBANDS	Always set to ZERO.
Scrambler seed	Always set to ZERO.
IDS	Always set to ZERO.
Number of SOC symbol repetitions (R_S)	Always set to ZERO.
Number of initialization data symbols in downstream PSF (s_{ds})	Always set to ZERO.
Downstream RMC offset	Always set to ZERO
CD time out	Always set to ZERO
DTFO downstream Band 1 start sub-carrier	Always set to ZERO.
MTU-R downstream operation bands	Always set to ZERO

Table 12-17 – MTU-R CLR message NPar(3) bit definitions

ITU-T G.994.1 SPar(2) bit	Definition of NPar(3) bits
Profiles	Each valid profile is represented by one bit in a field of 8 bits. The valid profiles are: P424a, P424amp, P424d, P424dmp, Q424c, Q424cmp, Q424d and Q424dmp. Each profile supported by the MTU-R is indicated by setting its corresponding bit to ONE (Note).
Duration of Channel Discovery 1-1	This 8-bit field indicates the minimum duration of the Channel Discovery 1-1 stage expressed in multiple of 8 192 symbol periods with cyclic extension requested by the MTU-R. The valid values are from 1 to 16. The MTU-O shall round up the time to the nearest superframe.
CE length multiplier	Each bit of this 9-bit field represents a CE length multiplier *m*, excluding the default value 10 (see clause 10.4.4). For each CE length multiplier that the MTU-R supports, the corresponding bit shall be set to ONE.
Number of symbol periods in PDX frame	Each bit of this 6-bit field represents an M_F value other than 36; specifically bit 1 shall be set to ONE indicating the MTU-R supports the M_F value 23. Other bits in this 6-bit field are reserved by ITU-T and shall be set to ZERO.
NOTE – A list of the profiles supported by the MTU-R is available in the DPU-MIB as MTUR_PROFILES inventory information.	

12.3.2.2.1.1 Short CLR messages

For operating modes defined in this Recommendation for which the SPAR(1) bit is set to ONE in a CLR message, the MTU-R is allowed to include only the NPAR(2) information, and not include the SPAR(2) and NPAR(3) information. If MTU-R does not include SPAR(2) and NPAR(3) information for at least one operating mode, it shall not include it for all operating modes defined in this Recommendation (i.e., no partial SPAR(2)/NPAR(3)).

In order to assure that the necessary capabilities information is exchanged prior to an MS message transaction, the MTU-R transmitting a short CLR message shall (in a subsequent transaction and prior to the MS message transaction) send an additional CLR message containing the complete set of NPAR(2), SPAR(2) and NPAR(3) information for all operating modes defined in this Recommendation (see Clause 12.3.2.2.1).

Additionally, to decrease the duration of the G.994.1 session, this additional CLR message shall have the SPAR(1) bit set to ZERO for all operating modes defined in this Recommendation which are outside the intersection of operating modes enabled in the CL and CLR messages sent previously.

12.3.2.2.2 MS messages

An MTU-R selecting the ITU-T G.9711 mode of operation in an ITU-T G.994.1 MS message shall set to ONE the ITU-T G.9711 SPar(1) bit as defined in Table 11.0.5 of [ITU-T G.994.1]. The NPar(2) (Table 11.71 of [ITU-T G.994.1]) and SPar(2) (Table 11.72 of [ITU-T G.994.1]) fields corresponding to the ITU-T G.9711 SPar(1) bit are defined in Table 12-18 and Table 12-19, respectively. For each ITU-T G.9711 SPar(2) bit set to ONE, a corresponding NPar(3) field shall also be present (beginning with Table 11.72.1 in clause 9.4 of [ITU-T G.994.1]). Table 12-20 shows the definitions and coding for the MTU-R MS NPar(3) fields.

Table 12-18 – MTU-R MS message NPar(2) bit definitions

ITU-T G.994.1 NPar(2) bit	Definition of NPar(2) bit
Default CE length	Set to ONE if and only if this bit is set to ONE in both the last previous CLR message and the last previous CL message. If set to ONE, both the MTU-O and the MTU-R shall use the default CE length $L_{CP} = m \times N/64$, where $m = 10$ and the CE length SPar(2) bit shall be set to ZERO.
Default number of symbol periods in PDX frame	Set to ONE if and only if this bit is set to ONE in both the last previous CLR message and the last previous CL message. If set to ONE, both the MTU-O and the MTU-R shall use the default M_F value 36 and the number of symbol periods in PDX frame SPar(2) bit shall be set to ZERO.

Table 12-19 – MTU-R MS message SPar(2) bit definitions

ITU-T G.994.1 SPar(2) bit	Definition of SPar(2) bit
Profiles	Always set to ONE.
DS transmission band	Always set to ZERO.
Number of symbol positions in downstream PSF	Always set to ZERO.
RFIBANDS	Always set to ZERO.
Duration of Channel Discovery 1-1	Always set to ZERO.
CE length	Shall be set to ONE if and only if this bit is set to ONE in both the last previous CLR message and the last previous CL message. If set to ONE, indicates that the CE length multiplier to be used by both the MTU-O and the MTU-R shall be communicated in the corresponding CE length multiplier NPar(3) field. If set to ZERO, the default CE length $L_{CP} = m \times N/64$, where $m = 10$ shall be used.
Number of symbol periods in PDX frame	Shall be set to ONE if and only if both the last previous CLR and the last previous CL messages have set this bit to ONE. If set to ONE, indicates that the number of symbol periods in PDX frame to be used by both the MTU-O and the MTU-R shall be communicated in the corresponding NPar(3) field. If set to ZERO, the mandatory value of $M_F = 36$ shall be used.
IARBANDS	Always set to ZERO
Scrambler seed	Always set to ZERO
IDS	Always set to ZERO
Number of SOC symbol repetitions (R_S)	Always set to ZERO
Number of initialization data symbols in downstream PSF (s_{ds})	Always set to ZERO
Downstream RMC offset	Always set to ZERO
CD time out	Always set to ZERO

Table 12-19 – MTU-R MS message SPar(2) bit definitions

ITU-T G.994.1 SPar(2) bit	Definition of SPar(2) bit
DTFO downstream Band 1 start sub-carrier	Always set to ZERO
MTU-R downstream operation bands	Always set to ZERO

Table 12-20 – MTU-R MS message NPar(3) bit definitions

ITU-T G.994.1 SPar(2) bit	Definition of NPar(3) bits
Profiles	Each valid profile is represented by one bit in a field of 6 bits. The valid profiles are: 106a, 106b and 212a. The profile selected by the MTU-R is indicated by setting its corresponding bit to ONE.
CE length multiplier	Each bit of this 9-bit field represents a CE length multiplier *m*, excluding the default value 10 (see clause 10.4.4). The MTU-R shall indicate the selected CE length multiplier by setting the corresponding bit to ONE. All other bits in this 9-bit field shall be set to ZERO. The selected CE length multiplier shall be a CE length multiplier that was indicated as a supported value in both the last previous CLR message and the last previous CL message.
Number of symbol periods in PDX frame	Each bit of this 6-bit field represents an M_F value other than 36. The MTU-R shall indicate the selected M_F value by setting the corresponding bit to ONE. All other bits of this 6-bit field shall be set to ZERO. The selected M_F value shall be an M_F value that was indicated as a supported value in both the last previous CLR message and the last previous CL message.

12.3.3 Channel discovery phase

12.3.3.1 Overview

The channel discovery phase is the first phase when the ITU-T G.9711 signals are exchanged between MTUs. The following tasks are completed during the channel discovery phase:

- Cancelling FEXT and NEXT from joining lines into active lines;
- Timing recovery and selection of pilot tone(s);
- Establishing communication between the MTU-O and MTU-R over the SOC;
- Exchange information necessary to set up and adjust modulation parameters (transmit PSD, window length, timing advance, and others)
- Selection of blackout subcarriers
- Cancelling FEXT and NEXT into joining lines
- Setting up optimized PSDs for both FDS and FUS in both transmission directions

The channel discovery phase consists of several stages, all described in the following clauses.

The following convention is used for the naming of stages of initialization and initialization signals:

– Stages of initialization are named XXX or O-XXX or R-XXX (e.g., O-VECTOR 1)
– Initialization signals are named O-P-XXX or R-P-XXX (e.g., O-P-VECTOR 1)

To synchronize different stages of the procedure (i.e., get stages of the initialization synchronously initiated and terminated at both MTU-O and MTU-R), MTU-O sends O-P-SYNCHRO signals. The content of the O-P-SYNCHRO signals is defined in clauses 12.3.3.3.3 – 12.3.3.3.10 and 12.3.4.3 (for O-P-SYNCHRO 6).

Figure 12-8 shows the details of the early stages of channel discovery phase, specifically the O-VECTOR 1, CHANNEL DISCOVERY 1-1, CHANNEL DISCOVERY 1 and EC TRAINING 1 stages.

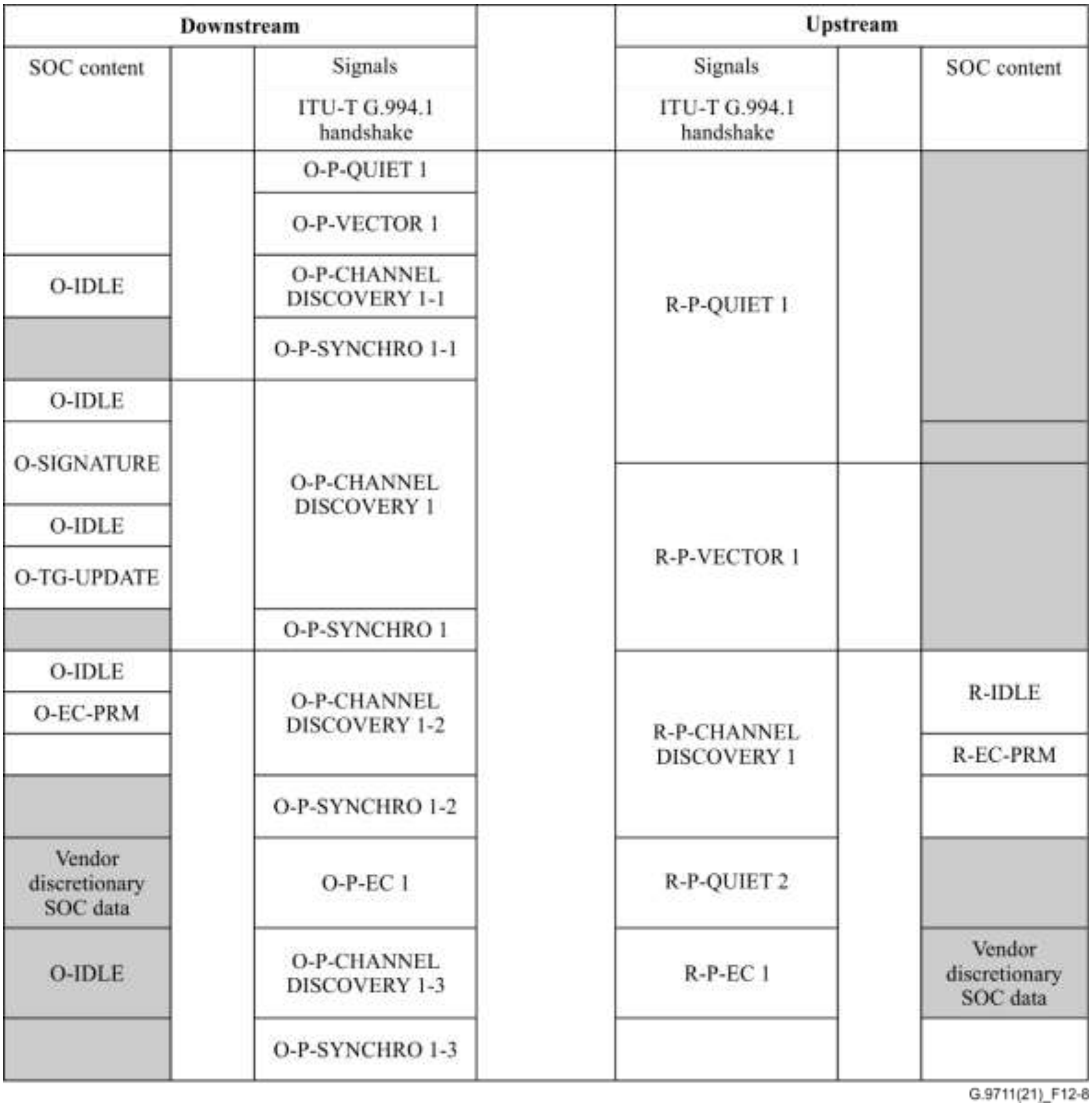


Figure 12-8 – The details of early stages of the channel discovery phase

Figure 12-9 shows the details of the later stages of channel discovery phase, specifically the CHANNEL DISCOVERY 2, R-VECTOR 1-1, EC TRAINING 1-1, VECTOR 2 and PARAMETER UPDATE stages.

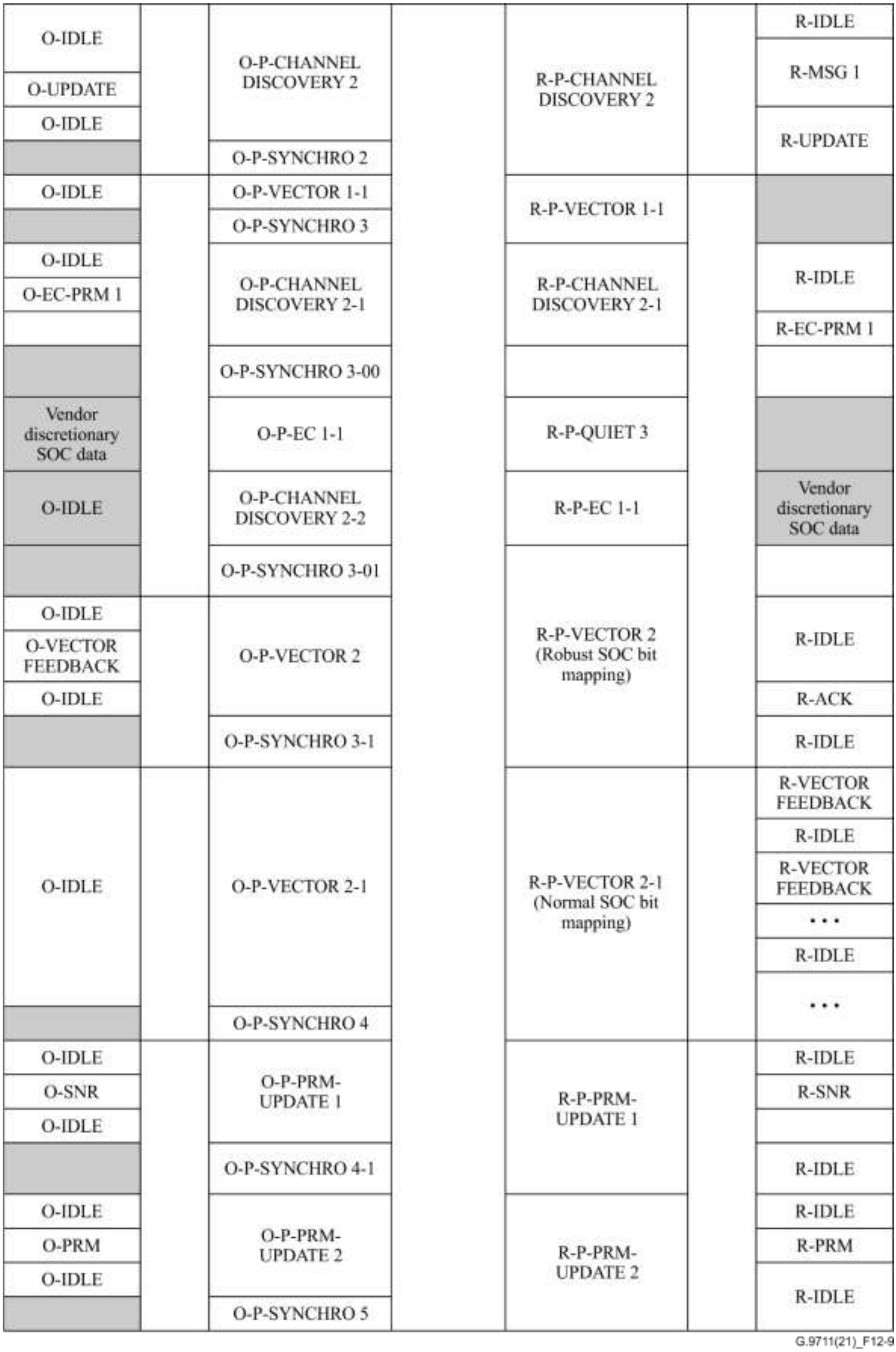


Figure 12-9 – The details of the later stages of the channel discovery phase

The detailed descriptions of the SOC messages exchanged and signals transmitted are presented in clauses 12.3.3.2 and 12.3.3.3, respectively.

12.3.3.1.1 O-VECTOR 1 stage

The MTU-O transmits a probe sequence over joining lines. Sync symbols are transmitted with non-zero power in both FDS and FUS if either the FDXC or the FDXZ framing mode is used. Sync symbols are transmitted with non-zero power only in FDS if the TDD framing mode is used.

NOTE 1 – During this stage, the VCE may estimate downstream FEXT channel couplings and O-NEXT (NEXT from one MTU-O to another MTU-O) channel couplings from the joining lines into active lines. After transmission of one or more probe sequences, the VCE may compute the new downstream precoder coefficients and obtain NEXT canceller coefficients for cancelling crosstalk from joining line(s) into active lines. Based on the computed precoder coefficients and NEXT coefficients, the VCE may also compute for all active lines their new gains and bit loadings, and decide on the PSD of the joining line to be used during next stages of initialization. The probe sequence used during this stage is determined by the VCE and not communicated to the MTU-R. To the end of this stage the joining MTU-O can transmit both sync symbols and data symbols in both FDS and FUS (its O-NEXT and FEXT into active lines are cancelled).

NOTE 2 – The MTU-O of the joining line may also preliminarily train its own echo canceller and its own NEXT canceller. Thus, the joining MTU-O is ready to receive data symbols (the NEXT from active lines and its own echo are cancelled for the receiver AFE settings).

The duration of O-VECTOR 1 is determined by the MTU-O. The MTU-R during this stage is in QUIET mode (no transmission). The minimum duration shall be at least 8 superframes, to allow the receiver, if desired, to synchronize properly its superframe timing already during this stage.

12.3.3.1.2 CHANNEL DISCOVERY 1-1 stage

The MTU-O continues transmission of sync symbols modulated by probe sequences in both FDS and FUS if either the FDXC or the FDXZ framing mode is used, and in FDS only if otherwise. The MTU-O also transmits SOC symbols in FDS only over the first $s_{ds\text{-}CD\text{-}1\text{-}1}$ (see clause 12.3.3.3.3.1) symbol positions (in FDS only) of each downstream logical frame counting only positions inside FDS (starting from the symbol position with index 0). The SOC is active during this stage and shall transmit O-IDLE. The SOC quadrant scrambler operates in reset mode.

The MTU-R is silent during this stage.

NOTE – This stage is intended for the MTU-R to acquire loop timing, including clock recovery, and symbol and PDX frame boundary alignments. It provides MTU-R with signals of predetermined, symbol-by-symbol repeated content (SOC IDLE) to facilitate good conditions for timing recovery. Sync symbol boundary alignment and initial FEQ training may also be performed at this stage. The precoder is active during this stage for showtime lines among themselves and for joining lines into the showtime lines.

The duration of the stage is determined by the MTU-O during ITU-T G.994.1 handshake and may be based on previous requests from MTU-Rs of joining lines. The MTU-O sends O-P-SYNCHRO 1-1 to indicate the end of the stage.

12.3.3.1.3 CHANNEL DISCOVERY 1 stage

The MTU-O continues transmission of sync symbols modulated by probe sequence over joining lines. Sync symbols are transmitted with non-zero power in both FDS and FUS if either the FDXC or the FDXZ framing mode is used. Sync symbols are transmitted with non-zero power only in FDS if either the TDD or the TDDZ framing mode is used. The MTU-O also transmits SOC symbols in FDS only over the first s_{ds} symbol positions of each downstream logical frame ($s_{ds} \leq M_{ds}$), counting only positions inside FDS.

The SOC is active during this stage; first O-IDLE is transmitted during all downstream SOC symbols of at least eight superframes and then the MTU-O transmits O-SIGNATURE message in AR mode. The O-SIGNATURE message carries a set of parameters that are required for operation of the MTU-R, such as modulation parameters, probe sequences, initial PSD mask and other (see clause 12.3.3.2.1).

To increase robustness, every transmitted SOC symbol shall be repeated R_S times starting from the beginning of the first downstream logical frame of the second superframe of this stage. The number of repetitions, R_S, is communicated to the MTU-R during the ITU-T G.994.1 handshake. Further, each SOC symbol is modulated by a corresponding bit of the IDS (see clause 12.3.2). The IDS is communicated to MTU-R during the ITU-T G.994.1 handshake.

The MTU-R synchronizes with the MTU-O and trains the FEQ. After achieving symbol timing and synchronization to the PDX frame, the MTU-R attempts to decode the O-SIGNATURE. The MTU-R stays silent until it successfully decodes O-SIGNATURE.

NOTE 1 – The SOC signal uses robust bit mapping, repetitions to operate in the presence of strong FEXT and potentially NEXT from active lines since FEXT from active lines into joining lines is not yet cancelled and upstream PSD during FUS in active lines is not yet adjusted. The IDS helps to mitigate crosstalk from other joining lines. In some cases, effectively only low-frequency tones can be used for receiving O-SIGNATURE. To further improve reception of downstream signals, the VCE may, in some cases, temporary reduce transmit PSD or even turn off upstream transmission in active lines at least during the mentioned s_{ds} symbol positions of FDS; the upstream transmission is further recovered at the end of Channel Discovery phase of the initialization.

NOTE 2 – To align upstream transmission of a joining line with active lines, the MTU-O sends to the MTU-R the initial value of the time gap T_{g1}' to be applied between upstream and downstream transmissions. The initial value of the time gap is indicated in O-SIGNATURE message; the time gap is further updated by the MTU-O by O-TG-UPDATE message (see clause 12.3.3.2.2) and O-UPDATE message (see clause 12.3.3.2.6).

NOTE 3 – In O-SIGNATURE, the MTU-O also sends markers that indicate time position of downstream and upstream probe sequences in active lines.

Upon decoding of O-SIGNATURE message, the MTU-R synchronizes to upstream and downstream probe sequences, applies parameter settings obtained from O-SIGNATURE message, and transitions to R-VECTOR 1 stage.

12.3.3.1.4 R-VECTOR 1 stage

After detection of R-P-VECTOR 1, the MTU-O shall stop transmitting O-SIGNATURE message and start transmission of O-IDLE.

The MTU-O shall estimate the correction to the initial value of the time gap T_{g1}' and communicate the updated time gap T_{g1}' to the MTU-R in the O-TG-UPDATE message. The MTU-O transmits the O-TG-UPDATE message in AR mode. The value of the time gap T_{g1}' is in the range indicated in clause 10.5 and depends on the used PDX framing type. In O-TG-UPDATE message the MTU-O may also indicate the fallback to TDD framing mode from FDXC framing mode or to TDDZ framing mode from FDXZ framing mode. In the case the fallback is indicated, the transmission line continues initialization in TDD or TDDZ framing mode. When the transmission line fallbacks to TDDZ, the value of M_{ds} is reduced by 1 from the value indicated in G.994.1 (see clause 10.5.3.1).

NOTE 1 – The decision to the fallback may be based (among others) on the observed propagation delay and the value of the CE.

The downstream SOC is active and continues transmission of the O-TG-UPDATE message until the MTU-O receives sufficient amount of upstream sync symbols and is ready to end this stage.

The MTU-R transmits FUS sync symbols only modulated by probe sequence. The transmission shall be according to the framing mode derived from the duplexing mode of the profile negotiated during G.994.1 and the value of *s* (see clause 10.5). The content of probe sequence, its time position and other transmission parameters shall be those received in O-SIGNATURE.

NOTE 2 – During this stage, before the upstream symbol alignment becomes sufficiently accurate, upstream FEXT channel estimation might not be necessarily used by the MTU-O to estimate an accurate time gap T_{g1}'.

NOTE 3 – MTU-R transmits sync symbols in FUS only because upstream timing is not yet adjusted when R-P-VECTOR 1 starts and thus upstream sync symbols sent during FDS may, in some cases, disturb downstream data.

Upon receiving the O-TG-UPDATE message, the MTU-R shall transmit FUS sync symbols modulated by probe sequence using the updated value of the time gap T_{g1}' received from the MTU-O in the O-TG-UPDATE message. The MTU-R shall also fall back to TDD or TDDZ framing mode if requested in O-TG-UPDATE.

NOTE 4 – During this stage, after the upstream symbol alignment becomes sufficiently accurate after its update via O-TG-UPDATE message, the VCE estimates upstream FEXT channels from the joining lines into all active lines, and from all active lines into all joining lines, and between joining lines. VCE also estimates the direct channel of other joining lines and updates the NEXT channel estimates at the MTU-O side. Further, the VCE estimates (or re-estimates) the NEXT channels from the MTU-Rs of joining lines into active lines operating in FDX mode. This estimation helps to determine the first MTU-R PSD limitation during FDS transmission, applicable for FDX lines. The adjustment of this limitation for TDD lines (if present in the binder), is available during R-VECTOR 1-1 stage.

After transmission of one or more probe sequences, the VCE may compute the upstream post-canceller coefficients for active lines and for joining lines (to cancel FEXT between all active lines and joining line(s)), update the NEXT coefficients at the DPU (to cancel NEXT from all joining lines into all active lines), and measure NEXT coupling from the MTU-Rs of joining lines into MTU-Rs of active lines. The necessary receiver gains for the joining lines and receiver gain update for active lines are established.

The MTU-O signals the completion of this stage by sending to the MTU-R an O-P-SYNCHRO 1 signal. After completion of this stage, joining lines can transmit upstream SOC symbols without disturbing transmission over active lines and crosstalk into joining lines is cancelled in the upstream direction.

R-VECTOR 1 stage is performed at the same time as the Channel Discovery 1 stage (see Figure 12-8).

12.3.3.1.5 EC TRAINING 1 stage

This stage is intended to train the MTU-R echo canceler (EC) and adjust the MTU-O echo canceller after updated values of the time gap T_{g1}' determined in O-TG-UPDATE message are applied.

The MTU-O and MTU-R exchange messages O-EC-PRM and R-EC-PRM containing parameters related to EC, including the time for EC training and the upstream probe sequences to be used during the MTU-R EC training. The probe sequences in this stage used by the MTUs in joining lines and corresponding probe sequences in active lines are structured in a way that it speeds up EC training (e.g., if only one of joining lines transmits -1 or +1 elements, while other joining lines and all active lines transmit 0-elements). The O-EC-PRM message also indicates to the MTU-R the probe sequences to be used and the upstream PSD to be applied in NPSF if line continues in FDX mode (this adjustment addresses operation with FDX lines in the same binder). Both messages are sent in AR mode.

To facilitate MTU-O EC and NEXT canceller training, the MTU-R stays quiet during the time period indicated in O-EC-PRM message. Further, the MTU-R applies the assigned probe sequence and runs it at least during the time period indicated in R-EC-PRM message. After that time period the MTU-O sends O-P-SYNCHRO 1-3, which indicates transition into O-P-Channel Discovery 2 stage.

NOTE – Transmission of the upstream SOC during FUS in R-P-EC 1 signal and of the downstream SOC during FDS in O-P-EC 1 signal is useful for applications with no crosstalk (e.g., coax); it gives the MTU-R and MTU-O more opportunities to train its EC. The content of SOC during these transmissions is vendor discretionary.

In case the line is initialized in TDD framing mode or TDD fall-back was requested during R-VECTOR 1 stage, this stage is skipped.

12.3.3.1.6 CHANNEL DISCOVERY 2 stage

The MTU-O continues transmission of sync symbols modulated by a probe sequence. Sync symbols are transmitted in both FDS and FUS if the FDXC or FDXZ framing mode is used. Sync symbols are transmitted with non-zero power only in FDS if either the TDD or the TDDZ framing mode is used. The MTU-O also continues transmission of SOC symbols over the first s_{ds} symbol positions of each downstream logical frame counting only positions inside FDS; no SOC symbols are transmitted in FUS.

The MTU-R transmits sync symbols modulated by a probe sequence. Sync symbols are transmitted in FUS and FDS if either the FDXC or FDXZ framing mode is used. Sync symbols are transmitted only in FUS if either the TDD or the TDDZ framing mode is used. The MTU-R also continues transmission of SOC symbols in FUS only over the first s_{us} symbol positions of each upstream logical frame ($s_{us} \leq M_{us}$) counting only positions in FUS; no SOC symbols are transmitted in FDS.

The SOC is active in both upstream and downstream; at the start of the stage both MTU-O and MTU-R transmits O-IDLE and R-IDLE, respectively. After transmission of R-IDLE, the MTU-R transmits R-MSG 1 message that, besides other parameters, communicates to the MTU-O the local estimate of the electrical length, and other relevant parameters, including transmit PSD limits in both FDS and FUS (see clause 12.3.3.2.5). The MTU-O acknowledges the reception of R-MSG 1 message by transmitting an O-UPDATE message that determines the final value of the electrical length, the final correction of time gap T_{g1}', and the upstream PSD adjustments (see clause 12.3.3.2.6). The MTU-R acknowledges reception of O-UPDATE message by sending a R-UPDATE message and continues transmission of R-IDLE until the end of the stage.

The MTU-O determines the duration of the CHANNEL DISCOVERY 2 stage and signals the completion of this stage by sending an O-P-SYNCHRO 2 signal.

12.3.3.1.7 R-VECTOR 1-1 stage

During R-VECTOR 1-1 stage the MTU-O continues transmission of sync symbols. Downstream sync symbols are transmitted in both FDS and FUS if the FDXC or FDXZ framing mode is used. Downstream sync symbols are transmitted with non-zero power only in FDS if either the TDD or the TDDZ framing mode is used. The MTU-O also continues transmission of O-IDLE over the SOC (over FDS only). The MTU-R transmits only sync symbols modulated by probe sequence in both FUS and FDS. Upstream sync symbols are transmitted in both FDS and FUS if the FDXC or FDXZ framing mode is used. Upstream sync symbols are transmitted with non-zero power only in FUS if either the TDD or the TDDZ framing mode is used. Upstream sync symbols are transmitted using the updated values of the time gap T_{g1}' and updated values of the transmit PSD, based on the information received from the MTU-O in the O-UPDATE message.

NOTE – During this stage, the VCE may repeat the procedures used during the R-VECTOR 1 stage to accommodate a new value of T_{g1}' and upstream PSD, and:

– may estimate crosstalk between all active and all joining lines;

– may compute updates of post-canceller coefficients;

– may compute updates of NEXT canceller and echo canceller coefficients at the DPU side;

– may update the measurements of NEXT coupling from joining lines into active lines at the CPE side.

At the end of the stage, post-canceller coefficients, FEQ gains and bit loading (except joining lines) are updated for all active and joining lines.

The MTU-O determines the duration of the R-VECTOR 1-1 stage and signals the completion of this stage by sending an O-P-SYNCHRO 3 signal.

12.3.3.1.8 EC TRAINING 1-1 stage

This stage is intended to update ECs of the MTU-O and MTU-R after the updated values of the transmit PSDs, based on the information received from the MTU-O in the O-UPDATE message, are applied.

The MTU-O and MTU-R exchange messages O-EC-PRM-1 and R-EC-PRM-1 containing parameters related to EC, including the time for EC training and the upstream probe sequences to be used during the MTU-R EC training. These probe sequences used by the MTUs in both active lines and joining lines are structured in the way that it speeds up EC training (e.g., if only one of joining lines transmits -1 or +1 elements, while other joining lines and all active lines transmit 0-elements). The O-EC-PRM message also indicates to the MTU-R the adjustment to the upstream PSD to be applied in NPSF if transmission line continues in FDX mode (this adjustment addresses operation with both FDX and TDD lines in the same binder). Both messages are sent in AR mode.

To facilitate MTU-O EC and NEXT canceller training, the MTU-R stays quiet during the time period indicated in O-EC-PRM-1 message. Further, the MTU-R applies the assigned probe sequences and run at least during the time period indicated in R-EC-PRM-1. After that time period the MTU-O sends O-P-SYNCHRO 3-01, which indicates transition into VECTOR 2 stage.

NOTE – Transmission of upstream SOC during FUS only in R-P-EC 1-1 and downstream SOC during FDS only in O-P-EC 1-1 is useful for applications with no crosstalk (e.g., coax) by giving the MTU-R and MTU-O more opportunities to train its EC. The content of SOC during these transmissions is vendor discretionary.

In case transmission line is initialized in TDD framing mode or TDD fall-back was requested during R-VECTOR 1 stage, this stage is skipped.

12.3.3.1.9 VECTOR 2 stage

The MTU-O continues transmission of sync symbols modulated by probe sequence. Downstream sync symbols are transmitted in both FDS and FUS if the FDXC or FDXZ framing mode is used. Downstream sync symbols are transmitted with non-zero power only in FDS if either the TDD or the TDDZ framing mode is used. The MTU-O also transmits SOC symbols in FDS only over the first s_{ds} symbol positions of each downstream logical frame counting only positions in FDS. The SOC is active; the MTU-O first transmits O-IDLE and then MTU-O transmits the O-VECTOR-FEEDBACK message that communicates to the MTU-R the requested parameters of the VF sample report and the new upstream SOC tone repetition rate.

The MTU-R transmits sync symbols modulated by the probe sequence. Upstream sync symbols are transmitted in both FDS and FUS if the FDXC or FDXZ framing mode is used. Upstream sync symbols are transmitted with non-zero power only in FUS if either the TDD or the TDDZ framing mode is used. The MTU-R also transmits SOC symbols in FUS only over the first s_{us} symbol positions in each upstream logical frame (see O-SIGNATURE message in Table 12-21 of clause 12.3.3.2.1) counting only positions in FUS. The SOC is active; the MTU-R first transmits R-IDLE, and upon reception of O-VECTOR-FEEDBACK message, the MTU-R sends an R-ACK message to indicate correct reception of the message. Upon reception of the R-ACK message, the MTU-O transmits an O-P-SYNCHRO 3-1 signal. Upon reception of the O-P-SYNCHRO 3-1 signal, the MTU-R starts transmission of a sequence of R-VECTOR-FEEDBACK messages containing either clipped error samples or DFT output samples with parameters as requested by the MTU-O and with the SOC modulation using the requested upstream SOC tone repetition rate.

NOTE – By using the vectoring feedback, the VCE may estimate downstream crosstalk from the active lines into the joining lines and between joining lines, and computes precoder coefficients to cancel the crosstalk from active lines into the joining lines and between joining lines. Based on the computed precoder coefficients, the VCE may compute for all lines PSD updates, new gains and new bit loading for active lines (if required).

At the end of the stage, the VCE applies precoder coefficients and PSD updates, and updates NEXT cancellation coefficients at the DPU to all active and joining lines. The VCE also measures NEXT coupling between active lines and joining line at the CPE side.

The MTU-O determines the duration of the VECTOR 2 stage and indicates the completion of this stage by sending an O-P-SYNCHRO 4 signal. After completion of this stage, any joining lines can transmit downstream and upstream data symbols without disturbing transmission over active lines and with crosstalk from active lines and other joining lines cancelled.

12.3.3.1.10 PARAMETER UPDATE stage

The MTU-O transmits sync symbols modulated by probe sequence. Downstream sync symbols are transmitted in both FDS and FUS if the FDXC or FDXZ framing mode is used. Downstream sync symbols are transmitted with non-zero power only in FDS if either the TDD or the TDDZ framing mode is used. The MTU-O also transmits SOC symbols in FDS over the first s_{ds} symbol positions of each downstream logical frame counting only FDS positions. In the second part of the PARAMETER UPDATE stage, if either FDXC or FDXZ framing is used, the MTU-O transmits additional SOC symbols in FUS over $s_{ds\text{-}NPSF}$ symbols starting from the symbol position offset by D_{RMCus} positions from the start of FUS ($s_{ds\text{-}NPSF} \leq M_{us}$).

The MTU-R transmits sync symbols modulated by probe sequence. Upstream sync symbols are transmitted in both FDS and FUS if the FDXC or FDXZ framing mode is used. Upstream sync symbols are transmitted with non-zero power only in FUS if either the TDD or the TDDZ framing mode is used. The MTU-R also transmits SOC symbols in FUS over the first s_{us} symbol positions of each upstream logical frame counting only FUS positions. In the second part of the PARAMETER UPDATE stage, if either FDXC or FDXZ framing is used, the MTU-R transmits additional SOC symbols in FDS over $s_{us\text{-}NPSF}$ symbols starting from the symbol position offset by D_{RMCds} positions from the first symbol position of FDS ($s_{us\text{-}NPSF} \leq M_{ds}$).

The upstream transmit PSD in FDX mode is different during FUS and FDS: cutbacks and updates computed during earlier stages are applied in FUS. The downstream transmit PSD is the same during FDS and FUS, since downstream NEXT is cancelled at the DPU.

The stage is divided into two sub-stages using signals O/R-P-PRM-UPDATE 1 and O/R-P-PRM-UPDATE 2. Division into two stages allows applying different downstream SOC settings before and after SNR measurements.

The SOC is active in both directions. First, both MTU-O and MTU-R transmit O-IDLE and R-IDLE, respectively, and then MTU-O and MTU-R exchange SOC messages O-SNR, R-SNR followed by SOC messages O-PRM, R-PRM to update transmission parameters of the MTU-O and the MTU-R that includes the final sets of subcarriers that may be used for transmission (MEDLEYGus, MEDLEYGds), the final PSDs for upstream and downstream (MREFPSDus, MREFPSD_NPus and MREFPSDds), the final sets of blackout subcarriers, and other parameters (see clause 12.3.3.2). From the received MEDLEYGds, MEDLEYGus sets, the MTUs derive their final sets of active subcarriers (MEDLEYds, MEDLEYus, respectively).

NOTE – During this stage, the VCE may compute the necessary updates of PSD and gains for both active lines and joining lines to perform downstream spectrum optimization and upstream spectrum optimization for both FDS and FUS; the obtained adjustments are applied from the beginning of the CA&E phase. For spectrum optimization the VCE may use the channel estimation, precoder coefficients, NEXT coupling coefficients (at both DPU and CPE sides), and SNR values received from the MTU-R. The VCE may also compute the corresponding adjustments in bit loading for all active lines. Implementation of these adjustments may require an OLR in active lines. A time period is assigned at the beginning of the stage for accurate SNR measurement and later for downstream PSD optimization.

The MTU-O terminates this phase by sending O-P-SYNCHRO 5 signal.

12.3.3.2 SOC messages transmitted during channel discovery phase

The SOC message exchange during the channel discovery phase is presented in Figure 12-10, which also shows the main content/tasks of each message. The detailed definition of each message is presented in clauses 12.3.3.2.1 to 12.3.3.2.16.

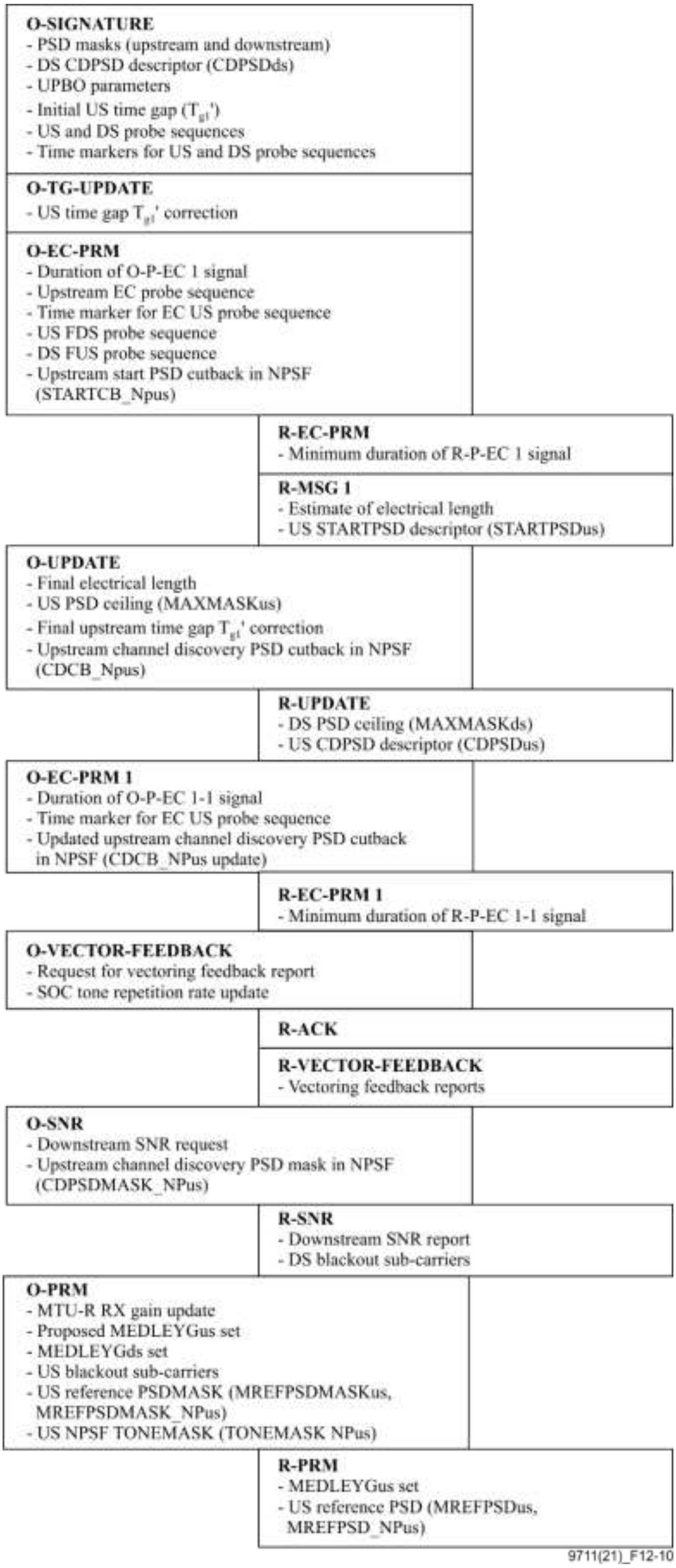


Figure 12-10 – SOC message exchange during the channel discovery phase

12.3.3.2.1 O-SIGNATURE

The O-SIGNATURE message indicates to the MTU-R all main transmission parameters to be used during the initialization.

Table 12-21– O-SIGNATURE message

Field	Field name	Format
1	Message descriptor	Message code
2	Global supported subcarriers in the downstream direction (SUPPORTEDCARRIERSGds set)	Bands descriptor
3	Global supported subcarriers in the upstream direction (SUPPORTEDCARRIERSGus set)	Bands descriptor
4	Downstream transmit PSD mask (PSDMASKds)	PSD descriptor
5	Upstream transmit PSD mask (PSDMASKus)	
6	Channel discovery downstream PSD (CDPSDds)	
7	Parameters for UPBO reference PSD (UPBOPSD)	Three bytes
8	Downstream minimum SNR margin (MINSNRMds)	Two bytes
9	Downstream target SNR margin (TARSNRMds)	Two bytes
10	Downstream transmit window length (β_{ds})	One byte
11	Initial value of the time gap T_{g1}'	Two bytes
12	Upstream probe sequence length ($Nprobe_{us}$)	One byte
13	Upstream FUS probe sequence descriptor	Variable
14	Reference superframe count (CNT_{SF})	Two bytes
15	Downstream probe sequence length ($Nprobe_{ds}$)	One byte
16	Downstream FDS probe sequence descriptor	Variable
17	Time marker indicating the start of upstream probe sequence	Two bytes
18	Time marker indicating the start of downstream probe sequence	Two bytes
19	Number of upstream data symbols (s_{us}) to be used during the initialization	One byte
20	Upstream RMC offset	One byte
21	UPBO reference electrical length (UPBOKLREF)	One byte
22	Number of downstream initialization data symbols for SNR estimation (S_{ds_snr})	One byte
23	Upstream maximum aggregate transmit power (MAXATPus)	Two bytes
24	Transmission timing grid shift (s)	Two bytes
25	Upstream DTFO band 1	Two bytes
26	MTU-R upstream operation band	Bands descriptor
27	Operation according to Annex X	One byte
28	DTFO Band 1 symbol assignment	5 bytes
29	Pilot tone groups used by other MTU-Rs	Tone descriptor
30	Downstream FDX mask (*fdxmaskds*)	Bands descriptor
31	Upstream FDX mask (*fdxmaskus*)	Bands descriptor
32	Downstream RMC carrier mask (RMCCARMASKds)	Bands descriptor

Field 1 "Message descriptor" is a unique one-byte code (00_{16}) that identifies the message. See Table 12-10 for a complete list of codes.

Field 2 "Global supported subcarriers in the downstream direction (SUPPORTEDCARRIERSGds)" conveys indices of all subcarriers that are allocated for transmission in the downstream direction towards all connected MTU-Rs, expressed as a set of bands. Each band is a group of subcarriers from the SUPPORTEDCARRIERSGds set with consecutive indices. The field shall be formatted as "band descriptor", using the format shown in Table 12-22.

Table 12-22 – Bands descriptor

Byte	Content of field
1	Number of bands to be described.
2-5	Bits 0-15: Index of the start subcarrier in band 1 (lowest frequency of band 1). Bits 16-31: Index of the stop subcarrier in band 1 (highest frequency of band 1).
6-9 (if applicable)	Bits 0-15: Index of the start subcarrier in band 2 (lowest frequency of band 2). Bits 16-31: Index of the stop subcarrier in band 2 (highest frequency of band 2).
etc.	etc.
NOTE – All values shall be coded as unsigned integers.	

The first byte of the descriptor shall contain the number of bands being specified. This number can be within the range from one to 32. Each group of four consecutive bytes shall describe the start and the stop subcarrier index of the band, both within the range from 43 to 8191.

For P2P initialization, the actual downstream supported carrier set (SUPPORTEDCARRIERSds) equals SUPPORTEDCARRIERSGds. In case of P2MP initialization, the actual downstream supported carrier set (SUPPORTEDCARRIERSds) corresponds to only those subcarriers from the SUPPORTEDCARRIERSds-G set that belongs to the downstream operation band of the joining MTU-R indicated during the G.994.1 handshake.

Field 3 "Global supported subcarriers in the upstream direction (SUPPORTEDCARRIERSGus)" conveys indices of all subcarriers that are allocated for transmission in the upstream direction by all connected MTU-Rs, expressed as a set of bands. Each band is a group of subcarriers from the SUPPORTEDCARRIERSGus set with consecutive indices. The field shall be formatted as "bands descriptor", using the format shown in Table 12-22.

For P2P initialization, the actual upstream supported carrier set (SUPPORTEDCARRIERSus) equals SUPPORTEDCARRIERSGus. In case of P2MP initialization, the actual upstream supported carrier set (SUPPORTEDCARRIERSus) includes only those subcarriers from the SUPPORTEDCARRIERSGus set that belongs to the upstream operation band of the joining MTU-R indicated in field 26.

Field 4 "Downstream transmit PSD mask (PSDMASKds)", indicates the PSD mask that is allowed in the downstream direction expressed as a set of breakpoints. The "PSD descriptor" format specified in Table 12-23 shall be used.

Table 12-23 – PSD descriptor

Byte	Content of field
1	Number of breakpoints being described.
2-5	Bits 0-15: Subcarrier index of the first breakpoint being described (lowest frequency). Bits 16-31: PSD level in steps of 0.1 dB with an offset of −140 dBm/Hz.
6-9	Bits 0-15: Subcarrier index of second breakpoint being described. Bits 16-31: PSD level in steps of 0.1 dB with an offset of −140 dBm/Hz.
etc.	etc.
NOTE 1 – The breakpoints shall be listed in ascending order of subcarriers indices. NOTE 2 – All values shall be coded as unsigned integers.	

The first byte of the descriptor shall contain the number of breakpoints being specified within the range from two to 32. Each group of four consecutive bytes shall describe one breakpoint as a PSD value at a certain subcarrier index. For example, a field value of 03200400_{16} means a PSD of $0320_{16} \times 0.1 - 140 = -60$ dBm/Hz on subcarrier index $0400_{16} = 1\ 024$.

The MTU-O shall comply with the conveyed PSD mask at all times. In addition, MTU-O shall comply with the requirements in the RFI bands and IAR bands determined during the ITU-T G.994.1 handshake phase, as specified in clause 12.3.2.1. The PSD level of intermediate unspecified subcarriers shall be obtained using a linear interpolation between the given PSD points (in dBm/Hz) with the frequency axis expressed in a linear scale.

The specified breakpoints may be either determined by the DPU-MIB or vendor discretionary.

NOTE 1 – Breakpoints should be selected such that the PSD between the breakpoints obtained using linear interpolation is sufficiently close to the PSD that is being described.

Field 5 "Upstream transmit PSD mask (PSDMASKus)" indicates the PSD mask allowed in the upstream direction expressed as a set of breakpoints. The "PSD descriptor" format specified in Table 12-23 shall be used and the number of breakpoints described shall be limited to ≤ 32.

The MTU-R shall comply with the conveyed PSD mask at all times. In addition, MTU-R shall comply with the requirements in the RFI bands and IAR bands determined during the ITU-T G.994.1 handshake phase, as specified in clause 12.3.2.1, and with the UPBO requirements, which may further reduce the upstream transmit PSD, as specified in clause 7.3.1.5.

Field 6 "Channel discovery downstream PSD (CDPSDds)" indicates the PSD at the U reference point in the downstream direction, both in FDS and FUS, during the early stages of the channel discovery phase (see clause 12.3.3.3) using breakpoints. The "PSD descriptor" format specified in Table 12-23 shall be used, and the number of breakpoints being described shall be from 2 to 32. The only valid PSD values obtained by the receiver using the interpolation procedure specified are for those subcarriers that belong to the SUPPORTEDCARRIERSds set, excluding the RFIBANDS and IARBANDS communicated during the ITU-T G.994.1 handshake phase; PSD values out of this set shall be ignored by the receiver. The valid CDPSDds values shall be less than or equal tothe downstream transmit PSD mask (PSDMASKds) (Field 4). The MTU-O shall set the CDPSDds breakpoints such that the valid values of CDPSDds obtained by the receiver either directly or by interpolation do not deviate from the actual values of the transmit PSD, as measured on the reference impedance at the U reference point, by more than 1 dB. If 32 breakpoints are insufficient to describe the entire SUPPORTEDCARRIERSds set, the field shall indicate the CDPSDds starting from the lowest index of the SUPPORTEDCARRIERSds set and cover as much spectrum as possible.

Field 7 "UPBO reference PSD (UPBOPSD)" contains the parameters to compute the reference PSD that shall be used for the calculation of UPBO as specified in clause 7.3.1.5. A set of UPBOPSD parameters (a', b') is defined for the entire upstream band. The values of a' and b' shall be coded as

12-bit unsigned integers and formatted as shown in Table 12-24.

Table 12-24 – UPBOPSD descriptor

Byte	Content of field
1-3	bits 0-11: value of a' bits 12-23: value of b'

The value of a is obtained by multiplying a' by 0.01 and adding it to 40. The range of values for a is between 40 and 80.95. The value of b is obtained by multiplying b' by 0.01. This allows values of b between 0 and 40.95 (see clause 7.3.1.5). In case UPBO shall not be applied, all 12 bits representing values a' and b' shall be set to ZERO (which corresponds to $a = 40$, $b = 0$).

Field 8 "Downstream minimum SNR margin (MINSNRMds)" is the minimum SNR margin the MTU-R shall tolerate. MINSNRMds is used by the MTU-R in the generation of a loss-of-margin (*lom*) defect (see clause 11.3.1.3). The field shall be formatted as a 16-bit unsigned integer with LSB weight of 0.1 dB and a valid range between 0 and 31 dB.

Field 9 "Downstream target SNR margin (TARSNRMds)" indicates the target SNR margin of the MTU-R receiver. This is the SNRM value that the MTU-R receiver shall achieve, or better, to successfully complete the initialization. The format used shall be the same as for field 8.

Field 10 "Downstream transmit window length (β_{ds})" shall contain the length of the downstream transmit window divided by 2, ($\beta_{ds}/2$), where β_{ds} is expressed in samples at the reference sampling rate $2N \times \Delta f$ corresponding to the used IDFT size. The valid values shall be as defined in clause 10.4.4 and coded as an 8-bit unsigned integer.

Field 11 "Initial value of the time gap T_{g1}'" indicates the time gap T_{g1}' to be used by the MTU-R at the start of R-P-VECTOR 1 stage. The value shall be expressed in number of samples at the reference sampling rate ($2N \times \Delta f$) corresponding to the used IDFT size (N). The value shall be coded as a 16-bit 2's complement integer.

NOTE 2 – The initial value of the time gap is determined by the VCE to cover the expected range of the loop length for a particular DP. An initial value that corresponds to maximum expected loop length is recommended.

Field 12 "Upstream probe sequence length ($Nprobe_{us}$)" defines the length of the upstream probe sequence (see clause 10.2.2.1) used on sync symbols in the FUS sub-frame. The valid values of $Nprobe_{us}$ are all multiples of 4 from 4 to 632. The value shall be coded as an 8-bit unsigned integer NPC_{us} using the following rule:

- $Nprobe_{us} = NPC_{us}$, *if* $NPC_{us} \leq 128$
- $Nprobe_{us} = 128 + 4 \times (NPC_{us} - 128)$, if $128 < NPC_{us} \leq 254$

The NPC_{us} value 255 is reserved by ITU-T.

The probe sequence to be used in the FDS sub-frame, if applicable, shall have the same length.

Field 13 "Upstream FUS probe sequence descriptor" defines the probe sequence allocated by the VCE to be modulated on the upstream sync symbols in FUS during in R-VECTOR 1 signal. The format is a binary string of length $2 \times Nprobe_{us}$ bits (see clause 10.2.2.1), with the first element of the probe sequence (element with index zero) mapped on bits [1:0] of the first byte in this field, second element mapped on bits [3:2] of the first byte of this field, etc., and the last element of the probe sequence (element index $Nprobe_{us} - 1$) mapped on the two MSBs of the last byte of the field. The bytes shall be transmitted in the order of increasing indices, i.e., the byte containing the element with index 0 is transmitted first. The length of the field shall be derived from Field 12 as $Nprobe_{us}/4$ bytes. The elements of the probe sequence shall be represented:

00 – for 0

01 – for 1

10 – for −1

11 – invalid.

Field 14 "Reference superframe count" carries the superframe count (CNT_{SF}) of the superframe in which O-P-SYNCHRO 1-1 signal was sent. The count shall be coded as a 16-bit unsigned integer.

Field 15 "Downstream probe sequence length ($Nprobe_{ds}$)" defines the length of the downstream probe sequence (see clause 10.2.2.1) used on sync symbols in the FDS sub-frame. The valid values of $Nprobe_{ds}$ are all multiples of 4 from 4 to 632. The value shall be coded as an 8-bit unsigned integer NPC_{ds} using the following rule:

- $Nprobe_{ds} = NPC_{ds}$, *if* $NPC_{ds} \leq 128$
- $Nprobe_{ds} = 128 + 4 \times (NPC_{ds} - 128)$, if $128 < NPC_{ds} \leq 254$

The NPC_{ds} value 255 is reserved by ITU-T.

The probe sequence to be used in the FUS sub-frame, if applicable, shall have the same length.

Field 16 "Downstream FDS probe sequence descriptor" defines the probe sequence allocated by the VCE to be modulated on the sync symbols in FDS from the beginning of the O-P-CHANNEL DISCOVERY 2 signal. The format is a binary string of length $2 \times Nprobe_{ds}$ bits, with the first element of the probe sequence (element with index 0) mapped on bits [1:0] of the first byte in this field, second element mapped on bits [3:2] of the first byte of this field, etc., and the last element of the probe sequence (element index $Nprobe_{ds} - 1$) mapped on the two MSBs of the last byte of the field. The bytes shall be transmitted in the order of increasing indices, i.e., the byte containing the element with index 0 is transmitted first. The length of the field shall be derived from field 15 as $Nprobe_{ds}/4$ bytes. The elements of the probe sequence shall be represented:

00 – for 0

01 – for 1

10 – for –1

11 – invalid.

Field 17 "Time marker indicating the start of upstream probe sequence" indicates the index of the upstream probe sequence element that would have been transmitted at the superframe in which O-P-SYNCHRO 1-1 signal was sent (assuming that the length of probe sequence is as defined in field 12). The index shall be coded as a 16-bit unsigned integer within the range from 0 to 631.

Field 18 "Time marker indicating the start of downstream probe sequence" indicates the index of the downstream probe sequence element that was transmitted at the superframe in which the O-P-SYNCHRO 1-1 signal was sent (assuming that the length of probe sequence is as defined in field 15). The index shall be coded as a 16-bit unsigned integer within the range from 0 to 631.

Field 19 "Number of upstream data symbols (s_{us}) to be used during the initialization" indicates the value of s_{us} to be used by the MTU-R during the channel discovery phase, as defined in clause 12.3.3.3.5.5. It shall be coded as a 6-bit unsigned integer within the range from 3 to M_{us}.

Field 20 "Upstream RMC offset" indicates the upstream RMC offset (see clause 10.5.1) represented in number of symbols as a 6-bit unsigned integer. The valid range and settings shall comply with the condition described in clause 10.5.1 using the value of M_{ds} indicated in the ITU-T G.994.1 CL message.

Field 21 "UPBO reference electrical length (UPBOKLREF)" contains the kl_{0_REF} parameter for the calculation of UPBO as specified in clause 7.3.1.5.2.2 for the entire upstream band.

The value shall be coded as an 8-bit unsigned integer with a LSB weight of 0.1 dB. The valid range of values is from 0 to 25.5 dB with a 0.1 dB step. The use of the special value 0 is described in clause 7.3.1.5.2.2.

Field 22 "Number of downstream initialization data symbols for SNR estimation (S_{ds_snr})" conveys the number of downstream data symbols in a logical frame that may be used during the initialization for SNR estimation starting from the O-P-PRM-UPDATE 1. The value shall be coded as an 8-bit unsigned integer. The valid range of values is from 4 to 32.

NOTE 3 – The DRA should configure the other showtime lines in the vectoring group to transmit at least $S_{ds\text{-}snr}$ data symbols during the first symbol positions in the downstream logical frame.

Field 23 "Upstream Maximum Aggregate Transmit Power (MAXATPus)" is the maximum value of the aggregate transmit power during initialization and the maximum value of the *ACTATPus* (see clause 11.4.1.5) during showtime that the MTU-R shall be allowed to transmit. The field shall be formatted as a 16-bit signed integer with LSB weight of 0.1 dBm and a valid range from –31 to 31 dBm.

Field 24 "Transmission timing grid shift (s)" is the transmission timing grid shift to be used by the MTU-O and MTU-R to determine the time gap between FDS and FUS (see clause 10.5.4). The value shall be expressed in number of samples at the reference sampling rate corresponding to the used IDFT size. The value shall be coded as a 16-bit unsigned integer. Valid values are from 0 to 16383 for 424MHz profiles. The special value 0 shall be used to indicate that the FDXZ framing mode is applied. Other values are intended for FDXC framing mode.

Field 25 "Upstream DTFO Band 1" indicates the start sub-carrier index of the DTFO band 1. The value is coded as a 16-bits unsigned integer. Value 0 is a special value indicating that the DTFO band 1 is disabled.

Field 26 "MTU-R upstream operation band" indicates to the MTU-R the boundaries of the actual upstream band that joining MTU-R shall use. The operational band consists of up to two sub-bands which start and stop frequencies formatted as a band descriptor shown in Table 12-22. In case the joining MTU-R uses the entire upstream band (e.g., P2P operation or first joining MTU-R to P2MP group) the number of bands described shall be 0.

Field 27 "Operation according to Annex X" indicates to the MTU-R that operation according to Annex X is selected. The value is coded as a single byte. The bit 0 (LSB) shall be set to 1 to indicate operation according to Annex X. Otherwise, it shall bit set to 0. Bits 1 to 7 are reserved by ITU-T and shall be ignored by the MTU-R.

Field 28 "DTFO Band 1 symbol assignment" is determined by the DRA and indicates symbol positions in the superframe occupied by symbols that shall use subcarriers from both DTFO Band 0 and DTFO Band 1 during initialization, while symbols on all other positions of the superframe shall not transmit in DTFO Band 1 and may transmit in DTFO Band 0. The field shall be formatted as defined in Table 12-25.

Table 12-25 – DTFO Band 1 symbol assignment

Field name	Byte	Bits	Description
Upstream DTFO Band 1 symbol assignment	1	[7:5]	Number of symbols with active Band 1 (from 0 to 7)
		[4:0]	Symbol position of the first symbol in the logical frame with active Band 1
	2-4	[23:12]	Logical frames with Band 1 active in the upstream defined as a bit map: – Bit 12 corresponds to the first logical frame of the superframe; – Bit 19 corresponds to the last logical frame of the superframe

Table 12-25 – DTFO Band 1 symbol assignment

Field name	Byte	Bits	Description
			(MF=36); – Bit 23 corresponds to the last logical frame of the superframe (MF=23).
Downstream DTFO Band 1 symbol assignment		[11:0]	Logical frames with Band 1 active in the downstream defined as a bit map: – Bit 0 corresponds to the first logical frame of the superframe; – Bit 7 corresponds to the last logical frame of the superframe (MF=36); – Bit 11 corresponds to the last logical frame of the superframe (MF=23).
	5	[7:5]	Number of symbols with active Band 1 (from 0 to 7)
		[4:0]	Symbol position of the first symbol in the logical frame with active Band 1

All symbols in any superframe, except the symbols residing on the positions of the superframe indicated in Table 12-25, shall use zero transmit power on subcarriers that belong to Band 1.

Field 29 "Pilot tone groups used by other MTU-Rs" indicates subcarriers (one or more groups) that are blocked for use to the MTU-R as those associated with pilot tones used by other MTU-Rs of the P2MP group within the P2MPOB of the joining MTU-R (see clause 10.4.5). , represented in a format of a tone descriptor, as shown in Table 12-26, with a group size equal to the pilot tone group size, *Gp*. These subcarriers are not a part of the MTU-R MEDLEY set.

Table 12-26 – Tone descriptor

Byte	Content of field
1	Number of tone groups (N)
2*k* to 2*k*+1 (Note)	bits 0-12: start sub-carrier index of k^{th} tone group bit 13: reserved by ITU-T. Set to 0 and ignored by receiver. bit 14-15: Group size, coded as $\log_2$(G). Valid values of G=1, 2, 4, 8
NOTE – If the value of N is different from 0, the value of *k* is from 1 (description of tone group 1) to N (description of the last tone group). If N=0 (no tone group in the descriptor), the field is not present.	

The first byte of the tone descriptor shall contain the number of tone groups selected by the MTU-R. If this number is zero, there shall be no further bytes in the descriptor. If the number of tone groups is not equal to zero, each group of two consecutive bytes in the descriptor describes one tone group. Each tone group is specified by a start sub-carrier index, *start_idx*, and a tone group size, *G*. The sub-carriers of the tone group are the *G* sub-carriers with indices from *start_idx* to *start_idx*+*G*-1, inclusive. For example, a field value 9000_{16} means a tone group of size 2^2=4 with *start_idx* = 1000_{16} = 4096, i.e., contains the sub-carriers with indices 4096, 4097, 4098 and 4099.

Field 30 "Downstream FDX mask (*fdxmaskds*)" conveys indices of all subcarriers that are masked in the downstream NPSF but not in the downstream PSF (*fdxmaskds*, see clause 7.3.1) expressed as a set of bands. The field shall be formatted as "band descriptor", using the format shown in Table 12-22. The valid number of bands is from 0 (no subcarrier in *fdxmaskds*) to 2, inclusive.

Field 31 "Upstream FDX mask (*fdxmaskus*)" conveys indices of all subcarriers that are masked in the upstream NPSF but not in the upstream PSF (*fdxmaskus*, see clause 7.3.1) expressed as a set of bands. The field shall be formatted as "band descriptor", using the format shown in Table 12-22.

The valid number of bands is from 0 (no subcarrier in *fdxmaskus*) to 2, inclusive.

Field 32 "Downstream RMC carrier mask (RMCCARMASKds)" conveys the frequency bands (including start and stop frequencies) from which the RTS_{ds} and $RTS\text{-}b_{ds}$ shall not include subcarriers. The field shall be formatted as "band descriptor", using the format shown in Table 12-22. The number of bands shall be zero, one or two.

12.3.3.2.2 O-TG-UPDATE

The O-TG-UPDATE message provides the MTU-R with an update for T_{g1}' time gap value and the selection of the framing mode. See Table 12-27.

Table 12-27 – O-TG-UPDATE message

Field	Field name	Format
1	Message descriptor	Message code
2	Time gap correction (ΔT_{g1}')	Two bytes
3	Fallback to TDD or TDDZ framing mode	One byte

Field 1 "Message descriptor" is a unique one-byte code (01_{16}) that identifies the message. See Table 12-10 for a complete list of codes.

Field 2 "Time gap correction (ΔT_{g1}')" indicates the correction of the time gap T_{g1}' relative to the current T_{g1}' value expressed in number of samples at the reference sampling rate corresponding to the used IDFT size. The new value of T_{g1}' is equal to the current value of T_{g1}' plus ΔT_{g1}'. The value shall be encoded in a 16-bit field using two's complement format. If the fallback to TDD is requested, the new value T_{g1}' shall refer to the TDD or TDDZ framing mode.

Field 3 "Fallback to TDD or TDDZ framing mode" indicates whether the transmission line shall fall back from FDXC framing mode to TDD framing mode or from FDXZ framing mode to TDDZ framing mode. The field shall be coded as an 8-bit unsigned integer. A value of 1 shall indicate the fallback to TDD framing mode or to TDDZ framing mode depending on the current framing mode. A value of 0 shall indicate no change in selected framing mode. That field shall be coded as 0 if the current framing mode is TDD.

12.3.3.2.3 O-EC-PRM

The O-EC-PRM messages provides the MTU-R with information about the probe sequence to be used for the update of the echo canceller (EC), the duration of the signal to update the MTU-O EC, the probe sequence used in the upstream and downstream NPSF and the Upstream start PSD cutback in the NPSF. See Table 12-28.

Table 12-28 – O-EC-PRM message

Field	Field name	Format
1	Message descriptor	Message code
2	Duration of O-P-EC 1 signal	Two bytes
3	Upstream EC probe sequence length (*Nprobe_ec_us*)	One byte
4	Upstream EC probe sequence descriptor	Variable
5	Time marker indicating the start of EC upstream probe sequence	One byte
6	Upstream FDS probe sequence descriptor	Variable
7	Downstream FUS probe sequence descriptor	Variable
8	Upstream start PSD cutback in NPSF (STARTCB_NPus)	One byte

Field 1 "Message descriptor" is a unique one-byte code (61_{16}) that identifies the message. See Table 12-10 for a complete list of codes.

Field 2 "Duration of O-P-EC 1 signal" indicates the duration of the O-P-EC-1 signal. The value is expressed in superframes. Valid values are from 8 to 512. It is coded as a 16 bits-unsigned integer.

Field 3 "Upstream EC probe sequence length (*Nprobe_ec_us*)" defines the length of the upstream probe sequence (see clause 10.2.2.1) used on sync symbols in FUS for MTU-R EC update. The range of valid values and format shall be the same as for the "Upstream EC probe sequence length" field included in O-SIGNATURE.

Field 4 "Upstream EC probe sequence descriptor" defines the probe sequence allocated by the VCE to be modulated on the upstream sync symbols in FUS during the R-P-EC 1 signal. The format is a binary string of length 2×*Nprobe_ec_us* bits. The range of valid values and the mapping of the bits of the binary string shall be the same as for the "Upstream FUS probe sequence descriptor" included in O-SIGNATURE. The EC probe sequence selected by the VCE should be orthogonal to probe sequences of all other transmission lines of the vectoring group over the duration of the EC probe sequence length.

NOTE – Orthogonality simplifies the training of the EC for the MTU-R during transmission of the R-P-EC 1 signal.

Field 5 "Time marker indicating the start of upstream EC probe sequence" indicates the index of the upstream EC probe sequence element that would have been transmitted at the superframe in which O-P-SYNCHRO 1 signal was sent (assuming that the length of probe sequence is as defined in field 2). The range of valid values and format shall be the same as for the "Time marker indicating the start of upstream probe sequence" included in O-SIGNATURE.

Field 6 "Upstream FDS probe sequence descriptor" defines the probe sequence allocated by the VCE to be modulated on the upstream sync symbols in FDS starting from R-P-VECTOR 2 signal. The format is a binary string of length 2×$Nprobe_{us}$ bits. The length of the field and the range of valid values and the mapping of the bits of the binary string shall be the same as for the "Upstream FUS probe sequence descriptor" included in O-SIGNATURE.

Field 7 "Downstream FUS probe sequence descriptor" defines the probe sequence allocated by the VCE to be modulated on the downstream sync symbols in FUS. The format is a binary string of length 2×$Nprobe_{ds}$ bits. The length of the field and the range of valid values and the mapping of the bits of the binary string shall be the same as for the "Downstream FDS probe sequence descriptor" communicated in O-SIGNATURE.

Field 8 "Upstream start PSD cutback in NPSF (STARTCB_NPus)" indicates the flat cutback for the STARTPSDus that shall be applied on NPSF. The upstream PSD in the NPSF (STARTPSD_NPus) shall be equal to STARTPSDus(f) -STARTCB_NPus. This field shall be coded as an 8-bit value with LSB weight of 0.5 dB. The valid range is from 0 dB to 63.5 dB.

12.3.3.2.4 R-EC-PRM

The R-EC-PRM messages provides the MTU-O with information about the duration of the signal to update the MTU-R EC. See Table 12-29.

Table 12-29 – R-EC-PRM message

Field	Field name	Format
1	Message descriptor	Message code
2	Minimum duration of R-P-EC 1 signal	Two bytes

Field 1 "Message descriptor" is a unique one-byte code (90_{16}) that identifies the message. See Table 12-10 for a complete list of codes.

Field 2 "Minimum duration of R-P-EC 1 signal" indicates the minimal duration of the R-P-EC-1 signal. The value is expressed in superframes. Valid values are from 8 to 512. It is coded as a 16 bits-unsigned integer.

12.3.3.2.5 R-MSG 1

The R-MSG 1 message provides MTU-O with MTU-R parameters that are relevant to continue the initialization.

Table 12-30 – R-MSG 1 message

Field	Field name	Format
1	Message descriptor	Message code
2	Estimate of electrical length	Two bytes
3	Start-up upstream PSD (STARTPSDus)	PSD descriptor
4	Upstream transmit window length (β_{us})	One byte
5	DS SOC symbol repetition rate (R)	One byte
6	DRR configuration data	Two bytes

Field 1 "Message descriptor" is a unique one-byte code (80_{16}) that identifies the message. See Table 12-10 for a complete list of codes.

Field 2 "Estimate of electrical length" conveys the estimate of the electrical length, expressed in dB (see clause 7.3.1.5.2.1), as determined by the MTU-R. The value shall be coded as a 16-bit number with LSB weight of 0.1 dB. The valid range of the electrical length is from 0 dB to 128 dB in 0.1 dB steps. Using this estimate of the electrical length, the MTU-R shall derive the initial upstream power back-off mask (UPBOMASK), as described in clause 7.3.1.5.2.2.

Field 3 "Start-up upstream PSD (STARTPSDus)" indicates the PSD at the U reference point transmitted in the upstream direction in PSF during the Channel Discovery 1 stage. The "PSD descriptor" format specified in Table 12-23 shall be used, and the number of breakpoints being described shall be from 2 to 32. The only valid PSD values obtained by the receiver using the interpolation procedure specified are those for subcarriers that belong to the SUPPORTEDCARRIERSGus set, excluding the RFIBANDS and IARBANDS communicated during the ITU-T G.994.1 handshake phase; PSD values out of this set shall be ignored by the receiver. The STARTPSDus values shall be less than or equal to the PSDMASKus (field 5 of O-SIGNATURE message), and below the initial UPBOMASK that corresponds to the electrical length value defined in field 2. The valid values of STARTPSDus, either those which are directly communicated or those obtained at the receiver by interpolation, shall not deviate from the actual value of the transmit PSD, as measured in the reference impedance at the U reference point, by more than 1 dB.

Field 4 "Upstream transmit window length (β_{us})" contains the length of the transmit window divided by 2 ($\beta_{us}/2$) that shall be used in the upstream direction during the initialization and showtime. The β_{us} value shall be expressed in the samples of the upstream sampling rate corresponding to the profile used (communicated during the ITU-T G.994.1 handshake phase). The range of valid values and format shall be the same as for field 10 of the O-SIGNATURE message.

Field 5 "DS SOC symbol repetition rate (R)" indicates the recommended DS SOC symbol repetition rate to be used in subsequent initialization procedures (valid values are defined for the ITU-T G.994.1 handshake – see Table 12-11). A special value FF_{16} indicates that MTU-R has no particular recommendation.

Field 6 "DRR configuration data" is two bytes long and conveys the MTU-R DRR configuration data (as received from the L2+ function at the MTU-R). Based on this information, the DRA determines the size (N_{RM}) of the resources metric in the RMC upstream dynamic resource report (DRRus) command sent in the upstream RMC (see Table 9-17). The DRA includes the value of N_{RM} in DRRus.request (N_{DRR}, N_{RM}) sent to the MTU-O (see Table 8-4). The MTU-O may use the value of N_{RM} to determine the upstream K_{RMC} to be conveyed in O-PMS message. The DRR configuration data shall be represented as two-byte field, formatted as defined in Table Y.2.

12.3.3.2.6 O-UPDATE

The O-UPDATE message is a response to R-MSG 1 message. It provides the MTU-R with an update for transmission parameters.

Table 12-31 – O-UPDATE message

Field	Field name	Format
1	Message descriptor	Message code
2	Final electrical length	Two bytes
3	Upstream PSD ceiling (MAXMASKus)	Two bytes
4	Final time gap correction (ΔT_{g1}')	Two bytes
5	Upstream Channel Discovery PSD cutback in NPSF (CDCB_NPus)	One byte

Field 1 "Message descriptor" is a unique one-byte code (02_{16}) that identifies the message. See Table 12-10 for a complete list of codes.

Field 2 "Final electrical length" contains the electrical length expressed in dB (see clause 7.3.1.5.2.2) that the MTU-R shall use to set its upstream PSD starting from the R-P-VECTOR 1-1 signal of initialization. The value shall be coded as a 16-bit number. The valid range of values is from 0 dB to 128 dB with a 0.1 dB step. This value may be same or different from the value reported by the MTU-R in R-MSG 1 message and shall be used by the MTU-R to determine the final UPBOMASK, as specified in clause 7.3.1.5.2.2. This updated UPBOMASK shall be used to form the upstream PSD mask CDPSDMASKus (see Table 7-4) applied to CDPSDus (field 3 of R-UPDATE message).

Field 3 "Upstream PSD ceiling (MAXMASKus)" indicates the PSD ceiling level of the upstream transmit PSD mask. If this level is lower than the PSDMASKus indicated in O-SIGNATURE, the MTU-R shall apply this ceiling level to PSDMASKus. Otherwise, the MTU-R shall ignore this field and continue with PSDMASKus. The mask resulting from this operation combined with the updated UPBOMASK (field 2) is referenced as CDPSDMASKus (see Table 7-4).This CDPSDMASKus shall be usedas the PSD mask to be applied to CDPSDus (field 3 of R-UPDATE message), i.e., CDPSDus ≤ CDPSDMASKus. This field shall be coded as a 16-bit value with LSB weight of –0.1 dB. The valid range is from 0 dBm/Hz to –90 dBm/Hz. A special value 1000_{16} shall indicate no limit to the upstream PSD ceiling level (under the constraints of the upstream transmit PSD mask).

Field 4 "Final time gap correction ΔT_{g1}'" indicates the final correction of the time gap T_{g1}' relative to the current Tg1' value expressed in samples, at the sampling rate corresponding to the used IDFT size. The new value of T_{g1}' is equal to the current value of T_{g1}' plus ΔT_{g1}'. The value shall be encoded in a 16-bit field using two's complement format.

Field 5 "Channel Discovery PSD cutback in NPSF (CDCB_NPus)" indicates the flat power back-off on the channel discovery upstream transmit PSD that shall be applied on NPSF. The channel discovery upstream PSD in the non-priority frame (CDPSD_NPus) shall be equal to CDPSDus(f)-CDCB_NPus. This field shall be coded as an 8-bit value with LSB weight of 0.5 dB. The valid range is from 0 dB to 63.5 dB. If transmission line is not joining in FDX mode, the field shall be set to zero and ignored by the receiver.

12.3.3.2.7 R-UPDATE

The R-UPDATE message is a response to an O-UPDATE message. It provides the MTU-O with updated parameters.

Table 12-32 – R-UPDATE message

Field	Field name	Format
1	Message descriptor	Message code
2	Downstream PSD ceiling (MAXMASKds)	Two bytes
3	Channel Discovery upstream PSD (CDPSDus)	PSD descriptor

Field 1 "Message descriptor" is a unique one-byte code (81_{16}) that identifies the message. See Table 12-10 for a complete list of codes.

Field 2 "Downstream PSD ceiling (MAXMASKds)" indicates the PSD ceiling level of the downstream transmit PSD mask. If this level is lower than the PSDMASKds indicated in O-SIGNATURE, the MTU-O shall apply this new ceiling level to PSDMASKds. Otherwise, the MTU-O shall ignore this field and continue with PSDMASKds. The resulting mask is referenced as V2PSDMASKds (see Table 7-4). This V2PSDMASKds shall be used as the downstream PSD mask to be applied to V2PSDds, i.e., V2PSDds ≤ V2PSDMASKds. This field shall be coded as a 16-bit value with LSB weight of –0.1 dB. The valid range is from 0dBm/Hz to –90 dBm/Hz. A special value 1000_{16} shall indicate no limit to the downstream PSD ceiling level (under the constraints of the downstream transmit PSD mask). In the case of P2MP operation, no limit to the downstream PSD ceiling level shall be selected, the field shall be set to the special value.

Field 3 "Channel Discovery upstream PSD (CDPSDus)" indicates the PSD at the U reference point transmitted in the upstream direction in PSF during the R-VECTOR 1.1 stage. The "PSD descriptor" format specified in Table 12-23 shall be used, and the number of breakpoints being described shall be from two to 32. The only valid PSD values obtained by the receiver using the interpolation procedure specified are those for subcarriers that belong to the SUPPORTEDCARRIERSGus set, excluding the RFIBANDS and IARBANDS communicated during the ITU-T G.994.1 handshake phase; PSD values out of this set shall be ignored by the receiver. The CDPSDus values shall be below the PSDMASKus (field 5 of O-SIGNATURE message) updated by applying the upstream PSD ceiling MAXMASKus, and below the final UPBOMASK that corresponds to the electrical length value defined in field 2 of O-UPDATE message. The valid values of CDPSDus, either those which are directly communicated or those obtained at the receiver by interpolation, shall not deviate from the actual value of the transmit PSD, as measured in the reference impedance at the U reference point, by more than 1 dB.

12.3.3.2.8 O-EC-PRM 1

The O-EC-PRM 1 messages provides the MTU-R with information about the probe sequence to be used for the update of the echo canceller (EC), the duration of the signal to update the MTU-O EC and the Updated Upstream Channel Discovery PSD cutback in NPSF. See Table 12-33.

Table 12-33 – O-EC-PRM 1 message

Field	Field name	Format
1	Message descriptor	Message code
2	Duration of O-P-EC 1-1 signal	Two bytes
3	Time marker indicating the start of EC upstream probe sequence	One byte
4	Updated Upstream Channel Discovery PSD cutback in NPSF (CDCBUPDATE_NPus)	One byte

Field 1 "Message descriptor" is a unique one-byte code (62_{16}) that identifies the message. See Table 12-10 for a complete list of codes.

Field 2 "Duration of O-P-EC 1-1 signal" indicates the duration of the O-P-EC 1-1 signal. The value is expressed in superframes. Valid values are from 8 to 512. It is coded as a 16 bits-unsigned integer.

Field 3 "Time marker indicating the start of upstream EC probe sequence" indicates the index of the upstream EC probe sequence element that would have been transmitted at the superframe in which O-P-SYNCHRO 3 signal was sent (assuming that the length of probe sequence is as defined in field 2). The range of valid values and format shall be the same as for the "Time marker indicating the start of upstream probe sequence" included in O-SIGNATURE.

Field 4 "Updated Channel Discovery PSD cutback in NPSF (CDCBUPDATE_NPus)" indicates the updated flat power back-off on the channel discovery upstream transmit PSD that shall be applied on NPSF. The updated channel discovery upstream PSD in the NPSF (CDPSD_NP1us) shall be equal to CDPSDus(f)-CDCBUPDATE_NPus. This field shall be coded as an 8-bit value with LSB weight of 0.5 dB. The valid range is from 0 dB to 63.5 dB.

NOTE – The MTU-O may decide to update the value after transmission of R-P-VECTOR 1-1 as that signal allows transmission of sync symbols in FDS.

12.3.3.2.9 R-EC-PRM 1

The R-EC-PRM 1 messages provides the MTU-O with information about the duration of the signal to update the MTU-R EC. See Table 12-34.

Table 12-34 – R-EC-PRM 1 message

Field	Field name	Format
1	Message descriptor	Message code
2	Minimum duration of R-P-EC 1-1 signal	Two bytes

Field 1 "Message descriptor" is a unique one-byte code (91_{16}) that identifies the message. See Table 12-10 for a complete list of codes.

Field 2 "Minimum duration of R-P-EC 1-1 signal" indicates the minimal duration of the R-P-EC-1-1 signal. The value is expressed in superframes. Valid values are from 8 to 512. It is coded as a 16 bits-unsigned integer.

12.3.3.2.10 O-VECTOR-FEEDBACK

The O-VECTOR-FEEDBACK message defines the required parameters of vectoring feedback report.

Table 12-35 – O-VECTOR-FEEDBACK message

Field	Field name	Format
1	Message descriptor	Message code
2	Vectoring report control parameters	Vectoring report configuration descriptor
3	Reference superframe count	Two bytes
4	US SOC tone repetition rate (p_{us})	One byte
5	VFRB update parameters (*q*, *s and reporting mode*)	One byte
6	LSBs of VFRB shift period (*z*)	One byte
7	Vectored bands	Variable
8	MSBs of VFRB shift period (*z*)	One byte

Field 1 "Message descriptor" is a unique one-byte code (03_{16}) that identifies the message. See Table 12-10 for a complete list of codes.

Field 2 "Vectoring feedback report control parameters" indicates values of the vectoring feedback report control parameters requested by the MTU-O for the MTU-R to apply in the vectoring feedback report. The format of the control parameters shall be as defined in the vectoring feedback report configuration descriptor, Table 11-44.

Field 3 "Reference superframe count" indicates the superframe count from which the report shall start (CNT_{SF_0}), as defined in clause 10.3.2.5.2. The count shall be coded as a two-byte unsigned integer.

Field 4 "US SOC tone repetition rate (p_{us})" indicates the tone repetition rate (p_{us}) of SOC normal bit mapping to be used by the MTU-R for vectoring feedback reporting in the subsequent R-VECTOR-FEEDBACK message. The field shall contain the upstream value p_{us} defined in clause 10.2.2.2.1, coded as an 8-bit unsigned integer.

Field 5 "VFRB update parameters (*q*, *s and reporting mode*)" indicates control parameters *q* (VF sample update period) and *s* (frequency shift step) facilitating, respectively, VFRB time identification (see clause 10.3.2.5.2) and VFRB frequency identification (see clause 10.3.2.5.1). Bits [3:0] indicate the value of *q* coded as a 4-bit unsigned integer, and bits [7:5] indicate the value of *s* coded as a 3-bit unsigned integer. Bit [4] indicates the reporting mode. If set to 1, the VFRB shall contain DFT output samples, otherwise the VFRB shall contain clipped error samples. Other bits are reserved by ITU-T.

Field 6 "LSBs of VFRB shift period (*z*)" indicates the 8 LSBs of the control parameter facilitating VFRB time identification (see clause 10.3.2.5.2) that is coded as a 16-bit unsigned integer. The 8 MSBs are indicated in field 8 of the O-VECTOR-FEEDBACK message.

Field 7 "Vectored bands" describes the number of vectored bands and the start and stop frequencies of the vectored bands requested in VFRB represented in a format of band descriptor (see Table 12-22). The size of the field depends on the number of reported vectored bands.

Field 8 "MSBs of VFRB shift period (*z*)" indicates the 8 MSBs of the control parameter facilitating VFRB time identification. If extended probe sequence length is not selected in the G.994.1 MS message, field 8 is set to 0.

12.3.3.2.11 R-ACK

R-ACK is a one-byte SOC message that acknowledges correct reception of the O-VECTOR-FEEDBACK message. The format shall be as defined in Table 12-36.

Table 12-36 – R-ACK message

Field	Field name	Format
1	Message descriptor	Message code

Field 1 "Message descriptor" is a unique one-byte code (82_{16}) that identifies the message. See Table 12-10 for a complete list of codes.

12.3.3.2.12 R-VECTOR-FEEDBACK

The R-VECTOR-FEEDBACK message delivers the vectoring feedback report. While receiving O-P-VECTOR 2 the MTU-R should avoid changing receiver parameters that may have an impact on the vectoring feedback reporting.

NOTE – Receiver parameters may include FEQ.

Table 12-37 – R-VECTOR-FEEDBACK message

Field	Field name	Format
1	Message descriptor	Message code
2	Superframe count	Two bytes
3	Vectoring feedback data	*N_VFRB* bytes

Field 1 "Message descriptor" is a unique one-byte code (83_{16}) that identifies the message. See Table 12-10 for a complete list of codes.

Field 2 "Superframe count" indicates the count of the superframe of the sync symbol to which the report relates. The count shall be coded as a 16-bit unsigned integer.

Field 3 "Vectoring feedback data" indicates the reported set of VF samples measured on the sync symbols in FDS requested by the MTU-O with parameters defined in fields 2, 5, 6 and 7 of the O-VECTOR-FEEDBACK message. The reported VF data shall use the VFRB format defined in clause 10.3.2.4.1.

12.3.3.2.13 O-SNR

The O-SNR message requests the downstream SNR and sets various initialization parameters.

Table 12-38 – O-SNR message

Field	Field name	Format
1	Message descriptor	Message code
2	Request for downstream FDS SNR	SNR request descriptor
3	$s_{ds\text{-}NPSF}$	1 byte
4	$s_{us\text{-}NPSF}$	1 byte
5	Upstream channel discovery PSD MASK in NPSF (CDPSDMASK_NPus)	PSD descriptor

Field 1 "Message descriptor" is a unique one-byte code (04_{16}) that identifies the message. See Table 12-10 for a complete list of codes.

Field 2 "Request for downstream SNR" indicates the set of subcarriers for which the downstream SNR report shall be delivered in R-SNR message. The requested set of subcarriers for which SNR shall be reported shall have a format as presented in Table 12-39.

Field 3 "$s_{ds\text{-}NPSF}$" indicates the number of downstream SOC symbols used in initialization signals inside the NPSF starting from O-P-PRM-UPDATE 2. The valid values are from $MNDSNOI_{us}$ to M_{us} symbols. The value is coded as an 8-bit unsigned integer. If FDX mode is disabled, that field shall contain *0*.

Field 4 "$s_{us\text{-}NPSF}$" indicates the number of upstream SOC symbols used in initialization starting from R-P-PRM UPDATE 2 signal. The valid values are from $MNDSNOI_{ds}$ to M_{ds} symbols. The value is coded as an 8-bit unsigned integer. If FDX mode is disabled, that field shall contain *0*.

Field 5 "Upstream channel discovery PSD MASK in NPSF (CDPSDMASK_NPus)" indicates the CDPSDMASK_NPus as defined in clause 7.3.2 (Table 7-3) on all SUPPORTEDCARRIERus set. The valid values of CDPSDMASK_NPus shall be lower than or equal to the CDPSDMASKus. The format shall be presented using the "PSD descriptor" format defined in Table 12-23 and the number of breakpoints being described shall be from two to 32. The update of PSD mask values obtained by the MTU-R on other subcarriers than the SUPPORTEDCARRIERus set shall be ignored. If FDX mode is disabled, that field shall contain a "PSD descriptor" with ZERO breakpoints.

Table 12-39 – SNR request descriptor

Byte	Content of field
1	Number of bands SNR shall be reported. Valid values are from 0 to 8.
2-5	Bits 0-15: Index of the start subcarrier in band 1 (lowest frequency of band 1). Bits 16-31: Index of the stop subcarrier in band 1 (highest frequency of band 1).
6-9 (if applicable)	Bits 0-15: Index of the start subcarrier in band 2 (lowest frequency of band 2). Bits 16-31: Index of the stop subcarrier in band 2 (highest frequency of band 2).
etc.	etc.

12.3.3.2.14 R-SNR

The R-SNR message reports the downstream SNR.

Table 12-40 – R-SNR message

Field	Field name	Format
1	Message descriptor	Message code
2	Downstream FDS SNR report	N_{SNR} bytes, where N_{SNR} is the number of subcarriers on which the SNR is requested in field#2 of the O-SNR message.
3	DS SOC tone repetition rate (p_{ds})	One byte
4	BLACKOUTds set	Tone descriptor
5	Second Updated Channel Discovery upstream PSD in NPSF (CDPSD_NP2us)	PSD descriptor

Field 1 "Message descriptor" is a unique one-byte code (84_{16}) that identifies the message. See Table 12-10 for a complete list of codes.

Field 2 "Downstream FDS SNR report" contains the downstream SNR report measured on active symbols in FDS requested by the MTU-O in the format defined for the O-SNR message. The reported value of the SNR for a particular subcarrier shall be coded as an 8-bit unsigned integer A using the rule $SNR = -32 + (A/2)$ dB. This format supports SNR range from –32 dB to +95 dB with the granularity of 0.5 dB. Values of SNR that exceed 95 dB shall be reported as 95 dB and values of SNR that are lower than –32 dB shall be reported as −32 dB. The bytes representing $SNR(k)$ values for different subcarriers shall be transmitted in ascending order of subcarrier index k, for the set as requested in field 2 of the O-SNR message. Subcarriers in the set for which SNR estimation is not available shall be set to FF_{16}. The values of SNR for the subcarriers that are not in the set shall not be reported.

Field 3 "DS SOC tone repetition rate (p_{ds})" indicates the tone repetition rate (p_{ds}) of SOC normal bit mapping to be used by the MTU-O in subsequent SOC messages. The field shall contain the downstream value p_{ds} defined in clause 10.2.2.2.1, coded as an 8-bit unsigned integer.

Field 4 "BLACKOUTds set" indicates the set of downstream blackout subcarriers using a tone descriptor format presented in Table 12-26. The MTU-O shall support 255 downstream blackout subcarriers.

Field 5 "Second Updated Channel Discovery upstream PSD in NPSF (CDPSD_NP2us)" indicates the PSD at the U reference point transmitted in the upstream direction in NPSF of the R-P-PRM-UPDATE 2 signal. The "PSD descriptor" format specified in Table 12-23 shall be used, and the number of breakpoints being described shall be from two to 32. The only valid PSD values obtained by the receiver using the interpolation procedure specified are those for subcarriers that belong to the SUPPORTEDCARRIERSGus set, excluding the RFIBANDS and IARBANDS communicated during the ITU-T G.994.1 handshake phase; PSD values out of this set shall be ignored by the receiver. The CDPSD_NP2us values shall be below the CDPSDMASK_NPus (field 5 of O-SNR message). The valid values of CDPSD_NP2us, either those which are directly communicated or those obtained at the receiver by interpolation, shall not deviate from the actual value of the transmit PSD, as measured in the reference impedance at the U reference point, by more than 1 dB. If FDX mode is disabled, this field shall contain a "PSD descriptor" with ZERO breakpoints.

12.3.3.2.15 O-PRM

The O-PRM message provides the MTU-R parameter update.

Table 12-41 – O-PRM message

Field	Field name	Format
1	Message descriptor	Message code
2	Proposed MEDLEYG set of US subcarriers	Band descriptor
3	Final MEDLEYG set of DS subcarriers	Band descriptor
4	MTU-R Rx gain update	Gain descriptor
5	BLACKOUTus set	Tone descriptor
6	US reference PSDMASK (MREFPSDMASKus)	PSD descriptor
8	Request for retrain	One byte
7	US reference PSDMASK in NPSF (MREFPSDMASK_NPus)	PSD descriptor
8	Upstream tone mask in NPSF (TONEMASK_NPus)	Band descriptor

Field 1 "Message descriptor" is a unique one-byte code (05_{16}) that identifies the message. See Table 12-10 for a complete list of codes.

Field 2 "Proposed MEDLEYG set of US subcarriers" includes a complete set of MEDLEYGus subcarriers using the band descriptor presented in Table 12-22, along with all subcarriers from the BLACKOUTus set (field 5) that fall within the range of frequencies for the included complete set of MEDLEYGus subcarriers. This set is proposed to the MTU-R to constrain the upstream MEDLEYus and MEDLEYGus sets.

Field 3 "Final MEDLEYG set of DS subcarriers" includes a complete set of MEDLEYGds subcarriers using the band descriptor presented in Table 12-22, along with all subcarriers from the BLACKOUTds set (R-SNR message, field 4) that fall within the range of frequencies for the included complete set of MEDLEYGds subcarriers. The final MEDLEYGds set shall consist of all subcarriers included in this field except the BLACKOUTds subcarriers. In P2P, the MEDLEY set of downstream subcarriers shall be the same as the MEDLEYGds set. In P2MP, the MEDLEY set of downstream subcarriers shall consist of all subcarriers of the MEDLEYGds set that belong to the current P2MPOB allocated to the link and that are not indicated as pilot tone groups used by other MTU-Rs plus the pilot tone groups outside of the P2MPOB associated with that link (see clause 12.3.3.2.1).

Field 4 "MTU-R Rx gain update" indicates the gain compensation factor per subcarrier to be applied by the MTU-R to its receiver stage to accommodate the transition from PRMPSDds (used during the PRM-UPDATE stage) to MREFPSDds (used during Channel Analysis & Exchange phase). The field shall be encoded as gain descriptor as defined in Table 12-42. The gain descriptor contains the gain compensation factors for a range of subcarriers in the MEDLEY set. Each subcarrier of the MEDLEYset is referenced by a MEDLEYset index, *m*, corresponding to its position in the MEDLEYset, i.e., $m = 0$ is the index of first subcarrier in the MEDLEYset, $m = 1$ is the index of the second one, etc. The bytes 1 & 2 of the gain descriptor contain the index *m* of the first subcarrier of the range and the bytes 3 & 4 contain the index *m* of the last subcarrier of the range. The following bytes contain the gain compensation factors of subcarriers arranged by ascending index *m*, expressed in dB. Each gain compensation factor expressed in dB shall be coded as an 8-bit unsigned integer, representing valid values –25.4 dB to +25.4 dB in increments of 0.2 dB (the values 0, 127 and 254 correspond to gain compensation factors of –25.4 dB, 0 dB, and +25.4 dB, respectively). The value 255 shall be a special value to indicate that the subcarrier does not carry any power. The compensation factor of the subcarriers outside of the range specified in the gain descriptor shall be 0 dB. To implement the MTU-R Rx Gain update, the MTU-R shall multiply its current settings of the gain stage in the receiver, for any subcarrier *i* in the MEDLEYds set, by its gain compensation factor.

The MREFPSDds shall comply to the MREFPSDMASKds which is equal to the V2PSDMASKds as specified in Table 7-4.

The increase of the aggregate received power at the U-R reference point at the transition from PRMPSDds to MREFPSDds shall not exceed 0.1 dB.

NOTE – The VCE may apply the following constraint to accommodate the above requirement:

$$\sum_{i} \left| \frac{1}{\text{gain compensation factor at the i} - \text{th subcarrier}} \right|^2 \leq 1.0233$$

Table 12-42 – Gain descriptor

Byte	Content of the field
1-2	MEDLEYds set index (m_0) of first subcarrier described
3-4	MEDLEYds set index (m_1) of last subcarrier described
5	Gain compensation factor for subcarrier with MEDLEYds set index m_0
6	Gain compensation factor for subcarrier with MEDLEYds set index m_0+1
...	....
5+m_1–m_0	Gain compensation factor for subcarrier with MEDLEYds set index m_1
NOTE – The gain compensation factor shall be included by ascending MEDLEYds set index.	

Field 5 "BLACKOUTus set" indicates the set of upstream blackout subcarriers using a tone descriptor format presented in Table 12-26.

The first byte of the tone descriptor shall contain the number of tones selected by the MTU-O. If this number is zero, there shall be no further bytes in the descriptor. If the number of tones is not equal to zero, each group of three consecutive bytes in the descriptor describes two tones. If the number of tones is odd, the last 12 bits in the last field shall be set to ZERO. The MTU-R shall support 255 upstream blackout subcarriers.

Field 6 "Upstream reference PSDMASK (MREFPSDMASKus)" indicates the MREFPSDMASKus in the PSF as defined in clause 7.3.2 (Table 7-3) on all proposed MEDLEYGus subcarriers indicated in field 2. The format shall be presented using the "PSD descriptor" format defined in Table 12-23 and the number of breakpoints being described shall be from two to 32. The update of PSD mask values obtained by the MTU-R on other subcarriers than the proposed MEDLEYGus set shall be ignored. The MREFPSDMASKus shall be lower than or equal to the CDPSDMASKus (see Table 7-4).

Field 7 "Request for retrain" indicates a retrain request from the MTU-O. The MTU-O can use it if it is expected that an optimization of the transmitter or receiver front end is needed for the proposed MREFPSDds, MREFPSD_NPds, MREFPSDMASKus or MREFPSDMASK_NPus. The field shall be coded as an unsigned integer with the value 0 indicating that no retrain is requested and with the value 1 if a retrain is requested. If the MTU-O requests a retrain, it shall abort the current initialization after receiving R-PRM message and shall start a new initialization from QUIET 1 stage (without the ITU-T G.994.1 phase) by sending O-P-QUIET-1. The MTU-R shall abort the current initialization after sending R-PRM message and shall transition to R-P-QUIET1. The negotiated values of the previous ITU-T G.994.1 phase shall be used in the new initialization. The timeout counter for initialization procedure shall be restarted.

Field 8 "Upstream reference PSDMASK in NPSF (MREFPSDMASK_NPus)" indicates the MREFPSDMASKus to be used in the NPSF as defined in clause 7.3.2 (Table 7-3) on all proposed MEDLEYGus subcarriers indicated in field 2. The format shall be presented using the "PSD descriptor" format defined in Table 12-23 and the number of breakpoints being described shall be from two to 32. The update of PSD mask values obtained by the MTU-R on other subcarriers than the proposed MEDLEYGus set shall be ignored. If FDX mode is disabled, that field shall contain a "PSD descriptor" with ZERO breakpoints. The MREFPSDMASK_NPus shall be lower than or equal to the CDPSDMASKus (see Table 7-4).

Field 9 "Upstream tonemask in NPSF (TONEMASK_NPus)" includes additional sub-carriers of the upstream MEDLEYGus set that shall not be transmitted in the NPSF. The format is using the band descriptor presented in Table 12-22. If FDX mode is disabled, that field shall contain a "Band descriptor" with ZERO bands.

12.3.3.2.16 R-PRM

The R-PRM message provides the MTU-O parameter update.

Table 12-43 – R-PRM message

Field	Field name	Format
1	Message descriptor	Message code
2	US reference PSD (MREFPSDus)	PSD descriptor
3	US reference PSD in NPSF (MREFPSD_NPus)	PSD descriptor
4	Final MEDLEYG set of US subcarriers	Band descriptor

Field 1 "Message descriptor" is a unique one-byte code (85_{16}) that identifies the message. See Table 12-10 for a complete list of codes.

Field 2 "Upstream reference PSD (MREFPSDus)" indicates the MREFPSDus as defined in clause 7.3.2 (Table 7-3) on all MEDLEYGus subcarriers indicated in field 4. The format shall be presented using the "PSD descriptor" format defined in Table 12-23 and the number of breakpoints being described shall be from 2 to 32. The update of PSD values obtained by the MTU-O on other subcarriers than MEDLEYGus set shall be ignored. The indicated breakpoint values and the interpolated values of MREFPSDus shall not deviate from the actual value of the transmit PSD, as measured in the termination impedance at the U reference point, by more than 1 dB. To derive MREFPSDus, the MTU-R shall consider the activation of DTFO Band 1 in showtime if sub-carriers of Band 1 are included in the "Proposed MEDLEYGus set of active US subcarriers" (see O-PRM) even if no symbols to carry DTFO Band 1 are assigned during initialization. In P2MP, the MTU-R shall also consider that the future P2MPOB may include any other subcarriers of the MEDLEYGus set proposed by the MTU-O after a DBR procedure.

Field 3 "Upstream reference PSD in NPSF (MREFPSD_NPus)" indicates the MREFPSD_NPus as defined in clause 7.3.2 (Table 7-3) on all MEDLEYGus subcarriers indicated in field 4. The format shall be presented using the "PSD descriptor" format defined in Table 12-23 and the number of breakpoints being described shall be from 2 to 32. The update of PSD values obtained by the MTU-O on other subcarriers than MEDLEYGus set shall be ignored. The indicated breakpoint values and the interpolated values of MREFPSD_NPus shall not deviate from the actual value of the transmit PSD, as measured in the termination impedance at the U reference point, by more than 1 dB. If transmission line does not join in FDX mode, that field shall contain a "PSD descriptor" with ZERO breakpoints.

Field 4 "Final MEDLEYG set of US subcarriers "includes a complete set of MEDLEYGus subcarriers using the band descriptor presented in Table 12-22, along with all subcarriers from the BLACKOUTus set (O-PRM, field 5) that fall within the range of frequencies for the included complete set of upstream MEDLEY subcarriers. The final MEDLEYG set of active US subcarriers shall consist of all subcarriers included in this field except the upstream BLACKOUTus subcarriers (O-PRM, field 5). This field shall contain only subcarriers that belong to the proposed MEDLEYG set of active US subcarriers as indicated in the field 2 of O-PRM message. To derive the final MEDLEYGus set of active US subcarriers, the MTU-R shall consider activation of DTFO Band 1 in showtime if sub-carriers of DTFO Band 1 are included in the "Proposed MEDLEYG set of active US subcarriers" (see O-PRM) even if no symbols to carry DTFO Band 1 are assigned during initialization. In P2P, the MEDLEY set of upstream subcarriers shall be the same as the MEDLEYGus set. In P2MP, the MEDLEY set of upstream subcarriers shall consist of all subcarriers of the MEDLEYGus set that belongs to the current P2MPOB. In P2MP, the MTU-R shall also consider that the future P2MPOB may include any other subcarriers of the MEDLEYGus proposed by the MTU-O after a DBR procedure.

12.3.3.3 Signals transmitted during channel discovery phase

The following subclauses summarise the signals transmitted by the MTU-O and MTU-R during the channel discovery phase.

Each signal is characterized by, at least:

– The number and position of initialization symbols inside the FDS and FUS sub-frames.

– The transmit PSD and the active subcarriers of the FDS and FUS initialization symbols.

– The transmit PSD and the active subcarriers of the FDS and FUS sync symbols.

– The probe sequence modulated on the FUS and FDS sync symbols.

– The type of modulation used on the initialization symbols:

  • SOC active or inactive, with or without repetition.

  • IDS active or inactive.

  • SOC quadrant scrambler in reset mode or in free running mode.

The number and position of initialization symbols in the PSF and NPSF and the presence of sync symbols in FUS, FDS, or both sub-frames define the structure of an initialization signal. Therefore, two initialization signals have the same structure if they have the same number of initialization symbols at the same positions inside each superframe and if the sync symbols are present at the same positions, i.e., in FUS, FDS or in both sub-frames.

Tables 12-44 and 12-45 summarize, for each signal transmitted by the MTU-O and MTU-R, respectively: the PSD, the active subcarriers, the number and positions of initialization symbols, the PSD and active subcarriers of sync symbols.

Table 12-44 – Active subcarriers, PSD and active symbol positions of signals transmitted by the MTU-O during "Channel Discovery" phase

Signal type (Note 8)	FDS, PSF					FUS, NPSF (Note 1)				
	Sync symbol (Note 6)		Initialization symbols			Sync symbol (Note 6)		Initialization symbols		
	PSD	Active subcarriers (Note 2)	PSD	Active subcarriers (Note 2)	Number active symbols (Note 3)	PSD	Active subcarriers (Note 2)	PSD	Active subcarriers (Note 2)	Number active symbols (Note 7)
O-P-VECTOR 1	STARTPSDds	SUPPORTEDCARRIERSds	N/A	N/A	0	STARTPDSds	SUPPORTEDCARRIERSds	N/A	N/A	0
O-P-CHANNEL-DISCOVERY 1-1, O-P-SYNCHRO 1-1	CDSPSDds	SUPPORTEDCARRIERSds	CDSPSDds	SUPPORTEDCARRIERSds of DTFO Band 0	$S_{ds\text{-}CD\text{-}1\text{-}1}$ (Note 4)	CDPSDds	SUPPORTEDCARRIERSds	N/A	N/A	0
O-P-CHANNEL-DISCOVERY 1, O-P-SYNCHRO 1	CDSPSDds	SUPPORTEDCARRIERSds	CDSPSDds	SUPPORTEDCARRIERSds of DTFO Band 0	S_{ds} (Note 4)	CDPSDds	SUPPORTEDCARRIERSds	N/A	N/A	0
O-P-CHANNEL-DISCOVERY 1-2, O-P-SYNCHRO 1-2 (Note 5)	CDSPSDds	SUPPORTEDCARRIERSds	CDSPSDds	SUPPORTEDCARRIERSds of DTFO Bands assigned during O-SIGNATURE	S_{ds}	CDPSDds	SUPPORTEDCARRIERSds	N/A	N/A	0
O-P-EC 1 (Note 5)	CDSPSDds	SUPPORTEDCARRIERSds	CDSPSDds	SUPPORTEDCARRIERSds of DTFO Bands assigned during O-SIGNATURE	S_{ds}	CDPSDds	SUPPORTEDCARRIERSds	N/A	N/A	0
O-P-CHANNEL-DISCOVERY 1-3, O-P-SYNCHRO 1-3 (Note 5)	CDSPSDds	SUPPORTEDCARRIERSds	CDSPSDds	SUPPORTEDCARRIERSds of DTFO Bands assigned during O-SIGNATURE	S_{ds}	Quiet	N/A	N/A	N/A	0
O-P-CHANNEL-	CDSPSDds	SUPPORTEDCARRIERSds	CDSPSDds	SUPPORTEDCARRIERSds of DTFO Bands	S_{ds}	CDPSDds	SUPPORTEDCARRIERSds	N/A	N/A	0

Table 12-44 – Active subcarriers, PSD and active symbol positions of signals transmitted by the MTU-O during "Channel Discovery" phase

DISCOVERY 2, O-P-SYNCHRO 2				assigned during O-SIGNATURE							
O-P-VECTOR 1-1, O-P-SYNCHRO 3	CDSPSDds	SUPPORTEDCARRIERSds	CDSPSDds	SUPPORTEDCARRIERSds of DTFO Bands assigned during O-SIGNATURE	s_{ds}	CDPSDds	SUPPORTEDCARRIERSds	N/A	N/A	0
O-P-CHANNEL-DISCOVERY 2-1, O-P-SYNCHRO 3-00 (Note 5)	V2PSDds	SUPPORTEDCARRIERSds	V2PSDds	SUPPORTEDCARRIERSds of DTFO Bands assigned during O-SIGNATURE	s_{ds}	V2PSDds	SUPPORTEDCARRIERSds	N/A	N/A	0
O-P-EC 1-1 (Note 5)	V2PSDds	SUPPORTEDCARRIERSds	V2PSDds	SUPPORTEDCARRIERSds of DTFO Bands assigned during O-SIGNATURE	s_{ds}	V2PSDds	SUPPORTEDCARRIERSds	N/A	N/A	0
O-P-CHANNEL-DISCOVERY 2-2, O-P-SYNCHRO 3-01 (Note 5)	V2PSDds	SUPPORTEDCARRIERSds	V2PSDds	SUPPORTEDCARRIERSds of DTFO Bands assigned during O-SIGNATURE	s_{ds}	Quiet	N/A	N/A	N/A	0
O-P-VECTOR 2, O-P-SYNCHRO 3-1	V2PSDds	SUPPORTEDCARRIERSds	V2PSDds	SUPPORTEDCARRIERSds of DTFO Bands assigned during O-SIGNATURE	s_{ds}	V2PSDds	SUPPORTEDCARRIERSds	N/A	N/A	0
O-P-VECTOR 2-1, O-P-SYNCHRO 4	V2PSDds	SUPPORTEDCARRIERSds	V2PSDds	SUPPORTEDCARRIERSds of DTFO Bands assigned during O-SIGNATURE	s_{ds}	V2PSDds	SUPPORTEDCARRIERSds	N/A	N/A	0
O-P-PRM-UPDATE 1, O-P-SYNCHRO 4-1	PRMPSDds	SUPPORTEDCARRIERSds	PRMPSDds	SUPPORTEDCARRIERSds of DTFO Bands assigned during O-SIGNATURE	s_{ds}	PRMPSDds	SUPPORTEDCARRIERSds	N/A	N/A	0
O-P-PRM-UPDATE 2,	PRMPSDds	SUPPORTEDCARRIERSds	PRMPSDds	SUPPORTEDCARRIERSds of DTFO Bands	s_{ds}	PRMPSDds	SUPPORTEDCARRIERSds	PRMPSDds	SUPPORTEDCARRIERSds of DTFO Bands	$s_{ds,NPSF}$

Table 12-44 – Active subcarriers, PSD and active symbol positions of signals transmitted by the MTU-O during "Channel Discovery" phase

O-P-SYNCHRO 5				assigned during O-SIGNATURE					assigned during O-SIGNATURE	

NOTE 1 –The MTU-O shall transmit active symbols, including sync symbols, in FUS only if FDXC or FDXZ framing modes is used. Otherwise, the MTU-O shall transmit quiet in FUS.

NOTE 2 – Active subcarriers shall always exclude RFIBANDS and IARBANDS. In addition, active subcarriers of the NPSF shall always exclude subcarriers of the FDXMASK.

NOTE 3 – Active symbols in FDS shall be allocated starting from the first symbol of the logical frame, i.e from the position given by the RMC offset (D_{RMCds}). If the number of active symbols s_{ds} is greater than M_{ds}-D_{RMCds}, the remaining active symbols shall be allocated starting from the first symbol of the following FDS sub-frame. During the symbol positions of FDS not occupied by active symbols, the MTU-O shall transmit quiet signal.

NOTE 4 – If the FDXZ framing is used, the last symbol of the FDS shall be an idle symbol (Z_i=0) if that symbol is a part of the s_{ds} symbols defined to be active ones.

NOTE 5 – Those signals are skipped if either the TDD or TDDZ framing modes are used.

NOTE 6 – The active subcarriers of the sync symbols include both the DTFO Band 0 and Band 1 (if defined).

NOTE 7 – Active symbols in FUS shall be allocated starting from the position determined by the upstream RMC offset (D_{RMCus}). If the number of active symbols s_{us} is greater than M_{us}-D_{RMCus}, the remaining active symbols (M_{us}-D_{RMCus}) shall be allocated starting from the first symbol of the following FUS sub-frame. During the symbol positions of FUS not occupied by active symbols, the MTU-O shall transmit quiet signal.

NOTE 8 – O-P-SYNCHRO X signals always use the same active subcarriers, the same PSD, and the same number of active symbols as the previously generated signal by the MTU-O.

Table 12-45 – Active subcarriers, PSD and active symbol positions of signals transmitted by the MTU-R during "Channel Discovery" phase

Signal type	FDS, NPSF (Note 1)					FUS, PSF				
	Sync symbol (Note 5)		Initialization symbols			Sync symbol (NOTE 5)		Initialization symbols		
	PSD	Active subcarriers (Note 2)	PSD	Active subcarriers (Note 2)	Number active symbols (Note 3)	PSD	Active subcarriers (Note 2)	PSD	Active subcarriers (Note 2)	Number active symbols (Note 6)
R-P-VECTOR 1	Quiet	N/A	N/A	N/A	0	STARTPSDus	SUPPORTEDCARRIERSGus	N/A	N/A	0
R-P-CHANNEL DISOCVERY 1 (Note 4)	Quiet	N/A	N/At	N/A	0	STARTPSDus	SUPPORTEDCARRIERSGus	STARTPSDus	SUPPORTEDCARRIERSus of DTFO bands assigned in O-SIGNATURE.	s_{us}
R-P-EC 1 (Note 4)	Quiet	N/A	N/A	N/A	0	STARTPSDus	SUPPORTEDCARRIERSGus	STARTPSDus	SUPPORTEDCARRIERSus of DTFO bands assigned in O-SIGNATURE.	s_{us}
R-P-CHANNEL DISCOVERY 2	STARTPSD_NPus	SUPPORTEDCARRIERSGus	N/A	N/A	0	STARTPSDus	SUPPORTEDCARRIERSGus	STARTPSDus	SUPPORTEDCARRIERSus of DTFO bands assigned in O-SIGNATURE.	s_{us}
R-P-VECTOR 1-1	CDPSD_NPus	SUPPORTEDCARRIERSGus	N/A	N/A	0	CDPSDus	SUPPORTEDCARRIERSGus	N/A	N/A	0
R-P-CHANNEL DISCOVERY 2-1 (Note 4)	CDPSD_NPus	SUPPORTEDCARRIERSGus	N/A	N/A	0	CDPSDus	SUPPORTEDCARRIERSGus	CDPSDus	SUPPORTEDCARRIERSus of DTFO bands assigned in O-SIGNATURE	s_{us}
R-P-EC 1-1 (Note 4)	Quiet	N/A	N/A	N/A	0	CDPSDus	SUPPORTEDCARRIERSGus	CDPSDus	SUPPORTEDCARRIERSus of DTFO bands assigned in O-SIGNATURE	s_{us}
R-P-VECTOR 2	CDPSD_NP1us	SUPPORTEDCARRIERSGus	N/A	N/A	0	CDPSDus	SUPPORTEDCARRIERSGus	CDPSDus	SUPPORTEDCARRIERSus of DTFO bands assigned in O-SIGNATURE	s_{us}
R-P-VECTOR 2-1	CDPSD_NP1us	SUPPORTEDCARRIERSGus	N/A	N/A	0	CDPSDus	SUPPORTEDCARRIERSGus	CDPSDus	SUPPORTEDCARRIERSus of DTFO bands assigned in O-SIGNATURE	s_{us}

Table 12-45 – Active subcarriers, PSD and active symbol positions of signals transmitted by the MTU-R during "Channel Discovery" phase

R-PRM-UPDATE 1	CDPSD_NP1us	SUPPORTEDCARRIERSGus	N/A	N/A	0	CDPSDus	SUPPORTEDCARRIERSGus	CDPSDus	SUPPORTEDCARRIERSus of DTFO bands assigned in O-SIGNATURE	s_{us}
R-PRM-UPDATE 2	CDPSD_NP2us	SUPPORTEDCARRIERSGus	CDPSD_NP2us	SUPPORTEDCARRIERSus of DTFO bands assigned in O-SIGNATURE	$s_{us,NPSF}$	CDPSDus	SUPPORTEDCARRIERSGus	CDPSDus	SUPPORTEDCARRIERSus of DTFO bands assigned in O-SIGNATURE	s_{us}

NOTE 1 –The MTU-R shall transmit active symbols, including sync symbols, in FDS only if FDXC or FDXZ framing modes is used. Otherwise, the MTU-R shall transmit quiet FDS.

NOTE 2 – Active subcarriers shall always exclude RFIBANDS and IARBANDS. In addition, active subcarriers of the NPSF shall always exclude subcarriers of the FDXMASK.

NOTE 3 – Active symbols in FDS shall be allocated starting from the first symbol of the logical frame, i.e from the position given by the RMC offset (D_{RMCds}). If the number of active symbols is greater than M_{ds}-D_{RMCds}, the remaining active symbols shall be allocated starting from the first symbol of the following FDS sub-frame. During the symbol positions of FDS not occupied by active symbols, the MTU-R shall transmit quiet signal.

NOTE 4 – Those signals are skipped if the TDD or TDDZ framing modes are used.

NOTE 5 – The active subcarrier of the sync symbols shall include both DTFO Band 0 and Band 1.

NOTE 6 – Active symbols in FUS shall be allocated starting from the position given by the upstream RMC offset (D_{RMCus}). If the number of active symbols is greater than M_{us}-D_{RMCus}, the remaining active symbols shall be allocated starting from the first symbol of the following FUS sub-frame. During the symbol positions of FUS not occupied by active symbols, the MTU-R shall transmit quiet signal.

12.3.3.3.1 Signals during QUIET 1 stage

12.3.3.3.1.1 O-P-QUIET 1

The O-P-QUIET 1 signal shall consist of QUIET symbols only.

The duration of O-P-QUIET 1 signal is variable with a valid range from 2 to 128 superframes. Its duration is determined by the MTU-O and is not necessarily an integer number of superframes.

The O-P-QUIET 1 signal shall be followed by the O-P-VECTOR 1 signal. The MTU-O terminates the QUIET 1 stage by starting transmission of the O-P-VECTOR 1 signal at a superframe boundary.

12.3.3.3.1.2 R-P-QUIET 1

The R-P-QUIET 1 signal shall consist of QUIET symbols only.

The R-P-QUIET 1 signal shall be continued until the MTU-R receives the O-SIGNATURE message.

12.3.3.3.2 Signals during O-VECTOR 1 stage

Upon completion of the O-VECTOR 1 stage, the VCE determines the downstream FEXT and O-NEXT cancellation coefficients, and the downstream PSD to be used during further stages of channel discovery phase (CDPSDds).

12.3.3.3.2.1 O-P-VECTOR 1

The O-P-VECTOR 1 signal shall consist of downstream sync symbols and quiet symbols only. Sync symbols shall be transmitted in both FDS and FUS if either the FDXC or the FDXZ framing mode is used. Sync symbols shall be transmitted only in FDS if the TDD framing mode is used. Quiet symbols shall be transmitted at all other symbol positions (see Figure 10-2). The sync symbols shall be generated and modulated by probe sequence as described in clause 10.2.2.1. The SOC shall be in its inactive state.

The O-P-VECTOR 1 signal shall use all subcarriers from the SUPPORTEDCARRIERSds set, including DTFO Band 0 and Band 1. The transmit PSD of all subcarriers in FDS and also in FUS (if transmission line joins in FDX mode) shall be equal to STARTPSDds.

The STARTPSDds shall comply to the STARTPSDMASKds as specified in Table 7-4.

The MTU-O shall use the probe sequence assigned to the initializing line by the vectoring control entity (VCE).

The duration of the O-VECTOR 1 stage is vendor discretionary, but shall be an integer number of superframes with a minimum of 8 superframes and a maximum number of superframes equal to floor(actual setting of *CD*_time_out_1/superframe duration) – 1, using *CD*_time_out_1 as specified in clause 12.3.1. The O-P-VECTOR 1 signal shall be followed by the O-P-CHANNEL-DISCOVERY 1-1 signal; transition to O-P-CHANNEL-DISCOVERY 1-1 signal determines the actual duration of the O-VECTOR 1 stage. The start time of the CHANNEL DISCOVERY 1-1 stage is determined by the VCE and shall be at the superframe boundary (i.e., it shall start at the symbol with index 0 of the first downstream logical frame of a superframe).

12.3.3.3.2.2 R-P-QUIET 1

During the O-VECTOR 1 stage the MTU-R shall continue transmission of the R-P-QUIET 1 signal (see clause 12.3.3.3.1.2).

12.3.3.3.3 Signals during CHANNEL DISCOVERY 1-1 stage

12.3.3.3.3.1 O-P-CHANNEL-DISCOVERY 1-1

During transmission of the O-P-CHANNEL-DISCOVERY 1-1 signal, the MTU-O facilitates timing acquisition at the MTU-R. The MTU-R uses the O-P-CHANNEL-DISCOVERY 1-1 signal to obtain loop timing, symbol timing, and PDX frame timing. Sync symbol boundary alignment, and initial FEQ training may also be performed at this stage.

The O-P-CHANNEL-DISCOVERY 1-1 signal shall consist of downstream sync symbols and initialization symbols. Sync symbols shall be transmitted in both FDS and FUS if either the FDXC or the FDXZ framing mode is used. Sync symbols shall be transmitted only in FDS if the TDD framing mode is used.

The SOC shall be in its active state. The SOC symbols shall be transmitted at the first $s_{ds\text{-}CD\text{-}1\text{-}1}$ symbol positions of each FDS downstream logical frame counting only positions inside FDS, except on the last symbol position of the downstream PSF sub-frame, if FDXZ framing mode is used; all other initialization symbols shall be quiet. IDS shall not be applied and there shall be no SOC symbol repetitions. The value of $s_{ds\text{-}CD\text{-}1\text{-}1}$ shall be set according to the following rule:

$$s_{ds\text{-}CD\text{-}1\text{-}1} = s_{ds}, \text{ if } D_{RMCds} + s_{ds} \le M_{ds}$$

$$s_{ds\text{-}CD\text{-}1\text{-}1} = M_{ds} \text{ otherwise}$$

The value of s_{ds} is determined by the VCE for the entire initialization procedure and is communicated to the MTU-R during the ITU-T G.994.1 handshake (see clause 12.3.2.1.1). The location of the sync symbol and the first data symbol in a PDX frame is determined by the parameter D_{RMCds} communicated to the MTU-R during the ITU-T G.994.1 handshake (see clause 12.3.2.1.1). The offset shall be applied as defined in clause 10.5.5.

NOTE – Each downstream logical frame overlaps the FDS of two consecutive PDX frames. It spans the last M_{ds}-D_{RMCds} symbol positions of the FDS of the first PDX frame and the first D_{RMCds} symbol positions of the FDS of the second PDX frame. So, when $s_{ds\text{-}CD\text{-}1\text{-}1} > M_{ds} - D_{RMCds}$, $s_{ds\text{-}CD\text{-}1\text{-}1} - M_{ds} + D_{RMCds}$ symbols are active in the second PDX frame in addition to the M_{ds}-D_{RMCds} active symbols in the first PDX frame.

The sync symbols shall be generated and modulated by probe sequences as described in clause 10.2.2.1. The probe sequence that modulates sync symbols is determined during the ITU-T G.994.1 handshake. It shall be continued from the previous stage with no interruption. Sync symbols shall use all subcarriers of the SUPPORTEDCARRIERSds set, including Band 0 and Band 1.

The initialization symbols of the O-P-CHANNEL-DISCOVERY 1-1 signal shall use all subcarriers from the SUPPORTEDCARRIERSds set in Band 0 only.

The transmit PSD shall be equal to CDPSDds, as determined during the O-VECTOR 1 stage, in FDS and also in FUS (if transmission line joins in FDX mode).

The SOC symbols shall use robust SOC bit mapping (see clause 10.2.2.2.1). From the start of the first superframe of the O-CHANNEL DISCOVERY 1-1 stage, the SOC shall transmit O-IDLE over all SOC symbols. The SOC quadrant scrambler shall be in reset mode (see clause 10.2.2.2).

The O-P-CHANNEL-DISCOVERY 1-1 signal shall be followed by the O-P-SYNCHRO 1-1 signal. The actual duration of the O-CHANNEL DISCOVERY 1-1 stage is determined by the VCE and shall be greater than or equal to the duration requested by the MTU-R of the initializing line during the ITU-T G.994.1 handshake (see clause 12.3.2.1.2). The start time of O-P-SYNCHRO 1-1 transmission shall be at the symbol with index zero of the first downstream logical frame of the superframe.

12.3.3.3.3.2 O-P-SYNCHRO 1-1

The O-P-SYNCHRO 1-1 signal provides an exact time marker for transition from the CHANNEL DISCOVERY 1-1 stage to the CHANNEL DISCOVERY 1 stage. The duration of the O-P-SYNCHRO 1-1 signal shall be one superframe.

The O-P-SYNCHRO 1-1 signal shall have the same structure (see clause 12.3.3.3) as O-P-CHANNEL-DISCOVERY 1-1. During transmission of the O-P-SYNCHRO 1-1 signal, the SOC shall be inactive.

The sync symbols shall be generated and modulated by probe sequences as described in clause 10.2.2.1. The elements of the probe sequence carried by sync symbols of the O-P-SYNCHRO 1-1 signal shall continue the probe sequence transmitted during the O-P-CHANNEL DISCOVERY 1-1 signal with no interruption. Sync symbols shall use all subcarriers of the SUPPORTEDCARRIERSds set, including Band 0 and Band 1.

The initialization symbols of the O-P-SYNCHRO 1-1 signal shall use all subcarriers from the SUPPORTEDCARRIERSds set in Band 0 only modulated as defined in clause 10.2.2.2. The SOC quadrant scrambler shall be in reset mode. The IDS shall not be applied.

The first $s_{ds\text{-}CD\text{-}1\text{-}1}$ symbol positions of the downstream logical frames of the O-P-SYNCHRO 1-1 signal shall carry:

– inverted symbols containing SOC IDLE (see clause 12.2.3 for the equivalent definition when the SOC is in the active state) with robust bit mapping in the first 3 logical frames,

– Symbols containing SOC IDLE with robust bit mapping in the 4th and 5th logical frames, and

– inverted symbols containing SOC IDLE with robust bit mapping in the rest of the logical frames.

The transmit PSD of the O-P-SYNCHRO 1-1 signal shall be equal to CDPSDds in FDS and also in FUS (if transmission line joins in FDX mode).

12.3.3.3.3.3 R-P-QUIET 1

During the CHANNEL-DISCOVERY 1-1 stage the MTU-R shall continue transmission of the R-P-QUIET 1 signal.

12.3.3.3.4 Signals during CHANNEL DISCOVERY 1 and R-VECTOR 1 stages

12.3.3.3.4.1 O-P-CHANNEL-DISCOVERY 1

During transmission of the O-P-CHANNEL-DISCOVERY 1 signal, the MTU-O communicates to the MTU-R all necessary information to start upstream transmission. The MTU-R also uses the O-P-CHANNEL-DISCOVERY 1 signal to obtain more accurate symbol timing, train the FEQ and align superframe count between MTU-O and MTU-R.

The O-P-CHANNEL-DISCOVERY 1 signal shall consist of downstream sync symbols and initialization symbols. Sync symbols shall be transmitted at each downstream sync symbol position used during the previous stage. Sync symbols shall be generated and modulated by probe sequences as described in clause 10.2.2.1. The probe sequence modulating sync symbols shall be continued from the previous stage with no interruption. Sync symbols shall use all subcarriers of the SUPPORTEDCARRIERSds set, including Band 0 and Band 1.

The SOC shall be in its active state. SOC symbols shall be transmitted at the first s_{ds} symbol positions of each downstream logical frame counting only position inside FDS, except on the last symbol position of the downstream PSF sub-frame if FDXZ framing mode is used; all other initialization symbols shall be quiet. SOC symbols shall use robust SOC bit mapping (see clause 10.2.2.2.1). If the transmission line falls back to TDDZ framing mode and the first s_{ds}

symbols positions of the downstream logical frame contains the last symbol of the downstream PSF sub-frames with the FDXZ framing mode, the value of s_{ds} shall be decreased by 1 upon the change of framing mode.

NOTE 1 – The decrease by 1 of the Mds (see 12.3.3.1.4) and possibly of the sds during the fallback to TDDZ is needed to keep the same number of active downstream symbols when the framing mode is changed.

NOTE 2 – Each downstream logical frame overlaps the FDS of two consecutive PDX frames. It spans the last M_{ds}-D_{RMCds} symbol positions of the FDS of the first PDX frame and the first D_{RMCds} symbol positions of the FDS of the second PDX frame. So, when $s_{ds}>M_{ds}-D_{RMCds}$, $s_{ds}-M_{ds}+D_{RMCds}$ symbols are active in the second PDX frame in addition to the M_{ds}-D_{RMCds} active symbols in the first PDX frame.

The initialization symbols of the O-P-CHANNEL-DISCOVERY 1 signal shall use all subcarriers from the SUPPORTEDCARRIERSds set in DTFO Band 0 only.

The transmit PSD shall be equal to CDPSDds, as determined during the O-VECTOR 1 stage in FDS and also in FUS (if transmission line joins in FDX mode). The actual value of CDPSDds is communicated to the MTU-R in the O-SIGNATURE message.

From the start of the first superframe of the O-CHANNEL DISCOVERY 1 stage (symbol with index 0 of the first downstream logical frame), the SOC shall transmit O-IDLE for a period of eight superframes (IDS and SOC symbol repetition are disabled in the first superframe) plus any number of additional symbols required to complete SOC repetition, followed by transmission of the O-SIGNATURE message, as defined in clause 12.3.3.2.1. The O-SIGNATURE message shall be sent in auto-repeat mode (see clause 12.2.2.1). After detection of the R-P-VECTOR 1 signal, the SOC shall stop transmission of O-SIGNATURE message and transmit O-IDLE followed by transmission of O-TG-UPDATE message, as defined in clause 12.3.3.2.1. The O-TG-UPDATE message shall be transmitted in auto-repeat mode. The SOC quadrant scrambler shall be in reset mode.

Starting from the beginning of the first downstream logical frame of the second superframe of this stage, every transmitted SOC symbol shall be repeated as defined in clause 10.2.2.3. The number of SOC symbol repetitions, R_s, shall be as selected during the ITU-T G.994.1 phase of initialization (see clause 12.3.2.1.2).

After repetition is applied, all SOC symbols shall be modulated by the IDS, as defined in clause 10.2.2.2. The IDS shall be as selected during the ITU-T G.994.1 phase of initialization.

During the transmission of O-IDLE that follows detection of R-P-VECTOR 1 signal, the MTU-O estimates the correction to the initial value of the time gap T_{g1}'. As the estimation is complete, the value is communicated to the MTU-R in the O-TG-UPDATE message. The duration of the O-IDLE is determined by the MTU-O and depends on the required estimation time.

The O-P-CHANNEL-DISCOVERY 1 signal shall be followed by the O-P-SYNCHRO 1 signal. Transition to O-P-SYNCHRO 1 signal determines the actual duration of the O-CHANNEL DISCOVERY 1 stage. The start time of O-P-SYNCHRO 1 signal transmission is determined by the VCE and shall be at the symbol with index zero of the first downstream logical frame of the superframe. Transmission of O-P-SYNCHRO 1 signal may terminate the last repetition of the O-TG-UPDATE message.

12.3.3.3.4.2 R-P-VECTOR 1

The transmission of the R-P-VECTOR 1 signal shall start from the following superframe after the MTU-R successfully detects the O-SIGNATURE message and adopts the upstream transmission parameters indicated in the O-SIGNATURE message. Prior to transmission of the R-P-VECTOR 1 signal, the MTU-R shall continue transmission of the R-P-QUIET 1 signal.

During transmission of the R-P-VECTOR 1 signal, the MTU-R applies the initial value of the time gap T_{g1}' communicated in O-SIGNATURE message.

NOTE – During transmission of the R-P-VECTOR 1 signal, the VCE may estimate the upstream FEXT channels between all transmission lines (both joining lines and active lines). In case FDX transmission is desired, the VCE may evaluate R-NEXT (NEXT from one MTU-R to another MTU-R) generated into active lines and the MTU-R may evaluate also the echo. Upon completion of the R-VECTOR 1 stage, the time position of upstream symbols of the joining lines is aligned with active lines and upstream FEXT cancellation matrices are established by the VCE for all active lines and joining lines, and upstream FEXT is cancelled and echo at the MTU-R may be cancelled. Using the R-NEXT evaluation, the VCE may compute the initial upstream PSD limit to be used during the FDS sub-frame. This PSD limit may be further re-estimated during the EC TRAINING 1 stage.

The R-P-VECTOR 1 signal shall consist of upstream sync symbols and quiet symbols only. Sync symbols shall be transmitted at each FUS upstream sync symbol position only regardless of the PDX framing mode. Quiet symbols shall be transmitted at all other upstream symbol positions. The FUS sync symbols shall be generated and modulated by probe sequences as described in clause 10.2.2.1. The SOC shall be in its inactive state.

The R-P-VECTOR 1 signal shall use all subcarriers from the SUPPORTEDCARRIERSGus set, as indicated in the O-SIGNATURE message, including Band 0 and Band 1. The transmit PSD (STARTPSDus) shall be derived using the estimated electrical length and UPBO parameters indicated in the O-SIGNATURE message.

The MTU-R shall use the probe sequence indicated in the O-SIGNATURE message, starting transmission from the bit of the sequence computed using the upstream probe sequence start marker value indicated in the O-SIGNATURE message.

During transmission of R-P-VECTOR 1 signal, the MTU-R shall monitor the SOC to detect the O-TG-UPDATE message. Upon reception of O-TG-UPDATE message, the MTU-R shall adjust the initial value of the time gap T_{g1}' to the value indicated in O-TG-UPDATE message and continue transmission of R-P-VECTOR 1 signal. The probe sequence shall continue with no interruption.

The duration of the R-VECTOR 1 stage is determined by the MTU-O: the MTU-R shall terminate transmission of the R-P-VECTOR 1 signal upon reception of the O-P-SYNCHRO 1 signal and shall transition to the EC-TRAINING 1 stage, if transmission line joins in FDX mode, or to the CHANNEL DISCOVERY 2 stage, if transmission line joins in TDD mode or a TDD fallback was indicated in O-TG-UPDATE message. The transition shall start from the symbol with index 0 of the upstream logical frame following the last symbol of the O-P-SYNCHRO 1 signal.

12.3.3.3.4.3 O-P-SYNCHRO 1

The O-P-SYNCHRO 1 signal provides an exact time marker for transition from the CHANNEL DISCOVERY 1 stage to the EC-TRAINING 1 stage, if transmission line joins in FDX mode, or to the CHANNEL DISCOVERY 2 stage, if transmission line joins in TDD mode or a TDD fallback was indicated in O-TG-UPDATE message. The duration of the O-P-SYNCHRO 1 signal shall be one superframe.

The O-P-SYNCHRO 1 shall have the same structure (see clause 12.3.3.3) as O-P-CHANNEL DISCOVERY 1. During transmission of the O-P-SYNCHRO 1 signal, the SOC is inactive.

The sync symbols shall be generated and modulated by the probe sequence as described in clause 10.2.2.1. The elements of the probe sequence carried by the sync symbol of the O-P-SYNCHRO 1 signal shall continue the probe sequence transmitted during the O-P-CHANNEL DISCOVERY 1 signal with no interruption. Sync symbols shall use all subcarriers of the SUPPORTEDCARRIERSds set, including Band 0 and Band 1.

The initialization symbols of the O-P-SYNCHRO 1 signal shall use all subcarriers from the SUPPORTEDCARRIERSds set in Band 0 only, modulated as defined in clause 10.2.2.2. The SOC quadrant scrambler shall be in reset mode. The IDS shall be applied as defined in clause 10.2.2.2.

The first s_{ds} symbol positions of all the downstream logical frames of the O-P-SYNCHRO 1 signal, except on the last symbol position of the downstream PSF sub-frame, if FDXZ framing mode is used, shall carry inverted symbols containing SOC IDLE (see clause 12.2.3 for the equivalent definition when the SOC is in the active state) with robust bit mapping.

The transmit PSD of the O-P-SYNCHRO 1 signal shall be equal to CDPSDds in FDS and also in FUS (if transmission line joins in FDX mode).

12.3.3.3.5 Signals during EC TRAINING 1 stage

This stage shall be skipped if transmission line is joining in TDD framing mode or TDD fallback was requested during R-VECTOR 1 stage. If skipped, both MTUs shall transition to the CHANNEL DISCOVERY 2 stage

12.3.3.3.5.1 O-P-CHANNEL-DISCOVERY 1-2

During transmission of the O-P-CHANNEL-DISCOVERY 1-2 signal, the MTU-O communicates to the MTU-R parameters related to echo cancellation (EC).

The O-P-CHANNEL-DISCOVERY 1-2 signal shall have the same structure (see clause 12.3.3.3) as the O-P-CHANNEL-DISCOVERY 1. The sync symbol shall be generated and modulated by the probe sequence as described in clause 10.2.2.1. The elements of the probe sequence carried by the sync symbols of the O-P-CHANNEL DISCOVERY 1-2 shall continue from the previous stage, with no interruptions on both FDS and FUS sync symbol positions. Sync symbols shall use all subcarriers of the SUPPORTEDCARRIERSds set, including DTFO Band 0 and Band 1.

The SOC shall be in its active state and use robust bit mapping. Every transmitted SOC symbol shall be repeated according to the number of repetitions, R_S, which is selected during the ITU-T G.994.1 phase of initialization (see clause 12.3.2.1.2). After repetition is applied, all SOC symbols shall be modulated by the IDS, as defined in clause 10.2.2.2. The IDS shall be the same as defined for O-P-CHANNEL-DISCOVERY 1 signal. The SOC quadrant scrambler shall be in reset mode.

The initialization symbols of the O-P-CHANNEL-DISCOVERY 1-2 signal shall use all subcarriers from the SUPPORTEDCARRIERSds set in DTFO Band 0 only, except on the symbol positions assigned in O-SIGNATURE (DTFO Band 1 symbol assignment) which shall use all subcarriers from the SUPPORTEDCARRIERSds set in both DTFO Band 0 and Band 1.

The transmit PSD shall be equal to CDPSDds in FDS and also in FUS (if transmission line joins in FDX mode).

The MTU-O shall start transmission of the O-P-CHANNEL-DISCOVERY 1-2 signal right upon completion of transmission of the O-P-SYNCHRO 1 signal, starting from the symbol with index zero of the following downstream logical frame. From the start of the first superframe of the O-CHANNEL DISCOVERY 1-2 signal, the SOC shall transmit O-IDLE for a period of 3 superframes, followed by transmission of the O-EC-PRM message, that indicates parameters to be applied in O/R-P-EC 1 signals and those associated with FDX mode. The O-EC-PRM message shall be sent in auto-repeat mode (see clause 12.2.2.1). During O-EC-PRM transmission, the MTU-O shall monitor the SOC to detect R-EC-PRM message from the MTU-R (which acknowledges O-EC-PRM message).

After MTU-O receives the R-EC-PRM message, it shall transmit O-P-SYNCHRO 1-2 signal. The start time of O-P-SYNCHRO 1-2 transmission is determined by the VCE. Transmission of O-P-SYNCHRO 1-2 signal may terminate transmission of O-EC-PRM message prior to completion of all SOC symbol repetitions.

12.3.3.3.5.2 O-P-SYNCHRO 1-2

The O-P-SYNCHRO 1-2 signal provides an exact time marker for transition from the O-P-CHANNEL DISCOVERY 1-2 signal to O-P-EC 1 signal. The O-P-SYNCHRO 1-2 signal shall have the same structure (see clause 12.3.3.3) as the O-P-CHANNEL-DISCOVERY 1-2 signal. The signal shall have the same duration as the O-P-SYNCHRO 1 signal. All initialization symbols shall carry inverted symbols containing SOC IDLE with robust bit mapping. During transmission of the O-P-SYNCHRO 1-2 signal, the SOC shall be inactive, the SOC quadrant scrambler shall be in reset mode, and the IDS shall be applied as defined in clause 10.2.2.2.

The sync symbols shall be generated and modulated by probe sequences as described in clause 10.2.2.1. The elements of the probe sequence carried by the sync symbols of the O-P-SYNCHRO 1-2 signal shall continue the probe sequence transmitted during the O-P-CHANNEL DISCOVERY 1-2 signal with no interruption. Sync symbols shall use all subcarriers of the SUPPORTEDCARRIERSds set, including DTFO Band 0 and Band 1.

The initialization symbols of the O-P-SYNCHRO 1-2 signal shall use all subcarriers from the SUPPORTEDCARRIERSds set in DTFO Band 0 only, except those assigned in O-SIGNATURE (DTFO Band 1 symbol assignment) to use all subcarriers from the SUPPORTEDCARRIERSds set in both DTFO Band 0 and Band 1, all modulated as defined in clause 10.2.2.2.

The transmit PSD of the O-P-SYNCHRO 2 signal shall be CDPSDds in FDS and also in FUS (if transmission line joins in FDX mode).

12.3.3.3.5.3 O-P-EC 1 signal

The O-P-EC 1 signal is to assist MTU-O echo canceller training. The duration of this signal shall be as indicated in O-EC-PRM message. The O-P-EC 1 signal shall have the same structure (see clause 12.3.3.3) as the O-P-CHANNEL-DISCOVERY 1-2 signal.

The MTU-O shall transmit O-P-EC 1 starting from symbol 0 of the logical frame that follows O-P-SYNCHRO 1-2.

The probe sequence transmitted during O-P-SYNCHRO 1-2 may be interrupted and a VCE discretionary probe sequence used instead on both FDS and FUS sync symbol positions.

The initialization symbols shall consist of subcarriers modulated with 2-bits constellation points selected in a vendor discretionary way. The constellation points may vary between subcarriers and between different initialization symbols. Each initialization symbol shall be repeated R_S times (as the SOC symbols). IDS shall be applied as defined in clause 10.2.2.2. The SOC quadrant scrambler shall be in reset mode.

The O-P-EC 1 signal shall use all subcarriers from the SUPPORTEDCARRIERSds set in DTFO Band 0 only, except those assigned in O-SIGNATURE (DTFO Band 1 symbol assignment) to use all subcarriers from the SUPPORTEDCARRIERSds set in both DTFO Band 0 and Band 1.

The transmit PSD shall be equal to CDPSDds in FDS and also in FUS (if transmission line joins in FDX mode).

The O-P-EC 1 signal shall be followed by the CHANNEL-DISCOVERY 1-3 signal.

12.3.3.3.5.4 O-P-CHANNEL-DISCOVERY 1-3

During transmission of the O-P-CHANNEL-DISCOVERY 1-3 signal, the MTU-R updates its echo canceller.

The MTU-O shall start transmission of the O-P-CHANNEL-DISCOVERY 1-3 signal right upon completion of transmission of the O-P-EC 1 signal, starting from the symbol with index zero of the following downstream logical frame.

The O-P-CHANNEL-DISCOVERY 1-3 signal shall consist of downstream sync symbols and initialization symbols. Sync symbols shall be transmitted only in the FDS sync symbol positions. Quiet shall be transmitted on FUS sync symbol positions. The sync symbol shall be generated and modulated by the probe sequence as described in clause 10.2.2.1. The elements of the probe sequence carried by the sync symbols of the O-P-CHANNEL DISCOVERY 1-3 shall continue the probe sequence transmitted during the O-P-EC 1 signal on FDS sync symbol positions with no interruption. Sync symbols shall use all subcarriers of the SUPPORTEDCARRIERSds set, including Band 0 and Band 1.

The SOC shall be in its active state and use robust bit mapping with SOC repetition, R_S. The SOC shall send O-IDLE. SOC symbols shall be transmitted in FDS only at the first s_{ds} symbol positions of each downstream logical frame (i.e., transmission of SOC symbols shall start at the symbol with index 0 of the first downstream logical frame in the superframe) counting only positions inside FDS; all other initialization symbols shall be quiet. During transmission of the O-P-CHANNEL DISCOVERY 1-3 signal the SOC shall send O-IDLE, the SOC quadrant scrambler shall be in reset mode and the IDS shall be applied as defined in clause 10.2.2.2.

The initialization symbols of the O-P-CHANNEL-DISCOVERY 1-3 signal shall use all subcarriers from the SUPPORTEDCARRIERSds set in DTFO Band 0 only except those assigned in O-SIGNATURE (DTFO Band 1 symbol assignment) to use all subcarriers from the SUPPORTEDCARRIERSds set in both DTFO Band 0 and Band 1.

The transmit PSD shall be equal to CDPSDds in FDS.

The O-P-CHANNEL-DISCOVERY 1-3 signal shall be followed by the O-P-SYNCHRO 1-3 signal, which determines the actual duration of the EC TRAINING 1 stage. The O-P-SYNCHRO 1-3 transmission shall be after the minimum duration of R-P-EC 1 signal indicated in R-EC-PRM message has expired, and shall start from the symbol with index 0 of the first downstream logical frame of a superframe.

12.3.3.3.5.5 R-P-CHANNEL-DISCOVERY 1

During transmission of the R-P-CHANNEL-DISCOVERY 1 signal, the MTU-R communicates its EC training related parameters to the MTU-O.

The R-P-CHANNEL DISCOVERY 1 signal shall consist of upstream sync symbols and initialization symbols. Sync symbols shall be transmitted at all upstream sync symbol positions, used during transmission of R-P-VECTOR 1 signal. Sync symbols shall be generated and modulated by probe sequences as described in clause 10.2.2.1. The probe sequence modulating sync symbols shall be continued from the R-P-VECTOR 1 signal with no interruption. Sync symbols shall use all subcarriers of the SUPPORTEDCARRIERSGus set, including Band 0 and Band 1.

The SOC shall be in its active state and use robust bit mapping. The SOC symbols shall be transmitted in the FUS only at the first s_{us} upstream symbol positions, counting only positions inside FUS; all other initialization symbols shall be quiet. The value of s_{us} is defined in field 19 of O-SIGNATURE message. The SOC quadrant scrambler shall be in reset mode.

NOTE – Each upstream logical frame overlaps the FUS of two consecutive PDX frames. It spans the last M_{us}-D_{RMCus} symbol positions of the FUS of the first PDX and the first D_{RMCus} symbol positions of the FUS of the second PDX frame. So, when s_{us}>M_{us}-D_{RMCus}, s_{us}-M_{us}+D_{RMCus} symbols are active in the second PDX frame in addition to the M_{us}-D_{RMCus} symbols active in the first PDX frame.

The initialization symbols of the R-P-CHANNEL DISCOVERY 1 signal shall use all subcarriers from the SUPPORTEDCARRIERSus set in DTFO Band 0 only except those assigned in O-SIGNATURE (DTFO Band 1 symbol assignment) to use all subcarriers from the SUPPORTEDCARRIERSus set in both DTFO Band 0 and Band 1.

The transmit PSD shall be equal to STARTPSDus.

The MTU-R shall start transmission of the R-P-CHANNEL-DISCOVERY 1 signal after reception of the O-P-SYNCHRO 1 signal, starting from the symbol with index 0 of the first upstream logical frame following completion of O-P-SYNCHRO 1 signal. From the start of the first superframe of the R-P-CHANNEL DISCOVERY 1 signal, the MTU-R shall transmit R-IDLE. Upon reception of O-EC-PRM message, the MTU-O shall acknowledge it by transmission of the R-EC-PRM message that shall be sent in auto-repeat mode (see clause 12.2.2.1). The transmission of R-EC-PRM message shall be terminated by reception of the O-P-SYNCHRO 1-2 signal that determines the actual duration of the R-P-CHANNEL DISCOVERY 1 signal. Upon reception of the O-P-SYNCHRO 1-2 signal, the MTU-R transmits R-P-QUIET 2 signal.

12.3.3.3.5.6 R-P-QUIET 2

The MTU-R shall start transmission of R-P-QUIET 2 starting from the symbol 0 of the first logical frame that follows the last symbol of the O-P-SYNCHRO 1-2 signal. The duration of R-P-QUIET 2 signal shall be equal to the duration of O-P-EC 1 signal, as indicated in O-EC-PRM message.

The structure of R-P-QUIET 2 signal shall be the same as R-P-QUIET 1 signal. The SOC during R-P-QUIET 2 signal is inactive.

The R-P-QUIET 2 signal shall be followed by R-P-EC 1 signal.

12.3.3.3.5.7 R-P-EC 1

The R-P-EC 1 signal is to assist MTU-R echo canceller training. The minimum duration of this signal is indicated in R-EC-PRM message.

The MTU-R shall start transmission of R-P-EC 1 signal after completion of R-P-QUIET 2 signal, starting from the symbol 0 of the first logical frame of the superframe that follows O-P-QUIET 2.

The R-P-EC 1 signal shall have the same structure (see clause 12.3.3.3) as the R-P-CHANNEL-DISCOVERY 1 signal. The probe sequence transmitted during R-P-EC 1 shall be one communicated in O-EC-PRM message. Sync symbols shall use all subcarriers of the SUPPORTEDCARRIERSGus set, including Band 0 and Band 1.

The initialization symbols shall consist of subcarriers modulated with 2-bits constellation points selected in a vendor discretionary way. The constellation points may vary between subcarriers and between different initialization symbols. The SOC quadrant scrambler shall be in reset mode.

The initialization symbols of the R-P-EC 1 signal shall use all subcarriers from the SUPPORTEDCARRIERSus set in DTFO Band 0 only, except those assigned in O-SIGNATURE (DTFO Band 1 symbol assignment) to use all subcarriers from the SUPPORTEDCARRIERSus set in both DTFO Band 0 and Band 1.

The transmit PSD during FUS shall be equal to STARTPSDus.

The R-P-EC 1 is terminated by reception of O-P-SYNCHRO 1-3 signal that determines the actual duration of R-P-EC 1. After reception of O-P-SYNCHRO 1-3 signal, the MTU-R transitions to the CHANNEL DISCOVERY 2 stage.

12.3.3.3.5.8 O-P-SYNCHRO 1-3

The O-P-SYNCHRO 1-3 signal provides an exact time marker for transition from the EC TRAINING 1 stage to the CHANNEL-DISCOVERY 2 stage. The O-P-SYNCHRO 1-3 signal shall have the same structure (see clause 12.3.3.3) as the O-P-CHANNEL-DISCOVERY 1-3 signal. The signal shall have the same duration as O-P-SYNCHRO 1 signal. All initialization symbols shall carry inverted symbols containing SOC IDLE with robust bit mapping. During transmission of the O-P-SYNCHRO 1-3 signal, the SOC shall be inactive. The SOC quadrant scrambler shall be in reset mode. The IDS shall be applied as defined in clause 10.2.2.2.

The sync symbols shall be generated and modulated by probe sequences as described in clause 10.2.2.1. The elements of the probe sequence shall continue the probe sequence transmitted on FDS sync symbol positions during the O-P-CHANNEL DISCOVERY 1-3 signal with no interruption. Sync symbols shall use all subcarriers of the SUPPORTEDCARRIERSds set, including Band 0 and Band 1.

The initialization symbols of the O-P-SYNCHRO 1-3 signal shall use all subcarriers from the SUPPORTEDCARRIERSds set in DTFO Band 0 only, except those assigned in O-SIGNATURE (DTFO Band 1 symbol assignment) to use all subcarriers from the SUPPORTEDCARRIERSds set in both DTFO Band 0 and Band 1, modulated as defined in clause 10.2.2.2.

The transmit PSD of the O-P-SYNCHRO 1-3 signal shall be CDPSDds in FDS.

12.3.3.3.6 Signals during CHANNEL DISCOVERY 2 stage

12.3.3.3.6.1 O-P-CHANNEL-DISCOVERY 2

During transmission of the O-P-CHANNEL-DISCOVERY 2 signal, the MTU-O communicates to the MTU-R the necessary information to update the upstream PSD and timing advance.

The O-P-CHANNEL-DISCOVERY 2 signal shall consist of downstream sync symbols and initialization symbols. Sync symbols shall be generated and modulated by probe sequences as described in clause 10.2.2.1. Sync symbols shall be transmitted in both FDS and FUS sync symbol positions if either the FDXC or the FDXZ framing mode is used. Sync symbols shall be transmitted only in FDS sync symbol positions if either the TDD or TDDZ framing mode is used. Sync symbols shall use all subcarriers of the SUPPORTEDCARRIERSds set, including Band 0 and Band 1.

The SOC shall be in its active state and use robust bit mapping. SOC symbols shall be transmitted in FDS only at the first s_{ds} symbol positions of each downstream logical frame counting only positions inside FDS; all other initialization symbols shall be quiet. During this stage every transmitted SOC symbol shall be repeated according to the number of repetitions, R_S, which is selected during the ITU-T G.994.1 phase of initialization (see clause 12.3.2.1.2). After repetition is applied, all SOC symbols shall be modulated by the IDS, as defined in clause 10.2.2.2. The IDS shall be the same as defined for O-P-CHANNEL-DISCOVERY 1 signal. The SOC quadrant scrambler shall be in reset mode.

The initialization symbols of the O-P-CHANNEL-DISCOVERY 2 signal shall use all subcarriers from the SUPPORTEDCARRIERSds set in DTFO Band 0 only, except those assigned in O-SIGNATURE (DTFO Band 1 symbol assignment) to use all subcarriers from the SUPPORTEDCARRIERSds set in both DTFO Band 0 and Band 1.

The transmit PSD shall be equal to CDPSDds in FDS and also in FUS (if transmission line joins in FDX mode).

The probe sequence modulating sync symbols shall be the one communicated in O-SIGNATURE message and O-EC-PRM message. The probe sequence communicated in O-SIGNATURE message and O-EC-PRM message shall be used in O-P-CHANNEL-DISCOVERY 2 signal with its element indices aligned such that they are the same as they would have been if the downstream probe sequences communicated in O-SIGNATURE message and O-EC-PRM message were actually used on all FDS sync symbol positions and on all FUS sync symbol positions, respectively, since the transmission of O-P-SYNCHRO 1-1 and both sequences were continued with no interruption, i.e., shall be kept consistent with the time marker of downstream probe sequence communicated in O-SIGNATURE. This rule shall be kept also for FDS in case if the TDD or TDDZ framing mode is used.

NOTE – This is to ensure that the probe sequence of a joining line has proper phase alignment with the probe sequences of the other transmission lines in the vectored group.

The MTU-O shall start transmission of the O-P-CHANNEL-DISCOVERY 2 signal right upon completion of transmission of the O-P-SYNCHRO 1 signal, if transmission line joins in TDD or TDDZ framing mode, or of the O-P-SYNCHRO 1-3 signal, if joining in FDXC or FDXZ framing mode continues, starting from the symbol with index zero of the following downstream logical frame. From the start of the first superframe of the O-CHANNEL DISCOVERY 2 stage, the SOC shall transmit O-IDLE until the MTU-O receives the R-MSG 1 message. The MTU-O shall acknowledge R-MSG1 by sending an O-UPDATE message, as defined in Table 12-31. The O-UPDATE message shall be sent in AR mode (see clause 12.2.2.1). The MTU-R acknowledges O-UPDATE message by sending R-UPDATE message. Reception of R-UPDATE message completes the message exchange of O-CHANNEL DISCOVERY 2 stage. After reception of R-UPDATE, the MTU-O shall transmit O-IDLE.

The O-P-CHANNEL-DISCOVERY 2 signal shall be followed by the O-P-SYNCHRO 2 signal, which determines the actual duration of the CHANNEL DISCOVERY 2 stage. The start time of O-P-SYNCHRO 2 transmission shall be at the symbol with index 0 of the first downstream logical frame of a superframe and is determined by the VCE. Transmission of O-P-SYNCHRO 2 signal may terminate transmission of O-IDLE prior to completion of all SOC symbol repetitions (R_S).

12.3.3.3.6.2 R-P-CHANNEL-DISCOVERY 2

During transmission of the R-P-CHANNEL-DISCOVERY 2 signal, the MTU-R communicates to the MTU-O all necessary information to update the downstream PSD.

The R-P-CHANNEL DISCOVERY 2 signal shall consist of upstream sync symbols and initialization symbols. Sync symbols shall be transmitted in both FDS and FUS sync symbol positions if either the FDXC or the FDXZ framing mode is used. Sync symbols shall be transmitted only in FDS sync symbol positions if either the TDD or TDDZ framing mode is used. Sync symbols shall be generated and modulated by probe sequences as described in clause 10.2.2.1. Sync symbols shall use all subcarriers of the SUPPORTEDCARRIERSGus set, including Band 0 and Band 1.

The probe sequence communicated in O-SIGNATURE message shall be used in FUS sync symbol positions of R-P-CHANNEL-DISCOVERY 2 signal with its element indices aligned such that they are the same as they would have been if the probe sequence used in R-P-VECTOR 1 signal would continue with no interruption, i.e., kept consistent with the time marker of upstream probe sequence communicated in O-SIGNATURE). This rule shall be kept for FUS also in case when the fallback to TDD occurs. In case transmission line continues joining in FDX mode, the probe sequence elements used on FDS sync symbol positions shall be those communicated in O-EC-PRM message. These element indices shall be aligned with the indices of FUS elements, such that they are consistent with the time marker of upstream probe sequence communicated in O-SIGNATURE.

The SOC shall be in its active state. SOC symbols shall be transmitted in FUS only at the first s_{us} upstream symbol positions counting only positions inside FUS; all other initialization symbols shall be quiet. The sync symbols shall be generated and modulated by probe sequences as described in clause 10.2.2.1. The SOC quadrant scrambler shall be in reset mode.

The initialization symbols of the R-P-CHANNEL DISCOVERY 2 signal shall use all subcarriers from the SUPPORTEDCARRIERSus set in DTFO Band 0 only, except those assigned in O-SIGNATURE (DTFO Band 1 symbol assignment) to use all subcarriers from the SUPPORTEDCARRIERSus set in both DTFO Band 0 and Band 1. SOC symbols shall use robust bit mapping (see clause 10.2.2.2.1).

The transmit PSD during FUS sub-frame shall be equal to STARTPSDus. The transmit PSD during FDS (if the joining line continues in FDX mode) shall be equal to STARTPSD_NPus.

The MTU-R shall start transmission of the R-P-CHANNEL-DISCOVERY 2 signal after reception of the O-P-SYNCHRO 1 signal, if transmission line joins in TDD mode or the fallback to TDD occurs, or of the O-P-SYNCHRO 1-3 signal, if joining in FDX mode continues, starting from the symbol with index 0 of the first upstream logical frame following completion of the corresponding O-P-SYNCHRO signal. From the start of the first superframe of the R-CHANNEL DISCOVERY 2 stage, the MTU-R shall transmit R-IDLE for a period of five superframes, followed by the R-MSG 1 message, as defined in Table 12-30. The R-MSG 1 message shall be sent in auto-repeat mode (see clause 12.2.2.1). The transmission of R-MSG 1 message shall be terminated upon reception of O-

UPDATE message. The MTU-R shall acknowledge the O-UPDATE message by sending R-UPDATE message, as defined in Table 12-32. The R-UPDATE message shall be sent in auto-repeat mode. The transmission of the R-UPDATE message shall be acknowledged by the O-P-SYNCHRO 2 signal that determines the actual duration of the CHANNEL DISCOVERY 2 stage. Upon reception of the O-P-SYNCHRO 2 signal, MTU-R shall transition to the R-VECTOR 1-1 stage starting from the symbol with index zero of the upstream logical frame that follows the last symbol of the O-P-SYNCHRO 2 signal.

12.3.3.3.6.3 O-P-SYNCHRO 2

The O-P-SYNCHRO 2 signal provides an exact time marker for transition from the CHANNEL DISCOVERY 2 stage to the R-VECTOR 1-1 stage. The O-P-SYNCHRO 2 signal shall have the same structure (see clause 12.3.3.3) as the O-P-CHANNEL-DISCOVERY 2 signal. The signal shall have the same duration as the O-P-SYNCHRO 1 signal. All initialization symbols shall carry inverted symbols containing SOC IDLE with robust bit mapping. During transmission of the O-P-SYNCHRO 2 signal, the SOC shall be inactive, the SOC quadrant scrambler shall be in reset mode, and the IDS shall be applied as defined in clause 10.2.2.2.

The sync symbols shall be generated and modulated by probe sequences as described in clause 10.2.2.1. The element of the probe sequence carried by the sync symbol of the O-P-SYNCHRO 2 signal shall continue the probe sequence transmitted during the O-P-CHANNEL DISCOVERY 2 signal with no interruption. Sync symbols shall use all subcarriers of the SUPPORTEDCARRIERSds set, including Band 0 and Band 1.

The initialization symbols of the O-P-SYNCHRO 2 signal shall use all subcarriers from the SUPPORTEDCARRIERSds set in DTFO Band 0 only, except those assigned in O-SIGNATURE (DTFO Band 1 symbol assignment) to use all subcarriers from the SUPPORTEDCARRIERSds set in both DTFO Band 0 and Band 1, all modulated as defined in clause 10.2.2.2.

The transmit PSD of the O-P-SYNCHRO 2 signal shall be CDPSDds in FDS and also in FUS (if transmission line joins in FDX mode).

12.3.3.3.7 Signals during R-VECTOR 1-1 stage

12.3.3.3.7.1 O-P-VECTOR 1-1

The MTU-O shall start transmitting the O-P-VECTOR 1-1 signal right after completion of the O-P-SYNCHRO 2 signal (starting from the symbol with index 0 of the following downstream logical frame). O-P-VECTOR 1-1 signal shall have the same structure (see clause 12.3.3.3) as the O-P-CHANNEL-DISCOVERY 2 signal. The SOC is in its active state and use robust bit mapping with SOC repetition, R_S. SOC shall send O-IDLE. The IDS shall be applied. The SOC quadrant scrambler shall be in the reset mode.

The sync symbols shall be generated and modulated by probe sequence as described in clause 10.2.2.1. The probe sequence modulating sync symbols shall be continued from the previous stage with no interruption.

The initialization symbols of the O-P-VECTOR 1-1 signal shall use all subcarriers from the SUPPORTEDCARRIERSds set in DTFO Band 0 only, except on the symbol positions assigned in O-SIGNATURE (DTFO Band 1 symbol assignment) which shall use all subcarriers from the SUPPORTEDCARRIERSds set both DTFO Band 0 and Band 1.

The transmit PSD shall be equal to CDPSDds in FDS and also in FUS (if the FDXC or FDXZ framing mode is used).

NOTE – During the R-VECTOR 1-1 stage, the VCE may adjust the post-canceller coefficients and FEQ gains at the MTU-O to accommodate the updates of the upstream time gap T_{g1}' and to accommodate the update of the upstream transmit PSD to CDPSDus as requested in O-UPDATE message.

The O-P-VECTOR 1-1 signal shall be followed by the O-P-SYNCHRO 3 signal, which determines the actual duration of the R-VECTOR 1-1 stage. The start time for the transmission of the O-P-SYNCHRO 3 signal shall be at the symbol with index 0 of the first downstream logical frame of a superframe and is determined by the VCE.

12.3.3.3.7.2 R-P-VECTOR 1-1

The MTU-R shall start transmitting the R-P-VECTOR 1-1 signal right after reception of the O-P-SYNCHRO 2 signal (starting from the symbol 0 of the following logical frame). The R-P-VECTOR 1-1 signal shall consist of upstream sync symbols and quiet symbols only. Sync symbols shall be transmitted in both FDS and FUS sync symbol positions if either the FDXC or the FDXZ framing mode is used. Sync symbols shall be transmitted only in FDS sync symbol positions if either the TDD or TDDZ framing mode is used. The sync symbols shall be generated and modulated by probe sequences as described in clause 10.2.2.1. The probe sequence modulating sync symbols shall be continued from the previous stage. The SOC shall be in its inactive state.

The applied US time gap T_{g1}' shall be updated as indicated in O-UPDATE message starting from symbol 0 of the first upstream logical frame of R-P-VECTOR 1-1 signal.

The R-P-VECTOR 1-1 signal shall use all subcarriers from the SUPPORTEDCARRIERSus set in DTFO Band 0 and DTFO Band 1.

The transmit PSD of the MTU-R during FUS shall be CDPSDus starting from the first superframe of R-P-VECTOR 1-1 signal. The CDPSDus shall comply to the CDPSDMASKus as specified in Table 7-4. The value of CDPSDus shall be computed using the final electrical length and updated value of PSD ceiling indicated in O-UPDATE message. The transmit PSD during FDS, if the joining line continues in FDX mode, shall be equal to CDPSD_NPus. The value of CDPSD_NPus shall be computed by applying the upstream PSD ceiling for FDS indicated in O-UPDATE message to the value of CDPSDus (see Table 7-4).

The R-P-VECTOR 1-1 signal shall be terminated upon reception of the O-P-SYNCHRO 3 signal. After reception of the O-P-SYNCHRO 3 signal, the MTU-R shall transition either to

- the VECTOR 2 stage in TDD or TDDZ framing mode or
- the EC TRAINING 1-1 stage in the FDXC or FDXZ framing mode

starting from the symbol with index 0 of the upstream logical frame that follows the last symbol of the O-P-SYNCHRO 3 signal.

12.3.3.3.7.3 O-P-SYNCHRO 3

The O-P-SYNCHRO 3 signal provides an exact time marker for transition from the R-VECTOR 1-1 stage to the EC TRAINING 1-1 stage. The O-P-SYNCHRO 3 signal shall have the same structure as the O-P-VETOR-1-1. The signal shall have the same duration as the O-P-SYNCHRO 1 signal. All initialization symbols shall carry inverted symbols containing SOC IDLE with robust bit mapping. During transmission of the O-P-SYNCHRO 3 signal, the SOC shall be inactive, the SOC quadrant scrambler shall be in reset mode, and the IDS shall be applied as defined in clause 10.2.2.2.

The sync symbols shall be generated and modulated by probe sequences as described in clause 10.2.2.1. The element of the probe sequence carried by the sync symbol of the O-P-SYNCHRO 3 signal shall continue the probe sequence transmitted during the O-P-VECTOR 1-1 signal with no interruption. Sync symbols shall use all subcarriers of the SUPPORTEDCARRIERSds set, including Band 0 and Band 1.

The initialization symbols of the O-P-SYNCHRO 3 signal shall use all subcarriers from the SUPPORTEDCARRIERSds set in DTFO Band 0 only, except those assigned in O-SIGNATURE

(DTFO Band 1 symbol assignment) to use all subcarriers from the SUPPORTEDCARRIERSds set in both DTFO Band 0 and Band 1, all modulated as defined in clause 10.2.2.2.

The transmit PSD of the O-P-SYNCHRO 3 signal shall be CDPSDds in FDS and also in FUS (if transmission line joins in FDX mode).

12.3.3.3.8 Signals during EC TRAINING 1-1 stage

12.3.3.3.8.1 O-P-CHANNEL-DISCOVERY 2-1

The O-P-CHANNEL-DISCOVERY 2-1 signal shall have the same structure as the O-P-CHANNEL-DISCOVERY 2 signal. The sync symbol shall be generated and modulated by the probe sequence as described in clause 10.2.2.1. The elements of the probe sequence carried by the sync symbols of the O-P-CHANNEL DISCOVERY 2-1 shall continue from the previous stage, with no interruptions. Sync symbols shall use all subcarriers of the SUPPORTEDCARRIERSds set, including Band 0 and Band 1.

The SOC shall be in its active state and use robust bit mapping. Every transmitted SOC symbol shall be repeated according to the number of repetitions, R_S, which is selected during the ITU-T G.994.1 phase of initialization (see clause 12.3.2.1.2). After repetition is applied, all SOC symbols shall be modulated by the IDS, as defined in clause 10.2.2.2. The IDS shall be the same as defined for O-P-CHANNEL-DISCOVERY 1 signal. The SOC quadrant scrambler shall be in reset mode.

The initialization symbols of the O-P-CHANNEL-DISCOVERY 2-1 signal shall use all subcarriers from the SUPPORTEDCARRIERSds set in DTFO Band 0 only, except those assigned in O-SIGNATURE (DTFO Band 1 symbol assignment) to use all subcarriers from the SUPPORTEDCARRIERSds set in both DTFO Band 0 and Band 1.

The transmit PSD shall be equal to V2PSDds, which is derived from R-UPDATE message. The V2PSDds shall be applied in FDS and also in FUS (if transmission line joins in FDX mode).

The MTU-O shall start transmission of the O-P-CHANNEL-DISCOVERY 1-2 signal right upon completion of transmission of the O-P-SYNCHRO 1 signal, starting from the symbol with index zero of the following downstream logical frame. From the start of the first superframe of the O-CHANNEL DISCOVERY 1-2 signal, the SOC shall transmit O-IDLE for a period of 3 superframes, followed by transmission of the O-EC-PRM 1 message, that indicates parameters to be applied in O/R-EC 1-1 signals. The O-EC-PRM 1 message shall be sent in auto-repeat mode (see clause 12.2.2.1). During O-EC-PRM 1 transmission, the MTU-O shall monitor the SOC to detect R-EC-PRM 1 message from the MTU-R (which acknowledges O-EC-PRM 1 message).

After MTU-O receives the R-EC-PRM 1 message, it shall transmit O-P-SYNCHRO 3-00 signal. Transmission of O-P-SYNCHRO 3-00 signal may terminate transmission of O-EC-PRM 1 message prior to completion of all SOC symbol repetitions.

12.3.3.3.8.2 O-P-SYNCHRO 3-00

The O-P-SYNCHRO 3-00 signal provides an exact time marker for transition from the CHANNEL DISCOVERY 2-1 signal to O-P-EC 1-1 signal. The O-P-SYNCHRO 3-00 signal shall have the same structure as O-P-CHANNEL DISCOVERY 2-1. The signal shall have the same duration as the O-P-SYNCHRO 1 signal. All initialization symbols shall carry inverted symbols containing SOC IDLE with robust bit mapping. During transmission of the O-P-SYNCHRO 3-00 signal, the SOC shall be inactive, the SOC quadrant scrambler shall be in reset mode, and the IDS shall be applied as defined in clause 10.2.2.2.

The sync symbols shall be generated and modulated by probe sequences as described in clause 10.2.2.1. The elements of the probe sequence carried by the sync symbols of the O-P-SYNCHRO 3-00 signal shall continue the probe sequence transmitted during the O-P-CHANNEL DISCOVERY 2-1 signal with no interruption. Sync symbols shall use all subcarriers of the SUPPORTEDCARRIERSds set, including Band 0 and Band 1.

The initialization symbols of the O-P-SYNCHRO 1-2 signal shall use all subcarriers from the SUPPORTEDCARRIERSds set in DTFO Band 0 only, except those assigned in O-SIGNATURE (DTFO Band 1 symbol assignment) to use all subcarriers from the SUPPORTEDCARRIERSds set in both DTFO Band 0 and Band 1, all modulated as defined in clause 10.2.2.2.

The transmit PSD of the O-P-SYNCHRO 2 signal shall be V2PSDds in FDS and also in FUS (if transmission line joins in FDX mode).

12.3.3.3.8.3 O-P-EC 1-1 signal

The O-P-EC 1-1 signal is to assist MTU-O echo canceller re-adjustment after T_{g1}' and PSD updates. The duration of this signal shall be as indicated in O-EC-PRM 1-1 message.

The MTU-O shall transmit O-P-EC 1-1 starting from symbol 0 of the logical frame that follows O-P-SYNCHRO 3-00. The O-P-EC 1-1 signal shall have the same structure (see clause 12.3.3.3) as the O-P-CHANNEL-DISCOVERY 2 signal.

The probe sequence transmitted during O-P-SYNCHRO 3-00 may be interrupted and a VCE discretionary probe sequence used instead on both FDS and FUS sync symbol positions.

The initialization symbols shall consist of subcarriers modulated with 2-bits constellation points selected in a vendor discretionary way. The constellation points may vary between subcarriers and between different initialization symbols. Each initialization symbol shall be repeated R_S times (as the SOC symbols). IDS shall be applied as defined in clause 10.2.2.2. The SOC quadrant scrambler shall be in reset mode.

The O-P-EC 1-1 signal shall use all subcarriers from the SUPPORTEDCARRIERSds set in DTFO Band 0 only, except those assigned in O-SIGNATURE (DTFO Band 1 symbol assignment) to use all subcarriers from the SUPPORTEDCARRIERSds set in both DTFO Band 0 and Band 1.

The transmit PSD shall be equal to V2PSDds in FDS and also in FUS (if transmission line joins in FDX mode).

The O-P-EC 1-1 signal shall be followed by the CHANNEL-DISCOVERY 2-2 signal.

12.3.3.3.8.4 O-P-CHANNEL-DISCOVERY 2-2

During transmission of the O-P-CHANNEL-DISCOVERY 2-2 signal, the MTU-R updates its echo canceller.

The MTU-O shall start transmission of the O-P-CHANNEL-DISCOVERY 2-2 signal right upon completion of transmission of the O-P-EC 1-1 signal, starting from the symbol with index zero of the following downstream logical frame.

The O-P-CHANNEL-DISCOVERY 1-3. The sync symbol shall be generated and modulated by the probe sequence as described in clause 10.2.2.1. The elements of the probe sequence carried by the sync symbols of the O-P-CHANNEL DISCOVERY 2-2 shall continue the probe sequence transmitted during the O-P-EC 1-1 signal on FDS sync symbol positions with no interruption. Sync symbols shall use all subcarriers of the SUPPORTEDCARRIERSds set, including Band 0 and Band 1.

The SOC shall be in its active state and use robust bit mapping with SOC repetition, R_S. During transmission of the O-P-CHANNEL DISCOVERY 2-2 signal the SOC shall send O-IDLE, the SOC quadrant scrambler shall be in reset mode and the IDS shall be applied as defined in clause 10.2.2.2.

The initialization symbols of the O-P-CHANNEL-DISCOVERY 2-2 signal shall use all subcarriers from the SUPPORTEDCARRIERSds set in DTFO Band 0 only, except those assigned in O-SIGNATURE (DTFO Band 1 symbol assignment) to use all subcarriers from the SUPPORTEDCARRIERSds set in both DTFO Band 0 and Band 1.

The transmit PSD shall be equal to V2PSDds in FDS and also in FUS (if transmission line joins in FDX mode).

The O-P-CHANNEL-DISCOVERY 2-2 signal shall be followed by the O-P-SYNCHRO 3-01 signal, which determines the actual duration of the EC TRAINING 1-1 stage. The O-P-SYNCHRO 3-01 transmission shall be after the minimum duration of R-P-EC 1-1 signal indicated in R-EC-PRM 1 message has expired, and shall start from the symbol with index 0 of the first downstream logical frame of a superframe.

12.3.3.3.8.5 R-P-CHANNEL-DISCOVERY 2-1

During transmission of the R-P-CHANNEL-DISCOVERY 2-1 signal, the MTU-O communicates to the MTU-R the parameters related to re-training of the EC.

The R-P-CHANNEL DISCOVERY 2-1 signal shall have the same structure as the R-P-CHANNEL DISCOVERY 2 signal. Sync symbols shall be generated and modulated by probe sequences as described in clause 10.2.2.1. The probe sequence modulating sync symbols shall be continued from the R-P-VECTOR 1-1 signal with no interruption. Sync symbols shall use all subcarriers of the SUPPORTEDCARRIERSGus set, including Band 0 and Band 1.

The SOC shall be in its active state and use robust bit mapping. The SOC quadrant scrambler shall be in reset mode.

The initialization symbols of the R-P-CHANNEL DISCOVERY 2-1 signal shall use all subcarriers from the SUPPORTEDCARRIERSus set in DTFO Band 0 only, except those assigned in O-SIGNATURE (DTFO Band 1 symbol assignment) to use all subcarriers from the SUPPORTEDCARRIERSus set in both DTFO Band 0 and Band 1.

The transmit PSD during FUS shall be equal to CDPSDus. The transmit PSD during FDS (if transmission line joins in FDX mode) shall be CDPSD_NPus.

The MTU-R shall start transmission of the R-P-CHANNEL-DISCOVERY 2-1 signal after reception of the O-P-SYNCHRO 3 signal, starting from the symbol with index 0 of the first upstream logical frame following completion of O-P-SYNCHRO 3 signal. From the start of the first superframe of the R-P-CHANNEL DISCOVERY 2-1 signal, the MTU-R shall transmit R-IDLE. Upon reception of O-EC-PRM 1 message, the MTU-O shall acknowledge it by transmission of the R-EC-PRM 1 message that shall be sent in auto-repeat mode (see clause 12.2.2.1). The transmission of R-EC-PRM 1 message shall be terminated by reception of the O-P-SYNCHRO 3-00 signal that determines the actual duration of the R-P-CHANNEL DISCOVERY 2-1 signal. Upon reception of the O-P-SYNCHRO 3-00 signal, the MTU-R transmits R-P-QUIET 3 signal.

12.3.3.3.8.6 R-P-QUIET 3

The MTU-R shall start transmission of R-P-QUIET 3 starting from the symbol 0 of the first logical frame that follows the last symbol of the O-P-SYNCHRO 3-00 signal. The duration of R-P-QUIET 3 signal shall be equal to the duration of O-P-EC 1-1 signal, as indicated in O-EC-PRM 1 message.

The structure of R-P-QUIET 3 signal shall be the same as R-P-QUIET 1 signal. The SOC during R-P-QUIET 3 signal is inactive.

The R-P-QUIET 3 signal shall be followed by R-P-EC 1-1 signal.

12.3.3.3.8.7 R-P-EC 1-1

The R-P-EC 1-1 signal is to assist MTU-R echo canceller re-training. The duration of this signal shall be as indicated in R-EC-PRM 1 message.

The R-P-EC 1-1 signal shall have the same structure (see clause 12.3.3.3) as the R-P-CHANNEL-DISCOVERY 2 except that quiet symbols shall be sent on the FDS sync symbol positions. The

MTU-R shall start transmission of R-P-EC 1-1 signal after completion of R-P-QUIET 3 signal, starting from the symbol 0 of the first logical frame of the superframe that follows O-P-QUIET 3.

The probe sequence transmitted during R-P-EC 1-1 shall be one communicated in O-EC-PRM 1 message and shall be applied on FUS sync symbol positions only. Sync symbols shall use all subcarriers of the SUPPORTEDCARRIERSGus set, including Band 0 and Band 1.

The initialization symbols shall consist of subcarriers modulated with 2-bits constellation points selected in a vendor discretionary way. The constellation points may vary between subcarriers and between different initialization symbols. The SOC quadrant scrambler shall be in reset mode.

The initialization symbols of the R-P-EC 1-1 signal shall use all subcarriers from the SUPPORTEDCARRIERSus set in DTFO Band 0 only, except those assigned in O-SIGNATURE (DTFO Band 1 symbol assignment) to use all subcarriers from the SUPPORTEDCARRIERSus set in both DTFO Band 0 and Band 1.

The transmit PSD during FUS shall be equal to CDPSDus. The transmit PSD during FDS (if transmission line joins in FDX mode) shall be equal to CDPSD_NP1us, which is computed by applying the updated upstream PSD cutback for FDS indicated in O-EC-PRM 1 message.

The R-P-EC 1-1 is terminated by reception of O-P-SYNCHRO 3-01 signal that determines the actual duration of R-P-EC 1-1. After reception of O-P-SYNCHRO 3-01 signal, the MTU-R transitions to the VECTOR 2 stage.

12.3.3.3.8.8 O-P-SYNCHRO 3-01

The O-P-SYNCHRO 3-01 signal provides an exact time marker for transition from the EC TRAINING 1-1 stage to the VECTOR 2 stage. The O-P-SYNCHRO 3-01 signal shall have the same structure (see clause 12.3.3.3) as the O-P-CHANNEL-DISCOVERY 2-2 signal. The signal shall have the same duration as the O-P-SYNCHRO 1 signal. All initialization symbols shall carry inverted symbols containing SOC IDLE with robust bit mapping. During transmission of the O-P-SYNCHRO 3-01 signal, the SOC shall be inactive, the SOC quadrant scrambler shall be in reset mode, and the IDS shall be applied as defined in clause 10.2.2.2.

The sync symbols shall be generated and modulated by probe sequences as described in clause 10.2.2.1. The elements of the probe sequence shall continue the probe sequence transmitted on FDS sync symbol positions during the O-P-CHANNEL DISCOVERY 2-2 signal with no interruption. Sync symbols shall use all subcarriers of the SUPPORTEDCARRIERSds set, including Band 0 and Band 1.

The initialization symbols of the O-P-SYNCHRO 3-01 signal shall use all subcarriers from the SUPPORTEDCARRIERSds set in DTFO Band 0 only, except those assigned in O-SIGNATURE (DTFO Band 1 symbol assignment) to use all subcarriers from the SUPPORTEDCARRIERSds set in both DTFO Band 0 and Band 1y, all modulated as defined in clause 10.2.2.2.

The transmit PSD of the O-P-SYNCHRO 3-01 signal shall be V2PSDds in FDS and also in FUS (if transmission line joins in FDX mode).

12.3.3.3.9 Signals during VECTOR 2 stage

12.3.3.3.9.1 O-P-VECTOR 2

The O-P-VECTOR 2 signal shall have the same structure as the O-P-CHANNEL-DISCOVERY 2 signal.

The SOC shall be in its active state and use robust bit mapping. The SOC symbol repetition rate, R_S, and the IDS shall be applied. The SOC quadrant scrambler shall be in the reset mode.

The initialization symbols of the O-P-VECTOR 2 signal shall use all subcarriers from the SUPPORTEDCARRIERSds set in DTFO Band 0 only, except those assigned in O-SIGNATURE

(DTFO Band 1 symbol assignment) to use all subcarriers from the SUPPORTEDCARRIERSds set in both DTFO Band 0 and Band 1.

The transmit PSD shall be V2PSDds in FDS and also in FUS (if transmission line joins in FDX mode).

The elements of the probe sequence carried by the sync symbols of the O-P-VECTOR 2 signal shall continue the probe sequence transmitted in the O-P-SYNCHRO 3, while accounting the interruption caused by transmission of O-P-EC 1-1, O-P-CHANNEL DISCOVERY 2-2, and O-P-SYNCHRO 3-01 signals, i.e, shall be kept consistent with the time marker of downstream probe sequence communicated in O-SIGNATURE. Sync symbols shall use all subcarriers of the SUPPORTEDCARRIERSds set, including Band 0 and Band 1.

The MTU-O shall start transmission of the O-P-VECTOR 2 signal right upon completion of transmission of the O-P-SYNCHRO 3 signal, if transmission line joins in TDD mode or the fallback to TDD occurs, or of the O-P-SYNCHRO 3-01 signal, if joining in FDX mode continues, starting from symbol 0 of the following logical frame. From the start of the O-P-VECTOR 2 signal, the SOC shall transmit O-IDLE for at least three superframes followed by an O-VECTOR-FEEDBACK message that communicates to the MTU-R a request to start reporting VF samples and the parameters of the VF samples to be reported, as defined in Table 12-35. The O-VECTOR-FEEDBACK message shall be sent using RQ mode (see clause 12.2.2.2).

After transmission of O-VECTOR-FEEDBACK message, the MTU-O shall transmit O-IDLE. Upon reception of the R-ACK message, the MTU-O shall transmit an O-P-SYNCHRO 3-1 signal starting from the symbol with index zero of the first downstream logical frame of a superframe. Transmission of the O-P-SYNCHRO 3-1 signal may terminate transmission of O-IDLE prior to the completion of the last SOC symbol repetition.

12.3.3.3.9.2 O-P-SYNCHRO 3-1

The O-P-SYNCHRO 3-1 signal provides an exact time marker for transition from R-P-VECTOR 2 (using robust bit mapping in the upstream direction) to R-P-VECTOR 2-1 (using normal bit mapping in the upstream direction). The O-P-SYNCHRO 3-1 signal shall have the structure (see clause 12.3.3.3) as the O-P-VECTOR 2 signal. The signal shall have the same duration as O-P-SYNCHRO 1 signal. All initialization symbols shall carry inverted symbols containing SOC IDLE with robust bit mapping. During transmission of the O-P-SYNCHRO 3-1 signal, the SOC is inactive. The SOC quadrant scrambler shall be in reset mode. The IDS shall be applied as defined in clause 10.2.2.2.

The sync symbols shall be generated and modulated by probe sequences as described in clause 10.2.2.1. The element of the probe sequence carried by the sync symbol of the O-P-SYNCHRO 3-1 signal shall continue the probe sequence transmitted during the O-P-VECTOR 2 signal with no interruption. Sync symbols shall use all subcarriers of the SUPPORTEDCARRIERSds set, including Band 0 and Band 1.

The initialization symbols of the O-P-SYNCHRO 3-1 signal shall use all subcarriers from the SUPPORTEDCARRIERSds set in DTFO Band 0 only, except those assigned in O-SIGNATURE (DTFO Band 1 symbol assignment) to use all subcarriers from the SUPPORTEDCARRIERSds set in both DTFO Band 0 and Band 1, all modulated as defined in clause 10.2.2.2.

The transmit PSD of the O-P-SYNCHRO 3-1 signal shall be V2PSDds in FDS and also in FUS (if transmission line joins in FDX mode).

12.3.3.3.9.3 O-P-VECTOR 2-1

During transmission of the O-P-VECTOR 2-1 signal, the MTU-O obtains VF samples from the MTU-R and computes precoding coefficient to cancel the downstream crosstalk from active lines into joining lines and between joining lines.

The MTU-O shall start transmission of O-P-VECTOR 2-1 signal after the last symbol of O-P-SYNCHRO 3-1 signal (starting from the symbol with index 0 of the first logical frame following the last symbol of O-P-SYNCHRO 3-1 signal).

The O-P-VECTOR 2-1 signal shall have the same structure as the O-P-CHANNEL-DISCOVERY 2 signal.

The SOC shall be in its active state and use robust bit mapping. The SOC symbol repetition rate, R_S, and the IDS shall be applied. The SOC quadrant scrambler shall be in reset mode.

The initialization symbols of the O-P-VECTOR 2-1 signal shall use all subcarriers from the SUPPORTEDCARRIERSds set in DTFO Band 0 only, except those assigned in O-SIGNATURE (DTFO Band 1 symbol assignment) to use all subcarriers from the SUPPORTEDCARRIERSds set in both DTFO Band 0 and Band 1. The transmit PSD shall be kept equal to V2PSDds in FDS and also in FUS (if transmission line joins in FDX mode) until the end of this stage and the precoder shall not be applied towards the joining lines.

The probe sequence modulating sync symbols shall be continued from the O-P-SYNCHRO 3-1 signals with no interruption. Sync symbols shall use all subcarriers of the SUPPORTEDCARRIERSds set, including Band 0 and Band 1.

From the start of O-P-VECTOR 2-1 signal the SOC shall transmit O-IDLE. Upon reception a number of R-VECTOR-FEEDBACK messages that is sufficient to perform channel estimation, the MTU-O computes the precoder coefficients and PSD updates for all active and all joining lines.

The MTU-O terminates transmission of R-VECTOR-FEEDBACK messages and completes this stage by sending the O-P-SYNCHRO 4 signal.

The actual duration of the O-P-VECTOR 2 signal is determined by the VCE. The start time of the O-P-SYNCHRO 4 signal transmission shall be at the symbol with index 0 of the first downstream logical frame of the superframe. Transmission of the O-P-SYNCHRO 4 signal may terminate transmission of O-IDLE prior to the completion of the last SOC symbol repetition.

After transmission of the O-P-SYNCHRO 4 signal, the MTU-O shall transition to the PARAMETER UPDATE stage.

12.3.3.3.9.4 R-P-VECTOR 2

The R-P-VECTOR 2 signal shall have the same structure as the R-P-CHANNEL-DISCOVERY 2 signal.

The SOC shall be in its active state and use a robust bit mapping. The SOC quadrant scrambler shall be in reset mode.

The initialization symbols of the R-P-VECTOR 2 signal shall use all subcarriers from the SUPPORTEDCARRIERSus set in DTFO Band 0 only except those assigned in O-SIGNATURE (DTFO Band 1 symbol assignment) to use all subcarriers from the SUPPORTEDCARRIERSds set in both DTFO Band 0 and Band 1.

The transmit PSD during FUS shall be equal to CDPSDus. The transmit PSD during FDS (if transmission line joins in FDX mode) shall be equal to CDPSD_NP1us.

The sync symbol shall be generated and modulated by the probe sequence as described in clause 10.2.2.1. The probe sequence modulating sync symbols shall be the same as in R-P-CHANNEL-DISCOVERY 2-1 signal with its element indices aligned such that they are the same as they would have been if the probe sequence used in R-P-CHANNEL-DISCOVERY 2-1 signal would be continued with no interruption, i.e., kept consistent with the time marker of upstream probe sequence communicated in O-SIGNATURE). Sync symbols shall use all subcarriers of the SUPPORTEDCARRIERSus set, including Band 0 and Band 1.

The MTU-R shall start transmission of the R-P-VECTOR 2 signal upon reception of the O-P-SYNCHRO 3 signal, if transmission line joins in TDD mode or the TDD fallback occurred, or of the O-P-SYNCHRO 3-01 signal, it joining line continues in TDD mode, starting from symbol 0 of the first upstream logical frame of the superframe following transmission of the corresponding O-P-SYNCHRO signal. From the start of R-P-VECTOR 2, the SOC shall send R-IDLE until the MTU-R acknowledges the O-VECTOR-FEEDBACK message by sending R-ACK message in RQ mode. Then it shall wait for the reception of the O-P-SYNCHRO 3-1 signal while sending R-IDLE.

12.3.3.3.9.5 R-P-VECTOR 2-1

During transmission of the R-P-VECTOR 2-1 signal, the MTU-R computes VF samples from the received O-P-VECTOR 2-1 signal and communicates to the MTU-O the VF samples, as requested by the MTU-O in the O-VECTOR-FEEDBACK message.

The MTU-R shall start transmission of R-P-VECTOR 2-1 from the symbol with index 0 of the first upstream logical frame of the superframe following transmission of O-P-SYNCHRO 3-1 signal.

The R-P-VECTOR 2-1 signal shall have the same structure as the R-P-CHANNEL-DISCOVERY 2.

The SOC shall be in its active state and use a normal bit mapping with SOC tone repetition rate *p* communicated in the O-VECTOR-FEEDBACK message. The SOC quadrant scrambler shall be in reset mode.

The initialization symbols of the R-P-VECTOR 2 signal shall use all subcarriers from the SUPPORTEDCARRIERSus set in DTFO Band 0 only, except those assigned in O-SIGNATURE (DTFO Band 1 symbol assignment) to use all subcarriers from the SUPPORTEDCARRIERSus set in both DTFO Band 0 and Band 1.

The sync symbol shall be generated and modulated by the probe sequence as described in clause 10.2.2.1. The elements of probe sequence modulating sync symbols shall be continued from the previous stage with no interruption. Sync symbols shall use all subcarriers of the SUPPORTEDCARRIERSGus set, including Band 0 and Band 1.

The transmit PSD during FUS shall be equal to CDPSDus. The transmit PSD during FDS (if transmission line joins in FDX mode) shall be equal to CDPSD_NP1us.

At the beginning of the first upstream logical frame following the O-P-SYNCHRO 3-1 signal, the MTU-R shall modify the modulation of its upstream SOC and send R-IDLE for at least one superframe followed by R-VECTOR-FEEDBACK messages separated by R-IDLE. Each R-VECTOR-FEEDBACK message contains a report on clipped error samples or DFT samples requested in the received O-VECTOR-FEEDBACK message, as defined in Table 12-37. The O-VECTOR-FEEDBACK messages shall be sent in NR mode. Reception of O-P-SYNCHRO 4 signal terminates the transmission of R-VECTOR-FEEDBACK messages.

The timing diagram of the R-VECTOR-FEEDBACK message transmission is presented in Figure 12-11. The vectoring feedback report on a particular element X of the downstream probe sequence shall begin transmission at a symbol time period between the upstream RMC symbol position of the sync frame in the superframe that carries element X and the upstream RMC symbol position of the next sync frame. The exact symbol at which the vectoring feedback report starts is under MTU-R control. If the SOC is busy sending the previous report at the specified time period for which a new report is to be started, the new vectoring feedback report shall be discarded. The maximum number of superframes (*q*) that the vectoring feedback report may utilize is determined by the vectoring feedback report parameters communicated in the O-VECTOR-FEEDBACK message (see Table 12-35). If the number of symbols required to convey the actual content of the report is less than the number of available upstream symbol positions (equal to $M_F \times q \times s_{us}$), R-IDLE symbols shall be transmitted to fill up the gap. The R-VECTOR-FEEDBACK message shall be transmitted in non-repeat (NR) mode with no acknowledgement on the R-VECTOR-FEEDBACK messages or their segments. The MTU-O shall select the vectoring feedback report parameters and the US SOC tone repetition rate such that the duration of the vectoring feedback report transmission, including the statistical overhead due to HDLC framing, is less than or equal to q superframes if time identification is used (see clause 10.3.2.5.2). In the case where frequency identification is used (see clause 10.3.2.5.1), q =1.

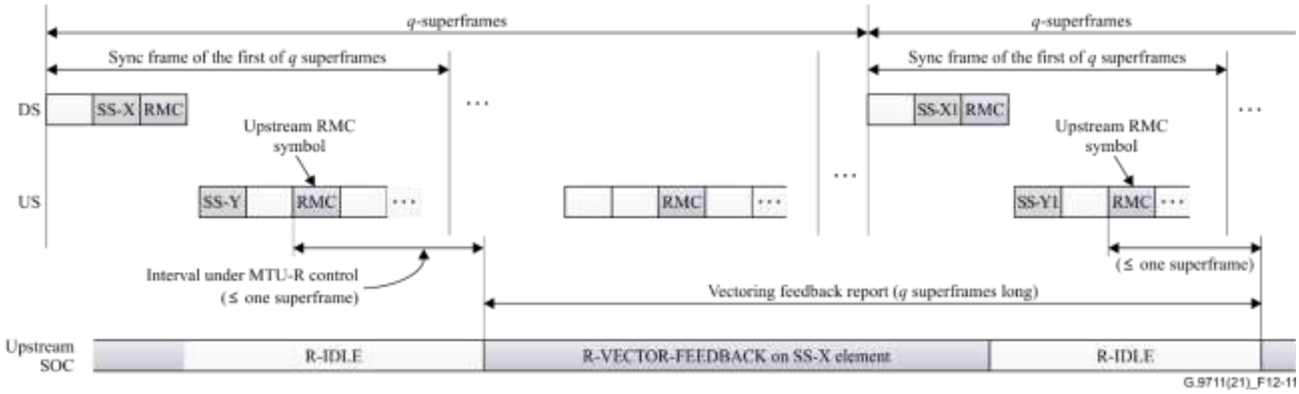


Figure 12-11 – Vectoring feedback timing diagram

The actual duration of the VECTOR 2 stage is determined by the VCE. Upon reception of the O-P-SYNCHRO 4 signal, the MTU-R shall complete transmission of the R-P-VECTOR 2-1 signal and transition to the PARAMETER UPDATE stage.

12.3.3.3.9.6 O-P-SYNCHRO 4

The O-P-SYNCHRO 4 signal provides an exact time marker for transition from the VECTOR 2 stage to the PARAMETER UPDATE stage. The O-P-SYNCHRO 4 signal shall have the same structure (see clause 12.3.3.3) as the O-P-VECTOR 2-1 signal. The signal shall have the same duration as O-P-SYNCHRO 1 signal. All initialization symbols shall carry inverted symbols containing SOC IDLE with robust bit mapping. During transmission of the O-P-SYNCHRO 4 signal, the SOC is inactive. The SOC quadrant scrambler shall be in reset mode. The IDS shall be applied as defined in clause 10.2.2.2.

The sync symbols shall be generated and modulated by probe sequences as described in clause 10.2.2.1. Sync symbol shall be transmitted at all downstream sync symbol positions used in the O-P-VECTOR 2-1 signal. The element of the probe sequence carried by the sync symbol of the O-P-SYNCHRO 4 signal shall continue the probe sequence transmitted during the O-P-VECTOR 2-1 signal with no interruption. Sync symbols shall use all subcarriers of the SUPPORTEDCARRIERSds set, including Band 0 and Band 1.

The initialization symbols of the O-P-SYNCHRO 4 signal shall use all subcarriers from the SUPPORTEDCARRIERSds set in DTFO Band 0 only, except those assigned in O-SIGNATURE (DTFO Band 1 symbol assignment) to use all subcarriers from the SUPPORTEDCARRIERSds set in both DTFO Band 0 and Band 1, all modulated as defined in clause 10.2.2.2.

The transmit PSD of the O-P-SYNCHRO 4 signal shall be V2PSDds in FDS and also in FUS (if transmission line joins in FDX mode).

12.3.3.3.10 Signals during PARAMETER UPDATE stage

12.3.3.3.10.1 O-P-PRM-UPDATE 1

During transmission of the O-P-PRM-UPDATE 1 signal, the MTU-O further optimizes its transmit PSD and communicates with the MTU-R to request a downstream SNR report.

The O-P-PRM-UPDATE 1 signal shall have the same structure as the O-P-CHANNEL-DISCOVERY 2.

The SOC shall be in its active state and use robust bit mapping. The SOC symbol repetition rate shall be set to 0 (no repetitions) and no IDS shall be applied. The SOC quadrant scrambler shall be in free running mode. The scrambler shall be initialized at the first SOC symbol of O-P-PRM-UPDATE 1 signal with the value communicated during the ITU-T G.994.1 handshake reset.

The sync symbol shall be generated and modulated by the probe sequence as described in clause 10.2.2.1. The elements of the probe sequence modulating sync symbols shall be continued from the previous stage with no interruption. Sync symbols shall use all subcarriers of the SUPPORTEDCARRIERSds set, including Band 0 and Band 1.

The initialization symbols of the O-P-PRM-UPDATE 1 signal shall use all subcarriers from the SUPPORTEDCARRIERSds set in DTFO Band 0 only, except those assigned in O-SIGNATURE (DTFO Band 1 symbol assignment) to use all subcarriers from the SUPPORTEDCARRIERSus set in both DTFO Band 0 and Band 1.

At the first symbol of the stage, the VCE updates the precoder and the downstream transmit PSD in all active and joining lines using the channel estimation results obtained during the VECTOR 2 stage. The transmit PSD after the update is PRMPSDds and shall be used in FDS and also in FUS (if transmission line joins in FDX mode). The PRMPSDds shall comply to the V2PSDMASKds as specified in Table 7-4.

NOTE – The PRMPSDds might be different from V2PSDds (e.g., the PSD might be higher at some subcarrier frequencies while lower at other subcarrier frequencies).

The MTU-O shall start transmission of the O-P-PRM-UPDATE 1 signal upon completion of transmission of the O-P-SYNCHRO 4 signal, from symbol 0 of the following logical frame. From the start of the first downstream logical frame of the O-P-PRM-UPDATE 1 signal, the SOC shall send O-IDLE and continue sending O-IDLE during at least ten superframes followed by an O-SNR message defined in Table 12-38. The O-SNR message shall be sent in the RQ mode.

After the MTU-R acknowledges by the R-SNR message defined in Table 12-40, the MTU-O shall send O-IDLE for a time period from 3 to 15 superframes, followed by transmission of the O-P-SYNCHRO 4-1 signal. The start of O-P-SYNCHRO 4-1 signal transmission is determined by the VCE.

12.3.3.3.10.2 O-P-SYNCHRO 4-1

The O-P-SYNCHRO 4-1 signal provides an exact time marker for transition from the O-P-PRM-UPDATE 1 signal (robust bit mapping) to transmission of the O-P-PRM-UPDATE 2 signal (normal bit mapping). The O-P-SYNCHRO 4-1 signal shall have the same structure (see clause 12.3.3.3) as O-P-PRM-UPDATE 1. The signal shall have the same duration as O-P-SYNCHRO 1 signal. All initialization symbols shall carry inverted symbols containing SOC IDLE with robust bit mapping. During transmission of the O-P-SYNCHRO 4-1 signal, the SOC shall be inactive. The SOC quadrant scrambler shall be in free running mode continued from the previous signal and the IDS shall not be applied.

The sync symbols shall be generated and modulated by probe sequences as described in clause 10.2.2.1. The element of the probe sequence carried by the sync symbol of the O-P-SYNCHRO 4-1 signal shall continue the probe sequence transmitted during the O-P-PRM-UPDATE 1 signal with no interruption. Sync symbols shall use all subcarriers of the SUPPORTEDCARRIERSds set, including Band 0 and Band 1.

The initialization symbols of the O-P-SYNCHRO 4-1 signal shall use all subcarriers from the SUPPORTEDCARRIERSds set in DTFO Band 0 only, except those assigned in O-SIGNATURE (DTFO Band 1 symbol assignment) to use all subcarriers from the SUPPORTEDCARRIERSds set in both DTFO Band 0 and Band 1, all modulated as defined in clause 10.2.2.2.

The transmit PSD of the O-P-SYNCHRO 4-1 signal shall be PRMPSDds in FDS and also in FUS (if transmission line joins in FDX mode).

12.3.3.3.10.2 O-P-PRM-UPDATE 2

During transmission of the O-P-PRM-UPDATE 2 signal, the MTU-O further optimizes its transmit PSD and communicates to the MTU-R the updated downstream and upstream PSD and other relevant parameters obtained during the PARAMETER UPDATE stage.

After transmission of O-P-SYNCHRO 4-1 signal is complete, the MTU-O shall start transmission of the O-P-PRM-UPDATE 2 signal from the symbol with index 0 of the following logical frame. The O-P-PRM-UPDATE 2 signal shall differ from O-P-PRM-UPDATE 1 signal only by:

– the SOC shall use normal bit mapping with SOC tone repetition rate p_{ds} indicated in R-SNR message;
– the SOC quadrant scrambler shall be back in reset mode;
– initialization symbols shall use the SUPPORTEDCARRIERSds subcarriers in DTFO Band 0 only, except those assigned in O-SIGNATURE (DTFO Band 1 symbol assignment) to use all subcarriers from the SUPPORTEDCARRIERSds set in both DTFO Band 0 and Band 1;
– s_{ds_NPSF} additional SOC symbols, as indicated in O-SNR, shall be transmitted in FUS starting at the symbol position offset by D_{RMCus} positions from the start of FUS (if transmission line joins in FDX).

NOTE – When $s_{ds\text{-}NPSF}>M_{us}\text{-}D_{RMCus}$, symbols are active in the FUS of two PDX frames. $M_{us}\text{-}D_{RMCus}$ symbols are active in the FUS of the first PDX frame and $s_{ds\text{-}NPSF}\text{-}M_{us}+D_{RMCus}$ symbols are active in the FUS of the second PDX frame.

After starting transmission of O-P-PRM-UPDATE 2 signal, the MTU-O shall first transmit O-IDLE for at least three superframes, followed by O-PRM message, as defined in Table 12-41. Upon reception of the R-PRM message defined in Table 12-43, the MTU-O shall continue transmitting O-IDLE for at least three superframes. The MTU-O completes this stage by sending the O-P-SYNCHRO 5 signal. The O-PRM message shall be sent using the RQ mode (see clause 12.2.2.2).

The actual duration of the O-P-PRM-UPDATE 2 signal is determined by the VCE and indicated to the MTU-R by transmission of O-P-SYNCHRO 5 signal. After transmission of the O-P-SYNCHRO 5 signal, the MTU-R shall transition to the channel analysis and exchange phase.

12.3.3.3.10.3 R-P-PRM-UPDATE 1

During transmission of the R-P-PRM-UPDATE 1 signal, the MTU-R communicates to the MTU-O the downstream SNR report.

The R-P-PRM-UPDATE 1 signal shall have the same structure as the R-P-CHANNEL-DISCOVERY 2 signal.

The SOC shall be in its active state and use normal bit mapping with SOC tone repetition rate p communicated in the O-VECTOR-FEEDBACK message. The SOC quadrant scrambler shall be in free running mode. The scrambler shall be initialized at the first SOC symbol of R-P-PRM-UPDATE 1 signal with the value communicated during the ITU-T G.994.1 handshake.

The initialization symbols of the R-P-PRM-UPDATE 1 signal shall use all subcarriers from the SUPPORTEDCARRIERSus set in DTFO Band 0 only, except those assigned in O-SIGNATURE (DTFO Band 1 symbol assignment) to use all subcarriers from the SUPPORTEDCARRIERSus set in both DTFO Band 0 and Band 1.

The sync symbol shall be generated and modulated by the probe sequence as described in clause 10.2.2.1. The elements of probe sequence modulating sync symbols shall be continued from the previous stage with no interruption. Sync symbols shall use all subcarriers of the SUPPORTEDCARRIERSGus set, including Band 0 and Band 1.

The transmit PSD during FUS shall be equal to CDPSDus. The transmit PSD during FDS (if transmission line joins in FDX mode) shall be equal to CDPSD_NP1us.

At the beginning of the first upstream logical frame following the O-P-SYNCHRO 4 signal, the MTU-R shall start transmission of the R-P-PRM-UPDATE 1 signal. From the start of the first upstream logical frame of the R-P-PRM-UPDATE signal, the SOC shall send R-IDLE until the MTU-R receives the O-SNR message. The MTU-R shall acknowledge the reception of O-SNR message by sending the R-SNR message and wait to receive the O-P-SYNCHRO 4-1 signal while sending R-IDLE.

12.3.3.3.10.4 R-P-PRM-UPDATE 2

During transmission of the R-P-PRM-UPDATE 2 signal, the MTU-R communicates to MTU-O relevant parameters obtained during the VECTOR 2 and PARAMETER UPDATE stages.

At the beginning of the first upstream logical frame following the O-P-SYNCHRO 4-1 signal, the MTU-R starts transmission of R-P-PRM-UPDATE 2 signal which is the same as R-P-PRM-UPDATE 1 signal except:

- the SOC quadrant scrambler shall be in reset mode;

- s_{us_NPSF} additional SOC symbols, as indicated in O-SNR, shall be transmitted in FDS starting at the symbol position offset by D_{RMCds} positions from the start of FDS (if transmission line joins in FDX)

- t the upstream PSD in FDS become CDPSD_NP2us that is communicated in O-SNR and based on the measurements during the VECTOR 2-1 stage.

NOTE – When $s_{us\text{-}NPSF}>M_{ds}\text{-}D_{RMCds}$, symbols are active in the FDS of two PDX frames. $M_{ds}\text{-}D_{RMCds}$ symbols are active in the FUS of the first PDX frame and $s_{us\text{-}NPSF}\text{-}M_{ds}+D_{RMCds}$ symbols are active in the FUS of the second PDX frame.

The SOC continues transmission of R-IDLE and waits for the O-PRM message. The MTU-R shall acknowledge the O-PRM message by sending the R-PRM message and shall continue transmission of R-IDLE.

The actual duration of the R-P-PRM-UPDATE 2 signal is determined by the VCE. Upon reception of the O-P-SYNCHRO 5 signal, the MTU-R shall complete transmission of the R-P-PRM-UPDATE 2 signal and transition to the channel analysis and exchange phase starting from the symbol with index 0 of the first upstream logical frame of the superframe following transmission of the O-P-SYNCHRO 5 signal.

12.3.3.3.10.5 O-P-SYNCHRO 5

The O-P-SYNCHRO 5 signal provides an exact time marker for transition from the PARAMETER UPDATE stage to the channel analysis and exchange phase. The O-P-SYNCHRO 5 signal shall have the same structure (see clause 12.3.3.3) as the O-P-PRM-UPDATE 2 signal. The signal shall have the same duration as O-P-SYNCHRO 1 signal. All initialization symbols shall carry inverted symbols containing SOC IDLE with normal bit mapping. During transmission of the O-P-SYNCHRO 5 signal, the SOC shall be inactive. The SOC quadrant scrambler shall be in reset mode. The IDS shall not be applied.

The sync symbols shall be generated and modulated by probe sequences as described in clause 10.2.2.1. Sync symbol shall be transmitted at all downstream sync symbol positions used in the O-P-PRM-UPDATE 2 signal. The elements of the probe sequence carried by the sync symbol of the O-P-SYNCHRO 5 signal shall continue the probe sequence transmitted during the R-P-PRM-UPDATE 2 signal with no interruption.

The initialization symbols of the O-P-SYNCHRO 5 signal shall use all subcarriers from the MEDLEYds set in DTFO Band 0 only, except those assigned in O-SIGNATURE (DTFO Band 1 symbol assignment) to use all subcarriers from the SUPPORTEDCARRIERSus set in both DTFO Band 0 and Band 1, all modulated as defined in clause 10.2.2.2.

The transmit PSD of the O-P-SYNCHRO 5 signal shall be PRMPSDds in FDS and also in FUS (if transmission line joins in FDX mode).

12.3.4 – Channel Analysis and Exchange phase

12.3.4.1 Overview

The channel analysis and exchange phase is the final phase of initialization. During this phase:

- the MTU-O and MTU-R are transmitting sync symbols modulated by probe sequences;
- the SOC is active in both upstream and downstream; in FDX mode, simultaneous upstream and downstream transmission is used;
- the MTU-O and MTU-R exchange capabilities and negotiate relevant parameters of TPS-TC (e.g., DTU size), PMS-TC (e.g., FEC parameters) and PMD (e.g., bits and gains tables) for showtime;
- for bits and gains setting, the MTU-O and MTU-R estimate the actual SNR in upstream and downstream directions, and in PSF and NPSF parts of PDX frame, respectively;
- for P2MP operation, the MTU-O determines the boundaries of the sub-bands facilitating the sharing of the total bandwidth between multiple MTU-Rs during the G.994.1 phase. The MTU-O and MTU-R estimate the actual SNR in upstream and downstream directions, and in PSF and NPSF parts of PDX frame, respectively, and determine bit and gain settings.

Both MTUs apply FDX transmission, i.e., sync symbols and SOC symbols are transmitted in both FDS and FUS, unless the transmission line is initialized in TDD or TDDZ framing mode; in the latter case the MTU-O transmits only during FDS and the MTU-R transmits only during FUS. The used PSDs in both FUS and FDS are those determined during the O-PRM stage of channel discovery phase.

At the end of this stage, both MTU-O and MTU-R apply the exchanged bits and gains tables and transition to showtime as described in clause 12.3.5.

Figure 12-12 presents the timing diagram for the stages of the channel analysis and exchange phase. It gives an overview of the sequence of signals transmitted and the sequence of SOC messages sent by the MTU-O and MTU-R during the channel analysis and exchange phase. The two inner columns show the sequences of signals that are transmitted (see clause 12.3.4.3), and the two outer columns identify the messages sent in the SOC (see clause 12.3.4.2). The shaded areas correspond to periods of time when SOC is inactive.

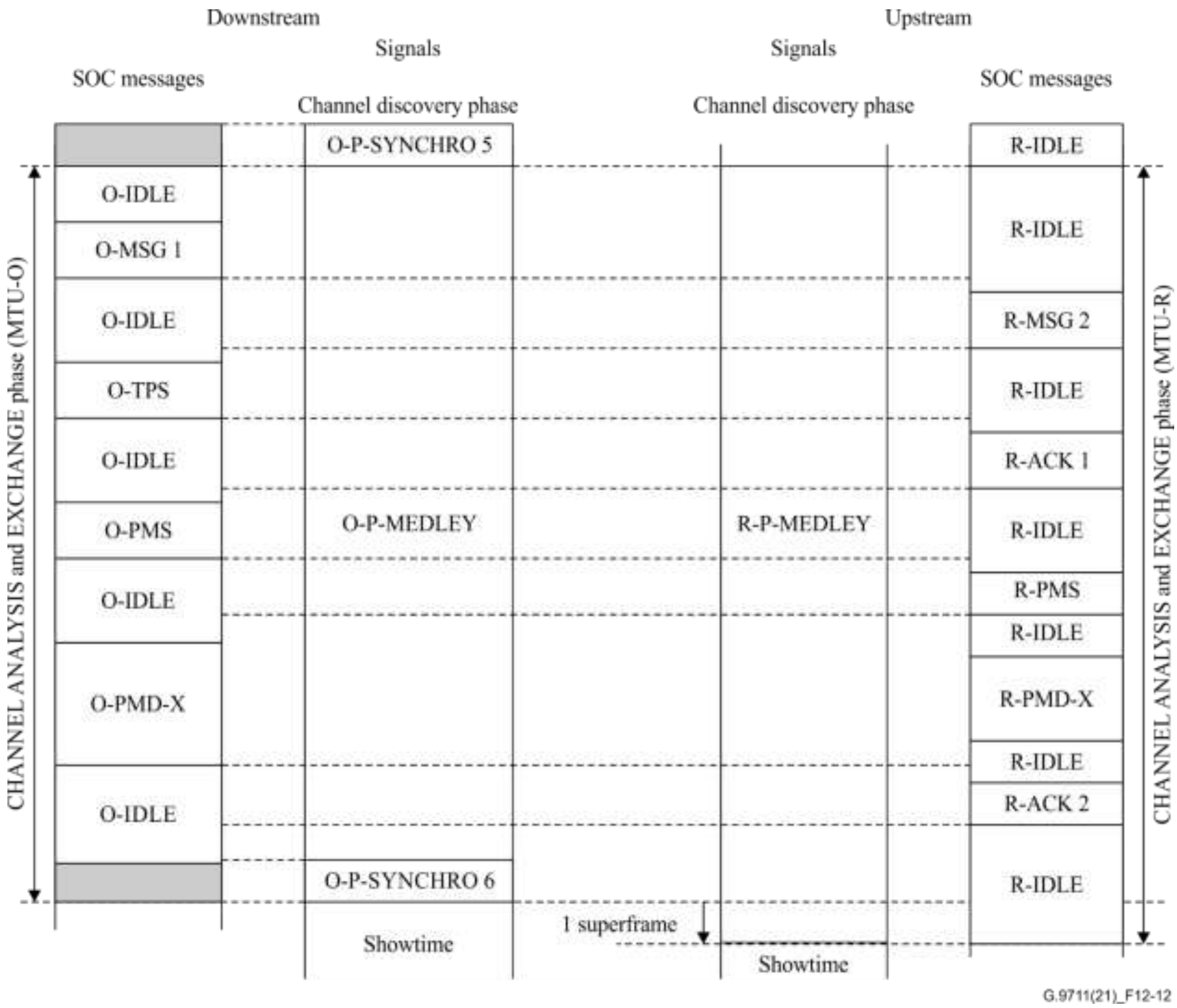


Figure 12-12 – Timing diagram of the channel analysis and exchange phase

The SOC messages shown in Figure 12-12 shall use the rules of the communication protocol defined in clause 12.2.2, using RQ mode. Symbol encoding of symbols shall be as defined in clause 10.2.2.2.

The channel analysis and exchange phase, as shown in Figure 12-12, involves the following steps:

1) The MTU-O sends the O-MSG 1 message, which contains the MTU-O's TPS-TC, PMS-TC and PMD related capabilities and main requirements for downstream transmission.
2) The MTU-R replies by sending the R-MSG 2 message, which indicates the MTU-R's TPS-TC, PMS-TC and PMD related capabilities and time synchronization requirement and period.
3) The MTU-O sends the O-TPS message to indicate the configuration of the TPS-TC and its required capabilities for both the upstream and the downstream directions.
4) The MTU-R acknowledges the O-TPS message with the R-ACK 1 message.
5) The MTU-O conveys the required PMS-TC parameters by sending the O-PMS message.
6) The MTU-R conveys the required PMS-TC parameters by sending the R-PMS message.
7) The MTU-O and MTU-R exchange all relevant components of the O-PMD and R-PMD messages, which contains the bit-loading and tone-ordering tables, and other PMD transmission parameters for the upstream and downstream, respectively.

8) After exchanging all relevant components of O-PMD and R-PMD messages, the MTUs are ready to transition to showtime. The MTU-R acknowledges the O-PMD-NPSF-1 (or O-PMD-PSF-2) message by sending the R-ACK 2 message. Upon reception the R-ACK 2 message, the MTU-O triggers the transition into showtime by transmitting the O-P-SYNCHRO 6 signal.

The PMD, PMS-TC and TPS-TC parameter settings negotiated during the channel analysis and exchange phase shall be applied starting from the first symbol of showtime. During the showtime some of these parameters can be modified using various OLR procedures (see clause 13), although in the range determined by the exchanged MTU capabilities.

12.3.4.2 SOC messages exchanged during channel analysis and exchange phase

Figure 12-13 illustrates the SOC message exchange between the MTU-O and MTU-R during the channel analysis and exchange phase. It also summarizes the main content of each message.

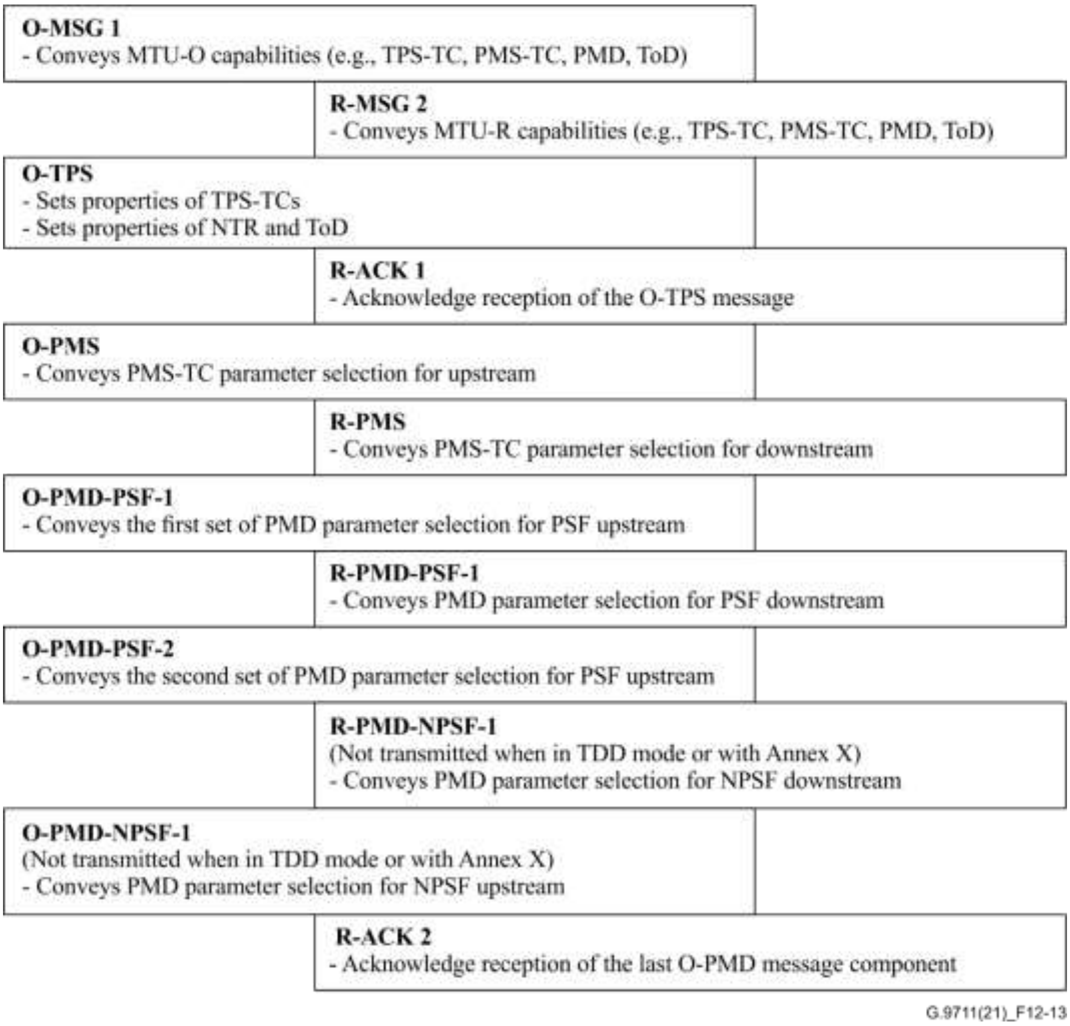


Figure 12-13 – SOC messages exchanged during the channel analysis and exchange phase

12.3.4.2.1 O-MSG 1

The O-MSG 1 message contains the capabilities of the MTU-O and the main requirements for downstream transmission (such as margin). The list of parameters carried by the O-MSG 1 message is shown in Table 12-46.

Table 12-46 – O-MSG 1 message

Field	Field name	Format
1	Message descriptor	Message code
2	NTR	One byte
3	TPS-TC capabilities	See Table 12-47
4	PMS-TC capabilities	See Table 12-48
5	Downstream rate adaptation downshift SNR margin (RA-DSNRMds)	Two bytes
6	Downstream rate adaptation downshift time interval (RA-DTIMEds)	Two bytes
7	Downstream rate adaptation upshift SNR margin (RA-USNRMds)	Two bytes
8	Downstream rate adaptation upshift time interval (RA-UTIMEds)	Two bytes
9	Downstream FRA time window (FRA-TIMEds)	One byte
10	Downstream FRA minimum percentage of degraded tones (FRA-NTONESds)	One byte
11	Downstream FRA minimum number of *rtx-uc* anomalies (FRA-RTX-UCds)	Two bytes
12	Downstream FRA vendor discretionary criteria (FRA-VENDISCds)	One byte
13	Channel-initialization policy (*CIpolicy*)	One byte
14	Fast retrain policy (*FRpolicy*)	One byte
15	Downstream *los* defect persistency (LOS-PERSISTENCYds)	One byte
16	Downstream *lom* defect persistency (LOM-PERSISTENCYds)	One byte
17	Downstream *lor* defect persistency (LOR-PERSISTENCYds)	One byte
18	Downstream reinit time threshold (REINIT-TIME-THRESHOLDds)	One byte
19	Downstream low *ETR* threshold (LOW-ETR-THRESHOLDds)	One byte
20	Downstream target SNR margin for RMC (TARSNRM-RMCds)	Two bytes
21	Downstream minimum SNR margin for RMC (MINSNRM-RMCds)	Two bytes
22	Downstream maximum bit loading for RMC (MAXBL-RMCds)	One byte
24	PMD capabilities	See Table 12-49
25	CD_time_out_1 during fast retrain	One byte
26	CD_time_out_2 during fast retrain	One byte
27	Supported Options	Two bytes
29	Upstream low ANDEFTR threshold (*low_ANDEFTR_threshold-us*)	Two bytes
30	Annex D descriptor	Variable
31	Downstream actual response time capability (*Tresp_max_act_ds*)	One byte
32	Downstream minimum retransmission shift capability (*RetShift_min_ds*)	One byte
33	Upstream low ANDEFTR0 threshold (low_ANDEFTR0_threshold-us)	Two bytes
34	Use of RRC and RRC symbols	One byte
35	Annex X descriptor	Variable

Field 1 "Message descriptor" is a unique one-byte code (07_{16}) that identifies the message. See Table 12-10 for a complete list of codes.

Field 2 "NTR" shall be set to 01_{16} if the MTU-O is transporting the NTR signal in the downstream direction, otherwise it shall be set to 00_{16}.

Field 3 "TPS-TC capabilities" indicates the TPS-TC capabilities of the MTU-O as shown in Table 12-47.

Table 12-47 – TPS-TC capabilities of the MTU-O

Field name	Format	Description
Number of supported QoS channels	One byte	Number of supported QoS channels in both directions inside the bearer channel. Valid values are 2 and 4. The field shall be coded as an unsigned integer.
Maximum Downstream NDR	Two bytes	Maximum NDR supported by the MTU-O for the downstream bearer channel. The value shall not exceed the *NDR_max* value defined in clause 11.4.2.2. The value shall be coded as a 16-bit unsigned integer representing the data rate as a multiple of 96 kbit/s.
Maximum Upstream NDR	Two bytes	Maximum NDR supported by the MTU-O for the upstream bearer channel. The value shall not exceed the *NDR_max* value defined in clause 11.4.2.2. The value shall be coded as a 16-bit unsigned integer representing the data rate as a multiple of 96 kbit/s.

Field 4 "PMS-TC capabilities" indicates the PMS-TC capabilities of the MTU-O as shown in Table 12-48.

Table 12-48 – PMS-TC capabilities of the MTU-O

Field name	Format	Description
Max DS net data rate	Two bytes	Indicates the maximum downstream net data rate supported. The unsigned 16-bit value is the net data rate divided by 96 kbit/s.
Max US net data rate	Two bytes	Indicates the maximum upstream net data rate supported. The unsigned 16-bit value is the net data rate divided by 96 kbit/s.

Field 5 "Downstream rate adaptation downshift SNR margin (RA-DSNRMds)": The definition and use of this parameter is specified in clause 13.2.1.1.2. The field shall be formatted as a 16-bit unsigned integer with LSB weight of 0.1 dB and has a valid range between zero and 31.0 dB (0136_{16}).

Field 6 "Downstream rate adaptation downshift time interval (RA-DTIMEds)": The definition and use of this parameter is specified in clause 13.2.1.1.2. The field shall be formatted as a 16-bit unsigned integer with LSB weight of one second and has a valid range between zero and 16 383 s ($3FFF_{16}$).

Field 7 "Downstream rate adaptation upshift SNR margin (RA-USNRMds)": The definition and use of this parameter is specified in clause 13.2.1.1.2. The field shall be formatted as a 16-bit unsigned integer with LSB weight of 0.1 dB and has a valid range between zero and 31.0 dB (0136_{16}).

Field 8 "Downstream rate adaptation upshift time interval (RA-UTIMEds)": The definition and use of this parameter is specified in clause 13.2.1.1.2. The field shall be formatted as a 16-bit unsigned integer with LSB weight of one second and has a valid range between 0 and 16 383 s ($3FFF_{16}$).

Field 9 "Downstream FRA time window (FRA-TIMEds)" contains the value of the FRA triggering parameter *fra-time-ds*. The parameter is used in the specification of the FRA procedure and is defined in clause 13.3.1.1.1.1.

The valid range of non-zero values is from one logical frame length to one superframe length in steps of one logical frame length. The valid value 0 shall be used to indicate that both monitoring of the percentage of degraded subcarriers (see clause 13.3.1.1.1.2) and monitoring of the number of *rtx-uc* anomalies (see clause 13.3.1.1.1.3) are disabled (see clause 13.3.1.1.1.5).

Field 10 "Downstream FRA minimum percentage of degraded tones (FRA-NTONESds)" contains the value of the FRA triggering parameter *fra-ntones-ds*. The parameter is used in the specification of the FRA procedure and defined in clause 13.3.1.1.1.2.

The valid range of non-zero values is from 1 to 100 (64_{16}) in steps of 1. The valid value 0 shall be used to indicate that monitoring of the percentage of degraded subcarriers is disabled (see clause 13.3.1.1.1.5). If the value of *fra-time-ds* is 0, then the value of *fra-ntones-ds* shall be set to 0.

Field 11 "Downstream FRA minimum number of *rtx-uc* anomalies (FRA-RTX-UCds)" contains the value of the FRA triggering parameter *fra-rtx-uc-ds*. The parameter is used in the specification of the FRA procedure and defined in clause 13.3.1.1.1.3.

The valid range of non-zero values is from 1 to 1 023 ($03FF_{16}$) in steps of 1. The valid value 0 shall be used to indicate that monitoring of the number of *rtx-uc* anomalies is disabled (see clause 13.3.1.1.1.5). If the value of *fra-time-ds* is 0, then the value of *fra-trx-uc-ds* shall be set to 0.

Field 12 "Downstream FRA vendor discretionary criteria (FRA-VENDISCds)" contains the value of the FRA triggering parameter *fra-vendisc-ds*. The parameter is used in the specification of the FRA procedure and defined in clause 13.3.1.1.1.4.

If set to ONE, then vendor discretionary FRA triggering criteria may be used. If set to ZERO, then vendor discretionary FRA triggering criteria shall not be used (see clause 13.3.1.1.1.5).

Field 13 "Channel-initialization policy (*CIpolicy*)" indicates the channel-initialization policy.

The field is formatted as [0000 000p].

– p = 0 to indicate that *CIpolicy*=0 shall be used

– p = 1 is reserved by ITU-T.

Field 14 "Fast-retrain policy (*FRpolicy*)" indicates the fast-retrain policy.

The field is formatted as [0000 000p].

– p = 0 to indicate that *FRpolicy*=0 shall be used

– p = 1 is reserved by ITU-T.

Field 15 "Downstream *los* defect persistency (LOS-PERSISTENCYds)" contains the value of the control parameter *los_persistency-ds* divided by 100. The parameter is used in the fast-retrain trigger criteria (see clause 12.1.4.2) and is defined in clause 12.1.4.3.1. The field has valid values from 1 to 20 (14_{16}) in steps of 1.

Field 16 "Downstream *lom* defect persistency (LOM-PERSISTENCYds)" contains the value of the control parameter *lom_persistency-ds*. The parameter is used in the fast-retrain trigger criteria (see clause 12.1.4.2) and is defined in clause 12.1.4.3.2. The field has valid values from 2 to 20 (14_{16}) in steps of 1.

Field 17 "Downstream *lor* defect persistency (LOR-PERSISTENCYds)" contains the value of the control parameter *lor_persistency-ds* divided by 100. The parameter is used in the fast-retrain trigger criteria (see clause 12.1.4.2) and is defined in clause 12.1.4.3.3. The field has valid values from 1 to 20 (14_{16}) in steps of 1.

Field 18 "Downstream reinit time threshold (REINIT-TIME-THRESHOLDds)" contains the value of the control parameter *reinit_time_threshold-ds*. The parameter is used in the conditions for declaring a High_BER event (see clause 12.1.4.3.4) and is defined in clause 12.1.4.3.4. The field has valid values from 5 to 31 ($1F_{16}$) in steps of 1.

Field 19 "Downstream low *ETR* threshold (LOW-ETR-THRESHOLDds)" contains the value of the control parameter *low_ETR_threshold-ds*. The parameter is used in the conditions for declaring a High_BER event (see clause 12.1.4.3.4) and is defined in clause 12.1.4.3.4. The field has non-zero valid values from 1 to 30 ($1E_{16}$) in steps of 1. The valid value 0 indicates that no High_BER event shall be declared based on *ETR0* being below the *ETR_min_eoc*.

Field 20 "Downstream target SNR margin for RMC (TARSNRM-RMCds)" indicates the target SNR margin for the downstream RMC. For definition of TARSNRM-RMC see clause 13.2.1.3.1. The field shall be formatted as a 16-bit unsigned integer with LSB weight of 0.1 dB and the valid range between 0 and 31 dB.

Field 21 "Downstream minimum SNR margin for RMC (MINSNRM-RMCds)" indicates the minimum SNR margin for the downstream RMC. For definition of MINSNRM-RMC see clause 13.2.1.3.1. The field shall be formatted as a 16-bit unsigned integer with LSB weight of 0.1 dB and the valid range between 0 and 31 dB.

Field 22 "Downstream maximum bit loading for RMC (MAXBL-RMC)" indicates the maximum allowed bit loading (the b_i value in case of TCM and the m_i value in case of PCS-LCM) for the downstream RMC subcarriers. For definition of MAXBL-RMC see clause 13.2.1.3.1. The field shall be formatted as an 8-bit unsigned integer. The valid values for b_i in case of TCM are all integers from 2 to 6, while in the case of PCS-LCM the valid values for m_i are all integers from 1 to 4.

Field 24 "PMD capabilities" indicates the PMD capabilities of the MTU-O as shown in Table 12-49.

Table 12-49 – PMD capabilities of the MTU-O

Field name	Format	Description
MTU-O maximum bit loading and MTU-O DTFO Band 1 bit loading	One byte: [00cb00aa]	aa: Indicates the maximum bit loading supported by the MTU-O transmitter: • aa = 00 – maximum bit loading bi = 12 bits if TCM is selected, mi = 13 bits if PCS-LCM is selected. • aa = 01 – maximum bit loading bi = 13 bits if TCM is selected, mi = 14 bits if PCS-LCM is selected. • aa = 10 – maximum bit loading bi = 14 bits if TCM is selected, mi = 15 bits if PCS-LCM is selected. • aa = 11 – Reserved by ITU-T b: b is set to ONE if the MTU-O only supports the same downstream bit-loading table and g_i values in the Band 1 of both the NOI_{PSF} and DOI. Otherwise, it shall be set to 0. c: c is set to ONE if the MTU-O only supports the same upstream bit loading and g_i values in the Band 1 of both the NOI_{PSF} and DOI. Otherwise, it shall be set to 0.

Field 25 "CD_time_out_1 during fast retrain" indicates the timeout for the transmission of O-P-CHANNEL-DISCOVERY 1-1 in case of a fast retrain. The value shall be coded as an 8-bit unsigned integer with valid values from 1 to 40 representing the timeout in steps of 1 second. The value shall be less than or equal to the CD_time_out_1 value negotiated during the last ITU-T G.994.1 session.

Field 26 "CD_time_out_2 during fast retrain" indicates the timeout for the initialization after the beginning of O-P-CHANNEL-DISCOVERY 1-1 in case of a fast retrain. The value shall be coded as an 8-bit unsigned integer with valid values from 1 to 80 representing the timeout in steps of 1 second. The value shall be less than or equal to the CD_time_out_2 value negotiated during the last

ITU-T G.994.1 session.

Field 27 "Supported options" indicates various options supported by the MTU-O. It is encoded as a 16-bit field [$b_{15}b_{14} \ldots b_0$] where b_{15} is the MSB and b_0 is the LSB.

Bits [$b_{15} \ldots b_8$] shall be used to indicate only the options for which settings are conveyed via the RMC command field "settings associated with supported options" (see Table 9-5 and Table 9-8):

– Bit b_8 shall be set to 1 if the MTU-O supports the RPF indicator bits in the upstream RMC command (see Table 9-8), set to 0 otherwise.

– Bit b_9 shall be set to 1 if the MTU-O supports the INM facility and the INM facility is enabled in the DPU-MIB and shall be set to 0 otherwise (see clause 11.4.4.7).

– Bits [$b_{15} \ldots b_{10}$] are reserved by ITU-T.

Bits [$b_7 \ldots b_0$] shall be used to indicate all other options:

– Bit b_0 (*SREC_allowed*) shall be set to 1 if SREC (see clause 13.2.1.5.4) has been allowed in the DPU-MIB as defined by SREC_ALLOWED.

– Bits [$b_7 \ldots b_1$] are reserved by ITU-T.

All bits reserved by ITU-T shall be set to 0 and ignored by the receiver.

Field 29 "Upstream low ANDEFTR threshold" contains the value of the control parameter *low_ANDEFTR_threshold-us*. The parameter is used in the conditions for declaring a *landeftr* defect at the MTU-R (see clauses 11.2.2.11 and 11.3.1.3).

The value shall not exceed the *NDR_max* value for the upstream defined in clause 11.4.2.2. The value shall be coded as a 16-bit unsigned integer representing the data rate as a multiple of 96 kbit/s.

Field 30 "Annex D descriptor" contains Annex D related parameters indicated by the MTU-O. The field has variable length; the format and content of this descriptor is defined in Table 12-50a.

Table 12-50a – Format of Annex D descriptor

Field name	Format	Description
Annex D parameter field length	One byte	Indicates the number of bytes in the Annex D parameter field. This field shall be set to ZERO if the Annex D parameter field is not present.
Annex D parameter field	Variable length	See clause D.6.1.1

Field 31 "Downstream actual response time capability (*Tresp_max_act_ds*)" contains the actual response time capability of the MTU-O expressed in DMT symbols (see clause 9.8.1). The valid values are all integers from 0 to ceiling($T_{resp\_max\_O}/T_{symb}$). The reported value shall be one that can support all relevant PDX frame configurations, including those in Annex D, if intended to be used.

Field 32 "Downstream minimum retransmission shift capability (*RetShift_min_ds*)" contains the value of the minimum downstream retransmission shift supported by the MTU-O (see clause 9.8.1) expressed in DMT symbols. The value is coded as a 2's complement 8-bits signed integer. The valid values are from $-(M_{us}$- $D_{RMCus})$ to 3. Negative values shall be allowed only if FDX mode is used.

Field 33 "Upstream low ANDEFTR0 threshold" contains the value of the control parameter *low_ANDEFTR0_threshold-us*. The parameter is used in the conditions for declaring a *landeftr0* defect at the MTU-R (see clauses 11.2.2.11 and 11.3.1.3).

The value shall not exceed the *NDR_max* value for the upstream defined in clause 11.4.2.2. The value shall be coded as a 16-bit unsigned integer representing the data rate as a multiple of 96 kbit/s.

Field 34 "Use of RRC and RRC symbols" indicates whether RRC is enabled or disabled and, if RRC is enabled, whether RRC symbols are allowed in NPSF. The two LSBs of the field is coded as follows:

00 – RRC disabled

01 – RRC enabled, RRC symbols not allowed

11 – RRC enable and RRC symbols allowed

10 – invalid setting

All other bits are reserved by ITU-T and shall be set to 0.

Field 35 "Annex X descriptor" contains Annex X related parameters indicated by the MTU-O. The field has variable length; the format and content of this descriptor is defined in Table 12-50b.

Table 12-50b – Format of Annex X descriptor

Field name	Format	Description
Annex X parameter field length	One byte	Indicates the number of bytes in the Annex X parameter field. This field shall be set to ZERO if the Annex X parameter field is not present.
Annex X parameter field	Variable length	See clause X.10

12.3.4.2.2 R-MSG 2

The R-MSG 2 message conveys MTU-R information to the MTU-O. The full list of parameters carried by the R-MSG 2 message is shown in Table 12-51.

Table 12-51 – R-MSG 2 message

Field	Field name	Format
1	Message descriptor	Message code
2	TPS-TC capabilities	See Table 12-52
3	PMS-TC capabilities	See Table 12-53
4	Time synchronization requirement	One byte
5	Time synchronization period (TSP)	One byte
6	Battery operation capability	One byte
7	PMD capabilities	See Table 12-54
8	Supported Options	Two bytes
10	Annex D descriptor	Variable
11	Upstream actual response time capability(*Tresp_max_act_us*)	One byte
12	Upstream minimum retransmission shift capability (*RetShift_min_us*)	One byte
13	Downstream maximum update period for DSQM (*T_upd_seq_max_ds*)	One byte
14	Downstream maximum update period for DCM (*T_upd_con_max_ds*)	One byte
15	Downstream minimum number of monitoring symbols in one update period for DCM (*N_con_min_ds*)	One byte
16	Downstream minimum time period between two adjacent monitoring symbols for DCM (*T_dcm_min_ds*)	One byte

Field 1 "Message descriptor" is a unique one-byte code (86_{16}) that identifies the message. See Table 12-10 for a complete list of codes.

Field 2 "TPS-TC capabilities" indicates the TPS-TC capabilities of the MTU-R, as shown in Table 12-52.

Table 12-52 – TPS-TC capabilities of MTU-R

Field name	Format	Description
Number of supported QoS channels	One byte	Number of supported QoS channels in both directions inside the bearer channel. Valid values are 2 and 4. The field shall be coded as an unsigned integer.
Maximum Downstream NDR	Two bytes	Maximum NDR supported by the MTU-R for the downstream bearer channel. The value shall not exceed the *NDR_max* value defined in clause 11.4.2.2. The value shall be coded as a 16-bit unsigned integer representing the data rate as a multiple of 96 kbit/s.
Maximum Upstream NDR	Two bytes	Maximum NDR supported by the MTU-R for the upstream bearer channel. The value shall not exceed the *NDR_max* value defined in clause 11.4.2.2. The value shall be coded as a 16-bit unsigned integer representing the data rate as a multiple of 96 kbit/s.

Field 3 "PMS-TC capabilities" indicates the PMS-TC capabilities of the MTU-R as shown in Table 12-53.

Table 12-53 – PMS-TC capabilities of MTU-R

Field name	Format	Description
Max DS net data rate	Two bytes	Indicates the maximum downstream net data rate supported. The unsigned 16-bit value is the net data rate divided by 96 kbit/s.
Max US net data rate	Two bytes	Indicates the maximum upstream net data rate supported. The unsigned 16-bit value is the net data rate divided by 96 kbit/s.

Field 4 "Time synchronization request" indicates whether or not ToD synchronization is required by the NT. The field shall be coded as a single byte [0000 000t], where:

– t=0 indicates that ToD synchronization is not required;

– t=1 indicates that ToD synchronization is required.

Field 5 indicates the time synchronization period (TSP), defined as maximum increment in number of superframes of the t1 instant number (see clause 8.5.1 and Figure 8-15) contained in two consecutive transmissions of the time synchronization eoc message. TSP is coded as an 8-bit unsigned integer n with valid values n = 10…255 (FF_{16}), indicating TSP = 16 × n.

Field 6 "Battery operation capability" indicates whether battery backup of CPE is available during power failures at the customer premises. The field shall be set to 01_{16} if backup battery is available and set to 00_{16} otherwise.

Field 7 "PMD capabilities" indicates the PMD capabilities of the MTU-R as shown in Table 12-54.

Table 12-54 – PMD capabilities of the MTU-R

Field name	Format	Description
MTU-R maximum bit loading and MTU-R DTFO Band 1 bit loading	One byte: [00cb00aa]	aa: Indicates the maximum bit loading supported by the MTU-R transmitter: • aa = 00 – maximum bit loading bi = 12 bits if TCM is selected, mi = 13 bits if PCS-LCM is selected. • aa = 01 – maximum bit loading bi = 13 bits if TCM is selected, mi = 14 bits if PCS-LCM is selected. • aa = 10 – maximum bit loading bi = 14 bits if TCM is selected, mi = 15 bits if PCS-LCM is selected. • aa = 11 – Reserved by ITU-T b: b is set to ONE if the MTU-R only supports the same downstream bit loading and g_i values in the Band 1 of both the NOI_{PSF} and DOI. Otherwise, it shall be set to 0. c: c is set to ONE if the MTU-R only supports the same upstream bit loading and g_i values in the Band 1 of both the NOI_{PSF} and DOI. Otherwise, it shall be set to 0.

Field 8 "Supported options" indicates various options supported by the MTU-R. It is encoded as a 16-bit field [$b_{15}b_{14} \dots b_0$] where b_{15} is the MSB and b_0 is the LSB.

Bits [$b_{15} \dots b_8$] shall be used to indicate only the options for which settings are conveyed via the RMC command field "settings associated with supported options" (see Table 9-5 and Table 9-8):

– Bit b_8 shall be set to 1 if the MTU-R supports the RPF indicator bits in the upstream RMC command (see Table 9-8), set to 0 otherwise;

– Bit b_9 shall be set to 1 if the MTU-R supports the INM facility and set to 0 otherwise (see clause 11.4.4.7).

– Bits [$b_{15} \dots b_{10}$] are reserved by ITU-T.

Bits [$b_7 \dots b_0$] shall be used to indicate all other options:

– Bit b_0 (support of upstream PCS-LCM) shall be set to 1 if upstream PCS-LCM is supported by the MTU-R and set to 0 if not supported.

– Bits [$b_7 \dots b_1$] are reserved by ITU-T.

All bits reserved by ITU-T shall be set to 0 and ignored by the receiver.

""Field 10 "Annex D descriptor" contains Annex D related parameters indicated by the MTU-R. The field has variable length; the format and content of this descriptor is defined in Table 12-55.

Table 12-55 – Format of Annex D descriptor

Field name	Format	Description
Annex D parameter field length	One byte	Indicates the number of bytes in the Annex D parameter field. This field shall be set to ZERO if the Annex D parameter field is not present.
Annex D parameter field	Variable length	See clause D.6.1.2

Field 11 "Upstream actual response time capability *(Tresp_max act_us)*" contains the actual response time capability of the MTU-R expressed in DMT symbols (see clause 9.8.1). The valid values are all integer values from 0 to ceiling($T_{resp\_max\_R}/T_{symb}$). The reported value shall be one that can support all relevant PDX frame configurations, including those in Annex D, if intended to be used.

Field 12 "Upstream minimum retransmission shift capability (*RetShift_min_us*)" contains the value of the minimum upstream retransmission shift supported by the MTU-R (see clause 9.8.1) expressed in DMT symbols. The value is coded as a 2's complement signed integer. The valid values are from $-(M_{ds}- D_{RMCds})$ to 3. Negative values shall be allowed only if FDX mode is used.

Field 13 "Downstream maximum update period for DSQM (*T_upd_seq_max_ds*)" contains the maximum update period for DSQM in downstream required by the MTU-R, expressed in number of superframes (see clause 10.7.3.2.2). It is coded as an 8 bit unsigned integer with a valid range from 1 to 64.

Field 14 "Downstream maximum update period for DCM (*T_upd_con_max_ds*)" contains the maximum update period for DCM in downstream required by the MTU-R, expressed in number of superframes (see clause 10.7.3.2.1).

Field 15 "Downstream minimum number of monitoring symbols in one update period for DCM (*N_con_min_ds*)" contains the minimum number of non-Z monitoring symbols in one update period for DCM (*T_upd_con_max_ds*) in downstream required by the MTU-R, expressed in number of symbols (see clause 10.7.3.2.1). It is coded as an 8 bit unsigned integer (*N_con_min_ds/2)-1*. A coded value of 0 corresponds with *N_con_min_ds*=2. A coded value of 255 corresponds with *N_con_min_ds*=512.

Field 16 "Downstream minimum time period between two adjacent monitoring symbols for DCM (*T_dcm_min_ds*)" contains the minimum time period between two adjacent DCM monitoring symbols for DCM in downstream required by the MTU-R, expressed in number of PDX frames (see clause 10.7.3.2.1).

12.3.4.2.3 O-TPS

The O-TPS message conveys the TPS-TC configuration for both upstream and downstream directions (determined by MTU-O). It is based on the capabilities that were indicated in O-MSG 1 and R-MSG 2 messages. The list of parameters carried by the O-TPS message is shown in Table 12-56.

Table 12-56 – O-TPS message

Field	Field name	Format
1	Message descriptor	Message code
2	TPS-TC configuration	See Table 12-57
3	Time synchronization enable	One byte
4	PMD configuration	One byte

Field 1 "Message descriptor" is a unique one-byte code (08_{16}) that identifies the message. See Table 12-10 for a complete list of codes.

Field 2 "TPS-TC configuration" specifies the TPS-TC configuration in the upstream and downstream directions, and is structured as shown in Table 12-57.

Table 12-57 – TPS-TC configuration

Field name	Format	Description
Downstream bearer channel configuration	Bearer channel descriptor	Contains the required configuration of the downstream bearer channel.
Number of enabled downstream QoS channels	One byte	Contains the number of enabled downstream QoS channels (*NCds*). The value shall be lower than or equal to the supported value indicated by the MTU-O and MTU-R. The field shall be coded as an unsigned integer.
Downstream QoS channel configuration	QoS channel descriptor(s)	Contains configuration descriptors of all enabled downstream QoS channels. These descriptors shall be included by increasing value of their *CID*, i.e., *CID*=0 first, followed by *CID*=1, up to *CID*=*NCds-1*.
Upstream bearer channel configuration	Bearer channel descriptor	Contains the required configuration of the upstream bearer channel.
Number of enabled upstream QoS channels	One byte	Contains the number of enabled upstream QoS channels (*NCus*). The value shall be lower than or equal to the supported value indicated by the MTU-O and MTU-R. The field shall be coded as an unsigned integer.
Upstream QoS channel configuration	QoS channel descriptor(s)	Contains configuration descriptors of all enabled upstream QoS channels. These descriptors shall be included by increasing value of their *CID*, i.e., *CID*=0 first, followed by *CID*=1, up to *CID*=*NCus-1*.
Upstream L2+ queues mapping enabled	One byte	0x00: Upstream L2+ queues mapping is undefined 0x01: Upstream L2+ queues mapping is defined in QMAP. Other values are reserved by ITU-T.
Upstream L2+ queues to QoS channel mapping (QMAP).	Two Bytes	Contains the mapping for eight L2+ upstream queues (*QID*=0..7) to QoS channels (*CID*=0..3). Two bits determine for each L2+ upstream QID the QoS channel (CID) to which the data traffic of the queue is mapped: $QMAP = \sum_{QID=0}^{7} CID(QID) \times 2^{2 \cdot QID}$. L2+ upstream queues shall only be mapped to enabled upstream QoS channels. Unused *QID* shall be mapped to *CID* = 0. If upstream L2+ queues mapping is undefined *QMAP* shall be set to 0x0000.

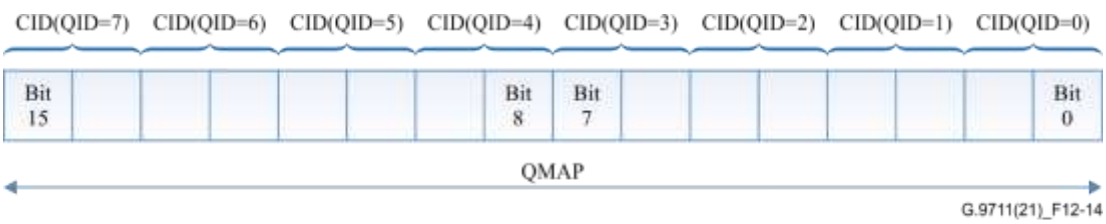


Figure 12-14 – The format of the QMAP

The bearer channel descriptor shall have a format as defined in Table 12-58.

Table 12-58 – Bearer Channel descriptor

Byte	Content of field
1 and 2	Maximum NDR (*NDR_max*)
3 and 4	Minimum ETR (*ETR_min*)
5 and 6	Minimum INP against SHINE (*INP_min_shine*)
7	SHINE ratio (*SHINEratio*)
8	Minimum INP against REIN (*INP_min_rein*)
9	Inter arrival time flag of REIN (*iat_rein_flag*)
10	Minimum R/N ratio (*rnratio_min*)

The field "Maximum NDR" shall contain the value for *NDR_max* selected by the MTU-O. This value of *NDR_max* shall not exceed the value of *NDR_max* indicated by the MTU-O in O-MSG 1 message and shall not exceed the value of *NDR_max* indicated by the MTU-R in R-MSG 2 message for the bearer channel. The value shall be coded as a 16-bit unsigned integer representing the data rate as a multiple of 96 kbit/s.

The field "Minimum ETR" shall contain the value of *ETR_min* (see clause 11.4.2.1) selected by the MTU-O. The value shall be coded as a 16-bit unsigned integer representing the data rate as a multiple of 96 kbit/s.

The field "Minimum impulse noise protection against SHINE" shall contain the value of *INP_min_shine* (see clause 11.4.2.4) selected by the MTU-O. The value shall be coded as a 16-bit unsigned integer representing the INP in multiple of symbol periods.

The field "SHINE ratio" shall contain the value *SHINEratio* (see clause 11.4.2.5) selected by the MTU-O. The value shall be coded as an 8-bit unsigned integer representing the *SHINEratio* as a multiple of 0.001.

The field "Minimum impulse noise protection against REIN" shall contain the value of *INP_min_rein* (see clause 11.4.2.6) selected by the MTU-O. The value shall be coded as an 8-bit unsigned integer representing the INP in multiple of symbol periods.

The field "Inter-arrival time flag of REIN" shall contain the value of *iat_rein_flag* (see clause 11.4.2.7) selected by the MTU-O. The value shall be coded as an 8-bit unsigned integer with valid values 0 to 3.

The field "Minimum R/N ratio" shall contain the value of *rnratio_min* (see clause 11.4.2.8) as selected by the MTU-O. The value shall be coded as an 8-bit unsigned integer representing the R/N ratio as a multiple of 1/32.

The QoS channel descriptors shall have a format as defined in Table 12-59.

Table 12-59 – QoS Channel configuration descriptor

Byte	Content of field
1	Maximum delay (*delay_max* or MAXDELAY)
2	Priority (PRIORITY)
3	Proactive retransmission (PROACTIVE_RTX_ON).

The field "Maximum delay" shall contain the value of *delay_max* (see clause 11.4.2.3) for the downstream QoS channel or the value of MAXDELAY (see clause 8.1) for the upstream QoS channel selected by the MTU-O. The value shall be coded as an 8-bit unsigned integer representing the delay in multiple of 0.25 ms.

The field "Priority" shall contain the priority of the value of PRIORITY (see clause 8.1) as selected by the MTU-O. The value shall be coded as an 8-bit unsigned integer with valid values 0 to 3.

The field "Proactive retransmission" shall contain the value of PROACTIVE_RTX_ON (see clause 9.8) as selected by the MTU-O. The value shall be coded as an 8 bit unsigned integer with valid values 0, 1, and 2.

Field 3 "Time synchronization enable" indicates whether ToD synchronization is enabled. The field shall be formatted as [0000 0b2b1b0].

Bits b1b0 define the status of ToD synchronization. The valid values are:

– If b1b0=00, ToD synchronization is disabled.
– If b1b0=01, ToD frequency synchronization with the PMD sample clock being frequency locked to the ToD network clock is used for time synchronization.
– If b1b0=10, ToD frequency synchronization via the processing of ToD phase difference values is used for time synchronization.
– b1b0=11 is reserved by ITU-T.

Bit b2 defines the status of NTR frequency synchronization:

– If b2=1, PMD sample clock is locked to the NTR
– If b2=0, PMD sample clock is independent from the NTR

Field 4 "PMD configuration" contains an 8-bit field [$b_7 \ldots b_0$].

The LSB b_0 defines the PMD coding scheme (TCM or PCS-LCM) in the downstream direction:

– If b_0=0, the PMD coding scheme is selected by the MTU-R.
– If b_0=1, the PMD coding scheme is forced to TCM by the DPU-MIB.

Other bits are reserved by the ITU-T. They shall be set to 0 and ignored by the receiver.

12.3.4.2.4 R-ACK 1

R-ACK 1 is an SOC message that acknowledges correct reception of the O-TPS message and provide the receiver delay in the upstream direction. The format shall be as defined in Table 12-60.

Table 12-60 – R-ACK 1 message

Field	Field name	Format
1	Message descriptor	Message code
2	Maximum receiver delay of upstream QoS channel with CID=0 (*delay_max*).	1 byte.
3	Maximum receiver delay of upstream QoS channel with CID=1 (*delay_max*).	1 byte.
4	Maximum receiver delay of upstream QoS channel with CID=2 (*delay_max*).	1 byte.
5	Maximum receiver delay of upstream QoS channel with CID=3 (*delay_max*).	1 byte.

Field 1 "Message descriptor" is a unique one-byte code (87_{16}) that identifies the message. See Table 12-10 for a complete list of codes.

Field 2 "Maximum receiver delay of upstream QoS channel with CID=0" contains the maximum receiver delay, *delay_max* (see clause 8.1) of the upstream QoS channel with CID=0. It is coded as a 8-bit unsigned integer representing the delay in multiple of 0.25 ms.

Fields 3, 4, and 5 contain the receiver delay of the upstream QoS channel with CID=1, 2, and 3, respectively, all coded as the field 2. If the upstream QoS channel is disabled, the value shall be set to 0.

12.3.4.2.5 O-PMS

The O-PMS message conveys the initial PMS-TC parameter settings that shall be used in the upstream direction during showtime. The list of parameters carried by the O-PMS message is shown in Table 12-61.

Table 12-61 – O-PMS message

Field	Field name	Format
1	Message descriptor	Message code
2	DPus	Data path descriptor
3	RMCPus	US RMC path descriptor
4	RMCPds	DS RMC path descriptor
5	Upstream RMC-ACK window shift	One byte
6	Annex D descriptor	Variable
7	Upstream PMD encoding scheme	One byte
8	Upstream RRC-ACK window shift	One byte

Field 1 "Message descriptor" is a unique one-byte code (09_{16}) that identifies the message. See Table 12-10 for a complete list of codes.

Field 2 "DPus" is a field that contains the PMS-TC parameters required for data path in the upstream direction. The "Data path descriptor" format specified in Table 12-62 shall be used. All values in Table 12-62 are unsigned integers.

Table 12-62 – Data path descriptor

Byte	Field	Format	Description
1 and 2	B_{DN0_PSF}	Two bytes	Contains the value of B_{DN0_PSF} for the data_quiet and data_idle symbols
3 and 4	B_{DN0_NPSF}	Two bytes	Contains the value of B_{DN0_NPSF} for the data_quiet and data_idle symbols
5 and 6	B_{DN01}	Two bytes	Contains the value of B_{DN01} for the data_data symbols
7 and 8	B_{DR0}	Two bytes	Contains the value of B_{DR0} for the RMC_quiet and RMC_idle symbols
9 and 10	B_{DR01}	Two bytes	Contains the value of B_{DR01} for the RMC_data symbols
11	RD	One byte	Contains the value of R_{FEC} for the data path
12	ND	One byte	Contains the value of N_{FEC} for the data path
13	Q	One byte	Number of FEC codewords per DTU

Field 3 "RMCPus" is a field that contains the PMS-TC parameters required for RMC in the upstream direction. The "RMC path descriptor" format specified in Table 12-63 shall be used. All values in Table 12-63 are unsigned integers.

Table 12-63 – RMC path descriptor

Byte	Field	Format	Description
1	K_{RMC}	One byte	Contains the value of K_{FEC} for the RMC path.

Field 4 "RMCPds" is a field that contains the PMS-TC parameters required for RMC in the downstream direction. The "RMC path descriptor" format specified in Table 12-63 shall be used.

Field 5 "Upstream RMC-ACK window shift" is a field that contains the ACK window shift in symbol periods for the upstream direction (see clause 9.7), expressed as a 2's complement signed integer. The valid range is from $-D_{RMC}$ to 20. Negative values shall be allowed only if FDX mode is used.

Field 6 "Annex D descriptor" contains Annex D related parameters indicated by the MTU-O. The field has variable length; the format and content of this descriptor is defined in Table 12-64.

Table 12-64 – Format of Annex D descriptor

Field name	Format	Description
Annex D parameter field length	One byte	Indicates the number of bytes in the Annex D parameter field. This field shall be set to ZERO if the Annex D parameter field is not present.
Annex D parameter field	Variable length	See clause D.6.1.3

Field 7 "Upstream PMD encoding scheme" indicates the encoding scheme selected in the upstream direction by the MTU-O. It is coded as unsigned 8-bit unsigned integer that is set to 0 if TCM is selected and set to 1 if PCS-LCM is selected. Other values are reserved by the ITU-T.

Field 8 "Upstream RRC-ACK window shift" is a field that contains the RRC-ACK window shift in symbol periods for the upstream direction (see clause 9.7.2), expressed as an unsigned integer. The valid range is between 4 and 12.

12.3.4.2.6 R-PMS

The R-PMS message conveys the initial PMS-TC parameter settings that shall be used in the downstream direction during showtime. The list of parameters carried by the R-PMS message is shown in Table 12-65.

Table 12-65 – R-PMS message

Field	Field name	Format
1	Message descriptor	Message code
2	DPds	Data path descriptor
3	Downstream RMC-ACK window shift	One byte
4	Downstream PMD encoding scheme	One byte
5	Downstream RRC-ACK window shift	One byte

Field 1 "Message descriptor" is a unique one-byte code (88_{16}) that identifies the message. See Table 12-10 for a complete list of codes.

Field 2 "DPds" is a field that contains the PMS-TC parameters required for data path in the downstream direction. The data path descriptor format specified in Table 12-62 shall be used.

Field 3 "Downstream RMC-ACK window shift" is a field that contains the ACK window shift in symbol periods for the downstream direction (see clause 9.7), expressed as a 2's complement signed integer. The valid range is from $-D_{RMC}$ to 20. Negative values shall be allowed only if FDX mode is used.

Field 4 "Downstream PMD encoding scheme" indicates the encoding scheme selected in the downstream direction by the MTU-R. It is coded as unsigned 8-bit that is set to 0 if TCM is selected and set to 1 if PCS-LCM is selected. Other values are reserved by the ITU-T.

Field 5 "Downstream RRC-ACK window shift" is a field that contains the RRC-ACK window shift in symbol periods for the downstream direction (see clause 9.7.2), expressed as an unsigned integer. The valid range is between 4 and 12.

12.3.4.2.7 O-PMD

The O-PMD message conveys the initial PMD parameter settings that shall be used in the upstream direction during showtime. To increase robustness of communications, the message is sent in three parts, O-PMD-PSF-1, O-PMD-PSF-2, and O-PMD-NPSF-1.

The list of parameter settings carried by the O-PMD-PSF-1 message is shown in Table 12-66 and one carried by the O-PMD-PSF-2 message is shown in Table 12-69. These two messages carry parameter settings related to operation in PSF only (both TDD and FDX modes).

The list of parameter settings carried by the O-PMD-NPSF-1 message is shown in Table 12-70. It carries parameter settings related to NPSF (FDX mode). The O-PMD-NPSF-1 message supports operation in FDX mode and shall be skipped in case of operation in TDD mode and when Annex X is used.

Table 12-66 – O-PMD-PSF-1 message

Field	Field name	Format
1	Message descriptor	Message code
2	Bit-loading table for data symbol during NOI and DOI (Band 0, FUS)	ceiling(NSC_{us0}/2) bytes
3	Number of RMC US subcarriers ($NSCR_{us}$)	Two bytes
4	Upstream RMC tone set (RTS_{us})	2 × $NSCR_{us}$ bytes
5	Bit-loading table for RMC US subcarriers	ceiling($NSCR_{us}$/2) bytes
6	Tone-ordering table	2 × (NSC_{us0}+NSC_{us1}) bytes
7	Initialization status	One byte
8	Bit-loading table for data symbol during NOI and DOI (Band 1, FUS)	ceiling($NSC_{us1}/2$) bytes
9	Upstream FRA sub-bands	Sub-band descriptor
10	Number of tones in upstream backup RMC tone set ($NSCR\text{-}b_{us}$)	Two bytes
11	Backup upstream RMC tone set ($RTS\text{-}b_{us}$)	2 × $NSCR\text{-}b_{us}$ bytes
12	Backup bit-loading table for upstream RMC	ceiling($NSCR\text{-}b_{us}$/2) bytes
13	Downstream RMCR lor persistency trigger (*rmcr_lor_trigger-ds*)	One byte
14	Upstream PCS-LCM parameters in NOI (only Band 0, FUS)	One byte
15	Upstream PCS-LCM parameters in NOI (Band 0 and Band 1, FUS)	One byte
16	Downstream DBR sub-band descriptor	Sub-band PSD descriptor
17	Upstream DBR sub-band descriptor	
18	DTFO container	Variable

Field 1 "Message descriptor" is a unique one-byte code ($0A_{16}$) that identifies the message. See Table 12-10 for a complete list of codes.

Field 2 "Bit-loading table for data symbol during NOI and DOI (Band 0, FUS)" contains the b_i values for every subcarrier in MEDLEYus of Band 0 (MEDLEYus-0). The b_i indicates the number of bits to be mapped by the MTU-R to the subcarrier *i*. In case of PCS-LCM coding, the b_i indicates the modulation index ($m_i = b_i$).

The b_i shall only be defined for subcarriers from the MEDLEYus-0 set (as indicated in O-PRM message), and shall be sent in ascending order of subcarrier index *i*.

Each b_i value shall be coded as a 4-bit unsigned integer with valid range from zero to 14. The four least significant bits of the first byte of this field represent the bit loading of the first subcarrier from the MEDLEYus-0 set. The four most significant bits of the first byte of this field represent the bit loading of the second subcarrier from the MEDLEYus-0 set. The four least significant bits of the second byte of this field represent the bit loading of the third subcarrier from the MEDLEYus-0 set, etc.

Field 3 "Number of RMC US subcarriers ($NSCR_{us}$)" indicates the number of subcarriers assigned for upstream RMC symbol coded as a 16-bit unsigned integer. The valid range is from 1 to 512 (0200_{16}).

Field 4 "Upstream RMC tone set (RTS_{us})" indicates the indices of the subcarriers used to encode the RMC in the upstream direction. Each subcarrier index shall be coded as a 16-bit unsigned integer value. The first encoded value shall correspond to the lowest subcarrier used to encode the RMC. The remaining indices shall be sent in increasing frequency order. The subcarriers for RTS_{us} shall be selected from the MEDLEYus-0 set. The RTS_{us} shall not include subcarriers from the frequency bands defined through the RMCCARMASKus in the DPU-MIB.

Field 5 "Bit-loading table for RMC US subcarriers" contains the bit loading (the b_i values in case of TCM and the m_i value in case of PCS-LCM) for every subcarrier in upstream RMC subcarrier set presented in field 3. The values shall be sent in ascending order of subcarrier index *i*. Each value shall be coded as a 4-bit unsigned integer. The valid values for b_i in case of TCM are 0 and all integers from 2 to 6, while in the case of PCS-LCM the valid values for m_i are all integers from 1 to 4.

Field 6 "Tone-ordering table" contains the tone-ordering table *t* for the upstream direction. The tone-ordering table contains the order in which the subcarriers shall be assigned bits in the upstream direction. The table shall include all subcarriers of the MEDLEYus set and only these subcarriers. Each subcarrier index shall be coded as a 16-bit unsigned integer value. The value of the first encoded index sent shall be equal to the index of the first entry in the tone-ordering table (*t*1, see clause 10.2.1.2). The remaining indices shall be sent in increasing order of the tone-ordering table t entries (*t*2, *t*3, ... $tNSC_{us0+NSCus1}$).

Field 7 "Initialization status":

If, within the constraints of the channel initialization policies defined in clause 12.3.7, the receiver is unable to select a set of values for the control parameters, the receiver shall reply with an "Initialization success/failure code" indicating the initialization failure cause.

If, within the constraints of the channel initialization policies defined in clause 12.3.7, the receiver is able to select a set of values of the control parameters, the "Initialization success/failure code" indicates the initialization success. Valid "Initialization success/failure codes" are as follows:

80_{16}: Initialization success;

81_{16}: Configuration error;

82_{16}: Configuration not feasible on transmission line;

00_{16}: Feature not supported.

Other values are reserved by the ITU-T.

If an initialization success/failure code 00_{16}, 81_{16} or 82_{16} is set:

– all bytes in field 3 shall be set to 0016 and values in fields 4, 5 and 6 shall be set to 00_{16} (one byte long); and

– the MTU-O shall return to L3 link state instead of L0 link state at the completion of the initialization procedures.

Field 8: "Bit-loading table for data symbol during NOI and DOI (Band 1, FUS)" contains the b_i values for every subcarrier in MEDLEYus-1 in DOI or NOI DTFO symbols (used only in FUS). The b_i shall indicate the number of bits to be mapped by the MTU-R to the subcarrier *i*. In case of PCS-LCM coding, the b_i indicates the modulation index ($m_i = b_i$).

The b_i shall only be defined for subcarriers from the MEDLEYus-1 set (as indicated in O-PRM message), and shall be sent in ascending order of subcarrier index *i*. The coding of the bi values shall be as defined in Field 2. This field shall not be present in the message if transmission line is not using DTFO.

Field 9 "Upstream FRA sub-bands" contains the start and stop frequencies of the FRA sub-bands (see clause 13.3.1.1) for the upstream direction. It shall be formatted as a band descriptor (see Table 12-22) and shall specify up to eight contiguous sub-bands.

Field 10 "Number of tones in upstream backup RMC tone set ($NSCR\text{-}b_{us}$)" indicates the number of subcarriers in the upstream backup RTS expressed as unsigned integer. The valid range of values is from 0 to 512 (0200_{16}). The value of zero shall not be sent if the control parameter *rmcr_lor_trigger-ds* in field 13 of O-PMD message is set to a non-zero value.

The MTU-R shall ignore the contents of fields 11 and 12 of the O-PMD message if the control parameter *rmcr_lor_trigger-ds* in field 13 of O-PMD message is set to zero.

Field 11 "Backup upstream RMC tone set ($RTS\text{-}b_{us}$)" indicates the indices of the subcarriers used to encode the backup RMC in the upstream direction. Subcarrier indices shall be formatted and represented as defined in Field 4 of O-PMD. The $RTS\text{-}b_{us}$ shall not include subcarriers from the frequency bands defined through the RMCCARMASKus in the DPU-MIB. This field shall not be sent if $NSCR\text{-}b_{us} = 0$.

Field 12 "Backup bit-loading table for upstream RMC" contains the b_i values for every subcarrier in upstream backup RMC subcarrier set presented in Field 10. The b_i shall indicate the number of bits to be mapped by the MTU-R to the subcarrier *i*. The b_i values shall be represented and sent as defined in Field 5 of O-PMD message. This field shall not be sent if $NSCR\text{-}b_{us} = 0$.

Field 13 "Downstream RMCR lor persistency trigger" contains the value of the control parameter *rmcr_lor_trigger-ds* represented as an unsigned integer in units of 50 ms. The parameter is used to declare that the downstream receive RMC is severely degraded (see clause 13.3.1.2.1). The valid range is defined in Table 13-17.

Field 14 "Upstream PCS-LCM parameters in NOI (only Band 0, FUS)" contains the upstream PCS-LCM parameters M_c and P in NOI symbols in FUS if only Band 0 is active. It is encoded as an 8-bit field [b7…b0] where b0 is the LSB. If PCS-LCM in the upstream is disabled, this field shall be set to 0. If PCS-LCM in the upstream is enabled:

– bits [b3:b0] contain the index of M_c coded as an unsigned integer. Valid indices are 0, 1, 2, 3, 4, 5 and 6 corresponding to M_c values 64, 96, 128, 192, 256, 384 and 512, respectively.

– bits [b7-b4] contain the value of $k = 4P/M_c$, coded as an unsigned integer, with valid values 0, 1, 2,…10 and a special value 15. If k is different from 15, $P = 0.25 \times k \times M_c$. Otherwise, $P = 7 \times M_c$.

Field 15 "Upstream PCS-LCM parameters in NOI (Band 0 and Band 1, FUS)" contains the upstream PCS-LCM parameters M_c and P in NOI symbols in FUS if both Band 0 and Band 1 are active. It is encoded as defined for field 14.

Field 16 "Downstream DBR sub-band descriptor" contains description of frequency sub-bands to assist the DBR procedure in the downstream direction. The format shall be as defined in Table 13-19. This field shall not be present in the message if P2MP mode is disabled.

Field 17 "Upstream DBR sub-band descriptor" contains description of frequency sub-bands to assist the DBR procedure in the upstream direction. The format shall be as defined in Table 13-19. This field shall not be present in the message if P2MP mode is disabled.

Field 18 "DTFO container" conveys description of DTFO parameters. The format shall be as defined in Table 12-67. If DTFO is disabled in a particular direction, the DTFO descriptor of the corresponding direction shall not be present in the message. If DTFO is disabled in both directions, the DTFO container field length shall be set to ZERO.

Table 12-67 – Format of DTFO container

Field	Field name	Format
1	DTFO container field length	One byte
2	Downstream DTFO description	DTFO descriptor (Table 12-68)
3	Upstream DTFO description	DTFO descriptor (Table 12-68)

Field 1 "DTFO container field length" indicates the number of bytes in the DTFO container field. If set to ZERO, the DTFO description fields shall not be present.

Field 2 "Downstream DTFO description" indicates the downstream DTFO monitoring parameter settings using the format in Table 12-68).

Field 3 "Upstream DTFO description" indicates the upstream DTFO monitoring parameter settings using the format in Table 12-68).

If a DTFO descriptor indicates that DCM is elected and activated, the DCM settings shall be applied starting in showtime from the reference superframe with superframe count as indicated in the descriptor. Within the reference superframe, the first DCM symbol shall be sent starting from the DCM active logical frame specified by the DCM active logical frame time marker for the DCM group with *TA_dcm* of the current link as identified in field 2 of the DTFO descriptor (see fig 10-46b). On the DCM symbol positions between the start of showtime and the first DCM symbol being sent, a quiet signal shall be sent in Band 1 on the subcarriers assigned to the link (i.e., an RMC_quiet or data_quiet symbol).

If a DTFO descriptor indicates that DSQM is selected and activated, and DTFO is activated, DSQM symbols shall be sent starting from the first logical frame of showtime, in every logical frame where it is required based on *T_upd_seq_max*.

If a DTFO descriptor indicates that neither DCM norDSQM is selected, neither DCM nor DSQM symbols shall be sent at the start of showtime, until a DCMU procedure instructs otherwise. In the latter case, the DTFO is activated on the link by means of a restoration procedure, as defined in clause 10.7.3.2.3.

Table 12-68 – Format of DTFO descriptor

Field	Field name	Format
1	DTFO monitoring control field	One byte
2	DCM symbol position on current transmission line (*TA_dcm*)	One byte
3	DCM reference superframe count	Two bytes
4	DCM period (*T_dcm*) for DCM group with TA_dcm=0	One byte
5	DCM active logical frame time marker for DCM group with TA_dcm=0	One byte
6	DCM period (*T_dcm*) for DCM group with TA_dcm=1	One byte
7	DCM active logical frame time marker for DCM group with TA_dcm=1	One byte
8	DCM period (*T_dcm*) for DCM group with TA_dcm=2	One byte
9	DCM active logical frame time marker for DCM group with TA_dcm=2	One byte
10	DCM sequence time marker	One byte
11	DCM sequence length (*N_dcm*)	One byte
12	DCM sequence descriptor	Variable

Field 1 "DTFO monitoring activation field" indicates the activationof DCM. It is encoded as an 8-bit field [$b_7b_6 \ldots b_0$] where b_7 is the MSB and b_0 is the LSB.

Bits [$b_2b_1b_0$] "DCM activatedon other transmission lines" form a status bit map indicating for each of the possible DCM symbol positions (TA_dcm) 0, 1 and 2 whether that DCM symbol position is used for a DCM group on another transmission line. For bit b_i the value 0 indicates that a DCM group is not activatedon any other transmission lines on DCM symbol position i, and a value 1 indicates that a DCM group is activatedon at least one other transmission line on DCM symbol position i.

NOTE 1 – To determine the DCM active logical frames and hence the DCM active symbol positions for the other transmission lines, the DCM active logical frame time marker and the DCM period (T_dcm) corresponding to the TA_dcm of that line are used, as well as the reference superframe count in the DTFO descriptor. As the reference superframe count may not be the first superframe of showtime, this determination may need calculating back from the reference superframe count to the start of showtime.

Bits [b_4b_3] "DTFO monitoring selection on current transmission line"

– Value [b_4b_3]=[00] indicates that no DTFO monitoring (i.e., neither DCM nor DSQM) is selected. In this case fields 2 to 12 of the DTFO descriptor shall not be present.
– Value [b_4b_3]=[01] indicates that DCM is selected.
– Value [b_4b_3]=[10] indicates that DSQM is selected.
– Value [b_4b_3]=[11] is reserved by ITU-T.

NOTE 2 – The DTFO monitoring selection is not affected by a change neither in DTFO enabled/disabled nor in DTFO active/inactive status. During showtime, the DTFO monitoring selection can be changed only with a DCMU procedure.

Bits [$b_7 \ldots$ b5] are reserved by ITU-T. All bits reserved by ITU-T shall be set to 0 and ignored by the receiver.

Fields 2 to 12 of the DTFO descriptor shall not be present if DCM is not selected on current transmission line and DCM is deactivated on all other transmission lines of the vectored group (i.e., [b_4b_3]=[00] or [10] and [$b_2b_1b_0$]=[000]) for the specified direction.

Field 2 "DCM symbol position (*TA_dcm*) on current transmission line" indicates for the current transmission line the symbol position of the DCM symbol within an active logical frame, with zero corresponding to the RMC symbol position. It is coded as an 8-bit unsigned integer. It also indicates which DCM group the current transmission line belongs to.

Field 3 "DCM reference superframe count" indicates the count identifying the reference superframe. The count shall be coded as a two-byte unsigned integer.

Field 4 "DCM period (*T_dcm*) for DCM group with TA_dcm=0" contains the time period of DCM monitoring symbols for DCM, expressed in number of PDX frames (see clause 10.7.3.2.1), for the DCM group corresponding to TA_dcm=0, as selected by the MTU-O. It is coded as an 8-bit unsigned integer with valid values 1 to 8 (for M_F=36) and 1 to 12 (for M_F =23) (one superframe) plus special value 255. If field 1 indicated that a DCM group with TA_dcm=0 is not activated on any other transmission line, the value shall be set to 255 at the transmitter and ignored at the receiver.

Field 5 "DCM active logical frame time marker for DCM group with TA_dcm=0" indicates the index of the DCM active logical frame within the reference superframe for the DCM group corresponding to TA_dcm=0. It is coded as an 8-bit unsigned integer with valid values 0 to 7 (in case of MF=36) or 0 to 11 (in case of MF=23) plus special value 255. The value 0 corresponds to the first logical frame in the reference superframe. If field 1 indicated that a DCM group with TA_dcm=0 is not activated on any other transmission line, the value shall be set to 255 at the transmitter and ignored at the receiver.

Field 6 "DCM period (*T_dcm*) for DCM group with TA_dcm=1" has similar definition as field 4 applied for the DCM group corresponding to TA_dcm=1.

Field 7 "DCM active logical frame time marker for DCM group with TA_dcm=1" has similar definition as field 5 applied for the DCM group corresponding to TA_dcm=1.

Field 8 "DCM period (*T_dcm*) for DCM group with TA_dcm=2" has similar definition as field 4 applied for the DCM group corresponding to TA_dcm=2.

Field 9 "DCM active logical frame time marker for DCM group with TA_dcm=2" has similar definition as field 5 applied for the DCM group corresponding to TA_dcm=2.

NOTE 3 – Which of the fields 4 to 9 is relevant in determining the actual positions of the DCM symbol on the current transmission line is determined by field 2 (*TA_dcm*).

Field 10 "DCM sequence time marker" indicates the index of the DCM sequence element corresponding with the DCM symbol position in the first DCM active logical frame of the superframe indicated in the reference superframe count. It is coded as an 8-bit unsigned integer with valid values 0 to (*N_dcm – 1*).

Field 11 "DCM sequence length (*N_dcm*)" defines the length of the DCM sequence (see clause 10.7.3.2.1). In the case sequential monitoring (DSQM) was selected, the value shall be set to zero. It is coded as an 8-bit unsigned integer.

Field 12 "DCM sequence descriptor" defines the DCM sequence allocated by the DRA to be modulated on the DCM symbols. The format is as described for probe sequence specification as in O-SIGNATURE field 16 "FDS probe sequence descriptor".

Table 12-69 – O-PMD-PSF-2 message

Field	Field name	Format
1	Message descriptor	Message code
2	Upstream g_i table, Band 0, FUS	3 × ceiling(NSC_{us0}/2) bytes
3	Upstream g_i table, Band 1, FUS	3 × ceiling(NSC_{us1}/2) bytes

Field 1 "Message descriptor" is a unique one-byte code ($0A_{16}$) that identifies the message. See Table 12-10 for a complete list of codes.

Field 2 "Upstream g_i table, Band 0, FUS" contains the g_i values for every subcarrier in MEDLEYus for Band 0 of FUS. The g_i shall indicate the scale factor that shall be applied to subcarrier *i*, relative to the gain that was used for that subcarrier during the transmission of R-P-MEDLEY. The g_is shall only be defined for subcarriers from the MEDLEYus set (as indicated in R-PRM message), and shall be sent in ascending order of subcarrier indices *i*. Each g_i value shall be represented as an unsigned 12-bit fixed-point quantity, with the binary point assumed just to the right of the third most significant bit. For example, a g_i with binary representation (MSB listed first) 000.010000000_2 would instruct the MTU-R to scale the constellation for subcarrier *i* by a gain of 0.25, so that the power of that subcarrier would be 12.04 dB lower than it was during R-P-MEDLEY. Each two g_i values of subcarriers 2*i* and 2*i*+1 shall be mapped onto a 24-bit field as follows: [$g_{2i}^M g_{2i} g_{2i} g_{2i}$ $g_{2i} g_{2i} g_{2i} g_{2i}$ $g_{2i} g_{2i} g_{2i} g_{2i}$ $g_{2i+1}^M g_{2i+1} g_{2i+1} g_{2i+1}$ $g_{2i+1} g_{2i+1} g_{2i+1} g_{2i+1}$ $g_{2i+1} g_{2i+1} g_{2i+1} g_{2i+1}$], where g_{2i}^M and g_{2i+1}^M are the MSBs of the g_{2i} and g_{2i+1} binary representations, respectively. If the NSC_{us0} is odd, the 12 LSBs shall be padded by 0 (and ignored by the receiver).

Field 3 "Upstream g_i table, Band 1, FUS" contains the g_i values for every subcarrier in MEDLEYus for Band 1 of FUS. The same coding as for Field 2 "Upstream g_i table, Band 0, FUS" shall be used. If Band 1 is disabled in O-SIGNATURE message, this field shall be skipped.

Table 12-70 – O-PMD-NPSF-1 message

Field	Field name	Format
1	Message descriptor	Message code
2	Upstream gi table, Band 0, FDS)	3 ×ceiling(NSC_{us0}/2) bytes
3	Bit-loading table for data symbol during NOI (Band 0, FDS)	ceiling(NSC_{us0}/2) bytes
4	Upstream PCS-LCM parameters in NOI (Band 0, FDS)	One byte

Field 1 "Message descriptor" is a unique one-byte code ($0A_{16}$) that identifies the message. See Table 12-10 for a complete list of codes.

Field 2 "Upstream g_i table, Band 0, FDS" contains the g_i values for every subcarrier in MEDLEYus for Band 0 of FDS. The same coding as for Field 2 "Upstream g_i table, Band 0, FUS" in O-PMD-PSF-2 message shall be used.

Field 3 "Bit-loading table for data symbol during NOI (Band 0, FDS)" contains the b_i values for every subcarrier in MEDLEYus-0 to be used during FDS (if transmission line joints in FDX mode). The b_i shall indicate the number of bits to be mapped by the MTU-R to the subcarrier *i*. In case of PCS-LCM coding, the b_i indicates the modulation index ($m_i = b_i$).

The b_i shall only be defined for subcarriers from the MEDLEYus-0 set (as indicated in O-PRM message), and shall be sent in ascending order of subcarrier index *i*. The coding of the bi values shall be as defined in Field 2.

Field 5 "Upstream PCS-LCM parameters in NOI (only Band 0, FDS)" contains the upstream PCS-LCM parameters *Mc* and *P* in NOI symbols in FDS if only Band 0 is active. It is encoded as defined for field 14 of O-PMD-PSF-1.

12.3.4.2.8 R-PMD

The R-PMD message conveys the initial PMD parameter settings that shall be used in the downstream direction during the showtime. To increase robustness of communications, the message is sent in three parts, R-PMD-PSF-1 and R-PMD-NPSF-1.

The list of parameter settings carried by the R-PMD-PSF-1 message is shown in Table 12-71. These parameter settings relate to operation in PSF only (both TDD and FDX modes).

The list of parameter settings carried by the R-PMD-NPSF-1 message is shown in Table 12-72. It carries parameter settings related to NPSF (FDX mode). The R-PMD-NPSF-1 message supports operation in FDX mode and shall be skipped in case of operation in TDD mode and when Annex X is used.

Table 12-71 – R-PMD-PSF-1 message

Field	Field name	Format
1	Message descriptor	Message code
2	Bit-loading table for data symbol during NOI and DOI (Band 0, FDS)	ceiling(NSC_{ds0}/2) bytes
3	Number of RMC DS subcarriers ($NSCR_{ds}$)	Two bytes
4	Downstream RMC tone set (RTS_{ds})	2 × $NSCR_{ds}$ bytes coded as follows:
5	Bit-loading table for RMC DS subcarriers	ceiling($NSCR_{ds}$/2) bytes
6	Tone-ordering table	2 × (NSC_{ds0}+NSC_{ds1}) bytes
7	Showtime pilot tones	Tone descriptor
8	Initialization status	One byte
9	Downstream FRA sub-bands	Sub-band descriptor
10	Number of tones in downstream backup RMC tone set ($NSCR\text{-}b_{ds}$)	Two bytes
11	Backup downstream RMC tone set ($RTS\text{-}b_{ds}$)	2 × $NSCR\text{-}b_{ds}$ bytes
12	Backup bit-loading table for downstream RMC	ceiling($NSCR\text{-}b_{ds}$/2) bytes
13	Bit-loading table for data symbol during NOI and DOI (Band 1, FDS)	ceiling(NSC_{ds1}/2) bytes
14	Downstream PCS-LCM parameters in NOI (only Band 0, FDS)	One byte
15	Downstream PCS-LCM parameters in NOI (Band 0 and Band 1, FDS)	One byte

Field 1 "Message descriptor" is a unique one-byte code (89_{16}) that identifies the message. See Table 12-10 for a complete list of codes.

Field 2 "Bit-loading table for data symbol during NOI and DOI (Band 0, FDS)" contains the b_i values for every subcarrier in MEDLEYds of Band 0 (MEDLEYds-0). The b_i shall indicate the number of bits to be mapped by the MTU-O to subcarrier i. In case of PCS-LCM coding, the b_i indicates the modulation index ($m_i = b_i$).

The b_i shall only be defined for subcarriers from the MEDLEYds-0 set (as indicated in O-PRM message), and shall be sent in ascending order of subcarrier index i.

Each b_i value shall be coded as a 4-bit unsigned integer with valid range from 0 to 14. Pairs of b_i values shall be packed into bytes in the same way as in the bit-loading table field of O-PMD message (see Table 12-66).

Field 3 "Number of RMC DS subcarriers ($NSCR_{ds}$)" indicates the number of subcarriers assigned for downstream RMC symbol represented as an unsigned integer. The valid range is from 1 to 512.

Field 4 "Downstream RMC tone set (RTS_{ds})" indicates the indices of the subcarriers used to encode the RMC in the downstream direction. Each subcarrier index shall be coded as a 16-bit unsigned integer value. The first encoded value shall correspond to the lowest subcarrier used to encode the RMC. The remaining indices shall be sent in increasing frequency order. The subcarriers for RTS_{ds}

shall be selected from the MEDLEYds-0 set. The RTS_{ds} shall not include subcarriers in the frequency bands defined through the RMCCARMASKds in the DPU-MIB.

Field 5 "Bit-loading table for RMC DS subcarriers" contains the bit loading (the b_i value in case of TCM and the m_i value in case of PCS-LCM) for every subcarrier in the downstream RMC subcarrier set presented in field 4 of the R-PMD message. The values shall be sent in ascending order of subcarrier indices *i*. Each value shall be represented as a 4-bit unsigned integer. The valid values for b_i in case of TCM are 0 and all integers from 2 to 6, while in the case of PCS-LCM the valid values for m_i are all integers from 1 to 4.

Field 6 "Tone-ordering table" contains the tone-ordering table *t* for the downstream direction. The tone-ordering table contains the order in which the subcarriers shall be assigned bits in the downstream direction. The table shall include all subcarriers of the MEDLEYds set and only these subcarriers. Each subcarrier index shall be coded as a 16-bit unsigned integer value. The value of the first encoded index sent shall be equal to the index of the first entry in the tone-ordering table (*t*1, see clause 10.2.1.2). The remaining indices shall be sent in increasing order of the tone-ordering table *t* entries (*t*2, *t*3, ... $tNSC_{ds0+NCSds1}$).

Field 7 "Showtime pilot tones" indicates the selection of pilot tones that the MTU-R intends to use during the showtime. The field shall be formatted as a tone descriptor, as shown in Table 12-26.

The MTU-R shall only select a tone as a pilot tone if the bit loading for that tone, as given in the bit-loading table (field 2), is equal to zero. The showtime pilot tones shall be modulated as specified in clause 10.2.2.3. The total number of showtime pilot tones shall not exceed 16.

Field 8 "Initialization status":

If, within the constraints of the channel initialization policies defined in clause 12.3.7, the receiver is unable to select a set of values for the control parameters, the "Initialization success/failure code" indicates the initialization failure cause. If, within the constraints of the channel initialization policies defined in clause 12.3.7, the receiver is able to select a set of values for the control parameters, the "Initialization success/failure code" indicates the initialization success. Valid "Initialization success/failure codes" are as follows:

80_{16}: Initialization success;

81_{16}: Configuration error;

82_{16}: Configuration not feasible on transmission line;

00_{16}: Feature not supported.

Other values are reserved by the ITU-T.

If an initialization success/failure code 00_{16}, 81_{16} or 82_{16} is set:

– all values in fields 3, 4, 5 and 6 shall be set to 0; and

– the MTU-R shall return to L3 link state instead of L0 link state at the completion of the initialization procedures.

Field 9 "Downstream FRA sub-bands" contains the start and stop frequencies of the FRA sub-bands (see clause 13.3.1.1) for the downstream direction. It shall be formatted as a band descriptor (see Table 12-22) and shall specify up to eight contiguous sub-bands.

Field 10 "Number of tones in downstream backup RMC tone set ($NSCR\text{-}b_{ds}$)" indicates the number of subcarriers in the downsteam backup RTS expressed as unsigned integer.

Field 11 "Backup downstream RMC tone set ($RTS\text{-}b_{ds}$) "indicates the indices of the subcarriers used to encode the backup RMC in the downstream direction. Subcarrier indices shall be formatted and represented as defined in Field 4 of R-PMD. The $RTS\text{-}b_{ds}$ shall not include subcarriers in the frequency bands defined through the RMCCARMASKds in the DPU-MIB.

Field 12 "Backup bit-loading table for downstream RMC" contains the b_i values for every subcarrier in downstream backup RMC subcarrier set presented in Field 10. The b_i shall indicate the number of bits to be mapped by the MTU-O to the subcarrier *i*. The b_i values shall be represented and sent as defined in Field 5 of R-PMD message.

Field 13 "Bit-loading table for data symbol during NOI and DOI (Band 1, FDS)" contains the b_i values for every subcarrier in MEDLEYds-1 in DOI or NOI DTFO symbols (used only in FDS). The b_i shall indicate the number of bits to be mapped by the MTU-R to the subcarrier *i*. In case of PCS-LCM coding, the b_i indicates the modulation index ($m_i = b_i$).

The b_i shall only be defined for subcarriers from the MEDLEYds-1 set (as indicated in O-PRM message), and shall be sent in ascending order of subcarrier index *i*. The coding of the bi values shall be as defined in Field 2. This field shall not be present in the message if transmission line is not using DTFO.

Field 14 "Downstream PCS-LCM parameters in NOI (only Band0, FDS)" contains the downstream PCS-LCM parameters M_c and *P* in NOI symbols in FDS if only Band 0 is active. It is encoded as defined for field 17 of O-PMD.

Field 15 "Downstream PCS-LCM parameters in NOI (Band 0 and Band 1, FDS)" contains the downstream PCS-LCM parameters *Mc* and *P* encoded in NOI symbols in FDS if Band 0 and Band 1 are active. It is encoded as defined for field 17 of O-PMD.

Table 12-72 – R-PMD-NPSF-1 message

Field	Field name	Format
1	Message descriptor	Message code
2	Bit-loading table for data symbol during NOI (Band 0, FUS)	ceiling(NSC_{ds0}/2) bytes
3	Downstream PCS-LCM parameters in NOI (only Band 0, FUS)	One byte

Field 1 "Message descriptor" is a unique one-byte code (99_{16}) that identifies the message. See Table 12-8 for a complete list of codes.

Field 2 "Bit-loading table for data symbol during NOI (Band 0, FUS)" contains the b_i values for every subcarrier in MEDLEYds-0 to be used during FUS (if transmission line joints in FDX mode). The b_i shall indicate the number of bits to be mapped by the MTU-R to the subcarrier *i*. In case of PCS-LCM coding, the b_i indicates the modulation index ($m_i = b_i$).

The b_i shall only be defined for subcarriers from the MEDLEYds-0 set (as indicated in O-PRM message), and shall be sent in ascending order of subcarrier index *i*. The coding of the b_i values shall be as defined in Field 2.

Field 3 "Downstream PCS-LCM parameters in NOI (only Band 0, FUS)" contains the downstream PCS-LCM parameters M_c and *P* encoded in NOI symbols in FUS if Band 0 and Band 1 are active. It is encoded as defined for field 17 of O-PMD.

12.3.4.2.9 R-ACK 2

The O-ACK is a one-byte SOC message that acknowledges correct reception of the last component of the O-PMD message, which is O-PMD-NPSF-1 in case of FDX mode and O-PMD-PSF-2 in case of TDD mode. The format shall be as defined in Table 12-73.

Table 12-73 – R-ACK 2 message

Field	Field name	Format
1	Message descriptor	Message code

Field 1 "Message descriptor" is a unique one-byte code ($8A_{16}$) that identifies the message. See Table 12-10 for a complete list of codes.

12.3.4.3 Signals transmitted during the channel analysis and exchange phase

The initialization symbols of all signals transmitted during the channel analysis and exchange phase shall use only subcarriers from the MEDLEYds set in DTFO Band 0 only, except those assigned in O-SIGNATURE (DTFO Band 1 symbol assignment) to use subcarriers from both DTFO Band 0 and Band 1 in the downstream direction and subcarriers from the MEDLEYus set in DTFO Band 0 only, except those assigned in O-SIGNATURE (DTFO Band 1 symbol assignment) to use subcarriers from both DTFO Band 0 and Band 1 in the upstream direction, as determined during PARAMETER UPDATE stage of the channel discovery phase.

The downstream transmit PSD of all signals shall be MREFPSDds in both FDS and FUS, and the upstream transmit PSD shall be MREFPSDus in FUS and MREFPSD_NPus in FDS. The MREFPSDus shall comply to the MREFPSDMASKus and the MREFPSD_NPus shall comply to the MREFPSDMASK_NPus, as they were established at the end of the channel discovery phase. The MREFPSDds, and MREFPSDus, MREFPSD_NPus shall be applied starting from the symbol with index 0 of the first downstream logical frame and the first upstream logical frame, respectively, of the first superframe of the channel analysis and exchange phase. The values of CE, β_{us} and β_{ds} shall be those determined at the end of the ITU-T G.994.1 handshake phase and channel discovery phase. The valid values for MREFPSD_NPus are restricted to values such that at every subcarrier in the MEDLEYset the PSD in the NPSFs is lower than or equal to the PSD in the PSF, i.e., MREFPSD_NPus(f) ≤ MREFPSD_us(f) (see Note).

The MTU-O shall determine the MREFPSDds over all subcarriers of the SUPPORTEDCARRIERSGds set.

NOTE – This restriction makes sure that the aggregate receive power in NPSF is not higher than in the PSF. This avoids issues due to overloading of the AFE at the upstream receiver.

The Table 12-74 and 12-75 summarizes for each signals transmitted by the MTU-O and MTU-R, respectively: the PSD, the active subcarriers, the number and positions of initialization symbols, the PSD and active subcarriers of sync symbols.

Table 12-74 – Active subcarriers, PSD and active symbol positions of signals transmitted by the MTU-O during "Channel Analysis and Exchange" phase

Signal type (Note 8)	FDS, PSF					FUS, NPSF (Note 1)				
	Sync symbol (Note 6)		Initialization symbols			Sync symbol (Note 6)		Initialization symbols		
	PSD	Active subcarriers (Note 2)	PSD	Active subcarriers (Note 2)	Number active symbols (Note 3)	PSD	Active subcarriers (Note 2)	PSD	Active subcarriers (Note 2)	Number active symbols (Note 7)
O-P-MEDLEY, O-P-SYNCHRO 6	MREF PSDds	MEDLEYds	MREFPS Dds	MEDLEYds of DTFO Bands assigned during O-SIGNATURE	s_{ds}	MREFPSDd s	MEDLEYds	MREFPSDds	MEDLEYds of DTFO Bands assigned during O-SIGNATURE	$s_{ds,NPSF}$

NOTE 1 –The MTU-O shall transmit active symbols, including sync symbols, in FUS only if FDXC or FDXZ framing modes is used. Otherwise, the MTU-O shall transmit quiet in FUS.

NOTE 2 – Active subcarriers shall always exclude RFIBANDS and IARBANDS. In addition, active subcarriers of the NPSF shall always exclude subcarriers of the FDXMASK.

NOTE 3 – Active symbols in FDS shall be allocated from the first symbol of the logical frame, i.e from the position given by the RMC offset (D_{RMCds}). If the number of active symbols is greater than M_{ds}-D_{RMCds}, the remaining active symbols shall be allocated starting from the first symbol of the FDS frame. During the symbol positions of FDS not occupied by active symbols, the MTU-O shall transmit quiet signal.

NOTE 6 – The active subcarrier of the sync symbols shall include both DTFO Band 0 and Band 1.

NOTE 7 – Active symbols in FUS shall be allocated starting from the position determined by the upstream RMC offset (D_{RMCus}). If the number of active symbols s_{us} is greater than M_{us}-D_{RMCus}, the remaining active symbols (M_{us}-D_{RMCus}) shall be allocated starting from the first symbol of the following FUS sub-frame. During the symbol positions of FUS not occupied by active symbols, the MTU-O shall transmit quiet signal.

NOTE 8 – O-P-SYNCHRO X signals always use the same active subcarriers, the same PSD, and the same number of active symbols as the previously generated signal by the MTU-O.

Table 12-75 – Active subcarriers, PSD and active symbol positions of signals transmitted by the MTU-R during "Channel Analysis and Exchange" phase

Signal type	FDS, NPSF (Note 1)					FUS, PSF				
	Sync symbol (Note 5)		Initialization symbols			Sync symbol (Note 5)		Initialization symbols		
	PSD	Active subcarriers (Note 2)	PSD	Active subcarriers (Note 2)	Number active symbols (Note 3)	PSD	Active subcarriers (Note 2)	PSD	Active subcarriers (Note 2)	Number active symbols (Note 6)
R-P-MEDLEY	MREFPSD_NPus	MEDLEYGus	MREFPSD_NPus	MEDLEYus of DTFO bands assigned in O-SIGNATURE. Excepting the sub-carriers of TONEMASK_NPus	$s_{us,NPSF}$	MREFPSDus	MEDLEYus	MREFPSDus	MEDLEYus of DTFO bands assigned in O-SIGNATURE	s_{us}

NOTE 1 –The MTU-R shall transmit active symbols, including sync symbols, in FDS only if FDXC or FDXZ framing modes is used. Otherwise, the MTU-R shall transmit quiet FDS.

NOTE 2 – Active subcarriers shall always exclude RFIBANDS and IARBANDS. In addition, active subcarriers of the NPSF shall always exclude subcarriers of the FDXMASK.

NOTE 3 – Active symbols in FDS shall be allocated from the first symbol of the logical frame, i.e from the position given by the RMC offset (D_{RMCds}). If the number of active symbols is greater than M_{ds}-D_{RMCds}, the remaining active symbols shall be allocated starting from the first symbol of the FDS frame. During the symbol positions of FDS not occupied by active symbols, the MTU-R shall transmit quiet signal.

NOTE 5 – The active subcarrier of the sync symbols shall include both DTFO Band 0 and Band 1.

NOTE 6 – Active symbols in FUS shall be allocated from the position given by the upstream RMC offset (D_{RMCus}). If the number of active symbols is greater than M_{us}-D_{RMCus}, the remaining active symbols shall be allocated starting from the first symbol of the FUS frame. During the symbol positions of FUS not occupied by active symbols, the MTU-R shall transmit quiet signal.

12.3.4.3.1 O-P-MEDLEY

During transmission of the O-P-MEDLEY signal the MTU-O transmits to the MTU-R and receives from the MTU-R the SOC messages specified in clause 12.2.4.2 that carry relevant parameters, including generic parameters and parameters of the TPS-TC, PMS-TC and PMD in the aim to set or negotiate common values of these parameters at the MTU-O and MTU-R. The O-P-MEDLEY is also used by the MTU-R to estimate the downstream SNR. The SNR in the FDS may be estimated over the first $S_{ds\text{-}snr}$ symbol positions in the downstream logical frame. The SNR over FUS (if transmission line join in FDX mode) may be estimated over the MNDSNOI symbol positions in FUS. The SNR in Band 1 may be estimated over the symbols positions assigned in O-SIGNATURE (DTFO Band 1 symbol assignment).

The O-P-MEDLEY signal has the same structure as the O-P-PRM-UPDATE 2 signal. The sync symbols shall be generated and modulated by probe sequences as described in clause 10.2.2.1. The probe sequence modulating sync symbols shall be continued from the last stage of the channel discovery phase with no interruption. Sync symbols shall use all subcarriers of the MEDLEYds set, including DTFO Band 0 and Band 1.

The SOC shall be in its active state. SOC symbols shall use normal bit mapping (see clause 10.2.2.2.1). The SOC tone repetition rate p_{ds} shall be as determined during the channel discovery phase. The SOC symbol repetition rate shall be set to zero (no repetitions) and no IDS shall be applied. The SOC quadrant scrambler shall be kept in free running mode (see clause 10.2.2.5.2). The scrambler shall be initialized at the first SOC symbol of O-P-MEDLEY signal with the seed obtained during the ITU-T G.994.1 handshake and continued until the end of O-P-MEDLEY signal. The MTU-O shall transmit all SOC messages in RQ mode.

The initialization symbols of the O-P-MEDLEY signal shall use all subcarriers from the MEDLEYds set in DTFO Band 0 only, except those assigned in O-SIGNATURE (DTFO Band 1 symbol assignment) to use all subcarriers from the MEDLEYds set in both DTFO Band 0 and Band 1.

The MTU-O shall start transmission of the O-P-MEDLEY signal right upon completion of transmission of the O-P-SYNCHRO 5 signal, from symbol with index zero of the following downstream logical frame. From the start of the first superframe of the O-P-MEDLEY, the SOC shall transmit O-IDLE for the three subsequent superframes and then transmit the O-MSG 1 message. After receiving acknowledgement from the MTU-R (via R-MSG 2 message), the MTU-O sends O-TPS message. After O-TPS message is acknowledged by the MTU-R (via R-TPS), the MTU-O sends O-PMS message. After O-PMS message is acknowledged by MTU-R (via R-PMS message), the MTU-O and MTU-R exchange all valid components of O-PMD and R-PMD messages, respectively.

After the last component of O-PMD message has been acknowledged by the MTU-R (via R-ACK 2 message), the MTU-O completes the message exchange by transmitting six superframes of O-IDLE and further terminates the O-P-MEDLEY signal by sending the O-P-SYNCHRO 6 signal. The start time of O-P-SYNCHRO 6 signal transmission shall be at the symbol with index zero of the first downstream logical frame of a superframe.

12.3.4.3.2 O-P-SYNCHRO 6

The O-P-SYNCHRO 6 signal provides an exact time marker for transition from the channel analysis and exchange phase to showtime. The structure of O-P-SYNCHRO 6 signal shall be the same as O-P- MEDLEY signal. The signal shall have the same duration as O-P-SYNCHRO 1 signal. All initialization symbols shall carry inverted symbols containing SOC IDLE with normal bit mapping. During transmission of the O-P-SYNCHRO 6 signal, the SOC shall be inactive. The SOC quadrant scrambler shall be in free running mode. The IDS shall not be applied.

The sync symbols shall be generated and modulated by probe sequences as described in clause 10.2.2.1. Sync symbol shall be transmitted at all downstream sync symbol positions used in the O-P-MEDLEY 1 signal. The element of the probe sequence carried by the sync symbol of the O-P-SYNCHRO 6 signal shall continue the probe sequence transmitted during the O-P-MEDLEY signal with no interruption. Sync symbols shall use all subcarriers of the MEDLEYds set, including DTFO Band 0 and Band 1.

The initialization symbols of the O-P-SYNCHRO 6 signal shall use all subcarriers from the MEDLEYds set in DTFO Band 0 only, except those assigned in O-SIGNATURE (DTFO Band 1 symbol assignment) to use all subcarriers from the MEDLEYds set in both DTFO Band 0 and Band 1, all modulated as defined in clause 10.2.2.2.

12.3.4.3.3 R-P-MEDLEY

During transmission of the R-P-MEDLEY signal the MTU-R receives from the MTU-O and transmits to the MTU-O the SOC messages specified in clause 12.2.4.2 that are carrying the relevant parameters, including generic parameters and parameters of the TPS-TC, PMS-TC and PMD in the aim to set or to negotiate common values of these parameters at the MTU-O and MTU-R. The R-P-MEDLEY signal is also used by the MTU-O to estimate the upstream SNR. The SNR in the FUS may be estimated over the first $S_{us\text{-}snr}$ symbol positions in the upstream logical frame. The SNR over FDS (if transmission line join in FDX mode) may be estimated over the MNDSNOI symbol positions in FDS. The SNR in Band 1 may be estimated over the symbols positions assigned in O-SIGNATURE (DTFO Band 1 symbol assignment).

The R-P-MEDLEY signal has the same structure as the R-P- PRM-UPDATE 2 signal and shall consist of upstream sync symbols and initialization symbols.

The sync symbols shall be generated and modulated by probe sequences as described in clause 10.2.2.1. The probe sequence modulating sync symbols shall be continued from the last stage of the channel discovery phase with no interruption. Sync symbols shall use all subcarriers of the MEDLEYGus set, including DTFO Band 0 and Band 1.

The SOC shall be in its active state. SOC symbols shall use normal bit mapping (see clause 10.2.2.2.1) with the number of tone repetitions p_{us} determined during the channel discovery phase. The SOC symbol repetition rate shall be set to 0 (no repetitions) and no IDS shall be applied. The SOC quadrant scrambler shall be kept in free running mode. The scrambler shall be initialized at the first SOC symbol of R-P-MEDLEY with the seed obtained during the ITU-T G.994.1 handshake and continued until the end of R-P-MEDLEY signal. The MTU-R shall transmit all SOC messages in RQ mode.

The initialization symbols of the R-P-MEDLEY signal shall use all subcarriers from the MEDLEYus set in DTFO Band 0 only, except those assigned in O-SIGNATURE (DTFO Band 1 symbol assignment) to use all subcarriers from the MEDLEYus set in both DTFO Band 0 and Band 1.

The MTU-R shall start transmission of the R-P-MEDLEY signal after reception of the O-P-SYNCHRO 5 signal, from the symbol with index 0 of the upstream logical frame that follows the last symbol of O-P-SYNCHRO 5 signal. From the start of the first superframe of the R-P-MEDLEY signal, the SOC shall transmit O-IDLE until reception of the O-MSG 1 message. The MTU-R shall acknowledge O-MSG 1 message by sending R-MSG 2 message and wait for reception of O-TPS message. The MTU-R shall acknowledge the O-TPS message by sending a R-TPS message and shall then wait for reception of an O-PMS message. The MTU-R shall acknowledge the O-PMS message by sending a R-PMS message and shall then wait for reception of an O-PMD message.

The MTU-R shall acknowledge the O-PMD message by sending a R-PMD message and shall then wait for reception of an O-ACK message followed by an O-P-SYNCHRO 6 signal (transmitted six superframes after O-ACK). After reception of the O-P-SYNCHRO 6 signal, the MTU-R shall transition into showtime as described in clause 12.3.5.

12.3.5 Transition to Showtime

The MTU-O shall transition to showtime starting from the symbol with index 0 of the downstream logical frame immediately following the O-P-SYNCHRO 6 signal. The MTU-R shall transition to showtime one superframe after the MTU-O transitions to showtime, starting from the symbol with index 0 of the first upstream logical frame. Before that transition, the MTU-R shall send R-IDLE. All DTU's of the downstream logical frames of the first superframe following O-P-SYNCHRO 6 shall be dummy DTUs.

The baseline bit-loading table of the NOI of the first downstream logical frame in showtime, in both Band 0 and Band 1, shall be the one specified in R-PMD message. The baseline bit-loading table and the g_i values of the NOI of the first upstream logical frame in showtime, in both Band 0 and Band 1, shall be one specified in O-PMD message.

The baseline bit-loading table of the DOI of the first downstream logical frame and the first upstream logical frame in showtime shall be, respectively, the same as for NOI (both b_i and g_i values). Those baseline bit-loading tables shall be indicated with SRA configuration change count SCCC=0 in the RMC. The FRA adjustment "no adjustment" shall be applied on the baseline bit-loading tables in the first logical frame of showtime. This adjustment shall be referred with FRA configuration change count FCCC = 0.

The configuration of the first downstream logical frame in showtime shall be TTR_{ds}=s_{ds}, TA_{ds}=0, $TBUDGET_{ds}$=s_{ds} in TDD mode and TTR_{PSFds}=s_{ds}, TTR_{NPSFds}=$s_{ds\text{-}NPSF}$, TA_{ds}=0, $TDOI_{ds}$=0, TA_B1_{ds}=0, T_B1_{ds}=0, $TBUDGET_{ds}$=s_{ds}+$s_{ds\text{-}NPSF}$ in FDX mode (i.e., NOI only). Further, configurations of the downstream logical frame is indicated in the downstream RMC message of the previous downstream logical frame. The configuration of the first upstream logical frame in showtime shall be as specified in the downstream RMC messages of the first downstream logical frame in showtime. If no RMC messages are decoded correctly, the default value shall be TTR_{us}=s_{us}, TA_{us}=0, $TBUDGET_{us}$=s_{us} in TDD mode and TTR_{PSFus}=s_{us}, TTR_{NPSFus}=$s_{us\text{-}NPSF}$, TA_{us}=0, $TDOI_{us}$=0, TA_B1_{us}=0, T_B1_{us}=0, $TBUDGET_{us}$=s_{ds}+$s_{ds\text{-}NPSF}$ in FDX mode (i.e., NOI only).

The data symbols transmitted in the first showtime logical frame shall use only subcarriers from the MEDLEYds set in DTFO Band 0 only in the downstream direction and subcarriers from the MEDLEYus set in DTFO Band 0 only in the upstream direction, except symbol positions assigned in O-SIGNATURE (DTFO Band 1 symbol assignment) to use subcarriers from both DTFO Band 0 and Band 1.

The transmit PSD of the first showtime logical frame in the downstream and upstream directions shall be STPSDds and STPSDus, STPSD_NPus (if transmission line joined in FDX mode), respectively. The STPSDds and STPSDus in the first showtime logical frame in the downstream and upstream directions shall use the tss_i that was used during the channel analysis and exchange phase of initialization.

The STPSDds shall comply to the MREFPSDMASKds as specified in Table 7-4.

The STPSDus shall comply to the MREFPSDMASKus as specified in Table 7-4.

The STPSD_NPus shall comply to the MREFPSDMASK_NPus as specified in Table 7-4.

The transmit PSD may be further adjusted using the corresponding OLR procedures (see clauses 13.2.1.1 and 13.2.2.1).

The superframe count after transition into showtime and the probe sequences used during the initialization for sync symbols shall continue from initialization with no interruption.

12.3.5.1 Establishment of DOI

The establishment of the DOI after entering showtime shall be done either by an initial restoration of the DOI DTFO block in each direction by the DRA (see clause 10.7.3.2.3) or using the procedure described in this clause.

In the downstream, the establishment of DOI shall be in two steps:

1) The VCE/DRA initiates a TIGA procedure (see clause 13.2.2.1) with a TIGA command containing settings for the DOI (this TIGA command may or may not contain settings for the NOI as well).
2) After a successful completion of the TIGA procedure, transmission in the DOI may be enabled by the VCE/DRA by setting *TDOI*>0.

In the upstream, the establishment of DOI shall be in two steps:

1) The VCE/DRA initiates an SRA procedure (see clause 13.2.1.1) with an SRA command containing settings for the DOI (this SRA command may or may not contain settings for the NOI as well).
2) After a successful completion of the SRA procedure, transmission in the DOI may be enabled by the VCE/DRA by setting *TDOI*>0.

12.3.6 Alignment of initialization procedures of multiple joining lines (Informative)

The procedures and rules described in this clause do not concern interoperability between the MTU-O and MTU-R, but are necessary to ensure vectored operation of joining lines, including FEXT cancellation and minimum distortions in active lines during the joining of multiple transmission lines.

In case multiple transmission lines are joining to the vectored group, their initialization procedures should be aligned. First, the transmission line that completes the ITU-T G.994.1 handshake becomes a member of the joining group (joining line) or a member of the waiting group (waiting line) using the rules presented in clause 12.3.6.1. Further, the transmission line proceeds depending on the group it has been assigned to as described in the following clauses.

12.3.6.1 Joining group and waiting group (Informative)

The MTU-O of the transmission line that completes the ITU-T G.994.1 handshake, while in O-QUIET 1 stage, monitors the status of the joining group. If the joining group gets open after MTU-O transitions into O-QUIET 1, the MTU-O considers the transmission line being in the joining group, and terminates the O-QUIET 1 stage, and continues initialization procedure as defined in clause 12.3.2.

If the joining group is closed, the MTU-O is in the waiting group. The MTU-O stays in the waiting group and goes back to ITU-T G.994.1 handshake after the *CD_time_out_1* timeout is reached or by request of the VCE (in case the VCE does not expect the joining group to open during a relevant time).

The MTU-R, after entering the QUIET 1 stage, attempts to receive the O-P-CHANNEL-DISCOVERY 1-1 signal. If no reception of O-P-CHANNEL-DISCOVERY 1-1 signal occurs within *CD_time_out_1* timeout after the start of the QUIET 1 stage, the MTU-R goes back to the ITU-T G.994.1 handshake.

12.3.6.2 Alignment of the initialization procedures of multiple joining lines (Informative)

If the joining group contains multiple transmission lines, initialization procedures of all joining lines are aligned, while each MTU-O performs the initialization procedure with the peer MTU-R, as defined in clause 12.3.2. The alignment includes at least the following rules:

1) The VCE controls the start and the end of O-P-VECTOR 1 signal transmission in all joining lines. This is necessary to ensure that downstream FEXT into active lines is estimated when all joining lines transmit simultaneously. It's also beneficial if transmission of O-VECTOR 1 stage ends in all lines simultaneously.

2) If a special probe sequence is used, the VCE controls the entry to O-P-CHANNEL-DISCOVERY 1-1 signal of all joining lines. This is necessary to ensure that downstream direct channel of the joining lines are properly estimated.

3) Transmission of O-P-SYNCHRO 1-1 signal is simultaneous in all joining lines. This is necessary to synchronize IDS in all joining lines.

4) Transmission of O-P-SYNCHRO 1 signal is simultaneous in all joining lines. This is necessary to align R-P-VECTOR 1 signals in all lines to ensure that upstream FEXT between all lines is estimated when all joining lines transmit simultaneously.

5) Transmission of O-P-SYNCHRO 3 signal is simultaneous in all joining lines. This is necessary to align R-P-VECTOR 1-1 signals in all lines and ensure that upstream FEXT between all lines is estimated when all joining lines transmit simultaneously.

6) Transmission of O-P-SYNCHRO 4 signal is simultaneous in all joining lines. This is necessary to align O-P-VECTOR 2 signals in all lines to ensure that downstream FEXT into joining lines is estimated when all joining lines transmit simultaneously.

7) Transmission of O-P-SYNCHRO 4-1 signal is simultaneous in all joining lines. This is necessary to align downstream PSD updates in all active and joining lines after VECTOR 2 stage.

12.3.6.3 Alignment of the parameters of multiple joining lines (Informative)

The VCE configures the following parameters for all joining lines:

1) A CE length that is equal to the value assigned for the active lines,

2) A PDX frame that has a number of symbol periods (M_F) equal to the value assigned for the active lines,

3) The number of downstream symbol positions (M_{ds}) that is the same as the value assigned for the active lines in a PDX frame,

4) Seeds for the quadrant scrambler that are different for all lines,

5) An IDS length that is the same as the length assigned for the active lines, where each line gets a particular IDS value determined by the VCE,

6) The number of SOC symbol repetitions, R_S, that is the same for all joining lines,

7) The number of initialization data symbols in the downstream direction (s_{ds}) that is the same for all joining lines,

8) The positions of upstream and downstream RMC symbols that are equal to the values assigned for the active lines,

9) Superframe timing of all initializing lines that is aligned with the superframe timing of active lines, as described in clause 10.8.

12.3.7 Channel initialization policies

The method used by the receiver to select the values of transceiver parameters described in this clause is implementation dependent. However, within the limit of the net data rate achievable by the local PMD, the selected values shall meet all of the constraints communicated by the transmitter prior to the end of the Channel Analysis & Exchange phase, including:

- $ETR_0 \geq ETR\_min\_eoc$.
- $NDR \leq NDR\_max$.

- INP
  - at least against a combined threat of worst-case REIN impulses as described by the retransmission control parameters *INP_min_rein* and *iat_rein_flag* and of worst-case SHINE impulses as described by the retransmission control parameter *INP_min_shine*, and
  - within the latency bounds defined by the control parameter *delay_max_0*
  - within the minimum R_{FEC}/N_{FEC} ratio *rnratio_min*
- *SNRM* ≥ *TARSNRM*
- *SNRM_RMC* ≥ TARSNRM-RMC.

If within these constraints, the receiver is unable to select a set of values for the control parameters, then the transmitter shall enter the SILENT state instead of entering the showtime state at the completion of the initialization procedures.

Within those constraints, the receiver shall select the values for the control parameters so as to optimize in the priority specified by the channel-initialization policy (*CIpolicy*). The channel-initialization policy applies only for the selection of the values exchanged during initialization, and does not apply during the showtime.

The following channel-initialization policy is defined:

– Policy ZERO

If *CIpolicy* = 0, then:

For downstream,

1) Maximize the *NDR* until the limit of *NDR_max*

For upstream,

1) Maximize the *NDR* until the limit of *NDR_max*
2) Maximize *SNRM* until the limit of *MAXSNRM*
3) Minimize excess margin with respect to MAXSNRM through gain adjustments (see clause 10.2.1.4.2)

Support of *CIpolicy* = 0 is mandatory.

The *CIpolicy* parameter values other than 0 are reserved for use by the ITU-T.

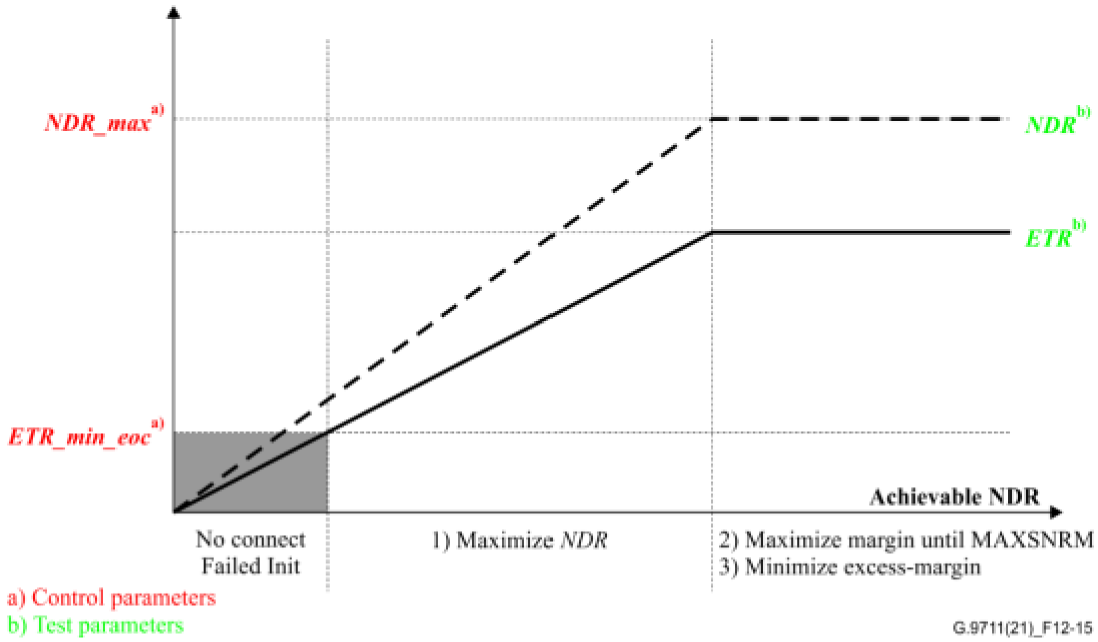


Figure 12-15 – Illustration of CIpolicy = 0

12.4 NT identification and authentication in P2MP operation

Figure 5-7a shows a separate path (consisting of a TPS-TC plus PMS-TC plus a share of the common PMD) is used for each NT. The DPU ME associates each path with an instance of the set of MGfast management objects. When an NT attempts to connect to the DPU, the DPU ME associates the NT to an already existing or newly created instance, based on NT identification (NT offering an identity to the DPU) during G.994.1 handshake. Once the MTU-O path and the connected MTU-R are both in showtime, the NT identity is verified through NT authentication (DPU verifying an NT identity) at Layer 2, see Annex A.

Each instance of the set of MGfast management objects includes the unique NT_ID of the associated NT. The NT_ID is 128-bits long and is determined by the NT vendor and hardcoded in the NT at production time. The NT_ID does not change with NT firmware updates.

NOTE 1 – Methods for generation of a unique NT_ID are described in [b-IETF RFC 4122]. These allow for the NT_ID to be based on (combinations or hash of) the MAC address, the serial number, the certificate, the timestamp, random numbers, etc.

To allow the DPU to associate an NT with a particular instance of the set of MGfast management objects, the NT sends the NT_ID during G.994.1 handshake (see Figure 12-16). If a single instance of the set of MGfast management objects exists in the DPU ME with the NT_ID presented by the NT during G.994.1 handshake and without a path in the MTU-O associated with this instance, then the DPU ME associates the NT with this instance. Otherwise, the DPU ME requests creation of a new instance, specifically for management of the new NT. This instance creation includes provisioning the DPU with the MGfast management objects for configuration of the new NT.

Once the DPU ME has associated the NT with a new or existing instance (during the G.994.1 handshake), the MTU-O creates a new MTU-O path (as shown in Figure 5-7a) which is also associated with this same instance. The MTU-O then starts initialization of the MTU-O path with the connected MTU-R in the NT. Through this instance, the DPU ME reports the management objects for the initialization and showtime of the MTU-O path and MTU-R.

Once the MTU-O path and connected MTU-R are both in showtime, the layer 1 connectivity between DPU and NT is established. If the operator has configured the Layer 2 to require IEEE 802.1X authentication, the DPU (as Authenticator) proceeds to authentication of the NT (i.e., verification of the NT_ID sent during G.994.1 handshake). The NT shall support IEEE802.1X authentication and at least the EAP-TLS authentication method as defined in [IETF RFC 5216]. The authentication protocol results in one of the authentication states "authenticated", "not authenticated" or "failed".

When an NT is not authenticated, the Layer 2 allows to pass only IEEE802.1X data, and drops other data sent to or from the NT. The MTU-O resources allocated to the NT may be limited, e.g., the bandwidth allocated by the DBR function or the number of symbols allocated by the DRA.

When an NT is authenticated, the Layer 2 allows to pass all data sent to or from the NT. The MTU-O resources allocated to the NT are intended to be optimized for best performance, e.g., the bandwidth allocated by the DBR function or the number of symbols allocated by the DRA.

NOTE 2 – NT authentication does not automatically imply the authorization of the service. Service authorization is usually the process to authenticate the subscriber. This may be based on login credentials or also on certificates. A full authorization would require subsequent NT identification, NT authentication and service authorization.

When authentication of an NT fails, e.g., after a vendor discretionary number of failed attempts to authenticate, the DPU requests the MTU-O to delete the path for the concerned NT. This is a policy decision out of the scope of this Recommendation.

When the MTU-O path returns to the O-SILENT state, the MTU-O shall delete the MTU-O path. Upon deletion of an MTU-O path, the DPU ME sets the associated instance's authentication state to "not authenticated".

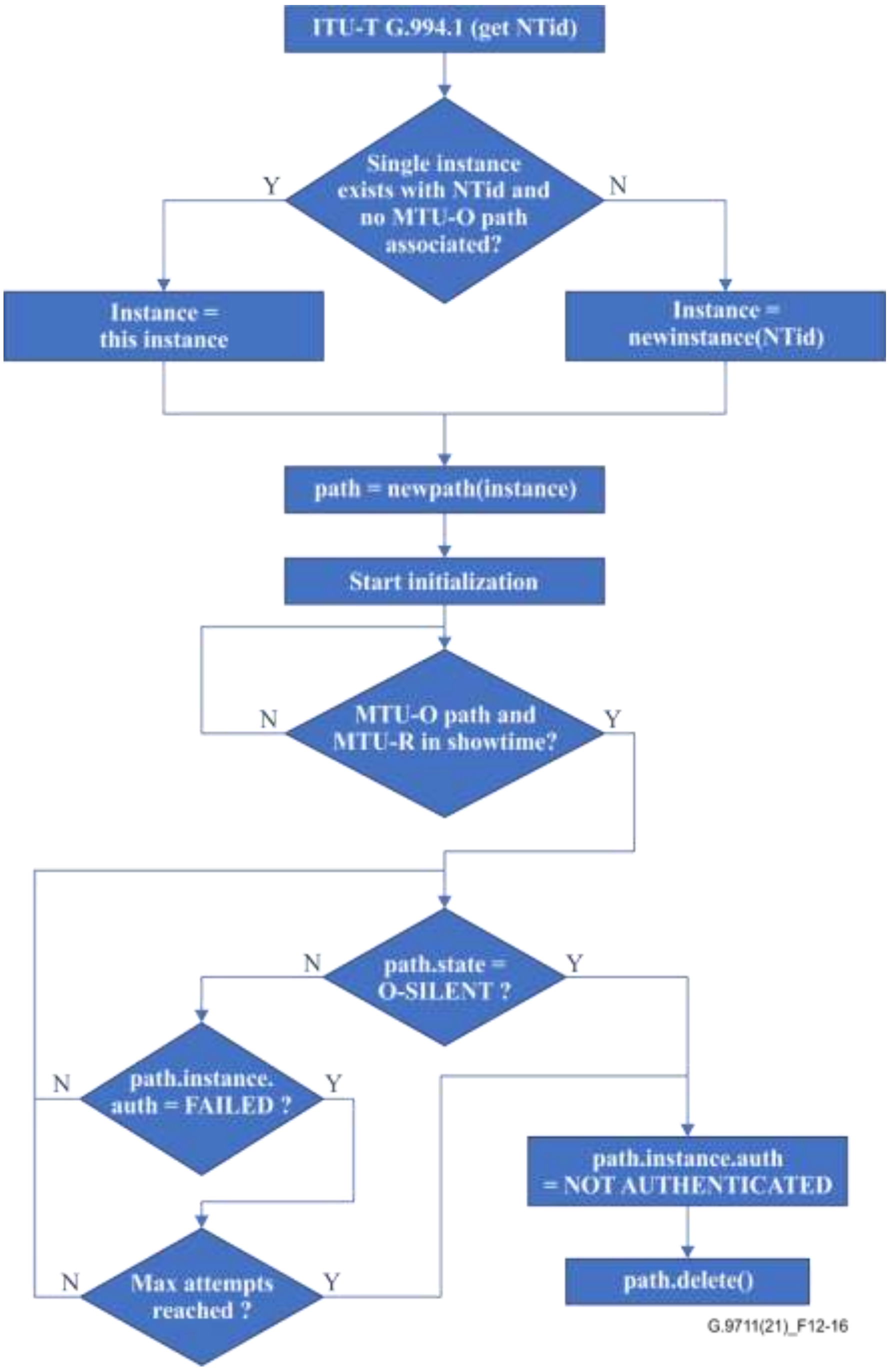


Figure 12-16 – NT identification and authentication

13 On-line reconfiguration (OLR)

13.1 Overview

13.1.1 Types of online reconfiguration

Types of OLR include seamless rate adaptation (SRA), bit swapping, transmitter initiated gain adjustment (TIGA), RMC parameter adjustment (RPA), fast rate adaptation (FRA), RMC recovery (RMCR), showtime sync symbol adaptation (SSA), showtime PSD adaptation (SPA) , and DBR.

Seamless rate adaptation (SRA) is used to reconfigure the *NDR* by modifying the bits or modulation index (b_i or m_i) and gains (g_i), the DTU size (parameters K_{FEC}, R_{FEC} and Q), and the PCS-LCM parameters (M_c and P), characterized by a change in the data frame parameters (B_{DR}, B_D). This SRA procedure is not applicable to the RMC. SRA is a mandatory capability. The procedures for SRA are defined in clause 13.2.1.1, and shall be implemented using OLR request types 1 and 2 eoc commands defined in Table 11-11.

Bit swapping is used to reallocate the bits and transmit power among the allowed subcarriers without changing the total number of data bytes loaded onto a data symbol, B_D. Bit swapping reconfigures the bits or modulation indices (b_i or m_i) and gains (g_i) without changing any other PMD or PMS-TC control parameters. Bit swapping is a mandatory capability. The procedure for bit swapping shall be implemented using OLR request types 1 and 2 eoc commands defined in Table 11-11. The bit swapping procedure is not applicable to the RMC tone set; a similar feature for the RMC tone set is implemented by using RPA.

Transmitter-initiated gain adjustment (TIGA) provides the VCE means to address changes in the downstream precoded direct channel gain (e.g., due to a change in the precoder). TIGA is a mandatory capability. The procedure for TIGA is defined in clause 13.2.2.1, and shall be implemented using the OLR request type 3 eoc command defined in Table 11-11.

RMC parameter adjustment (RPA) provides reconfiguration of the RMC parameters and shall be used to update the RMC tone set (*RTS*) and the bit loading for RMC subcarriers. RPA is a mandatory capability. The procedure for RPA is defined in clause 13.2.1.3, and shall be implemented using the OLR request type 4 eoc command defined in Table 11-11.

FRA provides fast adaptation of the bit rate. FRA changes the bits or modulation indices (b_i or m_i) of some groups of subcarriers (sub-bands). FRA is a mandatory capability. The procedure for FRA is defined in clause 13.3.1.1 using RMC commands defined in clause 9.6.4, and shall be implemented using RMC.

RMC recovery (RMCR) is used to recover the RMC when it fails in one or both transmission directions by using a backup *RTSBL* instead of the current one. RMCR is a mandatory capability. The RMCR procedure is defined in clause 13.3.1.2, and shall be implemented using the RMCR command defined in clause 9.6.4.

Showtime sync symbol adaptation (SSA) is used to update upstream sync symbol transmit gains (gi). SSA is a mandatory capability. The procedure of SSA is defined in clause 13.2.1.6, and shall be implemented using the eoc command defined in clause 11.2.2.24.

Showtime PSD adaptation (SPA) is used to request an adaptation of the MREFPSD value in the upstream NPSF (MREFPSD_NPus). SPA is a mandatory capability. The procedure of SPA is defined in 13.2.1.4. The preparation part of the procedure (SPA-PREP) shall be implemented using the eoc command defined in clause 11.2.2.21, while the adaptation part (SPA-SRA) of the procedure shall be implemented using the OLR request type 2 eoc command defined in Table 11-11.

DBR provides the DRA jointly with the VCE means to address changes in the operation frequency bands of the MTU-Rs in the P2MP group. DBR is a mandatory capability. The procedure for DBR is defined in clause 13.5, and shall be implemented using the eoc command defined in clause 11.2.2.22 and 11.2.2.23.

13.1.2 Types of bit-loading tables

A bit-loading table contains either the values of the bit loading b_i in case of TCM or the values of the modulation index m_i in case of PCS-LCM.

Per PDX sub-frame and operation interval, the following two bit-loading tables are defined for OLR purposes:

1) Baseline (reference) bit-loading table(s);
2) Active bit-loading table.

The symbol encoder (see clause 10.2) shall only use the active bit-loading table for encoding symbols. The baseline bit-loading table serves as a reference to construct the active bit-loading table. The active bit-loading table on subcarriers carrying data bits in both data symbols and RMC symbols shall be constructed by applying adjustments to the given baseline bit-loading table communicated via RMC (see clause 9.6.4, Receiver initiated FRA request command). The active bit-loading table on subcarriers belonging to RTS in RMC symbols shall use the b_{RMC} values. These adjustments to construct the active bit-loading table shall not change the baseline bit-loading table.

The baseline bit-loading table(s) shall only be updated via SRA, bit swapping or TIGA procedures. After a baseline bit-loading table update, the active bit-loading table shall be equal to the current baseline bit-loading table unless an adjustment is applied through an FRA procedure. The baseline bit-loading table may be again modified through an SRA, bit swapping or TIGA procedure.

The RTS and corresponding b_{RMC} values are updated via RPA and RMCR procedures (see Table 13.1).

13.1.3 Summary of OLR types

Table 13-1 includes a summary of the different OLR types and their relations with the different management channels and bit-loading types:

Table 13-1 – Summary of OLR types

OLR type	eoc-based OLR			RMC-based OLR		Bit-loading table affected
	Receiver initiated	**Transmitter initiated**	**DRA/VCE initiated**	**Receiver initiated**	**Transmitter initiated**	
SRA	√	–	–	–	–	Baseline
Bit swapping	√	–	–	–	–	Baseline
TIGA	–	√ (MTU-O only)	√	–	–	Baseline
RPA	√	–	–	–	–	Active
FRA	–	–	–	√	For further study	Active
RMCR	–	–	–	√	–	Active
DBR	–	–	√ (MTU-O only)	–	–	Baseline
SSA	√ (MTU-O only)	–	–	–	–	N/A
SPA	√ (MTU-O only)	–	–	–	–	Baseline
DCMU	–	–	√ (MTU-O only)	–	–	N/A

13.2 Eoc-based procedures

13.2.1 Receiver initiated procedures

Upon sending a receiver initiated OLR command, the initiator shall await a response. The OLR response may be an RMC command indicating when the reconfiguration requested by the OLR command shall take effect (see clause 13.2.1.1.5 for details and timing for SRA and clause 13.2.1.2.3 for bit swapping), or an eoc response indicating when the reconfiguration shall take place (see clause 13.2.1.3.3 for RPA) or a combination of the above (depending upon the OLR type), or an eoc response deferring or rejecting the reconfiguration. If the initiator receives an eoc response to defer or reject the reconfiguration, it shall abandon the last requested OLR command. A new OLR command may be initiated immediately, with the exception of reason code "wait", as defined in Table 11-23, for which initiation of a new eoc-based OLR procedure shall be deferred for at least

1 second.

Upon reception of a receiver initiated OLR command, the responder shall send either an OLR response to defer or to reject the reconfiguration, or an indication when the reconfiguration shall take effect (see clause 13.2.1.1.5 for details and timing for SRA and clause 13.2.1.3.3 for RPA). After sending the response, the responder shall reconfigure the affected PMD, PMS-TC and TPS-TC functions. The responder may defer or reject the OLR request; in this case it shall supply a reason code from those specified in Table 11-23.

An MTU receiver shall initiate an SRA when the conditions in clause 13.2.1.1.3 or clause 13.2.1.1.4 are satisfied.

An MTU receiver shall initiate bit swapping when the conditions in clause 13.2.1.2.2 are satisfied.

An MTU receiver shall initiate a RPA when the conditions in clause 13.2.1.3 are satisfied.

An MTU receiver shall only send OLR request commands that meet all of following constraints:

– INP
  - at least against a combined threat of worst-case REIN impulses as described by the retransmission control parameters *INP_min_rein* and *iat_rein_flag* and of worst-case SHINE impulses as described by the retransmission control parameter *INP_min_shine*, and
  - within the latency bounds defined by the control parameter *delay_max_0*
  - within the minimum R_{FEC}/N_{FEC} ratio *rnratio_min*

– Net Data Rate $NDR \leq NDR\_max$

13.2.1.1 SRA procedures

13.2.1.1.1 Parameters controlled by the SRA procedures

13.2.1.1.1.1 Parameters controlled by autonomous SRA in downstream

The SRA is accomplished by a coordinated change of the PMD parameters described in Table 13-2.

Table 13-2 – PMD parameters in autonomous SRA request in downstream

Parameter	Definition
d_SRA	Delta gain change in the MTU-O transmitter requested by the MTU-R. This parameter is a frequency independent real scalar. Valid values are $0.5 \leq d\_SRA \leq 1$ (see clause 11.2.2.5).
b_i	The actual number of bits per subcarrier for the baseline bit-loading table requested by the MTU-R. Valid values are all integers in the [0, MTU-O maximum bit loading] range, and with $b_i \leq$ the b_i values requested in the last TIGA message. "MTU-O maximum bit loading" is a capability indicated by the MTU-O during initialization in the O-MSG 1 message.
m_i	The actual modulation index per subcarrier for the baseline bit-loading table requested by the MTU-R. Valid values are all integers in the [0, MTU-O maximum bit loading] range, and with $m_i \leq$ the m_i values requested in the last TIGA message. "MTU-O maximum bit loading" is a capability indicated by the MTU-O during initialization in the O-MSG 1 message.
M_c *and P*	The actual circulant matrix size and the number of puncturing bits of the PCS-LCM code requested by the MTU-R. The valid values are specified in clause 10.2.1.3.5.1.

Autonomous SRA in downstream without change in d_SRA may be implemented using OLR request type 1 or 2. Autonomous SRA in downstream with change in d_SRA shall be implemented using OLR request type 1.

To implement the SRA, the MTU-R shall multiply its current settings of the gain stage in the receiver, for any subcarrier with g_i >0, by the value:

$$1/d\_SRA$$

The timing to apply SRA is specified in clause 13.2.1.1.5.

Both the receiver and the transmitter shall support all valid b_i and m_i values and shall support any change of these values provided the resulting b_i or m_i value is within the specified valid range.

SRA is accomplished by a change of the following PMS-TC parameters: B_D, B_{DR}, K_{FEC}, R_{FEC} and Q (see Table 9-2). If SRA is performed for any PDX sub-frame and operational interval, the values of K_{FEC}, R_{FEC} and Q shall be set the same for all PDX sub-frame and operational interval, i.e., the values of K_{FEC}, R_{FEC} and Q shall be equal for NOI_{PSF}, DOI_{PSF} and NOI_{NPSF}.

NOTE – Since a single set of values for K_{FEC}, R_{FEC} and Q is selected for NOI_{PSF}, DOI_{PSF} and NOI_{NPSF} (except for RRC symbols where B_D=0), this set needs to satisfy the requirement specified in clause 8.2 ($0.25 \leq (N_{DTU}+Q \times R_{FEC})/B_D \leq 4$) for NOI_{PSF} with Band 0 active ($B_D=B_{DN0}$), NOI_{PSF} with Band 0 and Band 1 active ($B_D=B_{DN01}$), DOI_{PSF} and NOI_{NPSF}.

13.2.1.1.1.2 Parameters controlled by autonomous SRA in upstream

The SRA is accomplished by a coordinated change of the PMD parameters described in Table 13-3.

Table 13-3 – PMD parameters in autonomous SRA request in upstream

Parameter	Definition
b_i	The actual number of bits per subcarrier for the baseline bit-loading table requested by the MTU-O. Valid values are all integers in the [0, MTU-R maximum bit loading] range. "MTU-R maximum bit loading" is a capability indicated by the MTU-R during initialization in the R-MSG 2 message.
g_i	The actual value of the gain adjuster, gi, per sub-carrier requested by the MTU-O. The valid values are specified in clause 10.2.1.4.2.
m_i	The actual modulation index per subcarrier for the baseline bit-loading table requested by the MTU-O. Valid values are all integers in the [0, MTU-R maximum bit loading] range. "MTU-R maximum bit loading" is a capability indicated by the MTU-R during initialization in the R-MSG 2 message.
M_c *and P*	The actual circulant matrix size and the number of puncturing bits of the PCS-LCM code requested by the MTU-O. The valid values are specified in clause 10.2.1.3.5.1.

Autonomous SRA in upstream without change in g_i may be implemented using OLR request type 1 or 2. Autonomous SRA in upstream with change in g_i shall be implemented using OLR request type 2.

Both the receiver and the transmitter shall support all valid b_i and m_i values and shall support any change of these values provided the resulting b_i or m_i value is within the specified valid range.

SRA is accomplished by a change of the following PMS-TC parameters: B_D, B_{DR}, K_{FEC}, R_{FEC} and Q (see Table 9-2). If SRA is performed for any PDX sub-frame and operational interval, the values of K_{FEC}, R_{FEC} and Q shall be set the same for all PDX sub-frame and operational interval, i.e., the values of K_{FEC}, R_{FEC} and Q shall be equal for NOI_{PSF}, DOI_{PSF} and NOI_{NPSF}.

NOTE – Since a single set of values for K_{FEC}, R_{FEC} and Q is selected for NOI_{PSF}, DOI_{PSF} and NOI_{NPSF} (except for RRC symbols where B_D=0), this set needs to satisfy the requirement specified in clause 8.2 ($0.25 \le (N_{DTU}+Q\times R_{FEC})/B_D \le 4$) for NOI_{PSF} with Band 0 active ($B_D=B_{DN0}$), NOI_{PSF} with Band 0 and Band 1 active ($B_D=B_{DN01}$), DOI_{PSF} and NOI_{NPSF}.

13.2.1.1.2 Parameters controlling the SRA procedures

The list of parameters controlling SRA procedures is presented in Table 13-4.

Table 13-4 – Parameters controlling the SRA procedures

Parameter	Definition
RA-USNRM *RA-UTIME* (Note)	The rate adaptation upshift SNR margin and time interval. These parameters define the interval of time the SNR margin should stay above the upshift SNR margin before the MTU shall attempt to increase the net data rate (see clause 13.2.1.1.4). The parameter can be different for the MTU-O (*RA-USNRMus* and *RA-UTIMEus*) and the MTU-R (*RA-UTIMEds*, *RA-USNRMds*). MTU-O: Configured through the DPU-MIB. MTU-R: Configured through the DPU-MIB and communicated to the MTU-R during initialization (O-MSG 1 message). The valid values for *RA-USNRMus* and *RA-USNRMds* are values from zero to 31.0 dB in steps of 0.1 dB. The valid values for *RA-UTIMEus* and *RA-UTIMEds* are values from 0 to 16 383 s in steps of 1 second.
RA-DSNRM *RA-DTIME* (Note)	The rate adaptation downshift SNR margin and time interval. These parameters define the interval of time the SNR margin should stay below the downshift SNR margin before the MTU shall attempt to decrease the net data rate (see clause 13.2.1.1.3). The parameter can be different for the MTU-O (*RA-DSNRMus* and *RA-DTIMEus*) and the MTU-R (*RA-DTIMEds*, *RA-DSNRMds*). MTU-O: Configured through the DPU-MIB. MTU-R: Configured through the DPU-MIB and communicated to the MTU-R during initialization (O-MSG 1 message). The valid values for *RA-DSNRMus* and *RA-DSNRMds* are values from 0 to 31.0 dB in steps of 0.1 dB. The valid values for *RA-DTIMEus* and *RA-DTIMEds* are values from 0 to 16 383 s in steps of 1 second.
NOTE – The parameters RA-USNRM and RA-DSNRM shall relate to the baseline bit-loading table. They have the same values as the DPU-MIB SRA-USNRM and SRA-DSNRM configuration parameters, respectively.	

13.2.1.1.3 SRA downshift procedure

If the SNR margin is below the downshift SNR margin (*RA-DSNRM*) and stays below that for more than the time specified by the minimum downshift rate adaptation interval (*RA-DTIME*), the MTU shall attempt to decrease the net data rate, such that the SNR margin is increased to a level higher than or equal to *RA-DSNRM* + 1 dB (see Figure 13-1a).

The SNR margin and downshift SNR margin here both relate to the baseline bit-loading table, i.e., the SNR margin shall be calculated under the assumption that the active bit-loading table is identical to the baseline bit-loading table.

In some cases, an SRA may be triggered without waiting for *RA-DTIME* and regardless of *RA-DSNRM*, e.g., if the active bit-loading table is different than the baseline bit-loading table after an FRA.

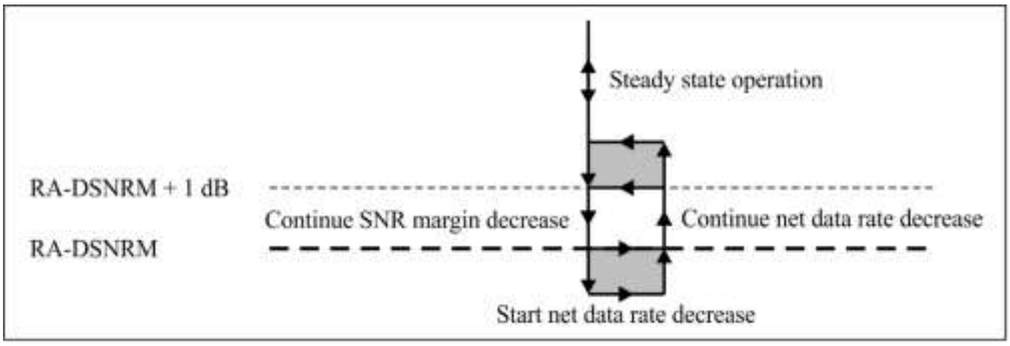


Figure 13-1a – SRA downshift procedure

13.2.1.1.4 SRA upshift procedure

If the SNR margin is above the upshift SNR margin (*RA-USNRM*) and stays above that for more than the time specified by the minimum upshift rate adaptation interval (*RA-UTIME*), the MTU shall attempt to increase the net data rate, such that the SNR margin is decreased to a level lower than or equal to *RA-USNRM* – 1 dB (see Figure 13-1b).

The SNR margin and upshift SNR margin here both relate to the baseline bit-loading table, i.e., the SNR margin shall be calculated under the assumption that the active bit-loading table is identical to the baseline bit-loading table.

In some cases, an SRA may be triggered without waiting for *RA-UTIME* and regardless of *RA-USNRM,* e.g., if the active bit-loading table is different than the baseline bit-loading table after an FRA.

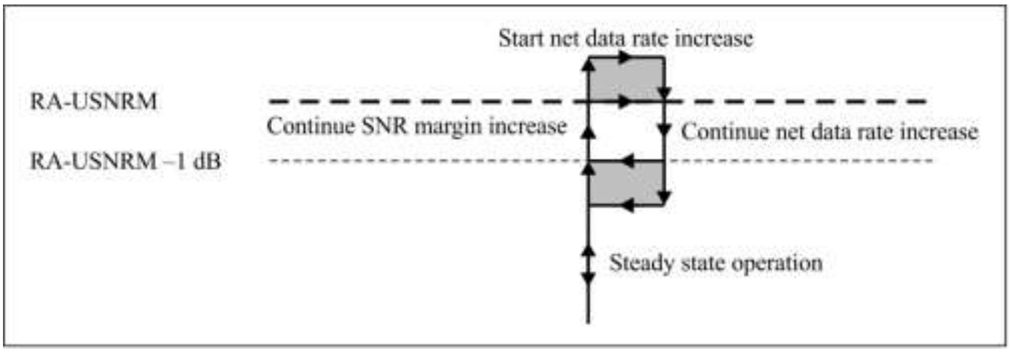


Figure 13-1b – SRA upshift procedure

13.2.1.1.5 Timing and synchronization for SRA

Update of the baseline bit-loading tables at the MTU-O and MTU-R requested via OLR requests types 1, 2 or 3 is synchronized by the associated RMC reply (SRA-R command, see Table 9-15).

Two counts shall be used to maintain synchronization between the configurations imposed by SRA (see clause 13.2.1.1.1) at the transmitter and the receiver ends:

1) The 4-bit SRA configuration change count (SCCC) is used to identify the particular configuration to be used. The SRA configuration change count shall be incremented by one whenever a new configuration change is initiated by the receiver and wrap around at count 1100_2, i.e., incrementing from 1100 to 0000, avoiding values 1101 through 1111, which are special values reserved for the TIGA procedure (see clause 13.2.2.1). In this way, the value of SCCC serves as a unique identifier for the configuration to be used.

   The SCCC shall only be incremented by the receiver.

The SCCC is incremented separately for the NOI_{PSF}, DOI_{PSF} and NOI_{NPSF} baseline bit-loading tables.

2) The 4-bit SRA superframe down count (SFDC) is used to indicate when a new configuration shall take effect. SFDC shall be decremented in the first RMC symbol of every superframe until reaching the value zero, which indicates the activation time of the new configuration. The decremented value shall be repeated in all subsequent RMC symbols of the respective superframe. The *d_SRA* scaling factor and new b_i or m_i, g_i, B_D, B_{DR}, M_c and P settings shall take effect at the RMC symbol of the first logical frame of the superframe for which the expected SFDC is 0. The new DTU setting (K_{FEC}, R_{FEC}, Q) shall take effect at the first DTU following the application of the new b_i or m_i. Figure 13-2 depicts the timing of the SRA transition.

The MTU that sends the RMC SRA-R command shall monitor the acknowledgement to this RMC command as received from the far end via the RMC (RMC ACK bit, see Table 9-5 and Table 9-8). If none of the RMC messages carrying the SRA-R command was acknowledged, upon reaching SFDC=0, the MTU shall continue transmitting the same SRA-R command using SFDC=0 until the SRA-R command is acknowledged for the first time. After acknowledgement is received, the MTU shall consider the procedure complete.

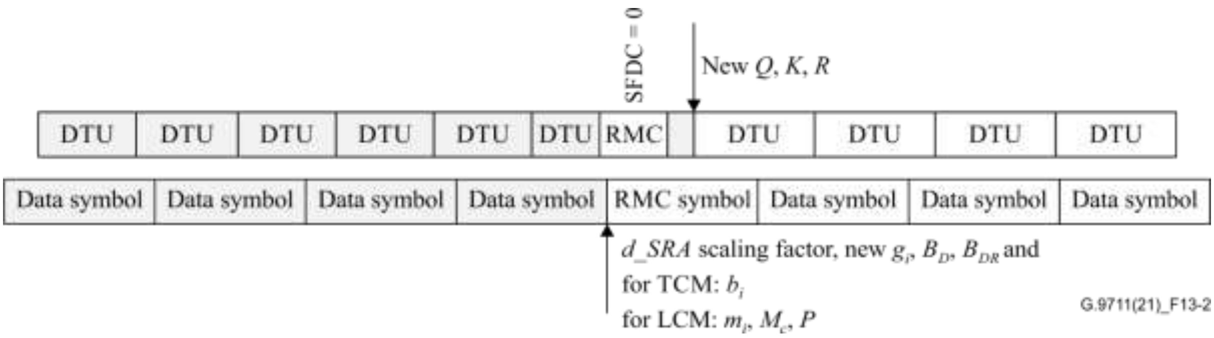


Figure 13-2 – Timing diagram of SRA transition

The receiver shall not initiate a new SRA procedure until the ongoing procedure, if any, has completed successfully or has failed due to rejection or has timed-out.

The timeout for OLR request (high priority command) is specified in Table 11-3. This timeout serves for both the eoc response (see Table 11-22) and the RMC response (SRA-R). If the sourcing MTU has not received SRA-R during this timeout and it has received at least the last RMC prior to expiration of this timeout with errors, the sourcing MTU shall wait an additional 100 ms for SRA-R before initiating another SRA request.

NOTE 1 – The response time of the MTU needs to take into account that, assuming no errors, the SRA-R should be received by the sourcing MTU at least once during the 50 ms timeout specified in Table 11-3.

The rules for repeating SRA requests are specified in clause 11.2.1.3. However, if the receiver extended the timeout by the additional 100 ms as specified above, it shall also not repeat the SRA request in this extended timeout. All SRA requests relating to a given PDX sub-frame and operation interval (NOI_{PSF}, DOI_{PSF} or NOI_{NPSF}) with the same SCCC count shall be considered identical. The transmitter shall discard requests with SCCC equal to or lower than the one currently in use, taking SCCC wraparound into account.

NOTE 2 – A response to an SRA request with reason code "busy" may indicate that the responding MTU is unable to initiate the requested SRA due to it being busy with an ongoing FRA countdown (see clause 13.3.1.1).

The range of valid initial values of SFDC shall be from 4 to 15.

13.2.1.1.6 Retransmission of DTUs across SRA transitions

Retransmissions of erroneous DTUs shall be supported across the SRA transition, by re-framing with the new DTU control parameters the data and/or management frame(s) previously transmitted with the old DTU parameters. This shall take place as follow:

– In case of DTU size increase, the transmitter shall construct the new DTU by either including an idle frame at the end of the data or management frames previously sent in the original DTU, or by extending the idle frame already present in the original DTU. An example of DTU size increase with the retransmission of two DTUs after the transition is depicted in the Figure 13-3a.

– In case of DTU size decrease, the transmitter shall insure that, during a time interval equal to the configured *delay_max_0* parameter preceding the DTU size change, all DTUs sent according to the old control parameters end with an idle frame whose size is at least equal to the difference between the new and old DTU sizes. Any of those DTUs that would need to be retransmitted after the DTU size decrease shall be constructed by truncating bytes of the idle frame of the original DTU to fit into the new DTU size. The ECS of the new DTU shall be calculated. An example of DTU size decrease with the retransmission of one DTU after the transition is depicted in the Figure 13-3b.

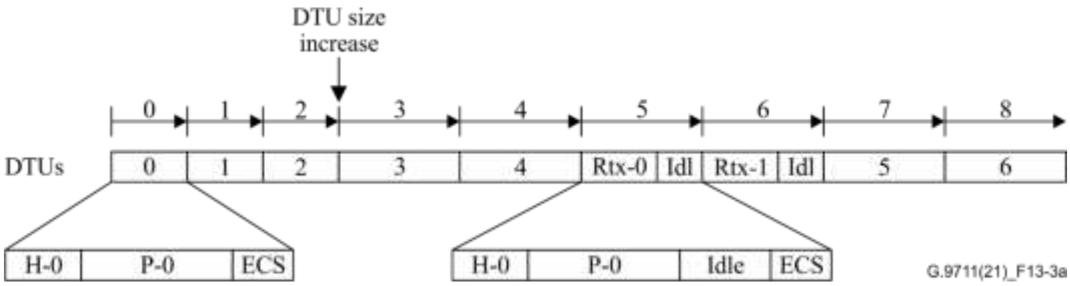


Figure 13-3a – Example of mapping of retransmitted DTU 0 and DTU 1 of old DTU size into a larger new DTU size

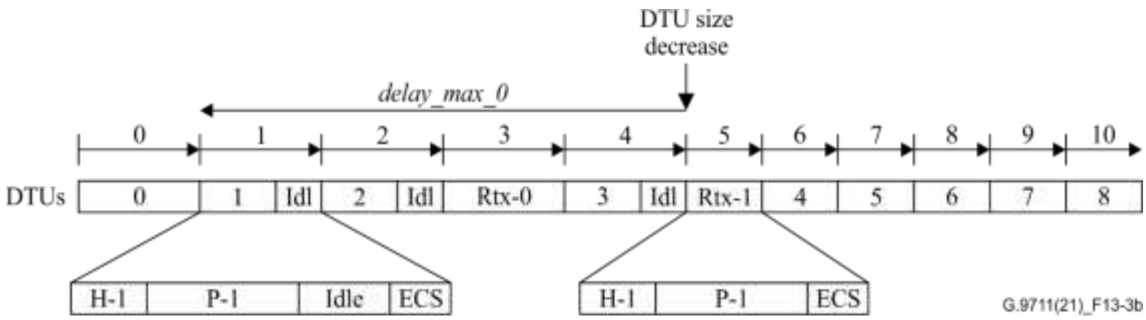


Figure 13-3b – Example of mapping of retransmitted and new DTU during the transition time of *delay_max_0*

13.2.1.2 Bit swapping procedure

13.2.1.2.1 Parameters controlled by bit swapping procedure

Bitswapping in downstream may be implemented using OLR request type 1 or 2. Bitswapping in upstream without change in g_i may be implemented using OLR request type 1 or 2. Bitswapping in upstream with change in g_i shall be implemented using OLR request type 2.

Bit swapping is accomplished by a coordinated change to the bits or modulation indices and gain values on the number of subcarriers in the baseline table. The details on formatting of bits or modulation indices and gains parameters are described in Table 13-3.

Both the receiver and the transmitter shall support any change of the b_i, m_i and g_i values, provided these values are within the specified valid range and the following constraints are met:

– The settings for the DTU (K_{FEC}, R_{FEC}, Q) shall remain unchanged;

– The B_D value shall remain unchanged whilst the setting of B_{DR} may change;

– The PCS-LCM parameters (Mc, P) shall remain unchanged.

NOTE 1 – The *ETR*, *NDR* and DPR may change with bit swapping, in the case the bit swapping changes the B_{DR}.

NOTE 2 – Due to change of B_{DR}, the *NDR* may change up to a value of 512 (subcarriers) × 12 bits / T_F. For example, for T_F = 750 µsec, this corresponds to 8.192 Mbit/s.

13.2.1.2.2 Bit swapping procedure

When the value of the SNR on particular subcarriers in the MTU drops below a vendor discretionary threshold, while the SNRM is still above the value of the downshift SNR margin (*RA-DSNRM*), the MTU shall initiate a bit swapping procedure. The SNR and the SNRM shall both be calculated under the assumption that the active bit-loading table is identical to the baseline bit-loading table.

The procedure comprises the following steps:

– The initiating MTU computes the set of b_i/m_i and g_i values (or only b_i/m_i values if modification of g_i is not applicable) that is necessary to resolve the drop of the SNR.

– The initiating MTU sends an OLR command of OLR request type 1 or type 2 (depending on whether both b_i/m_i and g_i need to be modified or the modification is for b_i/m_i only) that includes the new values of b_i/m_i and g_i together with the appropriate value of SCCC. The setting of the SCCC shall be as defined in clause 13.2.1.1.5.

– After sending the OLR command of OLR request type 1 or OLR request type 2, the initiating MTU shall wait for an SRA-R RMC command from the responding MTU, indicating the time of parameter modification.

– Upon reception of an OLR command of OLR request type 1 or OLR request type 2, the responding MTU shall either send an SRA-R RMC command or a valid eoc response (as defined in Table 11-22) to reject or defer the command.

13.2.1.2.3 Timing and synchronization for bit swapping

Timing and synchronization for bit swapping shall be maintained using the SCCC and SFDC, as defined in clause 13.2.1.1.5. The new b_i/m_i, g_i setting shall take effect at the RMC symbol of the first logical frame of the superframe for which the expected SFDC is 0 (see clause 13.2.1.1.5).

13.2.1.3 RPA procedure

The RPA procedure described in this clause is used to modify one or more parameters of the RMC channel defined in clause 13.2.1.3.2. With PCS-LCM, a modification of RMC parameters can modify the baseline bit-loading table as specified in clause 13.2.1.3.2.

If the RMCR procedure is disabled through the DPU-MIB (i.e., *rmcr_lor_trigger* = 0), the MTU shall initiate the RPA procedure when at least one of the following conditions (RPA-conditions) is met:

– The SNR margin of the RMC (SNRM-RMC) has dropped below the minimum threshold (MINSNRM-RMC) specified in the DPU-MIB;

– a *lor* defect has occurred (see clause 11.3.1.3).

If the RMCR procedure is enabled through the DPU-MIB (i.e., *rmcr_lor_trigger* > 0), the MTU shall initiate the RPA procedure when the following condition (RPA-condition) is met:

– The SNR margin of the RMC (*SNRM-RMC*) has dropped below the minimum threshold (MINSNRM-RMC) specified in the DPU-MIB.

In addition to the above cases for initiating the RPA procedure, the MTU may initiate the RPA procedure based on vendor-discretionary criteria regardless of whether the RMCR procedure is enabled or not. Examples for such conditions are:

– The SNR of the RMC has improved, allowing the usage of higher bit loading for the RMC;

– The SNR value on a particular subcarrier drops below a vendor discretionary threshold.

The RPA procedure initiated from the MTU-O and MTU-R is the same and shall include the following steps.

- Upon detection of RPA-conditions in the received RMC, the MTU receiver shall identify the new RMC parameters (see Table 13-6) and initiate the RPA procedure by sending an OLR command of OLR request type 4 (Update RMC parameters, see Table 11-11) via the eoc that indicates, for the receive direction:
  – the list of new RMC parameter values (new configuration);
  – the superframe count on which the new RMC parameters shall take effect. The minimum superframe count indicated in the first transmission of the RPA request shall be at least four superframes later than the superframe count when the eoc message carrying the RPA request is expected to be received (the value shall take into account the maximum transmission delay of the eoc message over the transmission line);
  – the 4-bit RPA configuration change count (RCCC) associated with the new configuration. The RCCC shall be incremented by one whenever the configuration changes, with wrap around at count 1111_2 The RCCC for a valid new configuration shall be greater than (accounting for wrapping around) the RCCC for the current configuration. The value of RCCC at the transition into showtime shall be set to 0, which means that the value of RCCC shall be set to 1 in the first RPA request command sent after the transition into showtime.
- After sending the "Update RMC parameters" command, the initiating MTU shall wait for the response that may be received via RMC (see Table 9-16) or via eoc (see Table 11-22) or via both, and may keep repeating the "Update RMC parameters" command until either the response is received via the RMC or eoc (whichever happens first). If no response is received, the initiating MTU may keep repeating the "Update RMC parameters" command until the sync frame of the superframe with the superframe count on which the new RMC parameters are expected to take effect.
- Upon reception of the "Update RMC parameters" command, the responding MTU shall respond via both the eoc (see Table 11-22) and the RMC (see Table 9-18), and perform the required parameter modifications starting from the RMC symbol of the sync frame of the superframe with the superframe count indicated in the "Update RMC parameters" command.
  – The responding MTU shall include the response over RMC (RPA-R command) into all transmitted RMC frames until the RMC frame transmitted in the sync frame of the superframe in which the update of RMC parameter occurs (not including this RMC frame).
  – The responding MTU shall respond to each received "Update RMC parameters" command, as defined in clause 11.2.2.5.
- The initiating MTU shall modify its RMC parameters starting from the RMC symbol of the sync frame of the superframe with the superframe count indicated in the "Update RMC parameters" command. The initiating MTU shall modify the parameters even in case it gets no acknowledgement over the eoc or over the RMC (including if it detects that RMC is

dysfunctional). However, the initiating MTU shall abort the procedure and refrain from making the requested changes in the RMC if it receives a reject OLR request type 4 on the "Update RMC parameters" command via the eoc or if it receives a RPA-R command with a reject indication via the RMC.

- The initiating MTU shall consider the RPA procedure complete upon modification of the RMC parameters at the designated time indicated in the RPA request command. The initiating MTU shall also consider the procedure complete after aborting the procedure as described in the previous bullet. Any message associated with the RPA procedure received after completion of this procedure shall be ignored. The initiating MTU may initiate a new RPA procedure only after completion of any ongoing RPA procedure.

NOTE – If the eoc, or the RMC, or both are unreliable, the initiating MTU cannot get confirmation whether the RPA request arrived or not. To improve robustness, the initiating MTU may continuously repeat the RPA request message, until acknowledgement via eoc or RMC arrives.

If a persistent *lor* defect on the upstream or downstream RMC (see clause 12.1.4.3.3) or a high BER event *reinit_time_threshold* occurs (see clause 12.1.4.3.4), the transmission line shall go to a controlled restart as defined in clause 12.1.4.

13.2.1.3.1 Parameters controlling the RPA procedures

The list of DPU-MIB parameters controlling RPA procedures is presented in Table 13-5.

The parameter values can be different for the upstream and downstream.

- MTU-O (upstream): Configured through the DPU-MIB.
- MTU-R (downstream): Configured through the DPU-MIB and communicated to the MTU-R during initialization (in O-MSG 1 message).

Table 13-5 – Parameters controlling the RPA procedures

Parameter	Definition
TARSNRM-RMC	The target SNR margin of the RMC is the minimum *SNRM-RMC* value that the MTU receiver shall achieve to successfully complete initialization. The valid values for *TARSNRM-RMCus* and *TARSNRM-RMCds* are values between 0 and 31.0 dB in steps of 0.1 dB.
MINSNRM-RMC	The minimum SNR margin of the RMC that is used to trigger a RPA procedure (see clause 13.2.1.3). The valid values for *MINSNRM-RMCus* and *MINSNRM-RMCds* are values between 0 and 31.0 dB in steps of 0.1 dB.
MAXBL-RMC	The maximum bit loading (b_i) or modulation index (m_i) allowed for RMC subcarriers. The valid values for *MAXBL-RMCus* and *MAXBL-RMCds* in case of TCM are integer values from 2 to 6. The valid values for *MAXBL-RMCus* and *MAXBL-RMCds* in case of PCS-LCM are integer values from 1 to 4.
RMCCARMASK	The *RTS* shall not include subcarriers from the frequency bands (including start and stop frequencies) defined through the RMCCARMASK in the DPU-MIB.

13.2.1.3.2 Parameters controlled by the RPA procedure

The RPA function shall be used for adjustment of PMD parameters related to the RMC. These adjustments are accomplished by a change to the bit loading, or set of subcarriers used for conveying RMC data. The details of these adjustments are described in Table 13-6.

Table 13-6 – Reconfigurable parameters of the RPA function

Parameter	Definition
RMC tone set (*RTS*)	Set of used subcarriers to be loaded with RMC data. The number of subcarriers used shall not exceed 512.
$b_{RMC\text{-}i}$	In case of TCM, the number of bits per RMC subcarrier with valid values of 0 and from 2 to 6.
$m_{RMC\text{-}i}$	In case of PCS-LCM, the modulation index per RMC subcarrier with valid values from 0 to 4.

Both the receiver and the transmitter shall support all valid $b_{RMC\text{-}i}$ and $m_{RMC\text{-}i}$ values and shall support any change of these values provided the resulting $b_{RMC\text{-}i}$ or $m_{RMC\text{-}i}$ value is within the specified valid range. The values of $b_{RMC\text{-}i}$ and $m_{RMC\text{-}i}$ shall also not exceed the DPU-MIB parameter MAXBL-RMC for the corresponding direction of transmission.

The *RTS* may be modified beyond the set determined during the initialization (see RTS_{us} and RTS_{ds} in clause 12.3.4.2).

If the *RTS* is modified with TCM, the new bit-loading and re-ordered tone table of the RMC symbol shall be recomputed as specified in clause 10.2.1.2.

If RTS is modified with PCS-LCM, a new baseline bit-loading table shall be constructed using the following procedure.

First, an intermediate baseline bit-loading table shall be constructed as follows:

– If all subcarriers of the new RTS are used (m_i>0), the modulation index of each subcarrier of the new *RTS* shall be equal to the minimum of:
  - the largest modulation index that has an *SCI* equal to the lowest *SCI* of all subcarriers of the new *RTS* of the old baseline bit-loading table, and;
  - the modulation index of that subcarrier in the old baseline bit-loading table.

  If at least one subcarrier of the new RTS is unused (m_i=0), the modulation index of each subcarrier of the new *RTS* shall be equal to the minimum of:
  - the largest modulation index of *SCI*=0, and;
  - the modulation index of that subcarrier in the old baseline bit-loading table.

– The modulation indices of subcarriers not belonging to the new RTS shall remain equal to those of the old bit-loading table.

Then, in order to have a number of subcarriers with *SCI*=1 and *SCI*=2 compatible with the PCS-LCM encoding in the new baseline bit-loading table, two additional steps shall apply to the intermediate baseline bit-loading table to derive the new baseline bit-loading table:

1) If the number of subcarriers with *SCI*=2 is not a multiple of 16 in the intermediate baseline bit-loading table, the modulation index of up to 15 subcarriers with *SCI*=2 shall be decreased to m_i=5, therefore belonging to *SCI*=1, in order to have a number of subcarriers with *SCI*=2 that is a multiple of 16. Those sub-carriers shall be the last subcarriers of the tone-ordering table that are not part of the new RTS and have *SCI*=2 in the intermediate baseline bit-loading table.

2) If after the previous step, the number of subcarriers with *SCI*=1 in the modified intermediate baseline bit loading is not a multiple 16, the modulation index of up to 15 subcarriers with *SCI*=1 shall be decreased to m_i=4, therefore belonging to *SCI*=0, in order to have a number of subcarriers with *SCI*=1 that is a multiple of 16. Those sub-carriers shall be the last subcarriers in the tone-ordering table that are not part of the new RTS and have *SCI*=1 in the modified intermediate baseline bit-loading table.

The new baseline bit-loading table shall use the same SCCC as the old baseline bit-loading table and any FRA adjustment on the old baseline bit-loading table shall also apply on the new baseline bit-loading table. Based on the new baseline bit-loading table, the new bit-loading and re-ordered tone table of the RMC and data symbol shall be recomputed as specified in clause 10.2.1.3.

13.2.1.3.3 Timing and synchronization for RPA

The MTU shall respond to the OLR command of OLR request type 4 within one superframe duration using the responses defined in Table 9-16 (over RMC) and Table 11-11 (over eoc).

The new RMC parameters requested by the RPA shall be applied by both MTUs starting from the RMC symbol of the sync frame of the superframe with the superframe count indicated in the OLR command of OLR request type 4 sent by the initiating MTU. With PCS-LCM, the new baseline bit-loading table, if applicable, shall apply from the same symbol.

13.2.1.4 SPA procedure

The SPA procedure shall be used to request an adaptation of the MREFPSD value in the upstream NPSF (MREFPSD_NPus). The SPA command and responses are defined in clause 11.2.2.21.

The SPA procedure consists of two parts:

- The SPA-PREP phase in which the MTU-O over eoc specifies the new *MREFPSDMASK_NPus* and the new *TONEMASK_NPus*, and the MTU-R over eoc responds with the new *MREFPSD_NPus*, followed by,
- An SPA-SRA phase in which the MTU-O over eoc specifies new bits and gains relative to the new *MREFPSD_NPus*, and in which the *MREFPSD_NPus*, *TONEMASK_NPus*, and all the parameters specified in the SPA-SRA are implemented at the MTU-O and MTU-R via synchronization by an associated RMC response (SRA-R command, see Table 9-15).

13.2.1.4.1 SPA-PREP procedure

The SPA-PREP command and responses are defined in clause 11.2.2.21.

The SPA-PREP eoc command is sent from the MTU-O to the MTU-R. Upon reception of the SPA-PREP command, the MTU-R shall send an SPA-PREP eoc response.

13.2.1.4.1.1 Parameters controlled by the SPA-PREP procedure

The SPA-PREP parameters in the SPA-PREP request are described in Table 13-7.

Table 13-7 – parameters in SPA-PREP request

Parameter	Definition
MREFPSDMASK_NPus	MREFPSDMASK to be used in the upstream NPSF. Definition and usage are identical as for field 8 of the O-PRM message (see clause 12.3.3.2.15).
TONEMASK_NPus	Subcarriers of the MEDLEYGus set (as used in the PSF) that shall not be transmitted in the NPSF. Definition identical as for field 9 of the O-PRM message (see clause 12.3.3.2.15).

The SPA-PREP parameters in the SPA-PREP response are described in Table 13-8.

Table 13-8 – parameters in SPA-PREP response

Parameter	Definition
MREFPSD_NPus	Actual MREFPSD to be used in the upstream NPSF. Definition and useage are identical as for field 3 of the R-PRM message (see clause 12.3.3.2.16).

The valid values for MREFPSD_NPus are restricted to values such that at every subcarrier in the MEDLEYGus set, the PSD in the NPSFs is lower than or equal to the PSD in the PSF, i.e., *MREFPSD_NPus(f)* ≤ *MREFPSD_us(f)* (Note).

NOTE – This restriction makes sure that the aggregate receive power in NPSF is not higher than in the PSF. This avoids issues due to overloading of the AFE at the upstream receiver.

13.2.1.4.2 SPA-SRA procedure

An SPA-SRA procedure is only allowed to be send after a preceding successful SPA-PREP procedure or after a preceding SPA-SRA procedure that failed due to timeout as a result of absence of SRA-R response.

The SPA-SRA command and responses are defined in clause 11.2.2.5.

The SPA-SRA eoc command is sent from the MTU-O to the MTU-R. Upon reception of the SPA-SRA command, the MTU-R shall send an SRA-R response.

13.2.1.4.2.1 Parameters controlled by the SPA-SRA procedure

The SPA-SRA function concerning the adjustment of PMD parameters is accomplished by a coordinated change to the new *MREFPSD_NPus* (as negotiated in the SPA-PREP phase) together with new bits and gain values relative to this new *MREFPSD_NPus* on the number of subcarriers in the baseline bit-loading table, and PMS-TC parameters.

The format of bits, gains and PMS-TC parameters is identical to the format for the autonomous SRA in upstream with change in g_i (OLR request type 2) (see clause 11.2.2.5).

13.2.1.4.2.2 Timing and synchronization for SPA-SRA

Update of the *MREFPSD_NPus* together with update of the bits and gain values of the baseline bit-loading tables at the MTU-O and MTU-R requested via SPA-SRA OLR request is synchronized by the associated RMC response (SRA-R command, see Table 9-15).

Two counts shall be used to maintain synchronization between the configurations imposed by SRA (see clause 13.2.1.1.1) at the transmitter and the receiver ends:

1) The 4-bit SRA configuration change count (SCCC)
2) The 4-bit SRA superframe down count (SFDC)

The use of SCCC and SFDC is identical to the use for the autonomous SRA.

The *MREFPSD_NPus* and new b_i, g_i, along with other PMD parameters settings shall take effect at the RMC symbol of the first logical frame of the superframe for which the expected SFDC is 0. The new PMS-TC parameters shall take effect at the first DTU following the application of the new b_i. Figure 13-4 depicts the timing of the SPA-SRA transition.

The MTU-R (that sends the RMC SRA-R command) shall monitor the acknowledgement to this RMC as specified for autonomous SRA.

After acknowledgement is received, the MTU-R shall consider the procedure complete.

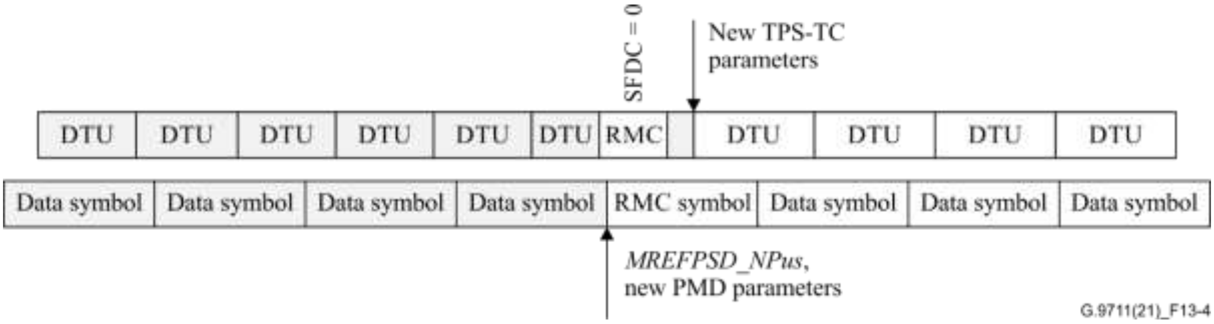


Figure 13-4 – Timing diagram of SPA-SRA transition

The receiver shall not initiate a new SRA procedure until the ongoing procedure, if any, has completed successfully or has failed due to rejection or has timed-out.

The specification of timeout (value and procedure), rules for repeating SRA requests, and valid initial values of SFDC are identical to the specification for autonomous SRA.

13.2.1.5 Showtime reconfiguration

13.2.1.5.1 Scope

This clause specifies a mechanism to reconfigure a transmission line by request from the NMS with a specified set of configuration parameters, applied during showtime without requiring a fast retrain or full re-initialization. This is achieved by using a showtime reconfiguration (SREC) procedure over the reconfigured transmission line.

13.2.1.5.2 Overview

13.2.1.5.2.1 Reconfiguration of the line

To force the transmission line into operation according to the new configuration, the ME-O sends a reconfiguration request primitive over the γ_MGMT reference point to the MME at the MTU-O (see Table 11-1), requesting reconfiguration of the transmission line according to the new parameters. Upon reception of this reconfiguration request primitive, depending on the changes requested in the current configuration, and whether the DPU-MIB allows use of SREC, the MME shall apply the new configuration according to the following:

- When the new configuration only requires changes of control parameters indicated as applicable to SREC-L in Table 13-9, and the use of SREC is allowed in the DPU-MIB, the MME shall initiate an SREC-L procedure in accordance with clause 13.2.1.5.3.1.
- When the new configuration requires changes of at least one control parameter indicated as applicable to SREC-R in Table 13-9, and use of SREC is allowed in the DPU-MIB, the MME shall initiate an SREC-R procedure in accordance with clause 13.2.1.5.3.2.
- When the new configuration requires changes of control parameters not listed in Table 13-9, or it requires changes of at least one control parameter indicated as applicable to SREC-

R in Table 13-9, or use of the SREC procedure is not allowed in the DPU-MIB, the MME shall trigger a fast retrain (see clause 12.1.4.2) to apply the new configuration; except when the new configuration involves a change of at least one control parameter exchanged during the G.994.1 phase, in which case the MME shall trigger a full initialization (see clause 12.3) instead of a fast retrain.

A successful reconfiguration of the transmission line using the SREC-R procedure is illustrated in Figure 13-5.

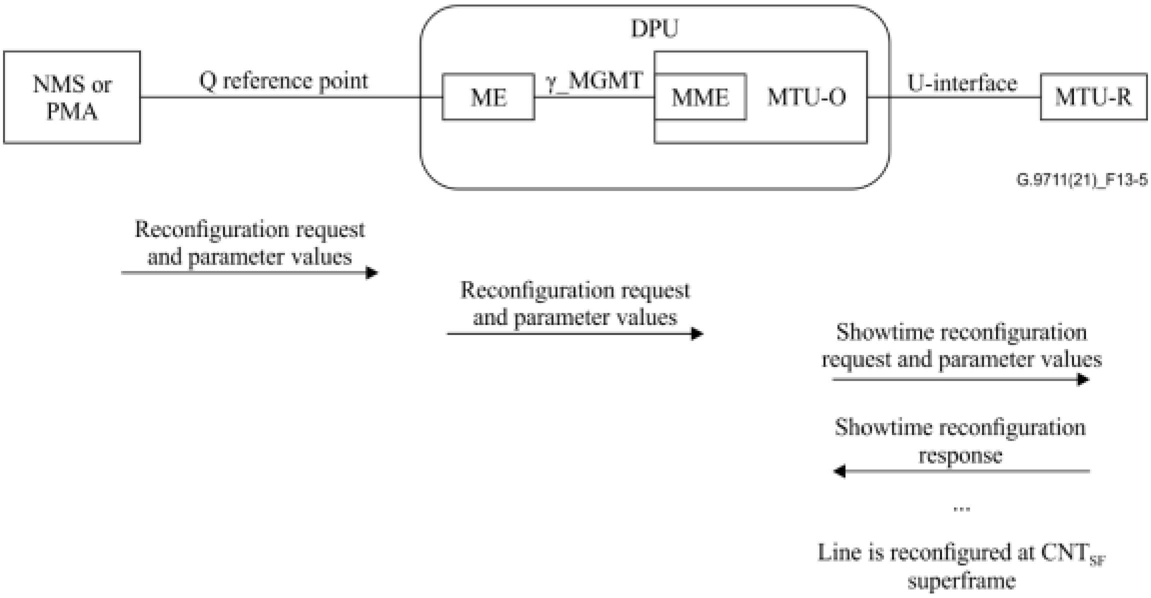


Figure 13-5 – Successful reconfiguration of the transmission line using the SREC-R procedure

If the SREC procedure completes successfully, the MME informs the ME-O using the *success_srec* primitive (see clause 13.2.1.5.4) at the end of the transition time period (see clause 13.2.1.5.3.3). A new SREC procedure may only be initiated after expiration of the transition time period.

If the SREC procedure fails, the MTU-O applies new configuration through a fast retrain (see clause 12.1.4.2) of the transmission line, or through a full re-initialization (see clause 12.3) of the transmission line.

13.2.1.5.2.2 Modification of configuration parameters

The list of configuration parameters that may be requested by the ME-O to be changed during showtime is shown in Table 13-9. The settings of the parameters that are requested by the ME-O to be reconfigured shall only be applied (i.e., without any rejection) by the MTUs, attempting to stay in showtime. The MTU-O shall report to the ME-O whether a configuration change in showtime was successful or not.

Table 13-9 also lists the names of control parameters that correspond to the configuration parameter names (as they apply at the Q reference point) and the applicable SREC procedure (local or remote).

Table 13-9 – Configuration parameters that may be requested by the ME-O to be changed during showtime

Category	Configuration parameter	Control parameter	Applicable procedure
Data rate	MAXNDRds	*NDR_max, downstream*	SREC-R
	MAXNDRus	*NDR_max, upstream*	SREC-R
	MINETRds	*ETR_min, downstream*	SREC-R
	MINETRus	*ETR_min, upstream*	SREC-R
Noise margins	TARSNRMds	*TARSNRM, downstream*	SREC-R
	TARSNRMus	*TARSNRM, upstream*	SREC-L
	MAXSNRMus	*MAXSNRM, upstream*	SREC-L
	MINSNRMds	*MINSNRM, downstream*	SREC-R
	MINSNRMus	*MINSNRM, upstream*	SREC-L
Seamless Rate Adaptation (SRA)	SRA–USNRMds	*RA-USNRM, downstream*	SREC-R
	SRA–UTIMEds	*RA-UTIME, downstream*	SREC-R
	SRA–USNRMus	*RA-USNRM, upstream*	SREC-L
	SRA–UTIMEus	*RA-UTIME, upstream*	SREC-L
	SRA–DSNRMds	*RA-DSNRM, downstream*	SREC-R
	SRA–DTIMEds	*RA-DTIME, downstream*	SREC-R
	SRA–DSNRMus	*RA-DSNRM, upstream*	SREC-L
	SRA–DTIMEus	*RA-DTIME, upstream*	SREC-L
RMC	TARSNRM–RMCds	*TARSNRM-RMC, downstream*	SREC-R
	TARSNRM–RMCus	*TARSNRM-RMC, upstream*	SREC-L
	MINSNRM–RMCds	*MINSNRM-RMC, downstream*	SREC-R
	MINSNRM–RMCus	*MINSNRM-RMC, upstream*	SREC-L
	MAXBL–RMCds	*MAXBL-RMC, downstream*	SREC-R
	MAXBL–RMCus	*MAXBL-RMC, upstream*	SREC-L
FRA	FRA–TIMEds	*FRA-TIME, downstream*	SREC-R
	FRA–TIMEus	*FRA-TIME, upstream*	SREC-L
	FRA–NTONESds	*FRA-NTONES, downstream*	SREC-R
	FRA–NTONESus	*FRA-NTONES, upstream*	SREC-L
	FRA–RTXUCds	*FRA-RTX-UC, downstream*	SREC-R
	FRA–RTXUCus	*FRA-RTX-UC, upstream*	SREC-L
	FRA-VENDISds	*FRA-VENDISC, downstream*	SREC-R
	FRA-VENDISus	*FRA-VENDISC, upstream*	SREC-L
Retransmission	SHINERATIOds	*SHINEratio, downstream*	SREC-R
	SHINERATIOus	*SHINEratio, upstream*	SREC-R
	INPMIN_REINds	*INP_min_rein, downstream*	SREC-R
	INPMIN_REINus	*INP_min_rein, upstream*	SREC-R
	RNRATIOds	*rnratio_min, downstream*	SREC-R
	RNRATIOus	*rnratio_min, upstream*	SREC-R

Table 13-9 – Configuration parameters that may be requested by the ME-O to be changed during showtime

Category	Configuration parameter	Control parameter	Applicable procedure
	MAXDELAYds	*delay_max, downstream*	SREC-R
	MAXDELAYus	*delay_max, upstream*	SREC-R
	INPMIN_SHINEds	*INP_min_shine, downstream*	SREC-R
	INPMIN_SHINEus	*INP_min_shine, upstream*	SREC-R
	IAT_REINds	*iat_rein_flag, downstream*	SREC-R
	IAT_REINus	*iat_rein_flag, upstream*	SREC-R
Fast Retrain	LOS-PERSISTENCYds	*los_persistency-ds*	SREC-R
	LOS-PERSISTENCYus	*los_persistency-us*	SREC-L
	LOM-PERSISTENCYds	*lom_persistency-ds*	SREC-R
	LOM-PERSISTENCYus	*lom_persistency-us*	SREC-L
	LOR-PERSISTENCYds	*lor_persistency-ds*	SREC-R
	LOR-PERSISTENCYus	*lor_persistency-us*	SREC-L
	REINIT_TIME_THRESHOLDds	*reinit_time_threshold-ds*	SREC-R
	REINIT_TIME_THRESHOLDus	*reinit_time_threshold-us*	SREC-L
	LOW_ETR_THRESHOLDds	*low_ETR_threshold-ds*	SREC-R
	LOW_ETR_THRESHOLDus	*low_ETR_threshold-us*	SREC-L

13.2.1.5.3 Showtime reconfiguration procedures

Two SREC procedures are specified:

- a local SREC procedure (SREC-L), as detailed in clause 13.2.1.5.3.1, and
- a remote SREC procedure (SREC-R), as detailed in clause 13.2.1.5.3.2.

All subclauses inside Clause 13.2.1.5, except Clause 13.2.1.5.3.2 and Clause 13.2.1.5.5, apply to the SREC-L procedure. All subclauses inside clause 13.2.1.5 except clause 13.2.1.5.3.1 apply to the SREC-R procedure.

Performance monitoring counters as specified in [ITU-T G.997.3] shall not be cleared due to the execution of an SREC-L or SREC-R procedure. Performance monitoring counters shall not be suspended during an SREC-L or SREC-R procedure.

The initiation of OLR procedures during the SREC procedure is allowed.

The new configuration shall always be applied. The transceivers should try to stay in showtime and not retrain during an SREC procedure. However, if a retrain occurs during an SREC procedure, the new values of configuration parameters shall be applied during re-initialization.

13.2.1.5.3.1 Local showtime reconfiguration (SREC-L) procedure

If the new configuration only requires changes of control parameter(s) indicated as applicable to SREC-L in Table 13-9, an SREC-L procedure shall be executed by the MME by applying the new configuration locally, at the MTU-O. No exchange with the MTU-R is required. Successful completion of the SREC-L procedure occurs upon the completion of the modification of the control parameters.

13.2.1.5.3.2 Remote showtime reconfiguration procedure

If the new configuration requires changes of control parameter(s) listed in Table 13-9 with at least one of these control parameters indicated as applicable to SREC-R, an SREC-R procedure shall be executed. The procedure includes the following steps:

1) The MTU-O shall initiate the SREC-R procedure by sending a showtime reconfiguration request command (see Table 13-10) to the MTU-R over the eoc indicating:
   – the list of parameter values for the new MTU-R configuration;
   – the superframe count, CNT_{SF}, on which the new configuration parameters shall take place at both the MTU-O and the MTU-R. The minimum superframe count indicated in the first transmission of the showtime reconfiguration request shall be at least 100 superframes later than the superframe count when the eoc message carrying the reconfiguration request command is expected to be received (the value shall take into account the maximum transmission delay of the eoc message);
   – the 8-bit showtime reconfiguration change count (SRECCC) associated with the SREC-R procedure. The SRECCC shall be incremented by one, with wrap around at count 11111111_2, when the configuration changes. The SRECCC for a new SREC-R procedure shall be greater than the SRECCC for the preceding SREC procedure (accounting for wrap around). The initial value of SRECCC immediately after the transition into showtime shall be 0, which means that the value of SRECCC shall be 1 in the first showtime reconfiguration request command sent after the transition into showtime.
2) Upon reception of the showtime reconfiguration request, the MTU-R may either accept the request by sending an acknowledgement in the showtime reconfiguration response or reject the request by sending a reject in the showtime reconfiguration response, as specified in Table 13-11. Accepting the request by the MTU-R means that the MTU-R shall modify its control parameters to be those of the showtime reconfiguration parameters received in the showtime reconfiguration request command starting from the DS RMC symbol of the PDX sync frame of the superframe with the superframe count indicated in the showtime reconfiguration request.
3) After sending the showtime reconfiguration request, the MTU-O shall wait for a showtime reconfiguration response (see Table 13-11). If the MTU-O receives no showtime reconfiguration response within the eoc protocol timeout (see clause 11.2.1.3), the MTU-O shall keep repeating the showtime reconfiguration request within a time period of 2 seconds after the first timeout as long as the time indicated by CNT_{SF} minus *delay_max_0* is not reached (see clause 11.2.1.3). If there is no showtime reconfiguration response after this time period of 2 seconds or if CNT_{SF} is reached the MTU-O shall abort the showtime reconfiguration procedure and trigger a retrain, which should be performed using the fast retrain procedure specified in clause 12.1.4.2.
4) If the MTU-O receives a showtime reconfiguration response acknowledgement, the MTU-O shall modify its control parameters to be those of the showtime reconfiguration parameters as requested by the NMS through the ME-O, starting from DS RMC symbol of the PDX sync frame of the superframe with the superframe count indicated in the showtime reconfiguration request command. If the MTU-O receives a reject in the showtime reconfiguration response, the MTU-O shall abort the SREC-R procedure and trigger a retrain, which should be performed using the fast retrain procedure specified in clause 12.1.4.2.

Successful completion of the SREC procedure occurs upon modification of control parameters in step 2 or step 4 (during the DS RMC symbol of the PDX sync frame of the superframe with the superframe count indicated in the showtime reconfiguration request command). After completion of the SREC procedure, a new SREC procedure may be initiated after expiration of the transition time period (see clause 13.2.1.5.3.3) associated with the latest SREC procedure.

NOTE – A new SREC procedure cannot be initiated until about 12 seconds after a previous successful SREC procedure was initiated.

If the procedure is aborted, or if there is a persistent *los* defect, persistent *lor* defect, or persistent *lom* defect either upstream or downstream (see clauses 12.1.4.3.1, 12.1.4.3.2 and 12.1.4.3.3), the transmission line shall retrain using the re-initialization procedure specified in clause 12.3.

Retrain triggers shall be in effect until DS RMC symbol of the PDX sync frame of the superframe with the superframe count indicated in the showtime reconfiguration request.

13.2.1.5.3.3 Transition time period

If an SREC-L or SREC-R procedure completes successfully, there is a transition time period of 10 seconds, during which retrain triggers for persistent *lom* defect and high_BER event shall be suspended to allow OLRs to settle the actual parameter values without retraining. The retrain triggers for persistent *los* defect and persistent *lor* defect are not suspended. The transition time period begins when the SREC procedure completes. After the end of the transition time period all retrain triggers take effect and a new SREC procedure, if requested by the ME-O, may be initiated.

If the transition time period follows an SREC-L procedure, the retrain triggers for persistent *lom* defect and high_BER event shall be suspended at the MTU-O. If the transition time period follows an SREC-R procedure, the retrain triggers for persistent *lom* defect and high_BER event shall be suspended at both the MTU-O and the MTU-R.

During the transition time period new additional triggers apply which shall initiate an SRA if:

- the current data rate is lower than the new minimum data rate, or
- the current data rate is higher than the new maximum data rate

Multiple OLR procedures may be initiated during the transition time period to meet data rate or other boundary conditions. These procedures may be initiated by either the MTU-O or the MTU-R and their initiation is not constrained by RA-DTIME and RA-UTIME.

13.2.1.5.4 Management of the showtime reconfiguration protocol

The following primitive is defined at the MTU-O:

- Successful SREC (*success_srec*): This primitive occurs at the end of the transition time period, each time the MME initiates an SREC-L or SREC-R procedure and the SREC procedure is successfully completed, and no re-initialization is triggered at any time from the beginning of the SREC procedure until the end of the transition time period.

If the MME initiates an SREC-L or SREC-R procedure and the SREC procedure is aborted or otherwise the MME (at the MTU-O or at the MTU-R) triggers a re-initialization at any time from the beginning of the SREC procedure until the end of the transition time period, a re-initialization associated with the reconfiguration request primitive from the ME-O is triggered and an *me_o_intrpt* anomaly shall occur (see clause 13.2.1.5.6).

Each time the MME initiates an SREC-L or SREC-R procedure, either a *success_srec* primitive or an *me_o_intrpt* primitive shall be sent by the MTU-O from the MME to the ME-O over the γ_MGMT_O reference point.

The control parameter *SREC_allowed* shall indicate whether the MME may use (*SREC_allowed* = true) or shall not use (*SREC_allowed* = false) the SREC procedure to force a new configuration onto the transmission line. The control parameter *SREC_allowed* shall be equal to the DPU-MIB configuration parameter SREC_ALLOWED. *SREC_allowed* applies to both local showtime reconfiguration and remote showtime reconfiguration.

13.2.1.5.5 Showtime reconfiguration request eoc commands

A showtime reconfiguration request is sent from the MTU-O to the MTU-R to initiate the remote SREC procedure. The showtime reconfiguration request contains the showtime reconfiguration change count (SRECCC), the superframe count at which the new configuration is to be applied (CNT_{SF}), and the new requested values of parameters.

The showtime reconfiguration request command is a low priority command. The first byte of the command shall be the command type assigned as shown in Table 11-6 (showtime reconfiguration request command). The remaining bytes of the command shall be as specified in Table 13-10.

Table 13-10 – Showtime reconfiguration request (sent by the MTU-O)

Name	Length (Bytes)	Byte number	Content	Format
Showtime reconfiguration request	54	2	01_{16} (Note)	
		3	showtime reconfiguration change count (SRECCC)	See clause 13.2.1.5.3.2
		4 and 5	CNT_{SF} at which the new configuration is to be applied	See clause 12.3.3.2.1 (O-SIGNATURE)
		2	01_{16} (Note)	
		3	showtime reconfiguration change count (SRECCC)	See clause 13.2.1.5.3.2
		4 and 5	CNT_{SF} at which the new configuration is to be applied	See clause 12.3.3.2.1 (O-SIGNATURE)
		6 and 7	*NDR_max, downstream*	See clause 12.3.4.2.3 (O-TPS)
		8 and 9	*NDR_max, upstream*	See clause 12.3.4.2.3 (O-TPS)
		10 and 11	*ETR_min, downstream*	See clause 12.3.4.2.3 (O-TPS)
		12 and 13	*ETR_min, upstream*	See clause 12.3.4.2.3 (O-TPS)
		14 and 15	*TARSNRM, downstream*	See clause 12.3.3.2.1 (O-SIGNATURE)
		16 and 17	*MINSNRM, downstream*	See clause 12.3.3.2.1 (O-SIGNATURE)
		18 and 19	*RA-USNRM, downstream*	See clause 12.3.4.2.1 (O-MSG 1)
		20 and 21	*RA-UTIME, downstream*	See clause 12.3.4.2.1 (O-MSG 1)
		22 and 23	*RA-DSNRM, downstream*	See clause 12.3.4.2.1 (O-MSG 1)
		24 and 25	*RA-DTIME, downstream*	See clause 12.3.4.2.1 (O-MSG 1)
		26 and 27	*TARSNRM-RMC, downstream*	See clause 12.3.4.2.1 (O-MSG 1)

Table 13-10 – Showtime reconfiguration request (sent by the MTU-O)

Name	Length (Bytes)	Byte number	Content	Format
		28 and 29	*MINSNRM-RMC, downstream*	See clause 12.3.4.2.1 (O-MSG 1)
		30	*MAXBL-RMC, downstream*	See clause 12.3.4.2.1 (O-MSG 1)
		31	*FRA-TIME, downstream*	See clause 12.3.4.2.1 (O-MSG 1)
		32	*FRA-NTONES, downstream*	See clause 12.3.4.2.1 (O-MSG 1)
		33 and 34	*FRA-RTX-UC, downstream*	See clause 12.3.4.2.1 (O-MSG 1)
		35	*FRA-VENDISC, downstream*	See clause 12.3.4.2.1 (O-MSG 1)
		36	*SHINEratio, downstream*	See clause 12.3.4.2.3 (O-TPS)
		37	*SHINEratio, upstream*	See clause 12.3.4.2.3 (O-TPS)
		38	*INP_min_rein, downstream*	See clause 12.3.4.2.3 (O-TPS)
		39	*INP_min_rein, upstream*	See clause 12.3.4.2.3 (O-TPS)
		40	*rnratio_min, downstream*	See clause 12.3.4.2.3 (O-TPS)
		41	*rnratio_min, upstream*	See clause 12.3.4.2.3 (O-TPS)
		42	*delay_max, downstream*	See clause 12.3.4.2.3 (O-TPS)
		43	*delay_max, upstream*	See clause 12.3.4.2.3 (O-TPS)
		44 and 45	*INP_min_shine, downstream*	See clause 12.3.4.2.3 (O-TPS)
		46 and 47	*INP_min_shine, upstream*	See clause 12.3.4.2.3 (O-TPS)
		48	*iat_rein_flag, downstream*	See clause 12.3.4.2.3 (O-TPS)
		49	*iat_rein_flag, upstream*	See clause 12.3.4.2.3 (O-TPS)
		50	*los_persistency-ds*	See clause 12.3.4.2.1 (O-MSG 1)
		51	*lom_persistency-ds*	See clause 12.3.4.2.1 (O-MSG 1)
		52	*lor_persistency-ds*	See clause 12.3.4.2.1

Table 13-10 – Showtime reconfiguration request (sent by the MTU-O)

Name	Length (Bytes)	Byte number	Content	Format
				(O-MSG 1)
		53	*reinit_time_threshold-ds*	See clause 12.3.4.2.1 (O-MSG 1)
		54	*low_ETR_threshold-ds*	See clause 12.3.4.2.1 (O-MSG 1)

Table 13-11 – Showtime reconfiguration response (sent by the MTU-R)

Name	Length (Bytes)	Byte number	Content
acknowledgement	3	2	80_{16} (Note)
		3	showtime reconfiguration change count (SRECCC)
reject	3	2	81_{16} (Note)
		3	showtime reconfiguration change count (SRECCC)
NOTE – All other values for this byte are reserved by ITU-T.			

13.2.1.5.6 near-end anomalies

The ME-O-Reinit anomaly is only defined at the MTU-O.

- ME-O-Reinit interruption (*me_o_intrpt*): This anomaly occurs upon entry into showtime after a re-initialization associated with a reconfiguration request from the ME-O (see clause 13.2.1.5.3) or associated with an o:_L0_request from the ME-O.

13.2.1.6 SSA procedure

The SSA procedure shall be used to force an adaptation of the upstream sync symbol transmit gains (g_i). The SSA command and responses are defined in clause 11.2.2.24.

The SSA command is sent from the MTU-O to the MTU-R. Upon reception of the SSA command, the MTU-R shall send an SSA response. The MTU-R shall apply the requested change only after sending the ACK message.The adaptation shall occur within 40 ms after sending the ACK message (see Figure 13-6). The MTU-R should respond to the SSA command, at the earliest opportunity (e.g., it is not required that the sending of the ACK response is delayed until the end of the current probe sequence).

The timing diagram of the SSA eoc command and response is shown in Figure 13-6.

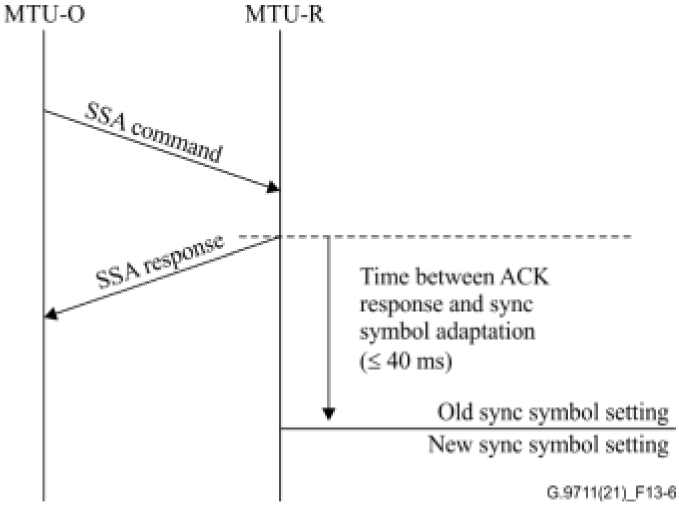


Figure 13-6 – Timing diagram of the SSA command and response

13.2.2 Transmitter initiated procedures

13.2.2.1 TIGA procedure

Upon instruction of the VCE over the γ_MGMT interface, the MTU-O shall send an eoc command of OLR request type 3 (TIGA), after which the MTU-O shall await a response. After reception of the OLR request type 3, the MTU-R shall not initiate any new SRA procedures until the TIGA procedure is complete. The MTU-R shall acknowledge the reception of the TIGA command by setting the TIGA-ACK bit to ONE in the upstream RMC command (see Table 9-4 and Table 9-8) and shall then send an OLR request type 1 (TIGARESP) command via the upstream eoc (see Table 11-11) or shall reject the TIGA command using an eoc response reject OLR request type 3 (see Table 11-22). The timeout on the setting of the TIGA-ACK bit (MTU-O TIGA-ACK timeout in Figure 13-7) or on sending the reject OLR request type 3 shall be equal to the timeout of the high priority eoc command (50ms). If a reject OLR request type 3 is sent, the TIGA-ACK bit shall not be set to ONE. The maximal time between the setting of the TIGA-ACK bit and the first transmission of the OLR request type 1 command in response to TIGA (TIGARESP) shall be 100ms.

If MTU-O receives an OLR request type 1 or type 2 during or after transmission of OLR request Type 3 prior to receiving a TIGA-ACK, it shall reject the OLR request using corresponding reject response (see Table 11-22) with reason code "wait".

NOTE – It is expected that in the aim to speed up starting TIGA, the MTU-O may reject already submitted SRA request because the modification of transmission parameters implied by this request will be anyway overridden by TIGA.

If the MTU-O has not detected the setting of the TIGA-ACK bit to ONE after the TIGA-ACK timeout expires, it may resend one or multiple time the TIGA command within two seconds from the first timeout, after which it shall abandon the message.

The OLR command of OLR request type 3 (TIGA) sent by the MTU-O may include a subcarrier parameter block for PSF only, for NPSF only, or for both PSF and NPSF. The OLR command shall include subcarriers for one operational interval (NOI or DOI) only.

If the MTU-R can accept the gains and bits requested in TIGA, it shall send the TIGARESP message with bb bits set to 00 (i.e., no subcarrier parameter blocks included, see Table 11-11). In this case, it is implied that *d_TIGARESP = 1* for the respective PSF or NPSF or both PSF and NPSF indicated in the corresponding TIGA command.

If the MTU-R cannot accept the gain compensation factors or bit loadings requested in TIGA, it shall send a TIGARESP message with bb and c bits set to an identical value as the bb and c bits in the corresponding TIGA.

The MTU-O shall acknowledge the reception of the TIGARESP by setting the TIGARESP-ACK bit to ONE in the downstream RMC command (see Table 9-5) followed by sending an SRA-R RMC command in the downstream RMC message (see Table 9-4 and Table 9-15) or shall reject the TIGARESP command using an eoc response reject OLR request type 1 (see Table 11-22). The timeout on the setting of the TIGARESP-ACK bit (MTU-R TIGARESP-ACK timeout in Figure 13-7) or the reject OLR request shall be equal to the timeout of the high priority eoc command (50ms). If a reject OLR request type 1 is sent, the TIGARESP-ACK bit shall not be set to ONE.

If the MTU-R has not detected the setting of the TIGARESP-ACK bit to ONE and has not received an SRA-R with a special SCCC value (see below) when TIGARESP-ACK timeout expires, it may re-send the TIGARESP command until the expiration time of the MTU-R TIGA timeout minus the time sufficient for the TIGARESP command to be applied (i.e., 50 ms). The MTU-R TIGA timeout starts when the TIGA-ACK bit is set to 1. The value of the MTU-R TIGA timeout is 1 second. When the MTU-R detects the SRA-R command with SFDC=0 or the MTU-R TIGA timeout expires, it shall set the TIGA-ACK bit to ZERO.

The MTU-O shall set the TIGARESP-ACK bit to ZERO when the first SRA-R command is transmitted.

Figure 13-7 shows the transactions over the eoc and RMC between the MTU-O and the MTU-R of a single transmission line as well as the timing of the TIGA procedure in case of non-segmented eoc messages.

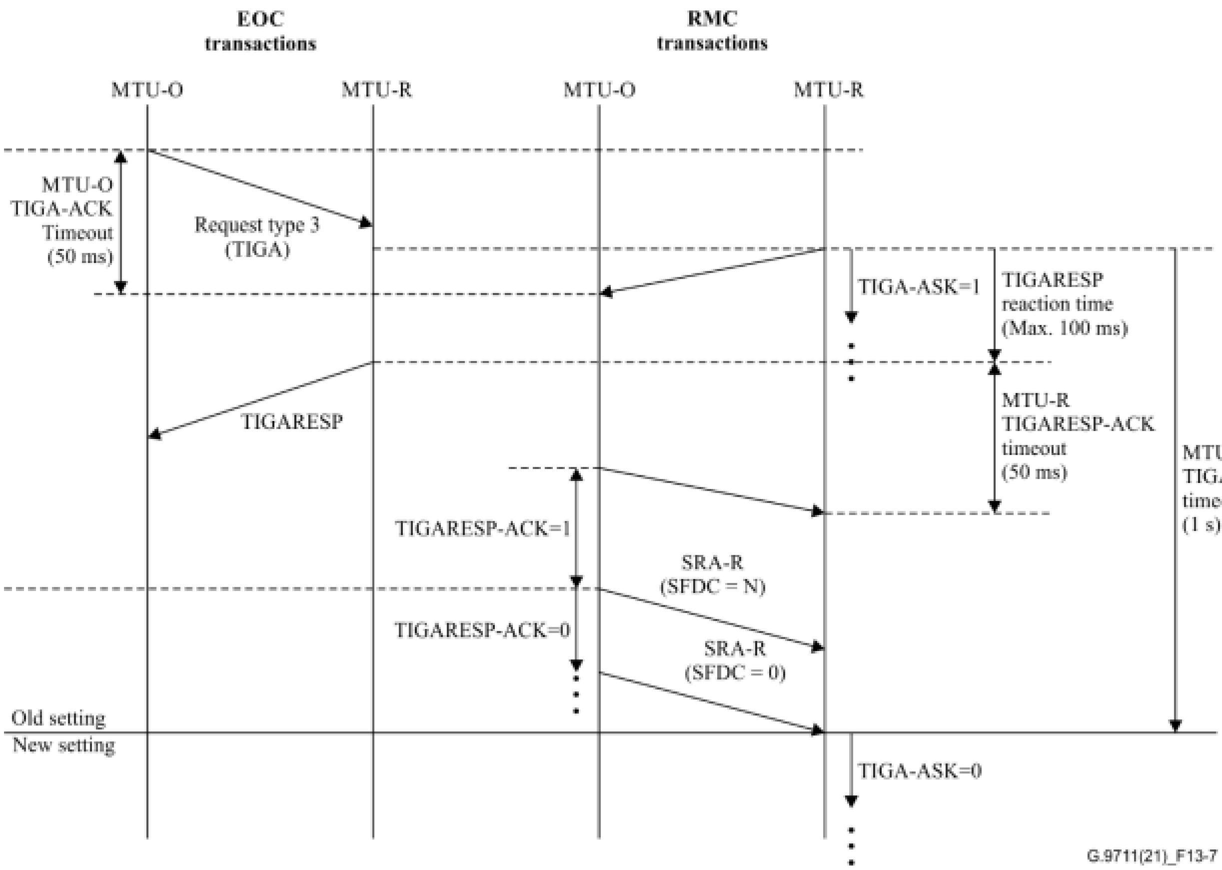


Figure 13-7 – TIGA procedure with non-segmented messages

In response to a TIGA-ACK or TIGARESP message, the VCE shall instruct (over the γ_MGMT interface), the MTU-O to either:

– send an SRA-R RMC command (see Table 9-4 and Table 9-15), to indicate the symbol position on which both MTU-O and MTU-R implement the new parameters values (see clause 13.2.2.1.2 for details and timing). The value of SCCC that the MTU-O shall send in the SRA-R command, shall be instructed by the VCE over the γ_MGMT interface with one of the following options:
  - the value of SCCC as received in the TIGARESP message, to indicate that the MTU-O did receive the TIGARESP message, and that the precoder, the relative gain compensation factors r_i, the baseline bit-loading table and all other parameter values shall be established corresponding to the values requested in the TIGARESP message, or
  - the special value SCCC=1111, to indicate that the MTU-O did not receive the TIGARESP message, but that nevertheless the precoder, the relative gain compensation factors r_i, and the baseline bit-loading table shall be established corresponding to the values indicated in the TIGA command, while all other parameter values which are part of a TIGARESP message shall stay unchanged, or
  - the special value SCCC=1110, to indicate that the MTU-O did not receive the TIGARESP message, but that nevertheless the precoder and the relative gain compensation factors r_i shall be established corresponding to the values indicated in the TIGA command, while the baseline bit-loading tables and all other parameter values that are part of a TIGARESP message shall stay unchanged, or
  - the special value SCCC=1101, to indicate that the MTU-O did not receive a TIGA-ACK, but that nevertheless the precoder and the relative gain compensation factors r_i shall be established corresponding to the values indicated in the TIGA command while the baseline bit-loading table and all other parameter values that are part of a TIGARESP message shall stay unchanged, or
  - resend the OLR request type 3 (TIGA) command in case the MTU-O did not receive the TIGA ACK.

Figure 13-8 shows the flowchart of the above TIGA procedure.

NOTE 1 – The detailed behaviour of the decision process by the VCE and management functions above the γ_MGMT interface are out of the scope of this Recommendation. Appendix II gives example use cases.

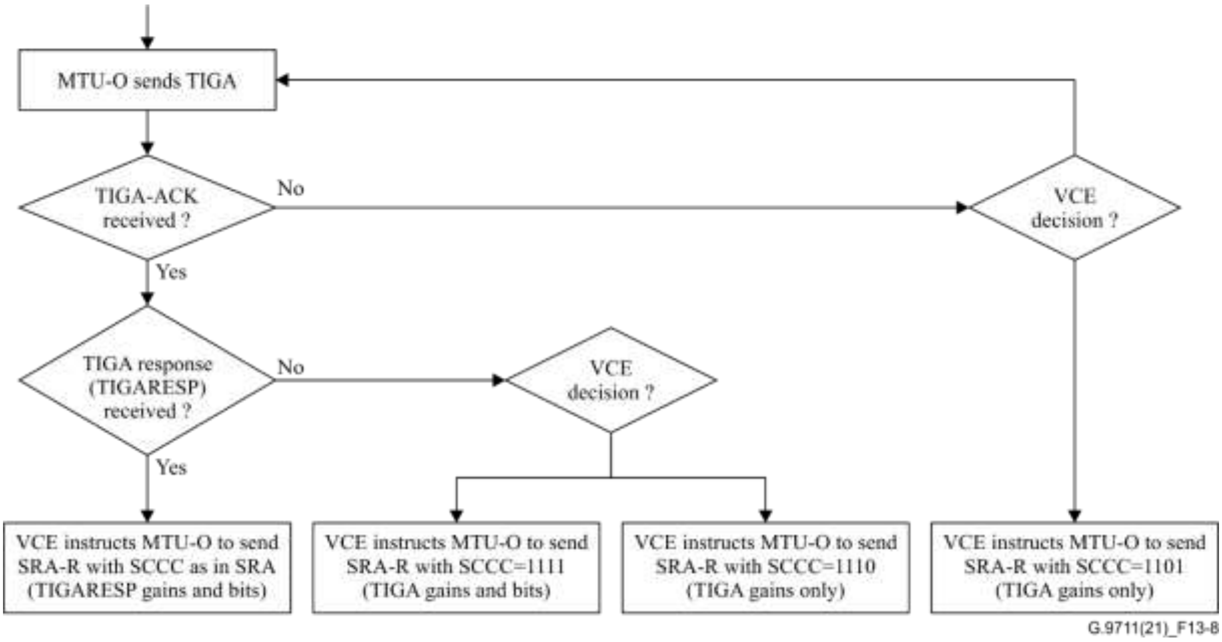


Figure 13-8 – Flowchart of TIGA procedure

The MTU-R shall implement the received SRA-R command as follows:

– If the value of SCCC is as initiated in the TIGARESP message, the MTU-R shall implement the parameter values it indicated in the TIGARESP message.

– If the SCCC value is the special value SCCC=1111, the MTU-R shall adapt its receiver settings in accordance with the gains and the baseline bit-loading table as indicated in the last TIGA command (all other parameter values which are part of a TIGARESP message shall be unchanged).

– If the SCCC value is the special value SCCC=1110, the MTU-R shall adapt its receiver settings in accordance with the gains as indicated in the last TIGA command (the baseline bit-loading table and other parameter values which are part of a TIGARESP message shall be unchanged).

– If the SCCC value is the special value SCCC=1101, the MTU-R should expect an unknown change in received signal magnitude and phase when SFDC reaches zero.

NOTE 2 – Use of the special values SCCC=1111, 1110 and 1101 may cause errors and/or may cause retrain.

13.2.2.1.1 Parameters controlled by the TIGA procedure

13.2.2.1.1.1 Parameters controlled by the TIGA request

The parameters are described in Table 13-12.

Table 13-12 – Parameters in a TIGA request

Parameter	Definition
i_start	Start subcarrier index.
i_stop	Stop subcarrier index.
r_i	Relative gain compensation factors for the MTU-R receiver gain stage, specified per subcarrier. Values may be real or complex. Valid values are specified in clause 11.2.2.5.
b_i	Requested number of bits per subcarrier to be allocated by the MTU-R. Valid values are all integers in the [0, MTU-O maximum bit loading] range. "MTU-O maximum bit loading" is a capability indicated during initialization by the MTU-O in the O-MSG 1 message.
m_i	Requested modulation index per subcarrier to be allocated by the MTU-R. Valid values are all integers in the [0, MTU-O maximum bit loading] range. "MTU-O maximum bit loading" is a capability indicated by the MTU-O during initialization in the O-MSG 1 message.

13.2.2.1.1.2 Parameters controlled by the TIGA response

The parameters are described in Table 13-13.

Table 13-13 – Parameters in a TIGA response

Parameter	Definition
d_TIGARESP	Delta factor requested by the MTU-R relative to the gain correction factors r_i in the TIGA message. This parameter is a frequency independent real scalar. Valid values are specified in clause 11.2.2.5.
i_start	Start subcarrier index (Note 1).
i_stop	Stop subcarrier index (Note 1).
b_i	Actual number of bits per subcarrier requested by the MTU-R. Valid values are all integers in the [0, MTU-O maximum bit loading] range, and with b_i values that do not exceed those requested in the corresponding TIGA message (Note 2). "MTU-O maximum bit loading" is a capability indicated by the MTU-O during initialization in the O-MSG 1 message.
m_i	Actual modulation index per subcarrier requested by the MTU-R. Valid values are all integers in the [0, MTU-O maximum bit loading] range, and with m_i values that do not exceed those requested in the corresponding TIGA message (Note 2). "MTU-O maximum bit loading" is a capability indicated by the MTU-O during initialization in the O-MSG 1 message.
NOTE 1 – For every PDX sub-frame type (PSF, NPSF, or both), the range of subcarrier indices (i.e., indices from i_start to i_stop) of the TIGARESP message shall include at least all subcarriers of the MEDLEYset included within the range of subcarrier indices of the TIGA request. NOTE 2 – For subcarriers that are beyond the TIGA frequency band: *i_start* (TIGARESP) ≤ *i* < *i_start* (TIGA) *i_stop* (TIGA) < *i* ≤ *i_stop* (TIGARESP), the b_i or m_i values requested by TIGARESP are determined solely by the MTU-R.	

NOTE 1 – Table 13-13 states that the bit loading or modulation index for the NOI in the TIGARESP message (bi/mi_TIGARESP_NOI) is upper limited by the bit loading or modulation index for the NOI in the TIGA message (bi/mi_TIGA_NOI). This limitation applies separately to the NOI in PSF and NOI in NPSF according to the parameters transmitted in the TIGA message for each PDX sub-frame. In addition to this mandatory upper limit, the bit loading bi/mi_TIGARESP_NOI should be upper limited by the bit loading that is based on the change in the SNR of the requested operation interval expected from the new values of r_i, and might be upper limited by other factors.

NOTE 2 – Table 13-13 states that the bit loading for the DOI in the TIGARESP message (bi/mi_TIGARESP_DOI) is upper limited by the bit loading for the DOI in the TIGA message (bi/mi_TIGA_DOI). In addition to this mandatory upper limit, the bit loading bi/mi_TIGARESP_DOI might be upper limited by other factors.

To implement the TIGA and TIGA response, the following rules shall apply:

For subcarriers with $r_i \neq 0$,

– For the NOI in a given PDX sub-frame (PSF or NPSF), the MTU-R shall multiply its current settings of the gain stage in the receiver of that PDX sub-frame, for any subcarrier *i* with g_i >0, by the value ($NOI\_r_i / NOI\_d\_TIGARESP$)

  $new\_NOI\_gainstage_i = current\_NOI\_gainstage_i \times (NOI\_r_i/NOI\_d\_TIGARESP)$

  where *NOI_d_TIGARESP* is either the value of *PSF_d_TIGARESP* or *NPSF_d_TIGARESP* depending on the PDX sub-frame type.

– For the DOI interval, the MTU-R shall multiply its current settings of the gain stage in the receiver of the NOI interval of the PSF, for any subcarrier *i* with g_i >0, by the value ($DOI\_r_i / NOI\_d\_TIGARESP$) and use these values for the new settings of the gain stage in the receiver during the DOI interval, i.e.,

  $new\_DOI\_gainstage_i = current\_NOI\_gainstage_i \times (DOI\_r_i/ NOI\_d\_TIGARESP)$

  where *NOI_d_TIGARESP* is the value of *PSF_d_TIGARESP*.

The TIGARESP shall address all the PDX sub-frames and operational interval as corresponding TIGA does; PSF only, NPSF only, or both PSF and NPSF, for a given operational interval (NOI or DOI).

For both PSF and NPSF, the new gain settings shall take effect starting from the RMC symbol of the first logical frame of the superframe for which the expected SFDC is 0.

NOTE 3 – This scaling is to help the MTU-R to keep its receiver gain adjusted after a precoder update.

For subcarriers with r_i = 0, the MTU-R shall set its receiver gain to a vendor discretionary non-zero value.

NOTE 4 – To revive suppressed subcarriers (r_i=0 and b_i or m_i=0), the VCE may facilitate FEQ training by the MTU-R receiver by precoding the sync symbols such that the phase of the channel measured at the MTU-R does not deviate significantly between the sync symbol and the data symbols in the NOI.

13.2.2.1.2 Timing and synchronization for TIGA

The final command in a TIGA procedure is the SRA-R. Timing and synchronization shall be identical as in SRA.

NOTE – By controlling the timing of the TIGA command and the reply to TIGARESP (SRA-R) at multiple MTU-Os, the VCE can control the precoder gain adaptation to be applied synchronously on all lines or asynchronously. See Appendix III for use cases.

13.3 RMC-based procedures

13.3.1 Receiver initiated procedures

13.3.1.1 FRA procedure

The list of DPU-MIB parameters controlling the FRA procedure is presented in Table 13-14. These parameters are used in the FRA triggering criteria defined in clause 13.3.1.1.1.5. This can be used in case of sudden noise increase or moderate changes in the channel transfer and crosstalk functions. FRA may be initiated by either MTU-O or MTU-R.

FRA may change the bit loading (b_i) or modulation index (m_i) of some subcarrier groups (sub-bands) and thus may result in a change to the number of bytes per data frame B_D and B_{DR}. For the RMC symbol, FRA shall have no effect on RMC subcarriers. The procedure for FRA shall be implemented using messages carried over RMC (see clause 9.6.4).

The FRA updates the active bit-loading table by providing adjustments to the baseline bit-loading table. These adjustments are defined per sub-band by the receiver and conveyed over the RMC using receiver initiated FRA request command (see Table 9-10 and Table 9-11). Eight sub-bands are defined in the upstream and in the downstream direction (see Table 9-12). The start and stop subcarriers of each sub-band for each direction are set during initialization (see clause 12.3.4.2.7 and clause 12.3.4.2.8). Different sub-bands may be used for upstream and downstream directions.

The MTU initiating FRA may apply the following adjustment tools when indicating MTU the active loading table (per sub-band) to the peer:

– Use the current baseline bit-loading table as the active bit-loading table with no adjustments.

– Relative decrease tool – the same reduction of bit loading is applied to all the subcarriers in the specified sub-band, except for subcarriers allocated for RMC (RTS).

– Bit-loading ceiling tool – limit the maximum bit loading according to the specified parameter value. The ceiling is applied to all the subcarriers in the specified sub-band except for subcarriers allocated for RMC (RTS).

No change shall be made to the re-ordered tone table t' upon implementation of FRA.

With TCM, the following rules shall apply to avoid the need to update table t':

– No new subcarriers with b_i =1 shall be created as a result of the implementation of FRA. After applying the adjustments required by the FRA, subcarriers resulting in loading values b_i =1 shall be zeroed (b_i =0). Thus, no new one-bit loading will be created by FRA. If the resulting b_i contains an odd number of one-bit constellation points, the last one-bit constellation according to re-ordered tone-ordering table shall be set to b_i=0.

– Tables *t'* (re-ordered tone table) shall not be recalculated and the ordering of table *b'* (re-ordered bit-allocation table) shall not change, even if one or more subcarriers previously loaded with b_i =1 are now loaded with b_i =0.

With PCS-LCM, the following rules shall apply to avoid the need to update table t':

– If for one or more subcarriers of the group of subcarriers corresponding to an SF the *SCI* changes or one or more subcarriers of that group is unused (mi=0) after adjustment of the base bit-loading table, each subcarrier of that group shall be set to a modulation index equal to the minimum of:

  - the largest modulation index that has an *SCI* equal to the lowest *SCI* of all subcarriers of that group after adjustment or m_i=4 if at least one subcarrier of that group is unused, and;
  - the modulation index obtained after adjustment of that subcarrier.

– Tables *t'* (re-ordered tone table) shall not be recalculated and the ordering of table *m'* (re-ordered bit-allocation table) shall not change, even if one or more subcarriers change of *SCI* or are unloaded ($\underline{m_i}$=0).

With PCS-LCM, only the number of shortening bits, S, shall be changed to accommodate the new LDPC codeword size after an FRA. The circulant matrix size, Mc, and the number of punctured bits, P, are not changed.

The upper limit on DTU size defined in clause 8.2 may result in a violation after an FRA. In this case, the DTU size shall be modified back to its valid range through a standard OLR procedure as soon as possible after the FRA.

After an MTU receives an FRA request, it shall respond within 5 ms by sending an indication via RMC when the requested new configuration shall take effect (see the 'Reply to FRA request (FRA-R)' command in Table 9-13 and Table 9-14).

The MTU sourcing the FRA request may repeat the same FRA request in every PDX frame until it receives an ACK or FRA-R, or it decides to abandon the FRA request, in which case the next FRA request initiated by the MTU shall have at least a new FCCC value.

After FRA-R is received, the sourcing MTU shall complete the FRA procedure by applying requested transmission parameters as defined in clause 13.3.1.1.3.

If the sourcing MTU does not receive FRA-R within 20 ms after the last FRA request (which might be a repeated FRA request) was sent, the sourcing MTU shall abandon the request.

NOTE – If RMC frames are received with no errors, the FRA-R is expected to arrive in less than 6ms (this takes into account the response time and some margin for transmission time).

13.3.1.1.1 Parameters controlling the FRA procedure

The list of DPU-MIB parameters controlling the FRA procedure is presented in Table 13-14. These parameters are used in the FRA triggering criteria defined in clause 13.3.1.1.1.5.

Each of the four FRA triggering parameters can have different values for the MTU-O (upstream) and the MTU-R (downstream).

- MTU-O (upstream): Configured through the DPU-MIB.
- MTU-R (downstream): Configured through the DPU-MIB and communicated to the MTU-R during initialization (in O-MSG 1 message).

Table 13-14 – Parameters controlling the FRA procedures

Parameter	Definition
FRA-TIME	FRA-TIME determines the duration of the FRA time window used in the standard FRA triggering criteria.
FRA-NTONES	FRA-NTONES determines the minimum percentage of subcarriers with b_i>0 or m_i>0 that are to be detected as degraded ones over the time window equal to FRA–TIME in order to arm the first FRA triggering criterion.
FRA-RTX-UC	FRA-RTX-UC determines the minimum number of *rtx–uc* anomalies received throughout a time window equal to FRA–TIMEds in order to arm the second FRA triggering criterion.
FRA-VENDISC	Determines whether vendor-discretionary FRA triggering criteria may be used.

The control parameters *fra-ntones* (see clause 13.3.1.1.1.2), *fra-rtx-uc* (see clause 13.3.1.1.1.3), and *fra-time* (see clause 13.3.1.1.1.1) are derived from the DPU-MIB parameters FRA-NTONES, FRA-RTX-UC, and FRA-TIME. The value zero for FRA-TIME in the DPU-MIB indicates that vendor discretionary values for *fra-ntones*, *fra-rtx-uc*, and *fra-time* may be used instead of the values configured in the DPU-MIB for FRA-NTONES, FRA-RTX-UC, and FRA-TIME, respectively.

The control parameter *fra-vendisc* is equal to the DPU-MIB parameter FRA-VENDISC. The value ONE for FRA-VENDISC indicates that vendor discretionary FRA triggering criteria may be used. The value ZERO for FRA-VENDISC indicates that vendor discretionary FRA triggering criteria shall not be used.

13.3.1.1.1.1 FRA time window (*fra-time*)

The *fra-time* is the duration of the time window used in the standard FRA triggering criteria (see clause 13.3.1.1.1.5). This time window shall be applied to contiguous non-overlapping time steps. The start time of this window is vendor discretionary. The valid range of non-zero values is from one logical frame length to the length of three superframes (24 logical frames for M_F=36, 36 logical frames for M_F=23) in steps of one logical frame length. The special value zero shall be used to indicate that both monitoring of the percentage of degraded subcarriers (see clause 13.3.1.1.1.2) and monitoring of the number of *rtx-uc* anomalies (see clause 13.3.1.1.1.3) are disabled. In this case, FRA can only be triggered by the vendor discretionary FRA criteria (see clause 13.3.1.1.1.4), if enabled.

NOTE – Due to computation and response times, FRA takes effect later than the set value of *fra-time*. The setting of *fra-time* should take this into account. The setting of *fra-time* relative to *delay_max_0* may impact the performance of the retransmission mechanism.

The *fra-time* defined for the downstream and upstream are denoted as *fra-time-ds* and *fra-time-us*, respectively, which are derived from the DPU-MIB parameters FRA-TIMEds, FRA-TIMEds.

13.3.1.1.1.2 Minimum percentage of degraded tones (*fra-ntones*)

The *fra-ntones* is the minimum percentage of loaded subcarriers (i.e., subcarriers with b_i>0 or m_i>0) that are detected as degraded throughout a time window equal to *fra-time* in order to arm the first FRA triggering criteria (see clause 13.3.1.1.1.5).

A degraded subcarrier is a subcarrier that has been identified as needing a reduction in active bit loading because, with its current active bit loading, it is expected to contribute substantially to the decrease of SNRM. The valid range of non-zero values is from one to 100 in step of one. The valid value zero shall be used to indicate that monitoring of the percentage of degraded subcarriers is disabled. If the value of *fra-time* is 0, then the value of *fra-ntones* shall be set to 0.

The *fra-ntones* defined for the downstream and upstream are denoted as *fra-ntones-ds* and *fra-ntones-us*, respectively.

13.3.1.1.1.3 Minimum number of *rtx-uc* anomalies (*fra-rtx-uc*)

The *fra-rtx-uc* is the minimum number of *rtx-uc* anomalies received throughout a time window equal to *fra-time* in order to arm the second FRA triggering criteria (see clause 13.3.1.1.1.5).

The valid range of non-zero values is from 1 to 1 023 in steps of 1. The valid value 0 shall be used to indicate that monitoring of the number of *rtx-uc* anomalies is disabled. If the value of *fra-time* is 0, then the value of *fra-rtx-uc* shall be set to 0.

The *fra-rtx-uc* defined for the downstream and upstream are denoted as *fra-rtx-uc-ds* and *fra-rtx-uc-us*, respectively.

13.3.1.1.1.4 Vendor discretionary criteria (*fra-vendisc*)

The *fra-vendisc* is set to ONE in order to allow vendor discretionary FRA triggering criteria to arm the third FRA triggering criteria (see clause 13.3.1.1.1.5).

If set to ONE, vendor discretionary FRA triggering criteria may be used. If set to ZERO, vendor discretionary FRA triggering criteria shall not be used.

The *fra-vendisc* defined for the downstream and upstream are denoted as *fra-vendisc-ds* and *fra-vendisc-us*, respectively.

13.3.1.1.1.5 FRA triggering criteria

The default setting of BLT status (see Table 9-12) for FRA is aa=00_2, i.e., no adjustment.

The MTU shall initiate an FRA request with BLT status being aa=01_2 or 10_2, for any valid combination of one PDX sub-frame, one operation interval, and one or more DTFO band(s) (see Table 9-12), except for the Band 1 in NOI_{PSF}, if and only if at least one of the following conditions hold:

- The *fra-time*>0 and the *fra-ntones*>0 and the percentage of subcarriers in the MEDLEY SET with b_i>0 or m_i >0 that are degraded throughout a time window equal to *fra-time* is at least *fra-ntones*;
- The *fra-time*>0 and the *fra-rtx-uc*>0 and the number of *rtx-uc* anomalies throughout a time window equal to *fra-time* is at least *fra-rtx-uc*;
- After restoration of a DTFO block by means of preamble signals on the subcarriers of the restored DTFO block;
- The *fra-vendisc* is set to ONE and the vendor discretionary FRA triggering criteria are met;

The MTU shall initiate an FRA request with BLT status being aa=01_2 or 10_2, over the Band 1 in NOI_{PSF}, if and only if after restoration of a DTFO block by means of preamble signals on the subcarriers of the restored DTFO block;

13.3.1.1.2 Parameters controlled by the FRA procedure

The FRA function allows updates to the active bit-loading table of both the NOI and the DOI. These updates are accomplished by a coordinated change to the bits values in the different sub-bands. The parameters controlled by FRA specify a configuration. These parameters are summarized in Table 13-15.

Table 13-15 – Reconfigurable parameters of the FRA function

Parameter	Definition
b_i	The number of bits per subcarrier with valid values all integers in the [0, Maximum bit loading] range, subject to the limitations in clause 13.3.1.1. "Maximum bit loading" is a capability indicated during initialization in the O-MSG 1 and R-MSG 2 messages for the MTU-O and MTU-R, respectively (and denoted "MTU-O maximum bit loading" and "MTU-R maximum bit loading" accordingly).
m_i	The modulation index per subcarrier with valid values all integers in the [0, Maximum bit loading] range, subject to the limitations in clause 13.3.1.1. "Maximum bit loading" is a capability indicated during initialization in the O-MSG 1 and R-MSG 2 messages for the MTU-O and MTU-R, respectively (and denoted "MTU-O maximum bit loading" and "MTU-R maximum bit loading" accordingly).
B_D	The number of DTU bytes in a normal (non-RMC) data frame. According to the FRA command, B_D of NOI or DOI is updated.
B_{DR}	The number of DTU bytes in an RMC data frame. According to the FRA command, B_{DR} of NOI or DOI is updated.

13.3.1.1.3 Timing and synchronization for receiver initiated FRA

Two counts are used to maintain synchronization between the configurations requested via FRA (see Table 9-10 to Table 9-14) at the transmitter and the receiver ends:

1) The 4-bit FRA configuration change count (FCCC) is used to identify the particular configuration to be used. The FCCC shall be incremented by one whenever a new configuration change is initiated by the receiver and shall wrap around at count 1111_2, i.e., incrementing from 1111_2 to 0000_2. In this way, the FCCC serves as a unique identifier for the configuration to be used.

   The FCCC is incremented separately for the NOI_{PSF}, DOI_{PSF} and NOI_{NPSF} active bit-loading tables.

2) The 4-bit FRA logical frame down count (LFDC) is used by the transmitter to indicate when a new configuration shall take effect. The initial LFDC value P0 is first set by the Reply to FRA request command. In the following P0 logical frames the Reply to FRA

commands shall include LFDC values decreased by 1 in every subsequent logical frame. The LFDC value is updated until reaching the value zero which indicates the activation time of the new configuration. The new FRA configuration shall take effect from the first symbol in the logical frame for which the expected LFDC indicated in the reply to FRA RMC command is 0. Further, the MTU shall update the identifier of the active bit-loading table accordingly (see Table 9-5 and Table 9-8 for the current active bit-loading table identifier field and Table 9-13 and Table 9-14 for the reply to FRA request commands).

All FRA requests with the same FCCC shall be considered identical. The transmitter shall discard FRA requests with an FCCC equal to or lower than the one currently in use, taking wraparound into account.

The allowed minimum initial LFDC shall be 1. The maximum bound for the initial LFDC is 15.

Example of a synchronization process for a receiver initiated FRA is given in Table 13-16. It depicts the transition from one FRA configuration (with FCCC = 10) to another one, with FCCC = 11, using the initial LFDC of 3 repeating the FRA change indication 3 times (with LFDC = 2, 1 and 0) by the transmitter before the new FRA configuration takes effect.

Table 13-16 – Example of a synchronization process for a receiver initiated FRA

Logical frame number	Receiver		Transmitter		Comments
	Configuration in use	FRA request command	Configuration in use	Reply to FRA message	
Initial stage	FCCC = 10		FCCC = 10		
1	FCCC = 10	FCCC = 11	FCCC = 10		Receiver initiates FRA request for a new configuration with FCCC = 11.
2	FCCC = 10	FCCC = 11	FCCC = 10		The receiver may repeat the same request using the same FCCC.
3	FCCC = 10		FCCC = 10	FCCC = 11, LFDC = 3	Transmitter replies to the FRA request message with a reply to FRA command and indicates the configuration change after three logical frames.
4	FCCC = 10		FCCC = 10	FCCC = 11, LFDC = 2	
5	FCCC = 10		FCCC = 10	FCCC = 11, LFDC = 1	
6	FCCC = 11		FCCC = 11	FCCC = 11, LFDC = 0	The requested FRA configuration takes effect, the active configuration identifier is FCCC = 11.

13.3.1.2 RMCR procedure

The RMCR procedure is used to restore the RMC in case it fails in either one or both directions using the backup RMC tone set and bit loading (*RTSBL*) and RMCR command (see clause 9.6). The RMCR procedure shall not be triggered if either the MTU-O or MTU-R does not indicate support of

RMCR during initialization (see clauses 12.3.4.2.1 and 12.3.4.2.2) or if RMCR is disabled through the DPU-MIB (see clause 13.3.1.2.3). To execute the procedure, each MTU applies the following rules:

1) If and only if the triggering criteria for RMCR are met (see clause 13.3.1.2.1), the MTU shall transmit the RMCR command and replace its receiver's current *RTSBL* with the backup *RTSBL*. The MTU shall keep sending the RMCR command in every following RMC symbol until the RMC has been recovered (see clause 13.3.1.2.2), which completes the RMCR procedure.

2) If and only if at least one of the following conditions is met, the MTU shall replace its transmitter's current *RTSBL* with the backup *RTSBL*:

   a) An RMCR command is received.

   b) The receive RMC has not recovered within 100 ms after applying the backup *RTSBL* to the receiver (as described in the previous bullet).

If the receive RMC has recovered (see clause 13.3.1.2.2), the RMCR procedure completes, the MTU shall stop sending the RMCR command, and may then update its backup *RTSBL* by using the eoc command "Update backup RTSBL" (see clause 11.2.2.20) as needed, and may use RPA to update its current *RTSBL* as needed.

NOTE – If RMC in one or both directions does not recover, the MTU will end up in re-initialization due to *lor* persistency (see clause 12.1.4.2).

13.3.1.2.1 RMCR triggering criteria

The MTU shall declare the receive RMC severely degraded if a *lor* defect persists for a period that is greater than or equal to *rmcr_lor_trigger*. The control parameter *rmcr_lor_trigger* shall be set to the same value as the configuration parameter RMCR_LOR_TRIGGER in the DPU-MIB. The parameter in the downstream direction is *rmcr_lor_trigger-ds*, and the parameter in the upstream direction is *rmcr_lor_trigger-us*. The valid range of *rmcr_lor_trigger* for both directions is defined in Table 13-17.

The MTU-R shall not trigger RMCR if the current downstream *RTSBL* is the same as the backup downstream *RTSBL*.

The MTU-O shall not trigger RMCR if the current upstream *RTSBL* is the same as the backup upstream *RTSBL*.

With PCS-LCM, an RMCR can modify the baseline bit-loading table as specified in clause 13.2.1.3.4.

13.3.1.2.2 RMCR recovery criteria

The MTU shall declare the receive RMC recovered when the *lor* defect terminates.

13.3.1.2.3 Parameters controlling the RMCR procedure

The DPU-MIB parameters controlling the RMCR procedure in both directions are presented in Table 13-17. The values of relevant parameters are communicated to the MTU-R during initialization (in O-MSG 1 and O-PMD messages).

Table 13-17 – DPU-MIB parameters controlling the RMCR procedure

MAXBL-RMC	The maximum bit loading (b_i) or modulation index (m_i) allowed for RMC subcarriers. The valid values for *MAXBL-RMCus* and *MAXBL-RMCds* in case of TCM are integer values from 2 to 6. The valid values for *MAXBL-RMCus* and *MAXBL-RMCds* in case of PCS-LCM are integer values from 1 to 4.
RMCR_LOR_TRIGGER	The persistency period of a *lor* defect to declare the receive RMC severely degraded. The valid values for *rmcr_lor_trigger-us* and *rmcr_lor_trigger-ds* are from 0 to 1000 ms in steps of 50 ms. Zero is a special value to disable the RMCR procedure. *rmcr_lor_trigger-us* shall be set to 0 if and only if *rmcr_lor_trigger-ds* is set to 0.
RMCCARMASK	The *RTS-b* shall not include subcarriers from the frequency bands (including start and stop frequencies) defined through the RMCCARMASK in the DPU-MIB.
NOTE – The setting for *rmcr_lor_trigger* for both upstream and downstream shall be less than the corresponding value of parameter *lor_persistency* in the corresponding transmission direction (see clause 12.1.4.3.3) by at least 200 ms.	

13.3.1.2.4 Parameters controlled by the RMCR procedure

The RMCR procedure replaces the current *RTSBL* with the backup *RTSBL* (which is determined at initialization and which may be updated during showtime). Change of *RTSBL* modifies the set of *RTS* subcarriers and their bit loading. The details of these adjustments are described in Table 13-18.

Table 13-18 – Reconfigurable parameters of the RMCR function

Parameter	Definition
RMC tone set (*RTS*)	Set of subcarriers to be loaded with RMC data after RMCR procedure is complete. The number of subcarriers used shall not exceed 512.
$b_{RMC\text{-}i}$	With TCM, the number of bits per RMC subcarrier with valid values of 0 and from 2 to 6.
$m_{RMC\text{-}i}$	With PCS-LCM, the modulation index per RMC subcarrier with valid values from 0 to 4.

Both the receiver and the transmitter shall support all valid $b_{RMC\text{-}i}$ and $m_{RMC\text{-}i}$ values and shall support any change of these values provided the resulting $b_{RMC\text{-}i}$ or $m_{RMC\text{-}i}$ value is within the specified valid range. The values of $b_{RMC\text{-}i}$ and $m_{RMC\text{-}i}$ shall also not exceed the DPU-MIB parameter MAXBL-RMC for the corresponding direction of transmission.

The backup *RTSBL* determined during initialization (see clauses 12.3.4.2.7 and 12.3.4.2.8) can be modified during showtime (see clause 11.2.2.20).

When the *RTS* switches to the setting of the *RTSBL* with TCM, the re-ordered tone table of the RMC symbol shall be recomputed as specified in clause 10.2.1.2.

When the *RTS* switches to the setting of the *RTSBL* with PCS-LCM, a new baseline bit loading shall be constructed as specified in clause 13.2.1.3.2. The new baseline bit-loading table shall use the same SCCC as the old baseline bit-loading table and any FRA adjustment on the old baseline bit-loading table shall also apply on the new baseline bit-loading table. Based on the new baseline bit-loading table, the new bit-loading and re-ordered tone table of the RMC and data symbol shall be recomputed as specified in clause 10.2.1.3

13.3.1.2.5 Timing and synchronization of RMCR

The eoc command "Update backup RTSBL" shall not be sent from either one of the MTUs while the RMCR procedure is ongoing.

While an RMCR procedure is ongoing, an MTU shall not initiate RPA.

If RMCR is triggered by an MTU, any ongoing RPA procedure for changing the current *RTSBL* (on the receive side) shall be aborted.

If an MTU received an RMCR command, while an RPA procedure is ongoing, i.e., this MTU was requested to perform an RPA parameter update, this RPA parameter update shall be aborted.

With PCS-LCM, the new baseline bit-loading table, if applicable, shall be applied together with the backup *RTSBL*.

13.3.2 Transmitter initiated procedures

13.3.2.1 FRA procedures

For further study.

13.4 Low power operation

The low power operation at times when user data traffic is low, is facilitated by the discontinuous operation (clause 10.7.1) and DTFO (clause 10.7) functionalities. The need for additional low power states (e.g., as defined in [b-ITU-T G.9701]) is for further study.

13.5 DBR procedure

13.5.1 Background

Both downstream and upstream DBR operation of a P2MP group comprises all MTU-Rs connecting to the same MTU-O via multiple links established over a transmission line.

The P2MP operation is facilitated using the principle of frequency division multiple access in Band 0: every MTU-R is assigned a frequency band which is a part of the total bandwidth used on the transmission line and shared by the P2MP group, and the frequency bands assigned to different MTU-Rs of a P2MP group do not overlap in Band 0. The subcarriers in Band 1 can be used only by one path at a time through DTFO (see clause 10.1.2).

To facilitate this approach, the total bandwidth of the transmission line, shared by the P2MP group is represented as a set of non-overlapping sub-bands. Each sub-band is a set of two or more subcarriers. The set of sub-bands is assigned at initialization and can be updated during showtime; it is determined by the DRA using a DBR Sub-band Description procedure (DBR-SD). The associated initialization message and eoc message, respectively, use a sub-bands descriptor in Table 13-19, that describes sub-bands in the order of associated subcarrier indices. The maximum number of sub-bands shall not exceed 32.

A DBR sub-band descriptor (SD) is defined separately for upstream and downstream.

Table 13-19 – DBR sub-bands descriptor (SD)

Byte	Content of field (Note)
1	Number of sub-bands to be described.
2-5	Bits 0-15: Index of the start subcarrier in sub-band 1 (lowest frequency of sub-band 1). Bits 16-31: Index of the stop subcarrier in sub-band 1 (highest frequency of sub-band 1).
6-9 (if applicable)	Bits 0-15: Index of the start subcarrier in sub-band 2 (lowest frequency of sub-band 2). Bits 16-31: Index of the stop subcarrier in sub-band 2 (highest frequency of sub-band 2).

etc.	etc.
NOTE – All values shall be represented as unsigned binary integers.	

The first byte of the descriptor shall contain the number of sub-bands being specified (from 1 to 32, inclusive). Each group of four consecutive bytes describes the start and the stop subcarrier indices of the sub-band. For 424-MHz profile both indices are in the range between 43 and 8191, inclusive. The minimum total number of active subcarriers in the sub-bands assigned for any active MTU-R shall be at least 512.

Each sub-band description is assigned a sub-band description index (SDI). The valid values for SDI are 0 and 1. The sub-band description that is set at initialization and shall be used at the start of the showtime is assigned SDI=0. Every update of the sub-band description shall use SDI value that is the complement of the current (active) SDI.

NOTE – SDI distinguishes between the currently used sub-band description and the sub-band description intended for use after the next DBR-R procedure.

The frequency band assigned to a particular path/MTU-R consists of a set of active sub-bands. For each path the associated sub-bands are defined by the DRA/MTU-O at initialization and can be updated during showtime using a DBR-PR command, which contains the sub-bands assignment (SA) descriptor formatted as a bit map according to Table 13-20 followed by a DBR-R RMC command.

Table 13-20 – Sub-band assignment (SA) descriptor

Bytes	Content of field
byte 0: [b7:b0] byte 1: [b15:b8] byte 2: [b23:b16] byte 3: [b31:b24]	Sub-Band Assignment descriptor formatted as a 32-bit map [b31:b0]. Bit b0 relates to the sub-band 1, bit b1 to sub-band 2, etc… Bits set to one signify active sub-bands assigned to the MTU-R (those intended to be used for transmission). Bits set to zero signify inactive (unused) sub-bands, i.e., those that shall not be used for transmission, except sync symbols.

A sub-band in Band 0 may be assigned as an active sub-band to only one MTU-R of a P2MP group at any given time; MTU-Rs operating in different P2MP groups may use overlapping active sub-bands.

The DBR procedure defined in Clause 13.5.2 seamlessly modifies the frequency bands of the MTU-Rs during showtime, in both upstream and downstream directions. The frequency band assigned to a particular MTU-R may be either increased or reduced due to bandwidth taken from or granted to other MTU-Rs. This could be done by changing the set of active sub-bands assigned to a particular MTU-R, i.e., switching active sub-bands from one MTU-R to another, adding new active sub-bands, or removing existing ones, or by changing the boundaries of one or more sub-bands.

The DBR procedure is controlled by the MTU-O (under supervision of the DRA and VCE): The DRA is responsible for tracking and coordinating bandwidth requirements in the upstream and downstream for each MTU-R of the P2MP group and re-assigning the sub-bands of MTU-Rs accordingly. The MTU-O may also assign additional bandwidth in response to a request from the MTU-R. The allocation of downstream and upstream sub-bands may vary over time, depending on the traffic needs, within the bounds determined by the ME and the PCE.

The RMC subcarriers are not a subject for re-assignment by the DBR. If necessary, the RMC subcarriers may be re-assigned before the DBR procedure or after the DBR procedure is complete by initiating an RPA procedure. The MTU-O initiates downstream RPA procedure using the eoc command DBR-RMC defined in clause 11.2.2.26.

13.5.2 Downstream DBR procedure

Since downstream is broadcasted to all connected MTU-Rs, no changes of crosstalk channels into other transmission lines are expected as a result of downstream DBR. Thus, downstream DBR in a given link of the transmission line does not necessarily require modification of the transmit downstream PSD in any link of this line and the precoders in this and other lines may stay unchanged.

However, pre-compensation signals in the link that is subject to downstream DBR may not be suitable for the granted subcarriers, and thus may need to be updated for performance optimization. This requires a precoder update in the entire vectored binder, and can be done by the VCE upon the DBR procedure or by using TIGA command(s) after the DBR procedure. Further, if the beneficiary MTU-Rs intend to use the granted subcarriers in FDX mode, their local echo-canceller has to be adjusted.

The functional timeline illustrating downstream DBR is presented in Figure 13-9. It includes three groups of functions: the DBR preparation, the DBR, and the post-DBR performance adjustment.

The preparation and performance adjustment are auxiliary background functions, assisting the DBR procedure. Parts shaded blue and green during the preparation for DBR are applied on the discretion of the MTU-O and VCE.

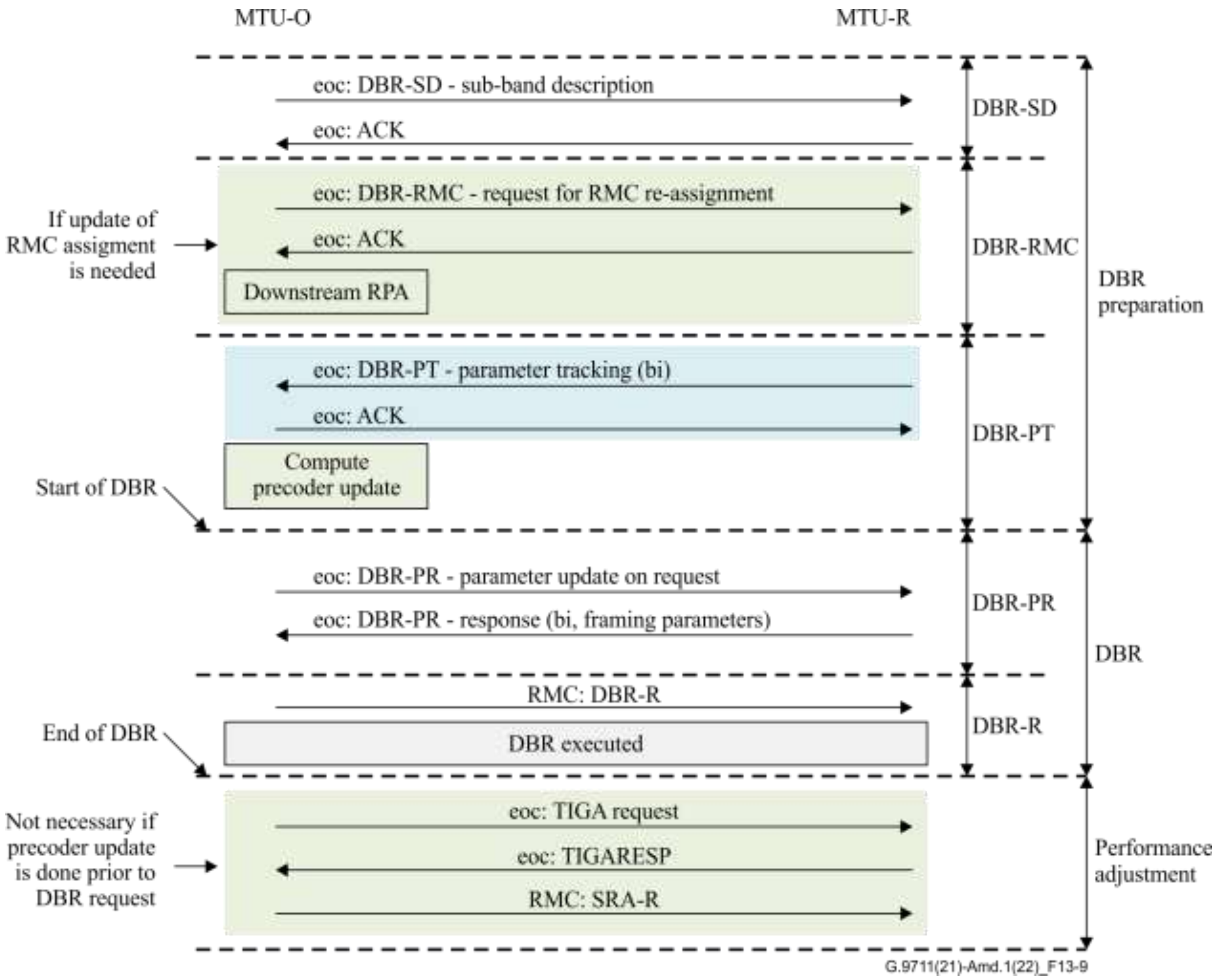


Figure 13−9 – Functional timeline of downstream DBR

The DBR preparation includes the following functionalities:

1) Update of the DBR sub-band description (DBR-SD)

It is performed by using DBR-SD eoc exchange if future update of the sub-band boundaries is required in the P2MP group (see clauses 13.5.1 and 13.5.2.2.1). The eoc exchange is initiated at the discretion of the MTU-O.

2) Update of the RMC assignment

If needed, this is performed by using the DBR-RMC command that requests the MTU-R to confine the RMC subcarriers within the requested frequency band that is suitable for the upcoming DBR (see clause 13.5.2.2.4), by using a standard downstream RPA procedure. The RMC re-assignment is initiated at discretion of the MTU-O.

3) DBR parameter tracking (DBR-PT)

This is an eoc exchange supporting continuous alignment of the downstream bit-loading tables between the MTU-O and all MTU-Rs of the P2MP group. The exchange is initiated at the discretion of the MTU-Rs, upon changes in the received signals detected by the MTU-Rs (see clause 13.5.2.2.2). The support of DBR-PT is optional for the MTU-O, and mandatory for the MTU-R if the MTU-R supports P2MP operation.

4) Precoder tracking

The VCE may constantly track the changes in the precoders of some or all of the sub-bands used by the P2MP group. The updates may be used to adjust the bit-loading and pre-compensation signals on granted subcarriers. The computation of precoder update is on the discretion of the MTU-O and the VCE.

The downstream DBR procedure includes the following functionalities:

1) The DBR parameter request (DBR-PR)

The DBR-PR eoc exchange is initiated by the MTU-O to obtain the downstream bit loading on all subcarriers, pilot tone settings, framing and other transmission parameters associated with the DBR from the MTU-R (see clause 13.5.2.2.3). If bit loading on subcarriers associated with the DBR is available prior to the DBR request (in case the MTU-O applies downstream DBR-PT function, which is optional for the MTU-O), a shortened version of DBR-PR response can be used (see clause 11.2.2.23).

2) The DBR request (DBR-R) RMC command

This command indicates the actual sub-bands to be used by the MTU-R (see clause 9.6.4). After reception of this command and associated down-count, both MTU-s forming the path simultaneously modify their downstream frequency band accordingly with the new SA communicated in the DBR-PR request command.

The post-DBR performance adjustment may include standard OLR procedures, such as TIGA or SRA, as well as adjustment of local echo cancellers in FDX mode (see clause 13.5.2.2.5).

13.5.2.1 The DBR procedure

With a completed DBR preparation, upon a DBR request, the MTU-O and all the MTU-Rs of P2MP group possess aligned DBR sub-band descriptions , while the VCE may also possess the necessary precoder updates to support bandwidth redistribution.

Via a DBR-PT exchange, the MTU-O and all the MTU-Rs of P2MP group may possess aligned downstream bit loadings for all subcarriers potentially involved in the DBR.

If some bit loadings are missing (due to no or incomplete DBR-PT exchange), theMTU-O shall request the bit-loading tables for subcarriers of specific sub-bands and also the associated framing parameters and pilot tones settings from this MTU-R using the DBR-PR procedure defined in clause 13.5.2.2.3. The DBR-PR eoc exchange provides the MTU-R with the actual SA and provides alignment of the bit loading, pilot tones settings, framing and other transmission parameter settings with the MTU-O.

Further, with the aim of speeding up downstream DBR procedure, the update of the precoder and echo canceller are performed after the DBR procedure, when new bands are enabled for all MTU-Rs.

The downstream DBR procedure shall comprise the following steps.

1) The DRA, as it determines the necessity in bandwidth re-distribution and identifies the set of subcarriers to be granted to each beneficiary MTU-R, sends to the MTU-O a request to initiate the downstream DBR procedure via a primitive DBR-R.request (see clause 8.1.1). This primitive contains the following parameters:
   – CNT_{LF} : the logical frame count on which bandwidth redistribution shall take effect.
   – *SDI* of the relevant sub-band descriptor (see Table 13-19);
   – *SA* to be applied by each MTU-R (see Table 13-20).

The DBR-R.request primitive shall be sent by the DRA to the MTU-O that is subject to DBR at least 96 logical frames before the beginning of the logical frame with the targeted logical frame count CNT_{LF} for the particular link.

2) The MTU-O, upon reception of the DBR-R.request primitive, initiates the DBR-PR procedure (see clause 13.5.2.2.3) that retrieves from each MTU-R the transmission parameters for the relevant subcarriers of the requested SA.
3) The MTU-O performs bandwidth redistribution by sending to all associated MTU-Rs from the P2MP group a DBR-R RMC command, that indicates to each MTU-R of the group the following parameters:
   • *DBRLFDC*: The DBR down count value, selected so that the down count reaches 0 at the downstream logical frame indicated by the corresponding DBR-R.request primitive (CNT_{LF}). For the downstream DBR procedure, the valid range of the initial value for *DBRLFDC* shall be from 8 (*min_init_DBRLFDC*) to 15, inclusive.
   • *DBRCCC:* the associated downstream DBR configuration change count.
   • *SDI:* Index of relevant sub-band description.

The DBR-R commands sent to all MTU-Rs of all P2MP groups that belong to the same vectored group shall be aligned in time, e.g., sent during the same RMC symbol period.

NOTE – The DBR procedure may assign to MTU-Rs different sub-bands within the currently active SD by using an SDI value of the active SD, but may also change the sub-bands boundaries by switching to a non-active SD by using an SDI value that is the complement of the SDI value of the active SD.

4) At the start of the indicated logical frame, both the MTU-O and all involved MTU-Rs switch to their new sub-band assignments determined by the requested SA and the SD values (indicated in the DBR-R command), and the new bit loadings on granted subcarriers, and new precoder settings (if available). All these changes shall take effect starting from the RMC symbol of the logical frame for which the *DBRLFDC* reaches 0. From this moment the DBRCC at both MTU-O and MTU-Rs shall be updated to the value indicated in DBR-R command.
5) The MTU-O indicates the completion of the DBR procedure to the DRA via the DBR-R.confirm primitive. After this step, the DRA may initiate downstream performance adjustment procedures (see Figure 13-9), as specified in clause 13.5.2.2.5.

The MTU-O shall not initiate other normal high priority messages commands (e.g., SRA, bitswap) until the DBR procedure has completed successfully (i.e., after the DBR-R RMC command) has failed due to rejection or has timed-out.

13.5.2.2 Auxiliary procedures related to downstream DBR

13.5.2.2.1 DBR-SD procedure

This procedure is intended to update the description of the sub-band boundaries and comprises the following steps.

1) The DRA, via the primitive DBR-SD.request sends to the MTU-O a request to initiate a DBR-SD, after the DRA has determined the need to change the current sub-bands boundaries.
2) Upon reception of the request, the MTU-O sends to all MTU-R(s) of a P2MP group a DBR-SD request eoc command that indicates the new sub-bands description for the future SD (see Table 11-67). This SD is non-active and gets an SDI value that is the complement of the SDI value one of the currently active SD.
3) Each MTU-R, upon reception of the DBR-SD request command, may either positively acknowledge or reject the request by using the response listed in Table 11-68.

The SD update is valid only after all MTU-Rs of the P2MP group have accepted the request. The updated non-active SD is stored at the MTU-O and all MTU-Rs of the P2MP group and shall have no effect on the active SD.

13.5.2.2.2 DBR-PT procedure

This is a procedure supporting the continuous alignment of the downstream bit-loading tables on all subcarriers of all sub-bands between the MTU-O and all MTU-Rs of the P2MP group. All the MTU-Rs of the P2MP group shall continuously perform tracking of SNR and estimated bit loading on all subcarriers of all the downstream sub-bands.

The report of the downstream bit loading is initiated at the discretion of the MTU-R, upon changes detected by the MTU-R. The DBR-PT eoc command (see clause 11.2.2.28) communicates to the MTU-O the estimated bit-loading values on all subcarriers of the MEDLEYGds set that are expected to be relevant for the upcoming DBR. The MTU-O acknowledges reception of the command or indicates if the content is invalid.

NOTE – The MTU-R can track the SNR and derive the estimated bit loading for subcarriers that are outside of its P2MPOB (determined by the currently applied SA) on the corresponding subcarriers of the downstream sync symbols.

Upon receiving the SA assignment, both MTU-O and MTU-R generate downstream bit-loading tables autonomously from the bit-loading values determined by DBR-PT exchange and the current bit-loading table used in the P2MPOB band, using the following rules:

– the downstream RMC tone set and corresponding bit loading shall stay unchanged;
– the boundaries of the Band 0 and Band 1 shall stay unchanged;
– all subcarriers that belong to the requested SA and part of the MEDLEYGds set shall be a part of the bit-loading table;
– all sub-carriers that belongs to the current P2MPOB band shall use the bit loading of the actual base line bit-loading table. Those value shall be further modified according to the bullets below.
– in case of using TCM, tones shall be ordered as defined in clause 10.2.1.2.1; even number of 1-bit constellations shall be reached by discarding the 1-bit subcarrier with the highest index, in both Band 0 and Band 1;

– in case of using PCS-LCM, tones shall be ordered as defined in clause 10.2.1.3.2. To form an SCI=2 group with the number of subcarriers multiple to *K*, up to *K*-1 subcarriers with highest indices that belong to SCI=2 shall be assigned m_i=5 and thus become SCI=1 subcarriers. Similarly, up to *K*-1 subcarriers with highest indices that belong to SCI=1 shall be assigned m_i=4 and thus become SCI=0 subcarriers. This shall be performed in both Band 0 and Band 1.

13.5.2.2.3 DBR-PR procedure

The procedure is intended to be used by the MTU-O to obtain the downstream framing and transmission parameters and optionally the bit loading on all subcarriers associated with the DBR from the MTU-R, as well as to indicate the downstream pilot tone settings. The procedure shall use the following parameters of the DBR-R.request primitive sent to the MTU-O:

– *SDI* of the relevant sub-band description (see Table 13-19);

– *SA* for each MTU-R (see Table 13-20).

The procedure shall comprise the following steps:

1) Upon reception of the DBR-R.request primitive, the MTU-O shall send to all the related MTU-Rs the DBR-PR request eoc command (see clause 11.2.2.23) that requests the downstream framing and transmission parameters (see Table 11-69) and optionally the bit loadings for the set of subcarriers in the SA indicated in the DBR-PR request eoc command for each beneficiary MTU-R (in case these downstream bit loadings are not available at the MTU-O), and indicates pilot tone groups used by other MTU-Rs of the P2MP group within the downstream band granted to the MTU-R and the out-of-band pilot tone groups that the MTU-R shall release for data transmission by other MTU-Rs. The MTU-O may send a DBR-PR command to any MTU-R that is not subject for this DBR as well.

2) Upon reception the DBR-PR request command, each of the beneficiary MTU-R(s) responds by indicating to the MTU-O the proposed bit loadings, the additional requested pilot tones within the newly granted part of the downstream band, framing and other transmission parameters in a DBR-PR response (see Table 11-73). In case downstream bit loading is available at both MTU-O and MTU-R via DBT-PT exchange, a shortened version of DBR-PR response can be used (see clause 11.2.2.23). The MTU-R may reject the DBR request in cases defined in Table 11-73.

3) The procedure is complete after the MTU-O collects acknowledgement responses from all the MTU-Rs.

Once the MTU-R receives a downstream DBR-PR request command, no downstream OLR type 1 or 2 shall be initiated by the MTU-R until the DBR-R command is complete. If the MTU-O receives from the MTU-R an OLR request type 1 or type 2 during or after transmission of DBR-PR request, it shall reject the OLR request using corresponding reject response (see Table 11-19) with reason code "wait" until the DBR-R procedure is complete.

NOTE – It is expected that in the aim to speed up starting the DBR-PR, the MTU-O may reject already received OLR requests of type 1 or type 2 because the modification of transmission parameters implied by this request will likely be irrelevant.

13.5.2.2.4 DBR-RMC procedure

The procedure is intended to modify downstream RMC tone set prior to a DBR procedure in the aim to keep RMC functional through the DBR procedure. The DBR-RMC procedure (see clause 11.2.2.26) is intended to be performed prior to the DBR procedure, as a part of DBR preparation, after the DBR-SD procedure. The DBR-RMC procedure bounds the RMC subcarriers within the frequency band that is available for the MTU-R both before and after the upcoming DBR procedure. This frequency band is determined by both the current and the upcoming *SA* settings (see clause 13.5.1).

The DBR-RMC procedure is performed after the DBR-SD procedure that determines the available RMC frequency band. The procedure shall comprise the following steps:

1) Upon reception of the DBR-RMC.request primitive, the MTU-O DBR-RMC procedure is initiated by the MTU-O sending to the MTU-R the DBR-RMC request eoc command (see clause 11.2.2.26) that indicates to the MTU-R the frequency band in which all downstream RMC subcarriers that belong to the particular path served by the MTU-R should reside. The MTU-O evaluates the sufficiency of the proposed frequency band to carry RMC (based on the routine channel estimation).
2) The MTU-R responds to DBR-RMC request with ACK if it can successfully allocate the RMC within the proposed frequency band and responds with NACK if it cannot or if the parameters indicated in DBR-RMC are invalid. In the event that the MTU-R is unable to allocate sufficient number of RMC tones in the proposed frequency band, it shall communicate the MTU-O the number of remaining unallocatedRMC bits.
3) After responding by ACK, the MTU-R shall initiate an RPA command that modifies the RMC tones accordingly. The MTU-R shall initiate the RPA at its first opportunity.
4) After receiving a NACK respond due to no possibility to allocate the RMC from at least one MTU-R, the DRA shall defer the DBR procedure. The DRA may request to repeat the DBR-RMC procedure, presumably widening the frequency band to allocate RMC tones for remaining unallocated RMC bits reported by the MTU-R. In the aim to reach wider frequency band for RMC for a particular MTU-R, the DRA may need to modify the *SA* or modify the sub-band assignment by running again a DBR-SD procedure.
5) The MTU-O passes the received ACK to DRA using the DBR-RMC.confirm primitive. This completes the DBR-RMC procedure for a particular link.

After performing DBR-RMC procedures over all links and receiving ACK responses from all requested MTU-Rs, the DRA may initiate the DBR procedure.

13.5.2.2.5 Downstream post-DBR performance adjustment stage

In the post-DBR performance adjustment stage (see Figure 13-9), various performance adjustments may be executed:

1) The MTU-O (under coordination from the VCE) may initiate a precoder update using a standard TIGA procedure. This TIGA procedure may be optionally executed, if the precoder update on subcarriers associated with the DBR is not available prior to the DBR request by the DRA (e.g., in case the DPU (MTU-O/VCE) does not support precoder tracking during the DBR preparation stage).
2) The MTU-Rs may initiate one or more autonomous SRA procedures (OLR Request Type 1) in the aim to adjust the bit loading.
3) The beneficiary MTU-Rs that intend to use the granted subcarriers in FDX mode may also adjust their local echo-cancellers. Further, the upstream transmit PSDs of the links of other lines may also be adjusted (for NEXT mitigation into the beneficiary MTU-Rs).

NOTE – It is expected that the initial bit-loading settings applied to all new granted subcarriers used in FDX mode are rather conservative (since it's prior the adjustment of echo cancellers and NEXT mitigation).

13.5.3 Upstream DBR procedure

Switching upstream subcarriers from one MTU-R to another may increase residual crosstalk in other transmission lines of the vectored group. This relates to the upstream FEXT, to the echo/NEXT at the MTU-R and even to the echo/NEXT at the DPU side if transmission lines are sufficiently short.

To avoid increase of residual crosstalk, the postcoder, the transmit PSDs of the MTU-Rs, and the echo/NEXT canceller at the DPU, and the echo canceller at the beneficiary MTU-R need to be adjusted upon DBR. This requires update of channel estimation and of the postcoder, of echo/NEXT cancellation/mitigation coefficients, and of gains and bit loadings on all granted subcarriers of all MTU-Rs of the vectored group that are involved in DBR prior to the DBR procedure. If VCE and MTU-O are not capable of routinely handling the updates of all these parameters continuously, their computation and related channel estimation have to be done after the DBR procedure, while DBR is performed with low bit loading and reduced MTU-R gain settings on granted subcarriers to avoid degradations in other transmission lines.

The functional timeline illustrating the upstream DBR is presented in Figure 13-10. It contains three groups of functions: the DBR preparation, the DBR, and the post-DBR performance adjustment. The preparation and performance adjustment are auxiliary background functions, assisting the DBR procedure. Parts shaded blue and green during the preparation for DBR are applied on the discretion of the MTU-O and VCE.

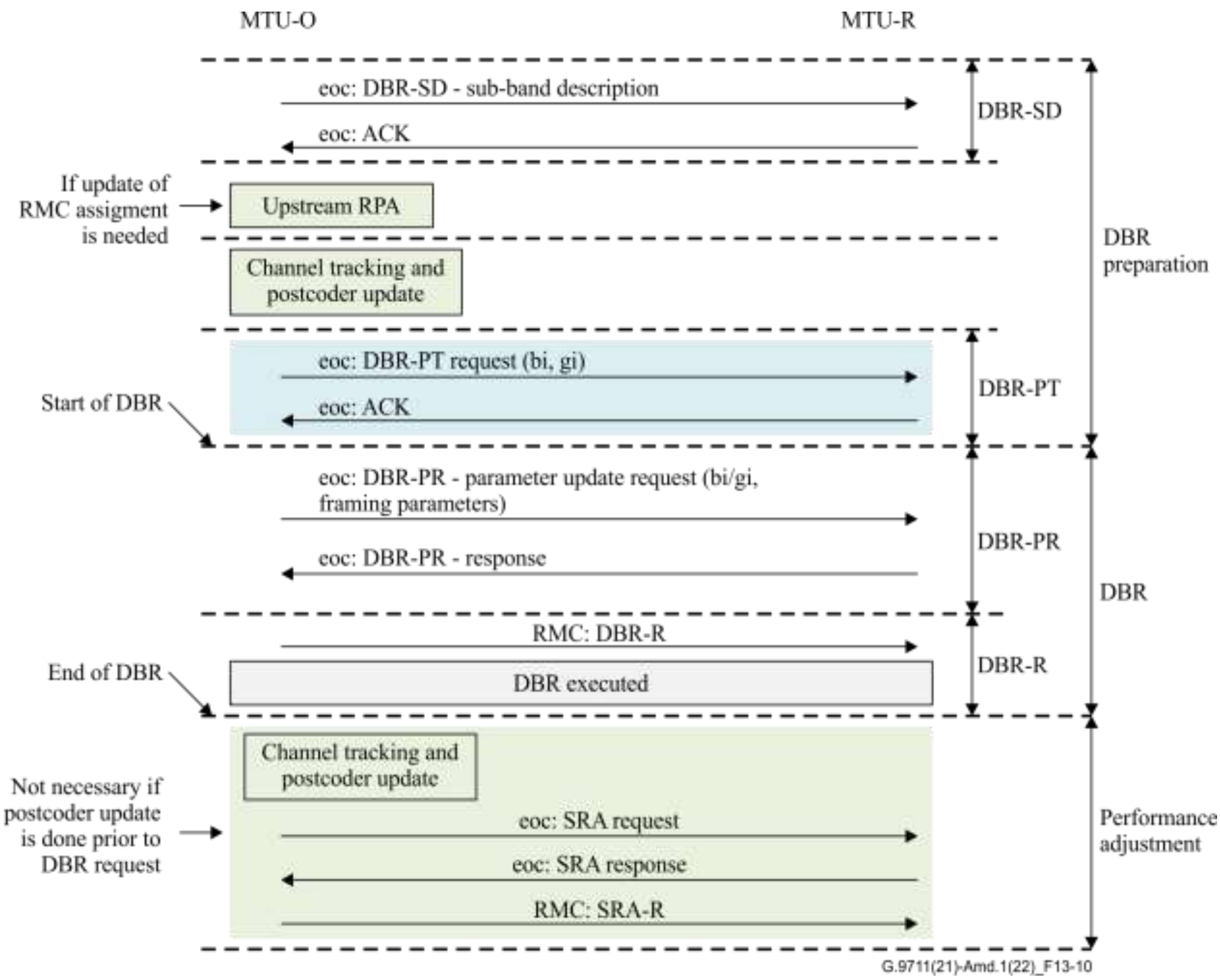


Figure 13-10 – Functional timeline of upstream DBR

The DBR preparation includes the following functionalities:

1) Update of the DBR sub-band description (DBR-SD)

It is performed using DBR-SD eoc exchange if future update of the sub-band boundaries is required in the P2MP group (see clause 13.5.1 and 13.5.3.2.1). The eoc exchange is initiated on discretion of the MTU-O.

2) Update of the RMC assignment

If needed, this is performed by using a standard upstream RPA procedure. The RPA re-assignment is initiated at the discretion of the MTU-O.

3) Postcoder tracking

The VCE may continuously track the channel and changes in the postcoder in all or part of the sub-bands used by the P2MP group. The updates may be used to adjust the bit loading and gains on granted subcarriers. The computation of postcoder update is on the discretion of the MTU-O and the VCE.

4) DBR parameter tracking (DBR-PT)

The MTU-O receiver may continuously derive and maintain updates for the upstream transmission parameters, i.e., bit-loading tables, gains between the MTU-O and each of MTU-Rs of the P2MP group. The eoc exchange provides alignment of transmission parameters between the MTU-O and all MTU-Rs of the P2MP group (see clause 13.5.3.2.2). The support of DBR-PT is optional for the MTU-O and mandatory for the MTU-R if the MTU-R supports P2MP operation.

The upstream DBR procedure includes the following functionalities:

1) The DBR parameter request (DBR-PR)

The DBR-PR eoc exchange is initiated by the MTU-O to indicate the upstream transmission parameters (bit loading and fine gains on subcarriers associated with the DBR, and framing and other transmission parameters) to each MTU-R of P2MP group that is involved in the DBR (see clause 13.5.3.2.3). If bit loading and fine gains associated with the DBR are available prior to the DBR-PR is sent (in case the MTU-O supports upstream DBR-PT function by tracking the postcoder settings and maintaining transmission parameters, which is optional for the MTU-O), a shortened version of DBR-PR request can be used (see clause 11.2.2.23).

2) The DBR request (DBR-R) RMC command

This command indicates the actual sub-bands to be used by the MTU-R (see clause 9.6.4). After reception of this command and associated down-count, both MTU-s forming the path simultaneously modify their upstream frequency band accordingly with the new SA communicated in the DBR-PR.

The post-DBR performance adjustment may include standard SRA procedures, as well as adjustment of local echo cancellers in FDX mode (see clause 13.5.3.2.4).

13.5.3.1 The DBR procedure

With a completed DBR preparation, upon a DBR request, the MTU-O and all the MTU-Rs of P2MP group possess aligned DBR sub-band descriptions , while the VCE may also possesses the necessary postcoder updates and echo/NEXT canceller updates to support bandwidth redistribution.

If post-coder updates on granted subcarriers are not available upon DBR request, with the aim of speeding up the upstream DBR procedure, the channel estimation and update of the postcoder and of the echo/NEXT canceller, are performed after the DBR, when updated sub-band assignments are enabled to all MTU-Rs.

NOTE – It is expected that before that update substantially reduced gains and very conservative bit loadings are applied on all newly granted subcarriers.

Via a DBR-PT exchange, the MTU-O and all the MTU-Rs of P2MP group may possess aligned upstream bit loadings and fine gain tables for all subcarriers potentially involved in the DBR. If some bit loadings are missing (due to no or incomplete DBR-PT exchange), the MTU-O shall compute these missing parameters for each MTU-R for specific sub-bands and communicate them to each corresponding MTU-R using the DBR-PR procedure defined in clause 13.5.3.2.3. The DBR-PR eoc exchange provides the MTU-R with the actual SA and provides alignment of the bit loading and fine gains (if not or incompletely obtained during DBR preparation), and framing and other transmission parameter settings with the MTU-O.

The upstream DBR procedure shall comprise the following steps.

1) The DRA, as it determines the necessity in bandwidth re-distribution and identifies the set of subcarriers to be granted to each beneficiary MTU-R sends to the MTU-O a request to initiate the upstream DBR procedure via a primitive DBR-R.request (see clause 8.1.1). This primitive contains the following parameters:

   – CNT_{LF} : the logical frame count on which bandwidth redistribution shall take effect.

   – *SDI* of the relevant sub-band descriptor (see Table 13-19);

   – *SA* to be applied by each MTU-R (see Table 13-20).

The DBR-R.request primitive shall be sent by the DRA to the MTU-Os that are subject to DBR at least 96 logical frames before the beginning of the logical frame with the targeted logical frame count CNT_{LF} for the particular link.

2) The MTU-O, upon reception the DBR-R.request primitive, initiates the DBR-PR procedure (see clause 13.5.3.2.3) that indicates to each MTU-R the transmission parameters for the relevant subcarriers of the requested SA.

   NOTE 1 – If no postcoder update on granted subcarriers is available, the MTU-O can use reduced gains on granted subcarriers to avoid crosstalk into other transmission lines of the vectored group, as described in Note 3-1. Alternatively, updates of the post-coder could be performed in Step 2 of the procedure, as described in Note 3-2.

3) The MTU-O performs bandwidth redistribution by sending to all associated MTU-Rs from the P2MP group a DBR-R RMC command, that indicates to each MTU-R the following parameters:

   • *DBRLFDC*: The DBR down count value, selected so that the down count reaches 0 at the upstream logical frame indicated by the corresponding DBR-R.request primitive (CNT_{LF}). For the upstream DBR procedure, the valid range of the initial value for *DBRLFDC* shall be from 8 (*min_init_DBRLFDC*) to 15, inclusive.

   • *DBRCCC:* the associated upstream DBR configuration change count.

   • *SDI:* Index of relevant sub-band description

The DBR-R commands sent to all MTU-Rs of all P2MP groups that belong to the same vectored group shall be aligned in time, e.g., sent during the same RMC symbol period.

NOTE 2 – The DBR procedure may assign to MTU-Rs different sub-bands within the currently active SD by using an SDI value of the active SD, but may also change the sub-bands boundaries by switching to a non-active SD by using an SDI value that is the complement of the SDI value of the active SD.

4) At the start of the indicated logical frame, both the MTU-O and all involved MTU-Rs switch to new sub-band assignments determined by the requested SA and the SD values (indicated in DBR-PR command), and the new bit loadings and gains on all granted subcarriers. The post-coder updates and NEXT/echo canceller updates are also applied, if available. All these changes shall take effect starting from the RMC symbol of the logical frame for which the *DBRLFDC* reaches 0. From this moment the DBRCC at both MTU-O and MTU-Rs shall be updated to the value indicated in DBR-R command.

5) The MTU-O indicates the completion of the DBR procedure to the DRA via the DBR-R.confirm primitive. After, the DRA may initiate upstream performance adjustment procedures (see Figure 13-10), as specified in clause 13.5.3.2.4.

The MTU-O shall not initiate other normal high priority messages commands (e.g., SRA, bitswap, etc.) until the DBR procedure has completed successfully (i.e. after the DBR-R RMC command) or has failed due to rejection or has timed-out.

NOTE 3 – In case the VCE is not capable of handling un-updated channel matrix and post-coder, and bit loading aligned with MTU-Rs prior to DBR procedure, at least these two methods can be used:

1) Start transmission of granted tones with low power (by applying reduced gains in Step 2 of the procedure). After the bandwidth is re-allocated (in Step 4), the gains are re-adjusted or revived, reaching the full performance over granted tones after channel estimation, in Step 5.
2) Within Step 2, the VCE performs a fast channel estimation (e.g., one probe sequence long) and computes updates of the channel matrix, post-coder, and echo/NEXT canceller coefficients on the granted tones. The performance on granted tones is finally optimized in Step 5.

13.5.3.2 Auxiliary procedures related to upstream DBR

13.5.3.2.1 DBR-SD procedure

This procedure is intended to update of the description of the sub-band boundaries and shall be as defined in clause 13.5.2.2.1.

13.5.3.2.2 DBR-PT procedure

This is a procedure supporting the continuous alignment of the upstream transmission parameters (bit loading and gain tables on all subcarriers,) of all upstream sub-bands between the MTU-O and all MTU-Rs of the P2MP group.

The DBR-PT reports to the MTU-R the upstream gains and estimated bit loadings; it is initiated at the discretion of the MTU-O, upon changes detected by the MTU-O. The DBR-PT eoc command (see clause 11.2.2.28) communicates to the MTU-R the gains and estimated bit-loading values on all subcarriers of the MEDLEYGus set that are expected to be relevant for the upcoming DBR. The MTU-R acknowledges reception of the command or indicates if the content is invalid.

Upon receiving the SA assignment, both MTU-O and MTU-R generate upstream bit-loading tables autonomously from the bit-loading values determined by DBR-PT exchange, using the same rules as defined for downstream in clause 13.5.2.2.2.

13.5.3.2.3 DBR-PR procedure

The procedure is intended to be used by the MTU-O to indicate the upstream framing and transmission parameters and optionally the bit loading and fine gains on all subcarriers associated with the DBR from the MTU-R. The procedure shall use the following parameters of the DBR-R.request primitive sent to the MTU-O:

– *SDI* of the relevant sub-band description (see Table 13-19);
– *SA* for each MTU-R (see Table 13-20).

The procedure shall comprise the following steps:

1) Upon reception of the DBR-R.request primitive, the MTU-O shall send to all the related MTU-R(s) the DBR-PR request eoc command (see clause 11.2.2.23) that indicates upstream transmission parameters for the set of subcarriers in the SA for each tributary and beneficiary MTU-R of the P2MP group and associated framing parameters (see Table 11-69). In case upstream bit loading and fine gains are available at both MTU-O and MTU-R via DBR-PT exchange, a shortened version of DBR-PR response can be used (see clause 11.2.2.23).
2) Upon reception the DBR-PR request command, each MTU-R responds to the MTU-O by acceptance or rejection of the DBR request in cases defined in Table 11-73.
3) The procedure is complete after the MTU-O collects acknowledgement responses from all the MTU-Rs.

Once the MTU-R has accepted the DBR-PR request, the MTU-R shall start monitoring the RMC messages for the DBR-R RMC command. When the MTU-R detects more than *min_init_DBRLFDC* consecutive RMC messages in error, the transmitter shall generate only quiet symbols until reception of a correct RMC message. Once a correct message is received, the MTU-R shall resume normal data transmission while continuing to monitor the RMC messages. This mode of operation shall last until the DBR-R RMC command is received but no longer than 2 seconds after acceptance of the DBR-PR.

NOTE – This mode of operation prevents an MTU-R from transmitting in the band assigned to another path if the RMC is corrupted. The maximum duration of that mode of operation allows the MTU-O to abort the DBR procedure.

13.5.3.2.4 Upstream post-DBR performance adjustment stage

In the post-DBR performance adjustment stage (see Figure 13-10), the following performance adjustments may be executed:

1) The MTU-O (under coordination from the VCE) may initiate a postcoder update. This update may be optionally executed, if the postcoder update on subcarriers associated with the DBR was not available prior to the DBR request by the DRA (e.g. in case the DPU (MTU-O/VCE) does not support postcoder tracking during the DBR preparation stage).
2) The MTU-Rs may initiate one or more autonomous SRAs (OLR Request Type 2) in the aim to adjust the bit loading and fine gains.
3) The beneficiary MTU-Rs that intend to use the granted subcarriers in FDX mode may adjust their local echo-cancellers. Further, upstream transmit PSDs of other lines may also be adjusted (for NEXT mitigation into the beneficiary MTU-Rs and MTU-Rs connected to other P2MP groups).

NOTE – It is expected that the initial bit-loading settings applied to all new granted subcarriers used in FDX mode are rather conservative (since it's prior the adjustment of echo cancellers and NEXT mitigation).

13.5.4 Bidirectional DBR procedure

In case it is necessary to re-assign simultaneously both the downstream and upstream band assignments in order to avoid that the same frequencies are assigned in both directions to different links, this clause defined the procedure to reassign simultaneously the downstream and upstream band to a given MTU-R.

The procedure includes three groups of functions: the DBR preparation, the DBR, and the post-DBR performance adjustment.

The DBR preparation function is performed independently for the downstream and the upstream directions, with the order of tributary functionalities that is MTU-O discretionary. The downstream DBR preparation is the same as the one specified for the downstream DBR in clause 13.5.2 and the upstream DBR preparation is the same as the one specified for the upstream DBR in clause 13.5.3.

The post-DBR performance adjustment function after the bidirectional DBR procedure is performed independently for the upstream and the downstream directions, with the order of tributary functionalities that is MTU-O discretionary. The post-DBR performance adjustment for the downstream is the same as the one specified for the downstream DBR in clause 13.5.2. The post-DBR performance adjustment for the upstream is the same as the one specified for the upstream DBR in clause 13.5.3.

The bidirectional DBR procedure includes the following functionalities:

1) The DBR parameter request (DBR-PR)

The bidirectional DBR-PR eoc exchange is initiated by the MTU-O:

– To obtain the downstream bit loading on all subcarriers, pilot tone settings, framing and other transmission parameters associated with the DBR from the MTU-R (see clause 13.5.4.2). If bit loading on subcarriers associated with the DBR is available prior to the

DBR request (in case the MTU-O supports downstream DBR-PT function, which is optional for the MTU-O), a shortened version of DBR-PR response can be used (see clause 11.2.2.23).

– To indicate the upstream transmission parameters (bit loading and fine gains on subcarriers associated with the DBR, and framing and other transmission parameters) to each MTU-R of P2MP group that is involved in the DBR (see clause 13.5.4.2). If bit loading and fine gains associated with the DBR are available prior to the DBR-PR is sent (in case the MTU-O supports upstream DBR-PT function by tracking the postcoder settings and maintaining transmission parameters, which is optional for the MTU-O), a shortened version of DBR-PR request can be used (see clause 11.2.2.23).

2) The DBR request (DBR-R) RMC command

This command indicates the actual sub-bands to be used by the MTU-R (see clause 9.6.4). After reception of this command and associated down-count, both MTU-s forming the path simultaneously modify their downstream and upstream frequency bands according to the new downstream SA and upstream SA communicated in the DBR-PR.

13.5.4.1 The bidirectional DBR procedure

With a completed DBR preparation for both upstream and downstream, upon DBR request, the MTU-O and all the MTU-Rs of P2MP group possess aligned DBR sub-band descriptions. Via DBR-PT exchanges, the MTU-O and all the MTU-Rs of P2MP group may possess aligned downstream and upstream, bit loadings for all subcarriers potentially involved in the DBR.

If some downstream bit loadings are missing (due to none or incomplete DBR-PT exchange), the MTU-O shall request these missing bit-loading values from this MTU-R for specific sub-bands during the bidirectional DBR-PR procedure. If some upstream bit loadings are missing, the MTU-O shall indicate the bit loading for specific sub-bands during the bidirectional DBR-PR procedure. The bidirectional DBR-PR procedure is defined in clause 13.5.4.2. The bidirectional DBR-PR eoc exchange provides the MTU-R with the actual downstream and upstream SAs and provides alignment of the bit loading (if not or incompletely obtained during DBR preparation), pilot tones settings, framing and other transmission parameter settings with the MTU-O.

The bidirectional DBR procedure shall comprise the following steps.

1) The DRA, as it determines the necessity in bandwidth re-distribution and identifies the set of subcarriers to be granted to each beneficiary MTU-R, sends to the MTU-O a request to initiate the bidirectional DBR procedure via a primitive bidirectional DBR-Rbidir.request (see clause 8.1.1). This primitive contains the following parameters:
   - CNT_{LF} : the logical frame count on which bandwidth redistribution shall take effect.
   - downstream and upstream *SDIs* of the relevant sub-band descriptor (see Table 13-19);
   - downstream and upstream *SAs* to be applied by each MTU-R (see Table 13-20).

   The DBR-R.request primitive shall be sent by the DRA to the MTU-O that is subject to DBR at least 96 logical frames before the beginning of the logical frame with the targeted logical frame count CNT_{LF} for the particular link.

2) The MTU-O, upon reception of the DBR-R.request primitive, initiates the bidirectional DBR-PR procedure (see clause 13.5.2.2.3) that:
   - retrieves from each MTU-R the transmission parameters for the relevant subcarriers of the requested downstream SA and;
   - indicates to each MTU-R the transmission parameters for the relevant subcarriers of the requested upstream SA.

3) The MTU-O performs the DBR by sending to all associated MTU-Rs from the P2MP group a DBR-R RMC command, that indicates to each MTU-R of the group the following parameters:

- *DBRLFDC*: The DBR down count value, selected so that the down count reaches 0 at the downstream logical frame indicated by the corresponding DBR-R.request primitive (CNT_{LF}). For the bidirectional DBR procedure, the valid the valid range of the initial value for *DBRLFDC* shall be from 8 (*min_init_DBRLFDC*) to 15, inclusive.
- *DBRCCC:* the associated bidirectional DBR configuration change count.
- downstream *SDI:* Index of relevant downstream sub-band description
- upstream *SDI:* Index of relevant upstream sub-band description

The DBR-R commands sent to all MTU-Rs of all P2MP groups that belong to the same vectored group shall be aligned in time, e.g., sent during the same RMC symbol period.

NOTE – The DBR procedure may assign to MTU-Rs different sub-bands within the currently active SD by using an SDI value of the active SD, but may also change the sub-bands boundaries by switching to a non-active SD by using an SDI value that is the complement of the SDI value of the active SD.

4) At the start of the indicated logical frame, both the MTU-O and all involved MTU-Rs switch to their new sub-band assignments determined by the requested downstream and upstream SA and the SD values (indicated in the DBR-R command), and the new bit loadings on granted subcarriers. All these changes shall take effect starting from the RMC symbol of the logical frame for which the *DBRLFDC* reaches 0. From this moment the DBRCC at both MTU-O and MTU-Rs shall be updated to the value indicated in DBR-R command.

5) The MTU-O indicates the completion of the DBR procedure to the DRA via the DBR-R.confirm primitive. After this step, the DRA may initiate downstream and upstream performance adjustment procedures, as specified in clause 13.5.2.2.5 and 13.5.3.2.4.

The MTU-O shall not initiate other high priority commands (e.g., SRA, bitswap…) until the DBR procedure has completed successfully (i.e., after the DBR-R RMC command), has failed due to rejection or has timed-out.

13.5.4.2 Bidirectional DBR-PR procedure

The procedure is intended to be used by the MTU-O:

– to obtain the downstream framing and transmission parameters and optionally the bit loading on all subcarriers associated with the DBR from the MTU-R, as well as to indicate the downstream pilot tone settings;

– to indicate the upstream framing and transmission parameters and optionally the bit loading and fine gains on all subcarriers associated with the DBR from the MTU-R.

The procedure shall use the following parameters of the bidirectional DBR-R.request primitive sent to the MTU-O:

– downstream *SDI* of the relevant sub-band description (see Table 13-19);

– upstream *SDI* of the relevant sub-band description (see Table 13-19);

– downstream *SA* for each MTU-R (see Table 13-20).

– upstream *SA* for each MTU-R (see Table 13-20).

The procedure shall comprise the following steps:

1) Upon reception of the bidirectional DBR-R.request primitive, the MTU-O shall send to all related MTU-Rs the DBR-PR request eoc command (see clause 11.2.2.23).

   The DBR-PR shall

   – request the downstream framing and transmission parameters (see Table 11-69) and optionally the bit loadings for the set of subcarriers in the downstream SA indicated in the DBR-PR request eoc command for each beneficiary MTU-R (in case these downstream bit loadings are not available at the MTU-O);
   – indicate the pilot tone groups used by other MTU-Rs of the P2MP group within the downstream band granted to the MTU-R and the out-of-band pilot tone groups that the MTU-R shall release for data transmission by other MTU-Rs;
   – indicate the upstream transmission parameters for the set of subcarriers in the upstream SA for each tributary and beneficiary MTU-R of the P2MP group and associated framing parameters (see Table 11-69). In case upstream bit loading and fine gains are available at both MTU-O and MTU-R via DBR-PT exchange, a shortened version of DBR-PR request can be used (see clause 11.2.2.23).

   The MTU-O may send a DBR-PR command to any MTU-R that is not subject for this DBR as well.

2) Upon reception the DBR-PR request command, each of the beneficiary MTU-R(s) responds by indicating to the MTU-O the proposed downstream bit loadings, the additional requested pilot tones within the newly granted part of the downstream band, framing and other transmission parameters in a DBR-PR response (see Table 11-73). In case downstream bit loading is available at both MTU-O and MTU-R via DBT-PT exchange, a shortened version of DBR-PR response can be used (see clause 11.2.2.23). The MTU-R may reject the DBR request in cases defined in Table 11-73.

3) The procedure is complete after the MTU-O collects acknowledgement responses from all the MTU-Rs.

Once the MTU-R receives a bidirectional DBR-PR request command, no downstream OLR type 1 or 2 shall be initiated by the MTU-R until the DBR-R command is complete. If MTU-O receives an OLR request type 1 or type 2 during or after transmission of DBR-PR request, it shall reject the OLR request using corresponding reject response (see Table 11-19) with reason code "wait" until the DBR-R procedure is complete.

NOTE 1 – It is expected that in the aim to speed up starting the DBR-PR, the MTU-O may reject already received OLR requests of type 1 or type 2 request because the modification of transmission parameters implied by this request will likely be irrelevant.

Once the MTU-R has accepted the DBR-PR request, the MTU-R shall start monitoring the RMC messages for the DBR-R RMC command. If the MTU-R detects more than minDBRLFDC consecutive RMC messages in error, the transmitter shall generate only quiet symbols until reception of a correct RMC message. Once a correct message is received, the MTU-R shall resume normal data transmission while continuing to monitor the RMC messages. This mode of operation shall last until the DBR-R RMC command is received but no longer than 2 seconds after acceptance of the DBR-PR.

NOTE 2 – This mode of operation prevents an MTU-R from transmitting in the band assigned to another path if the RMC is corrupted. The maximum duration of that mode of operation allows the MTU-O to abort the DBR procedure.

13.6 DCMU procedure

The DCMU procedure shall be used to request a DCM update (DCMU) as well as a change of the monitoring type (i.e., no DTFO Monitoring, DCM or DSQM).

The parameters controlled in the DCMU procedure are described in clause 13.6.1.

The DCMU procedure is initiated from the MTU-O and shall include the following steps:

- Upon instruction of the DRA, the MTU-O shall initiate a DCMU procedure by sending a DCM parameter update command to the MTU-R (DCM parameter update, see Table 11-78) via the eoc that indicates:
  - the list of new DCM parameter values (new configuration);
  - the superframe count on which the new DCM parameters shall take effect. The minimum superframe count indicated in the first transmission of the DCMU request shall be at least four superframes later than the superframe count when the eoc message carrying the DCMU request is expected to be received (the value shall take into account the maximum transmission delay of the eoc message over the link);
  - the 4-bit DCMU configuration change count (DCMUCCC) associated with the new configuration. The DCMUCCC shall be incremented by one whenever the configuration changes, with wrap around at count 1111_2 The DCMUCCC for a valid new configuration shall be greater than (accounting for wrapping around) the DCMUCCC for the current configuration. The value of DCMUCCC at the transition into showtime shall be set to 0, which means that the value of DCMUCCC shall be set to 1 in the first DCMU request command sent after the transition into showtime.
- After sending the "DCM parameter update" command, the MTU-O shall wait for the response that may be received via eoc (see Table 11-79), and may keep repeating the "DCM parameter update" command until the response is received via the eoc. If no response is received, the MTU-O may keep repeating the "DCM parameter update" command until the sync frame of the reference superframe.
- Upon reception of the "DCM parameter update" command, the MTU-R shall respond via the eoc (see Table 11-79), and perform the required parameter modifications starting from the reference superframe with superframe count indicated in the "DCM parameter update" command. The MTU-R shall respond to each received "DCM parameter update" command, as defined in clause 11.2.2.25.
- The MTU-O shall modify its DCM parameters starting from the reference superframe with superframe count indicated in the "DCM parameter update" command. However, the MTU-O shall abort the procedure and refrain from making the requested changes if it receives a reject on the "DCM parameter update" command via the eoc (see Table 11-80).
- The MTU-O shall consider the DCMU procedure complete upon modification of the DCM parameters at the designated time indicated in the DCMU request command. The MTU-O shall also consider the procedure complete after aborting the procedure as described in the previous bullet. Any message associated with the DCMU procedure received after completion of this procedure shall be ignored. The MTU-O may initiate a new DCMU procedure only after completion of any ongoing DCMU procedure.

NOTE – If the eoc is unreliable, the MTU-O cannot get confirmation whether the DCMU request arrived or not. To improve robustness, the MTU-O may continuously repeat the DCMU request message, until acknowledgement via eoc arrives.

In a given transmission direction, the DTFO status (active or inactive) is not modified by the DCMU procedure if the DTFO monitoring selection indicates DCM or DSQM monitoring in that direction. If the DTFO monitoring indicates no DTFO monitoring, the DTFO shall be disabled when the DCMU procedure is complete and shall stay disabled until another DCMU procedure modifies the DTFO monitoring to either DCM or DSQM. Once DCM or DSQM monitoring is selected, the DTFO is enabled or disabled at the discretion of the DRA and for the downstream direction indicated in the MTU-O DTFO RMC command.

13.6.1 Parameters controlled by the DCMU procedure

The parameters are described in Table 13-21.

The upstream and downstream direction have different instances of these parameters denoted with a subscript us resp ds contained in separate DTFO descriptors.

Table 13-21 – Parameters in a DCMU request

Parameter	Definition
DCMUCCC	DCMU configuration change count
DTFO monitoring control field	See DTFO descriptor (Table 12-68)
DCM symbol position on current transmission line (*TA_dcm*)	See DTFO descriptor (Table 12-68)
DCM reference superframe count	See DTFO descriptor (Table 12-68)
DCM period (*T_dcm*) for DCM group with TA_dcm=0	See DTFO descriptor (Table 12-68)
DCM active logical frame time marker for DCM group with TA_dcm=0	See DTFO descriptor (Table 12-68)
DCM period (*T_dcm*) for DCM group with TA_dcm=1	See DTFO descriptor (Table 12-68)
DCM active logical frame time marker for DCM group with TA_dcm=1	See DTFO descriptor (Table 12-68)
DCM period (*T_dcm*) for DCM group with TA_dcm=2	See DTFO descriptor (Table 12-68)
DCM active logical frame time marker for DCM group with TA_dcm=2	See DTFO descriptor (Table 12-68)
DCM sequence time marker	See DTFO descriptor (Table 12-68)
DCM sequence length (*N_dcm*)	See DTFO descriptor (Table 12-68)
DCM sequence descriptor	See DTFO descriptor (Table 12-68)

13.6.2 Timing and synchronization for DCMU

The new DTFO parameters requested by the DCMU shall be applied by both MTUs starting from the reference superframe with superframe count indicated in the DCMU command sent by the MTU-O.

If DCM is selected in the DTFO descriptor of the DCMU, within the reference superframe, the first DCM symbol using the updated parameters shall be sent starting from the DCM active logical frame specified by the DCM active logical frame time marker for the DCM group with *TA_dcm* of the current link as identified in field 2 of the DTFO descriptor (see fig 10-46b). If the DTFO descriptor changes the selected monitoring type from DCM to DSQM or to no DTFO monitoring, the DCM symbols shall not be sent starting from the first logical frame after the DCM active logical frame corresponding to the last element of the DCM sequence as specified in the previous DTFO descriptor.

A DCM parameter update request shall only request a change to the transmission of DCM symbols where the change is coinciding with boundaries between complete DCM sequences sent on the transmission line.

NOTE – DCM parameter update requests that only inform about the DCM status on other transmission lines do not need to coincide with the boundaries between complete DCM sequences sent on the own transmission line.

14 Electrical requirements

14.1 Balance

14.1.1 Longitudinal conversion loss

Longitudinal conversion loss (LCL) is a measure of the degree of unwanted transversal signal produced at the input of the MTU due to the presence of a longitudinal signal on the connecting leads. The longitudinal voltage (V_{cm}) to transversal voltage (V_{diff}) ratio shall be measured in accordance with [ITU-T G.117] and [ITU-T O.9]. During the measurement, the transceiver under test shall be powered, and in the L3 state (see clause 12.1).

$$\mathrm{LCL} = 20\log_{10}\left|\frac{V_{cm}}{V_{diff}}\right| \mathrm{dB}$$

The LCL of the MTU shall be greater than or equal to 38 dB in the frequency band up to 12 MHz. The LCL above 12 MHz is for further study. The termination impedance of the transceiver for LCL measurement shall be R_V resistive and equal to the termination impedance of the the metallic wire, see [ITU-T G.9710] Annex P. The LCL shall be measured at the U-O2 (U-R2) reference point. LCL shall be measured in the frequency band between the lower of the lowest pass-band frequency in the upstream and downstream directions and the highest frequency supported by the selected profile (see Table P.1).

NOTE 1 – The equipment balance should be better than the anticipated access network balance in order to minimize the unwanted emissions and susceptibility to external RFI.

NOTE 2 – MTU performance may benefit from even higher balance. Where subject to repetitive electrical impulse noise, systems operating at frequencies where the cable balance may be 50 dB could be limited in capacity by a 38 dB balance.

NOTE 3 – The required LCL may be increased in a future revision of this Recommendation.

NOTE 4 – The LCL requirements may be extended in a future revision of this Recommendation, to include dynamic balance requirements to include perturbations due to active to quiescent impedance state changes in low power link states driven by fluctuating traffic demand.

NOTE 5 – LCL is only applicable on balanced signals (Annex P) and not on unbalanced signals (Annex Q).

14.1.2 Common mode port impedance

For further study.

14.2 Differential port impedance

The port impedance at the U-R reference point of an MTU-R at a given frequency and point in time is defined as *Z*(*f*,*t*).

For TDD framing mode, the measurement of *Z*(*f*,*t*) shall be taken separately:

– over the time interval when the transceiver is transmitting (symbol positions from 0 to M_{us}–1, including quiet symbol transmissions) resulting in *Z_TX*(*f*,*t*), and

– over the time interval when the transceiver is receiving (symbol positions from 0 to M_{ds}–1) resulting in *Z_RX*(*f*,*t*)

At any given frequency *f* between f_{tr1} and f_{tr2} as defined in [ITU-T G.9710], and for any set (*t1*, *t2*) of a time interval the *Z_TX*(*f*, *t*) shall satisfy:

$$\left|\frac{Z\_TX(f,t1)}{Z\_TX(f,t2)} - 1\right| \leq 0.20$$

At any given frequency *f* between f_{tr1} and f_{tr2} as defined in [ITU-T G.9710], and for any set (*t1*, *t2*) of a time interval the *Z_RX*(*f*,*t*) shall satisfy:

$$\left|\frac{Z\_RX(f,t1)}{Z\_RX(f,t2)} - 1\right| \le 0.20$$

For FDXC, FDXZ and TDDZ framing modes, the measurement of *Z*(*f*,*t*) shall be taken over all symbol position (from 0 to *MF*, including quiet symbols). At any given frequency f between f_{tr1} and f_{tr2} as defined in [ITU-T G.9710], and for any set (t1, t2) of a time interval the *Z*(*f*, *t*) shall satisfy:

$$\left|\frac{Z(f,t1)}{Z(f,t2)} - 1\right| \le 0.20$$

NOTE – This requirement is applicable starting from the beginning of the Channel Discovery phase of initialization.

Annex A

Secure NT Identification and Authentication based on IEEE 802.1X

(This annex forms an integral part of this Recommendation.)

A.1 Scope

This annex provides means to perform secure NT Identification and Authentication at the beginning of showtime. The NT_ID sent during ITU-T G.994.1 handshake phase uniquely identifies the NT. The description below specifies how to verify the NT_ID of the joining NT or the operating NT by authenticating this NT based on [IEEE 802.1X].

A.2 Abbreviations and acronyms

AAA Authentication, Authorization, and Accounting

AS Authentication Server

AU Authenticator

CN Common Name attribute

EAP Extensible Authentication Protocol

SU Supplicant

UUID Universally Unique IDentifier

A.3 Introduction

Identification of the NT is provided by the 128-bits long unique NT_ID, which is assigned to the NT prior to its joining to the network. The NT_ID is sent by the joining MTU-R during the ITU-T G.994.1 handshake phase, see clause 12.4. The secure verification of the NT_ID is based on [IEEE 802.1X].

[IEEE 802.1X] is a protocol for link layer authentication, port access control, and key establishment and maintenance. Establishment of particular credentials used for authentication (e.g., certificates, passwords, public keys, etc.) is not part of the [IEEE 802.1X]. Instead, the [IEEE 802.1X] frames encapsulate packets of the IETF extensible authentication protocol (EAP) which supports a variety of credential types (e.g., passwords, RSA-based public keys, smart cards etc.) as well as mechanisms for negotiating authentication capabilities and policies. The EAP is specified in [b-IETF RFC 3748].

The IEEE 802.1X authentication process involves three parties: a Supplicant, an Authenticator, and an Authentication Server. The Supplicant is a client device (NT) that wishes to join the network. For the application described in this Annex, the Authenticator is usually located in the DPU; and the Authentication Server is typically a host running software supporting the RADIUS (Remote Authentication Dial-In User Service) and EAP protocols. RADIUS is a networking protocol [b-IETF RFC 2865] that provides centralized Authentication, Authorization, and Accounting (AAA), and management for users who connect and use a network service.

A.4 References

[IETF RFC 4648] IETF RFC 4648 (2006), *The Base16, Base32, and Base64 Data Encodings*.

[IETF RFC 5280] IETF RFC 5280 (2008), *Internet X.509 Public Key Infrastructure Certificate and Certificate Revocation List (CRL) Profile*.

[IETF RFC 6234] IETF RFC 6234 (2011), *US Secure Hash Algorithms (SHA and SHA-based HMAC and HKDF)*.

A.5 Reference model

The reference model for NT Identification and Authentication is shown in Figure A.1. It is based on [IEEE 802.1X] and contains the associated entities required for an Authentication in terms of [IEEE 802.1X]:

– the Supplicant (SU) is the NT that wishes to attach to the access network;

– the Authenticator (AU) is contained in the DPU;

– the Authentication Server (AS) might be physically co-located within the authenticator hardware (DPU) or located higher up in the network, as shown in Figure A.1.

The communication between AU and AS is not in scope of this annex, but the RADIUS protocol according to [b-IETF RFC 2865] may be used. The AU relays EAP messages between SU and AS. The AS performs NT identification and authentication. The AU performs the authorization of the controlled port where the NT is attached. Based on the authentication result provided by the AS, the AU authorizes or unauthorizes the NT to access the port. The AU may force the SU for periodic re-authentication as per [IEEE 802.1X].

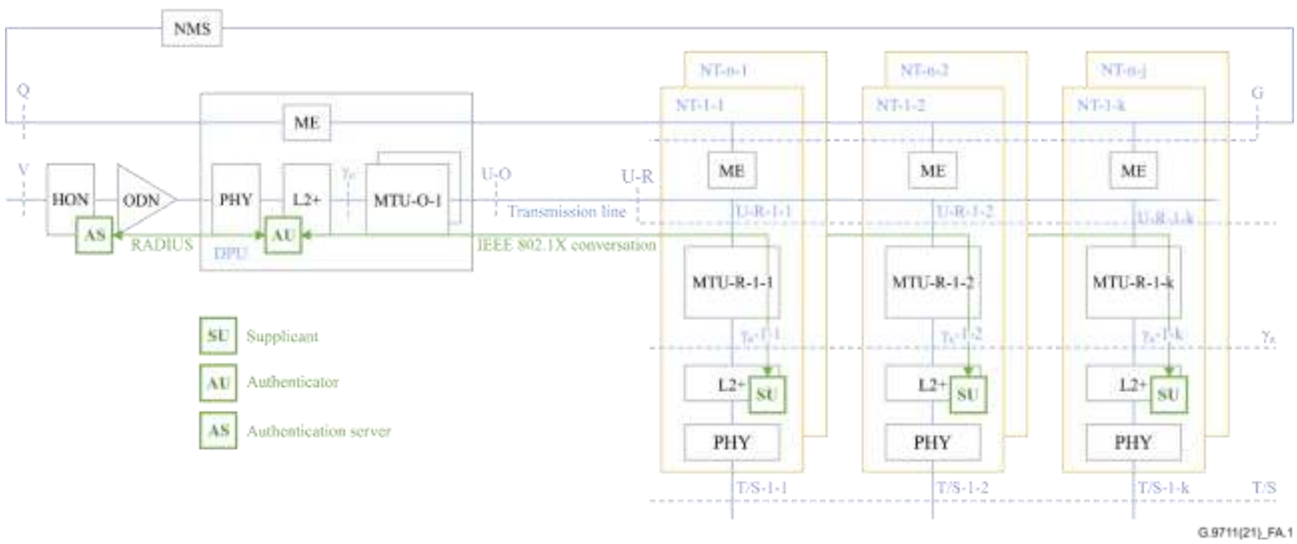


Figure A.1 – IEEE 802.1X reference model for G.mgfast

A.6 NT identification

The NT_ID shall be 128-bits long and shall uniquely identify the NT. The NT_ID is determined by the NT vendor and hardcoded in the NT at production time. The NT_ID shall not change with NT software updates (e.g., as defined in Annex S).

This annex supports two options for the generation of a unique NT_ID defined in this clause.

A.6.1 NT Identification based on UUID

Methods for generation of a unique NT_ID based on a universally unique identifier (UUID) are described in [b-IETF RFC 4122]. These allow for the NT_ID to be based on (combinations or hash of) the MAC address, the serial number, the timestamp, random numbers, etc. In case the UUID is longer than 128 bits, a hash algorithm may be applied to generate 128 bits from the UUID that could be used as an NT_ID.

NOTE – If the NT_ID is generated by other methods, it should be noted that the NT_ID has to be unique without coordination between vendors. Therefore, the usage of a plain serial number or a simple combination with other fixed information (e.g., vendor identification) is considered as insufficient. The full 128 bits should be used when an NT_ID is generated.

The verification of an NT_ID generated by the methods described in this clause requires a certificate bound to the NT_ID with a public key certificate chain from a suitable authority (e.g., NT vendor or network operator), which can be verified during the [IEEE 802.1X] authentication procedure.

The NT certificate subject field shall contain the NT_ID. The 128 bits-long binary NT_ID shall be encoded in 32 US-ASCII characters as hexadecimal numbers (Base 16 encoding according to [IETF RFC 4648]). These 32 US-ASCII characters build the Common Name attribute (CN) of the NT certificate (e.g., CN=090DE61F1BD1C1629531DC0CC7D3B830). For better readability, the 32 US-ASCII characters may be separated in groups (e.g., CN=090DE61F-1BD1-C162-9531-DC0CC7D3B830) using hyphens ('-', US-ASCII code 0x2D).

A.6.2 NT Identification based on certificate fingerprint

This clause describes the generation of an NT_ID based on a fingerprint from a public key certificate. Verification of this NT_ID does not require a public key certificate chain from a suitable authority. In this case it will not be possible to verify a specific property of an NT (e.g., vendor) but it will allow re-recognition of an NT and will prevent impersonation with a forged NT_ID.

The NT shall possess a certificate. For the case described in this clause it may be a self-signed certificate. This certificate shall have a CN, that contains the string "NT_ID-fingerprint" (e.g., CN=NT_ID-fingerprint). The NT shall compute the certificate fingerprint from the public key certificate using SHA-256 according to [IETF RFC 6234] as described in [IETF RFC 5280] (signatureValue). The NT_ID sent during ITU-T G.994.1 handshake shall consist of the first 128 bits of the certificate fingerprint.

NOTE – The public key certificate includes the CN and other attributes.

A.7 NT Authentication

The [IEEE 802.1X] protocol is used to perform mutual authentication between the network (i.e., the AU and AS) and client (i.e., the SU). The SU, AU, and AS using this annex shall support the EAP-TLS authentication protocol according to [IETF RFC 5216]. The support of other EAP methods is optional for DPU and NT. The AU acts like a security guard to protect access to the network.

During the ITU-T G.994.1 handshake phase, the 128-bit long NT_ID is sent from the NT to the DPU with the aim of identifying the NT. If the NT_ID is unknown to the DPU, the process described in clause 12.4 is applied first before initialization continues. Once this process, if necessary, is complete, the transmission line gets initialized and reaches showtime, while the AU keeps the status of the NT as "unauthenticated". When an NT is in state "unauthenticated", the AU allows L2+ function of the DPU to pass only [IEEE802.1X] data, and drops other data sent to or from the NT. After successful authentication, the AU sets the status of the NT to "authenticated" and the AU allows L2+ function of the DPU to pass all data sent to or from the NT.

NOTE – In order to get full access to all services an additional service or subscriber authorization may be required, which is beyond the scope of this Annex. This second stage authorization may use different means including an additional [IEEE 802.1X] authentication procedure. It may lead to data traffic restrictions at different stages of the network including the DPU.

The AU shall initialize mutual authentication between the NT and the DPU by transmitting EAP-Request/Identity packets to the NT with EAP-Type = EAP-TLS. The supplicant NT responds to the AU with an EAP-Response/Identity packet that contains the 128-bits long NT_ID as the Identity, see Table A.1.

Table A.1 – Format of Identity in EAP-Response/Identity packet

Name	Length (bytes)	Byte	Content
NT_ID	16	1-16	Binary NT_ID
NT_REALM	variable	17+	Optional field formatted as "@<realm>" e.g., to identify Authentication Server (See [b-IETF RFC 3748])

The authentication process shall continue according to the protocol described in [IETF RFC 5216] with the following details.

Since EAP-TLS requires mutual authentication, the AS shall also use a TLS certificate during the authentication process. The AS may use a reduced TLS certificate, which is not required to be valid or contain a certificate chain, but shall at least have following valid fields:

- Version
- Serial number
- Algorithm information
- Issuer distinguished name
- Validity period of the certificate
- Subject distinguished name
- Subject public key information.

The SU shall not derive any action from the TLS certificate presented by the AS. Specifically, the SU shall not terminate the authentication procedure or drop Layer 2 data in case the certificate of the AS does not match certain criteria.

In order to verify the NT_ID sent during the ITU-T G.994.1 handshake phase, the SU shall present a certificate matching the NT_ID. First, the AU shall verify that the NT_ID received during the ITU-T G.994.1 handshake phase matches the NT_ID in the EAP-Response/Identity packet sent by the SU, see Table A.1. In case of a mismatch the corresponding MTU-O shall terminate showtime, enter L3 link state, and the AU shall keep the authentication state "unauthenticated". In case of a match, the AU shares the NT_ID in the EAP-Response/Identity packet with the AS. In case the AS is outside the DPU, this may be through the RADIUS protocol.

In case authentication is not required the AU shall not start the [IEEE 802.1X] protocol and act as if the authentication is successful.

Further, if the NT_ID is derived from the certificate fingerprint as specified in clause A.6.2, the AS shall check if the fingerprint calculated from the public key certificate presented during the EAP-TLS authentication process matches the NT_ID in the EAP-Response/Identity packet sent by the SU.

In case the NT_ID is not derived from the certificate fingerprint, as described in A.6.1, the EAP certificate message sent by the supplicant shall contain a public key certificate chain from a suitable authority (e.g., NT vendor or network operator) for successful verification. The AS shall check if the NT_ID received in the EAP-Response/Identity packet sent by the SU matches the NT_ID provided in the TLS certificate subject.

Regardless the option used, in case of a mismatch, the authentication is unsuccessful. The AS informs the AU of the unsuccessful authentication (e.g., through RADIUS protocol if not co-located) and the AU sends an EAP-Success message indicating unsuccessful authentication to the SU, and the corresponding MTU-O shall terminate showtime, enter L3 link state, and the AU shall keep the authentication status of the NT as "unauthenticated".

In case of a match, the AS informs the AU of the successful authentication (e.g., through RADIUS protocol if not co-located) and the AU sends an EAP-Success message indicating successful authentication to the SU and the AU sets the authentication state to "authenticated".

The identification and authentication process is depicted in Figure A.2.

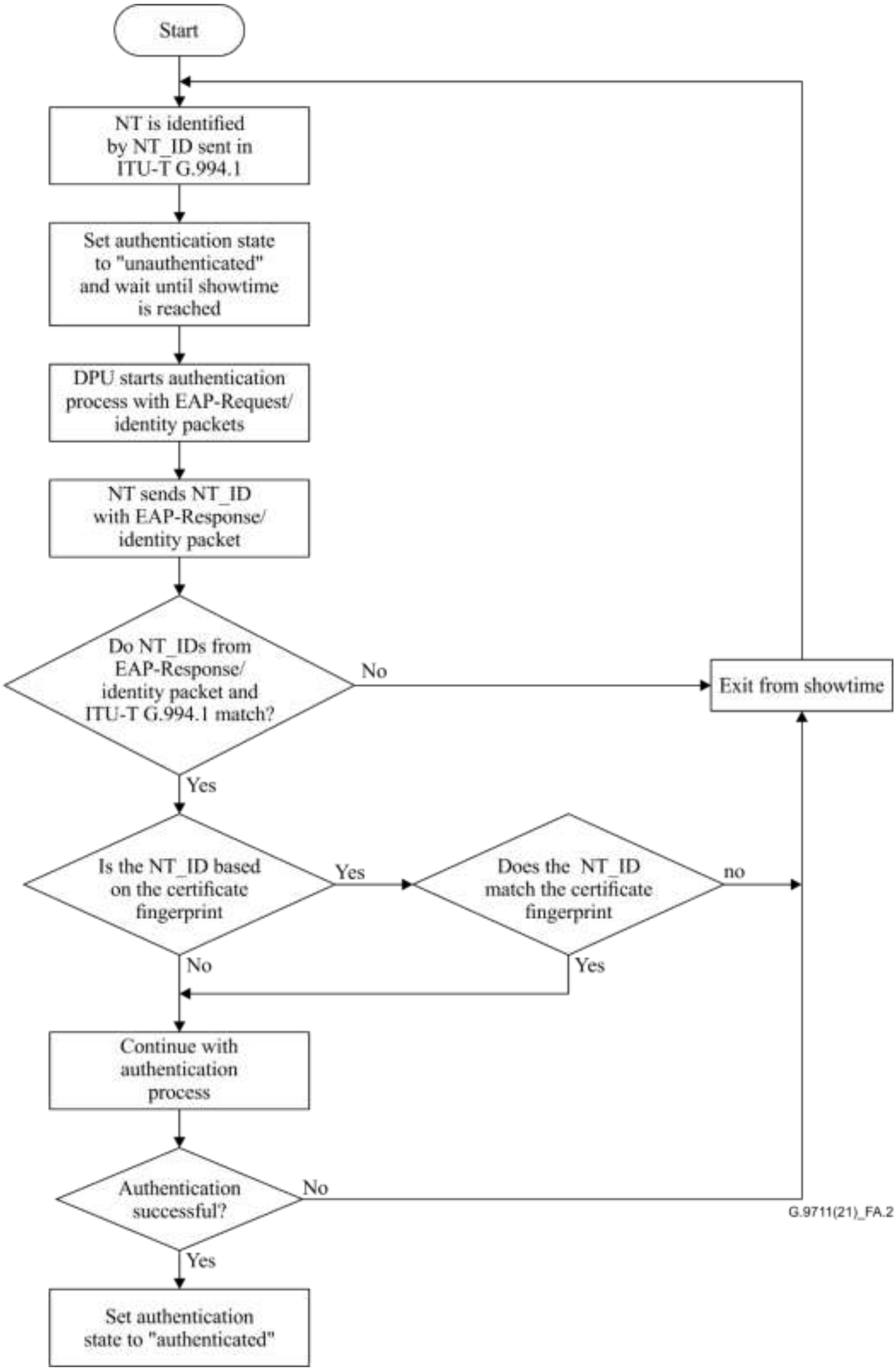


Figure A.2 – NT identification and authentication process

Annexes B and C

Annexes B and C are intentionally left blank.

Annex D

Operation with dynamic time assignment

(This annex forms an integral part of this Recommendation.)

D.1 Scope

This annex specifies operation of ITU-T G.9711 transceivers with dynamic time assignment (DTA).

Unless otherwise and specifically stated in this annex, all definitions and requirements specified in the main body of this Recommendation are applicable for transceivers compliant with this annex.

Support of this annex is mandatory for the MTU-O and MTU-R if either TDD framing mode or FDXC framing mode is applied. Support of this annex for the MTU-O and MTU-R for other framing modes is for further study. Support of DTA by the DRA is optional.

D.2 Definitions

This annex defines the following terms:

D.2.1 crosstalk environment: An operational environment with non-negligible crosstalk between transmission lines. Non-negligible crosstalk is such that, with no coordination between the transmission lines, there may be impact on the performance of a transmission line due to operation of other transmission lines.

D.2.2 crosstalk-free environment: An operational environment with no or negligible crosstalk between transmission lines. Negligible crosstalk is such that, with no coordination between the transmission lines, there is no impact on the performance of any transmission line due to operation of other transmission lines.

D.2.2 independent dynamic time assignment: A variant of dynamic time assignment where the changes of the PDX frame configuration are executed independently for all active lines of the vectored group.

D.2.3 coordinated dynamic time assignment: A variant of dynamic time assignment where the changes of the PDX frame configuration are executed synchronously for all active lines of the vectored group.

D.3 Abbreviations and acronyms

This annex uses the following abbreviations and acronyms:

DTA Dynamic Time Assignment

cDTA Coordinated Dynamic Time Assignment

iDTA Independent Dynamic Time Assignment

D.4 Reference model(s)

The reference model of a DPU intended for operation with DTA is given in Figure D.1. The reference model in Figure D.1 is consistent with the one in Figure 5-2, except that the DTA functionality has been introduced.

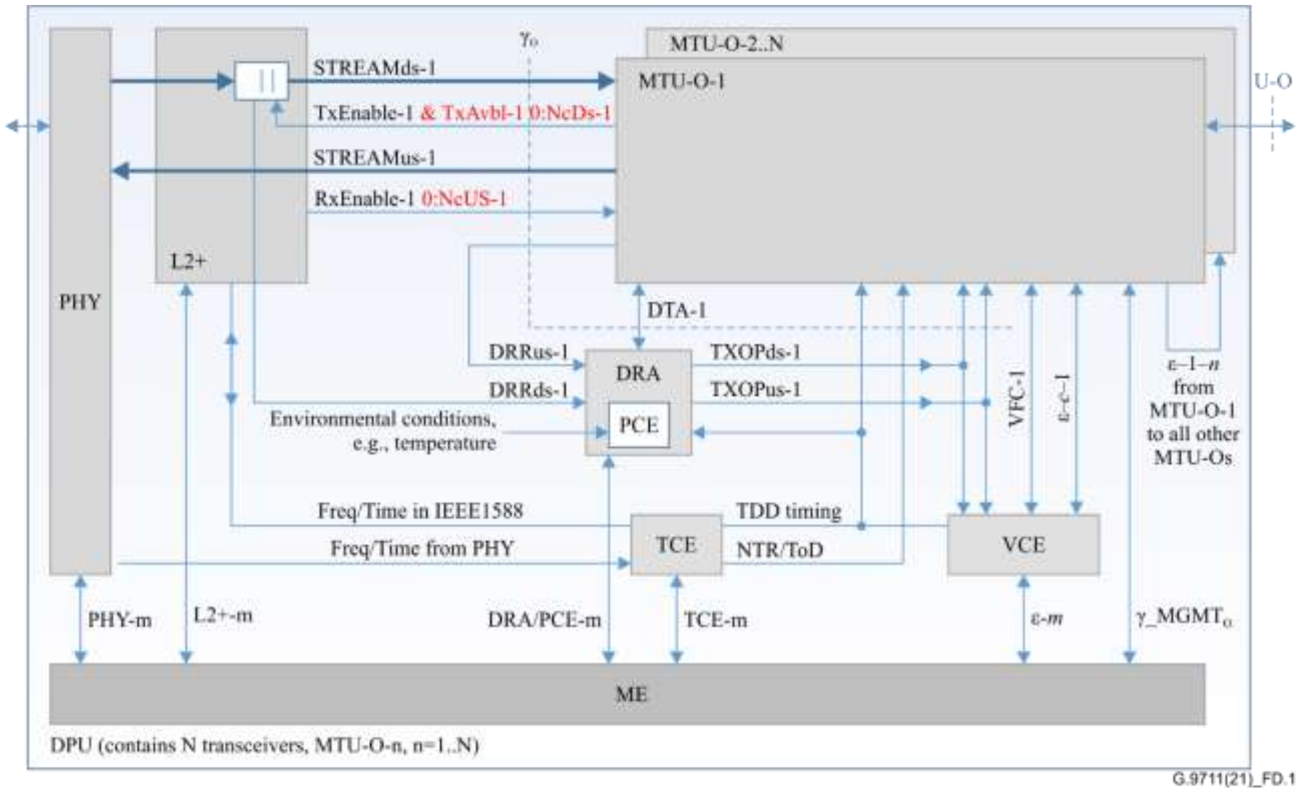


Figure D.1 – Reference model of a DPU intended for operation with DTA

For DTA, the DRA block monitors traffic-related information from each MTU-O and the L2+ block (given for each direction, downstream and upstream). Based on this information, and knowledge of the current M_{ds} and M_{us} for the vectored group, the DRA decides when to make changes to the PDX frame configuration.

In crosstalk-free environments (see Annex X) changes of the PDX frame configuration are executed independently for all active lines of the vectored group. This variant of DTA is called independent dynamic time assignment (iDTA). In case of crosstalk, coordination between the transmission lines is required and PDX frame configurations are executed synchronously for all active lines of the vectored group. This variant of DTA is called coordinated dynamic time assignment (cDTA).

In case of iDTA the DRA instructs individual MTU-Os and in case of cDTA the DRA instructs all MTU-Os on active lines of the vectored group to change synchronously the number of symbol periods to be allocated to the FDS and (M_{ds}), thereby resulting in a change to the number of symbol periods allocated to the FUS upstream (M_{us}) as well.

To implement changes to the PDX frame configuration associated with DTA, the DRA initiates the DTA procedure specified in clause D.5.2. See Annex T for higher layers control aspects of DTA.

D.5 Dynamic time assignment (DTA)

DTA is used to dynamically set and update the sharing of the PDX frame between FUS and FDS, by changing the number of FDS symbol periods (M_{ds}) of the PDX frame during showtime, on individual (iDTA) or all active lines of the vectored group (cDTA), upon request by the DRA. To perform the change synchronously for cDTA, the timing of the change is provided by the DRA to all MTU-Os on active lines of the vectored group.

Support of DTA is mandatory for an MTU that indicates support of this annex during the handshake phase of initialization (see clause D.6.1).

NOTE 1 – iDTA and cDTA are handled differently by the DRA. However, it does not make any difference for the individual MTU-R if the DTA procedure is applied for iDTA or cDTA.

NOTE 2 – cDTA functionality specified in this annex assumes that all MTU-Os and MTU-Rs connected to active lines of the vectored group have indicated support for this annex. Operation of cDTA when one or more MTU-Os or MTU-Rs on active lines of the vectored group does not support cDTA functionality is vendor discretionary.

D.5.1 DTA-related primitives at the γ_O reference point

In addition to the DRA primitives specified in Table 8-4, the DTA-related DRA primitives at the γ_O reference point are summarized in Table D.1. The physical implementation of these primitives is vendor discretionary.

Table D.1 – DTA-related DRA primitives of the data flow at the γ_O reference point

Primitive name (parameters)	Direction	Description
DTA.request (M_{ds}, *TBUDGETds*, *TBUDGETus*, CNT_{LF})	DRA → MTU-O	Requests the MTU-O to initiate an iDTA or cDTA update using the provided values of M_{ds} and CNT_{LF}, as specified in clauses D.5.2 and D.5.6.1, and the *TBUDGETds* and *TBUDGETus* to be used at the transition until new values are received from the DRA.
DTA.confirm	MTU-O → DRA	Confirms to the DRA that the iDTA or cDTA update corresponding to the DTA1.request has been scheduled by the MTU-O.
DTA.reject	MTU-O → DRA	Indication to the DRA that the MTU-O has rejected a DTA request due to the transmission line being in a link state other than L0

If the MTU-O receives a DTA.request primitive and the transmission line is in link state L0, the MTU-O shall initiate an iDTA or cDTA update as specified in clause D.5.6.1 such that the new value of M_{ds} and associated parameters will be applied starting from the first symbol of the PDX frame in which the downstream logical frame with count CNT_{LF} indicated in the request primitive starts. Once the update using the one-step procedure is scheduled, the MTU-O shall send the DTA1.confirm primitive to the DRA at the earliest opportunity before the update takes effect.

The DRA is allowed to send another DTA.request primitive only after the time instant associated with the logical frame count indicated in the DTA.request primitive.

The DRA shall coordinate sending the DTA.request primitive with the link state request as described in clause T.3.

If the MTU-O receives a DTA request primitive when the transmission line is in a link state other than L0, the MTU-O shall ignore this request and shall send a DTA.reject primitive to the DRA.

D.5.2 The DTA procedure

The DRA indicates the request for a DTA update to individual or all MTU-Os on active lines of the vectored group via the DRA primitive DTA.request (See clause D.5.1). In case of cDTA the requests contain the same new value of M_{ds} for all transmission lines and values of CNT_{LF} selected such that the change of M_{ds} is scheduled to occur at the same instance in time for all transmission lines. Upon such an indication, the MTU-Os initiate the DTA update by sending the 'DTA update' RMC command (see clause D.5.11) to the corresponding MTU-Rs. The value of DTAFDC conveyed in the command is selected so that the down count reaches 0 at the downstream logical frame indicated by the corresponding DTA.request primitive (CNT_{LF}). The DTA.request primitive shall be sent by the DRA to the MTU-Os at least 'min used initial DTAFDC' + 1 logical frames before the beginning of the logical frame with count CNT_{LF} for the particular transmission line. These commands synchronize the update of the M_{ds} parameter for the individual transmission lines as specified in clause D.5.6. The details of updating M_{ds}, the requirements, and the impact on the PDX frame parameters are described in clauses D.5.3 and D.5.4.

In case of cDTA, when a transmission line of the vectored group becomes a joining line (either a new transmission line through a full initialization or a transmission line that undergoes a fast retrain or re-initialization), the DRA shall issue DTA updates to all MTU-Os to transition to the handshake M_{ds} (hs_M_{ds}).The MTU-O of the joining line shall remain in the QUIET 1 stage until the DRA informs the MTU-O that the DTA procedure is complete for all active lines of the vectored group. The DRA shall not issue any further DTA updates until the joining line enters showtime. Once the joining line enters showtime, the DRA may initiate DTA updates.

The DRA shall not initiate a new DTA update procedure until the current DTA update procedure has been completed in all active lines of the vectored group.

NOTE – The DRA makes the decision to initiate the DTA updates. See Annex T for higher-layer control aspects of the DTA.

D.5.3 Valid values of M_{ds} for DTA

With DTA enabled, the MTU shall support the ranges of values of M_{ds} as a function of M_F according to Table D.2 (rather than those in Table 10-13):

Table D.2 – M_{ds} values to support as a function of M_F

M_F	M_{ds} values supported
36	from 5 to 31
23	from 5 to 19

NOTE – For a given M_{ds}, the value of M_{us} is determined according to the definition of the PDX frame structure in clause 10.5 as $M_{us} = M_F – K – M_{ds}$.

D.5.4 The PDX frame prior to and after a DTA update

The DTA procedure modifies the number of downstream symbol periods M_{ds} in a PDX frame, and correspondingly the number of upstream symbol periods M_{us}, while the duration of the PDX frame $M_F = M_{ds} + M_{us} + K$ and all other parameters of the PDX frame remain unchanged. The RMC symbol offsets (D_{RMCds} and D_{RMCus}) and the downstream and upstream ACK window shifts (DS_ACK_WINDOW_SHIFT and US_ACK_WINDOW_SHIFT) shall also remain unchanged after the DTA procedure is complete.

If DTA is enabled, the RMC symbol offsets D_{RMCds} and D_{RMCus} shall be selected during initialization such that just prior to and immediately after any DTA update, the following conditions are met (see Figure D.2):

$$M_{us} – D_{RMCus} – K + D_{RMCds} \geq 4 \quad (1)$$

$$M_{ds} – D_{RMCds} – K + D_{RMCus} \geq 3 \quad (2)$$

NOTE – Equations (1) and (2) ensure that:

- The time period between the US RMC to the DS RMC (sent in the following PDX frame) is at least 4 symbols;
- The time period between the DS RMC to the US RMC (of the same PDX frame), is at least 3 symbols.

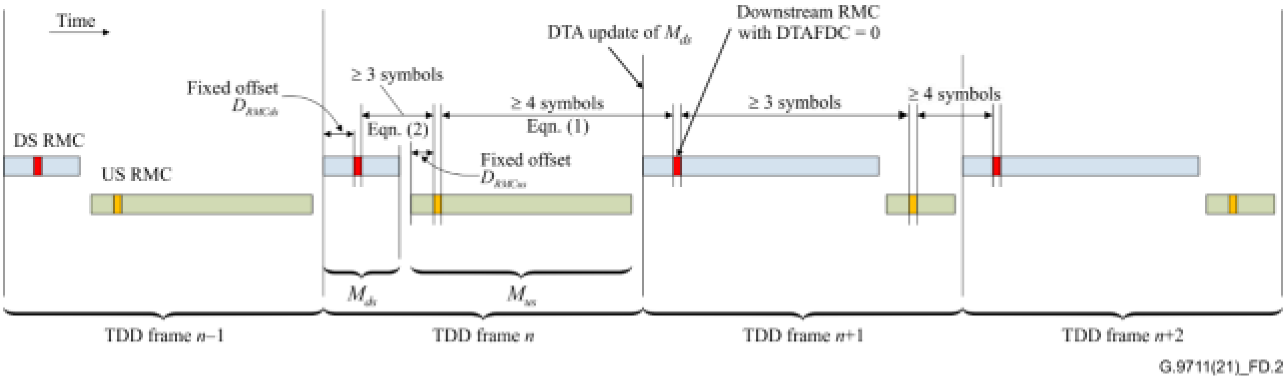


Figure D.2 – TDD framing mode PDX frame structure before and after a DTA update in the case of a one-step DTA procedure

NOTE – As explained above, the only parameter of the PDX frame that is changed by a DTA update is M_{ds} (and M_{us} as a result), while the other parameters of the PDX frame such as the duration of the PDX frame, the RMC symbol offsets and the ACK window shifts are unchanged. As a result, the size of the downstream ACK window, associated with the first PDX frame that is using the new M_{ds} value:

- will be greater than the downstream ACK window size of the previous PDX frame if M_{ds} increased due to the DTA update.
- will be less than the downstream ACK window size of the previous PDX frame if M_{ds} decreased due to the DTA update.

The upstream ACK window size will not be affected by a DTA update.

D.5.4.1 Performance during transitions

After the completion of a DTA procedure, for a period no longer than the configured maximum delay (*delay_max_0*), the ErrorFreeThroughput (EFTR), and INP may be worse than the EFTR and INP expected with the new PDX frame parameters.

NOTE – Jitter on the packets may also increase for the same period of time.

D.5.5 Superframe structure for DTA

The superframe structure shall be as specified in clause 10.6, except that PDX frames within the superframes during which DTA updates are applied may have different values of M_{ds}.

D.5.6 Timing and synchronization for DTA

The 'DTA update' RMC command contains the M_{ds} values that determine the actual and the new PDX frame configurations and a 4-bit DTA frame down count (DTAFDC) that indicates when the new PDX frame configuration shall take effect.

The actual number of downstream symbol periods (Mds_old) in the 'DTA update' RMC command represents the M_{ds} value in the current PDX frame. The new number of downstream symbol periods (Mds_new) in the 'DTA update' RMC command represents the M_{ds} value when the DTA update takes effect.

A suitable minimum initial value of DTAFDC has to be determined by the DRA. The MTU-Rs indicate during initialization with the R-MSG 2 message (see parameter 'min initial DTAFDC' in Table D.14) their capability. In case of cDTA, the value of 'min used initial DTAFDC' that is used during showtime shall be greater than or equal to the largest 'min initial DTAFDC' value that has been indicated by any of the MTU-Rs in R-MSG 2. A tradeoff between desired adaptation speed and robustness will determine the minimum value that is used during showtime ('min used initial DTAFDC'). The value of 'min used initial DTAFDC' is indicated by the MTU-Os to the MTU-Rs during initialization with the O-PMS message (see parameter 'min used initial DTAFDC' in Table D.13) and can be updated during showtime using the eoc command described in clause

D.5.12. The MTU-O shall use an initial value of DTAFDC in the 'DTA update' RMC command that is in the range of this 'min used initial DTAFDC' and 15, inclusive.

NOTE 1 – Even if the MTU-Rs have indicated the support of small values of 'min initial DTAFDC' it could be useful to select a larger value for 'min used initial DTAFDC' and to indicate this value to the MTU-Rs. A larger value of 'min used initial DTAFDC' may increase the robustness since the MTU-R can expect a DTA frame down count (DTAFDC) of length at least 'min used initial DTAFDC'. This may help to increase the probability of a successful DTA update and may decrease the probability that the MTU-R has to stop using the FUS part of the PDX frame (see clause D.5.6.3).

NOTE 2 – In order to minimize the potential unexpected FEXT channel change in case an MTU-R misses the 'DTA update' RMC command, the impedance of the MTU-R should not change significantly between the transmitting and receiving state at any given frequency f between ftr1 and ftr2 as defined in [ITU-T G.9710].

The first 'DTA update' RMC command initiating a new DTA update shall contain a DTAFDC value in the range of valid initial values, the requested new M_{ds} (Mds_new) value, and the current M_{ds} (Mds_old) value. Following this command, the MTU-O shall repeat the 'DTA update' RMC command in the RMC messages of the subsequent logical frames, while decrementing DTAFDC in each logical frame by 1 until DTAFDC reaches the value of zero, which indicates the activation of the new PDX frame configuration. The new M_{ds} setting and associated logical frame configurations shall be applied by both the MTU-O and MTU-R starting from the PDX frame that contains the 'DTA update' RMC command with DTAFDC = 0 (see Figure D.2). From that PDX frame, the US RMC symbol position shall be changed to the new position with respect to the new M_{ds} according to D_{RMCus}. The latter completes the DTA update procedure. The MTU-O concludes the completion of the DTA update procedure when it switches to the new M_{ds} value and receives an upstream transmission from the MTU-R according to the new M_{ds} value, with US RMC symbol at the correct position.

D.5.6.1 General requirements to increase robustness

For the reason of robustness, the MTU-Os shall continue sending the 'DTA update' RMC command in the downstream RMC messages after the end of the down count with DTAFDC = 0, and both the actual number and updated number of FDS symbol periods, set to the new M_{ds} value, at least until the DTA update procedure has completed, i.e., the MTU-O has switched to the new M_{ds} value and received an upstream transmission from the MTU-R according to the new M_{ds} value with upstream RMC symbol at the correct position.

If an MTU-R has received a 'DTA update' RMC command, from the down count indicated in this command the MTU-R can infer when the update will take effect and also that there will not be any further update for 'min used initial DTAFDC' frames beyond that. Outside this window, if the MTU-R has not successfully decoded at least one of the 'min used initial DTAFDC' most recent RMC transmissions, there is a possibility that it may have missed an ongoing DTA update procedure, and therefore it shall refrain from any upstream transmission during the current PDX frame. Instead, the MTU-R shall transmit QUIET symbols in this PDX frame (including the upstream sync symbol position if the current PDX frame is a sync frame), until it decodes an RMC transmission.

NOTE 1 – By transmitting quiet symbols, the MTU-R can present a differential port impedance at the U-R reference point which is equal to the one applied when the transceiver is transmitting.

NOTE 2 – The above requirement ensures that no unwanted near-end crosstalk is generated in case there is an MTU-R that has missed a change of the PDX frame configuration due to transmission errors. The MTU-R may continue to transmit with the correct frame configuration once it has correctly received a single RMC.

D.5.6.2 Logical frame parameter in DTA

During the DTA procedure, the number of symbols in FDS and FUS may change because of the change of M_{ds}, and the US RMC symbol position may also change. The MTU-O shall take the M_{ds} change into account such that the logical frame configuration parameters (see Tables 9-6 and 9-7) are consistent with the M_{ds} value for each logical frame that those parameters are applied. Specifically, switching to logical frame configuration parameters consistent with new M_{ds} value, while using the standard rules defined in Table 9-5, shall be applied, for both upstream and downstream, starting from the first PDX frame corresponding DTAFDC = 0, while logical frame parameters corresponding to old M_{ds} shall be applied in logical frames of all PDX frames corresponding to DTAFDC > 0.

The DRA shall send a TxOPds.indicate primitive and a TxOPus.indicate primitive requesting to set the logical frame parameters to $TTR_{ds,PSF} = M_{ds}$, $TTR_{us,PSF} = M_{us}$, $TTR_{ds,NPSF} = M_{us}$ and $TTR_{us,NPSF} = M_{ds}$ either before or together with the DTA request primitive (DTA.request). The DRA shall send the TxOP.indicate and DTA request primitives over the γ-reference point such that the new logical frame settings are communicated as the MTU-O transmits the corresponding DTA update command over the RMC.

NOTE 1 – In case the TxOP primitives are sent together with the DTA request primitive, those primitives need to be sent by the DRA at least the actual initial used DTAFDC + 3 logical frames before the downstream logical frame counter reaches the value CNT_{LF} indicated in the DTA request.

From the moment the DTA request primitive and associated TxOP primitives are sent to the MTU-O, until the end of the down count of the last step of the procedure, no update of the TxOp.indicate primitive in both upstream and downstream shall be allowed. Instead, the setting of the logical frame parameters shall be handled autonomously by the MTU-O as described in clause D.5.6.2.1.

After the completion of the DTA update procedure, the logical frame configurations shall comply with the following conditions in TDD mode:

$$TTR_{ds} = M_{ds},\ TBUDGET_{ds} \leq M_{ds},\ TA_{ds} = 0,$$

$$TTRus = Mus,\ TBUDGETus \leq Mus,\ TAus = 0,$$

or with the following conditions in FDX mode:

$$TTR_{ds,PSF} = M_{ds},\ TTR_{ds,NPSF} = M_{us},\ TBUDGET_{ds} \leq M_F\text{-}K,$$

$$TTR_{us,PSFs} = M_{us},\ TTR_{us,NPSF} = M_{ds},\ TBUDGET_{us} \leq M_F\text{-}K,$$

where $TBUDGET_{ds}$ and $TBUDGET_{us}$ may be updated by the DRA via the TxOp.indicate primitive.

NOTE 2 – If the first received DTA update command is one with DTAFDC = 0, the transition to new M_{ds} value with correct upstream and downstream framing parameters will likely not occur before the next PDX frame.

D.5.6.2.1 RMC content during one step procedure

The particular RMC messages in which MTU-O communicates upstream and downstream logical frame configurations to the MTU-R shall be the following:

– In all RMC messages with DTAFDC > *1*: in TDD mode, $TTR_{ds} = M_{ds}\_old$, $TBUDGET_{ds} \leq M_{ds}\_old$, $TA_{ds} = 0$; in FDX mode, $TTR_{ds,PSF} = M_{ds}\_old$, $TTR_{ds,NPSF}=M_{us}\_old$, $TBUDGET_{ds} \leq M_F\text{-}K$. In both modes, $TBUDGET_{ds}$ is obtained from the latest TxOP.indicate primitive.

– In all RMC messages with DTAFDC > *2*: in TDD mode, $TTR_{us} = M_{us}\_old$, $TBUDGET_{us} \leq M_{us}\_old$, $TA_{us} = 0$; in FDX mode, $TTR_{us,PSF}=M_{us}\_old$, $TTR_{us,NPSF}=M_{ds}\_old$, $TBUDGET_{us} \leq M_F\text{-}K$. In both modes, $TBUDGET_{us}$ is obtained from the latest TxOP.indicate primitive.

– In all RMC messages with DTAFDC ≤ *1* (including those with DTAFDC = 0 that are sent before the completion of the DTA update procedure): in TDD mode, $TTR_{ds} = M_{ds}\_new$, $TBUDGET_{ds} \leq M_{ds}\_new$, $TA_{ds} = 0$; in FDX mode, $TTR_{ds,PSF} = M_{ds}\_new$, $TTR_{ds,NPSF} = M_{us}\_new$, $TBUDGET_{ds} \leq M_F\text{-}K$. In both modes, $TBUDGET_{ds}$ is obtained from the DTA.request primitive.

– In all RMC messages with DTAFDC ≤ *2* (including those with DTAFDC = 0 that are sent before the completion of the DTA update procedure): in TDD mode, $TTR_{us} = M_{us}\_new$,

$TBUDGET_{us} \leq M_{us}\_new$, $TA_{us} = 0$; in FDX mode, $TTR_{us,PSF}=M_{us}\_new$, $TTR_{us,NPSF}=M_{ds}\_new$, $TBUDGET_{us} \leq M_F\text{-}K$. In both modes, $TBUDGET_{us}$ is obtained from the DTA.request primitive.

The logical frame parameters corresponding to the new M_{ds} to be applied in the first PDX frame with DTAFDC = 0, in the last step of the DTA update procedure, shall be as defined in the relevant RMC messages sent by the MTU-O, applied using the rules defined in Table 9-5. If the MTU-R did not receive the RMC message containing the DTA command with DTAFDC = *1*, the following settings shall be used: in TDD mode, $TTR_{ds} = M_{ds}\_new$, $TBUDGET_{ds} = M_{ds}\_new$, $TA_{ds} = 0$, and $IDF = IDF$; in FDX mode, $TTR_{ds,PSF} = M_{ds}\_new$, $TTR_{ds,NPSF} = M_{us}\_new$, $TBUDGET_{ds} = M_F\text{-}K$ and $IDF = IDF$. *IDF* is the value indicated in the last update of the TxOPds/TxOPus primitive.

If the MTU-R did not receive the RMC message containing the DTA command with DTAFDC = *2*, the following settings shall be used: in TDD mode, $TTR_{us} = M_{us}\_new$, $TBUDGET_{us} = M_{us}\_new$, $TA_{us} = 0$, and $IDF = IDF$; in FDX mode, $TTR_{us,PSF}=M_{us}\_new$, $TTR_{us,NPSF}=M_{ds}\_new$, $TBUDGET_{us} = M_F\text{-}K$ and $IDF=IDF$. *IDF* is the value indicated in the last update of the TxOPds/TxOPus primitive.

The MTU-R shall apply these parameters also in all the following PDX frames with DTAFDC = 0 associated with not yet implemented DTA update (i.e., until completion of the DTA update procedure).

D.5.7 Transceiver related DTA control parameters

The following control parameters facilitate DTA operation at transceiver level:

- DTA allowed (*DTA_allowed*);
- Handshake M_{ds} (hs_M_{ds});
- Minimum M_{ds} for DTA ($DTA\_min\_M_{ds}$);
- Maximum M_{ds} for DTA ($DTA\_max\_M_{ds}$);
- Maximum net data rate for DTA (*DTA_NDR_max*);
- Maximum net data rate (*NDR_max*);
- Minimum expected throughput (*ETR_min*).

Some of the parameters specified in this section are DRA control parameters (see Annex T) that are also used by the MTUs.

D.5.7.1 DTA allowed (*DTA_allowed*)

The control parameter *DTA_allowed* determines whether DTA operation is allowed. Valid values are 0 (DTA disallowed), 1 (DTA allowed).

Table D.3 specifies the actions to be taken by the MTU-O depending on the value of *DTA_allowed* and the selection of Annex X during O-SIGNATURE, and shows the resultant status of DTA.

Table D.3 – Enabling/disabling of DTA

DTA_allowed	Annex X selected	Action	Result
0	N/A	The MTU-O shall disable DTA and indicate this to the MTU-R during initialization (DTA_enabled shall be set to 00_{16}, see Table D.9).	DTA disabled
1	0	The MTU-O shall enable cDTA and indicate this to the MTU-R during initialization (DTA_enabled shall be set to 01_{16}, see Table D.9).	cDTA enabled
1	1	The MTU-O shall enable iDTA and indicate this to the MTU-R during initialization (DTA_enabled shall be set to 01_{16}, see Table D.9).	iDTA enabled

The control parameter *DTA_allowed* shall be set to the same value as the DPU-MIB configuration parameter DTA_ALLOWED.

D.5.7.2 Minimum M_{ds} for DTA (*DTA_min_*M_{ds})

The control parameter *DTA_min_*M_{ds} provides the minimum number of FDS symbol periods M_{ds} in a PDX frame the DRA is allowed to request. *DTA_min_*M_{ds} shall be within the range of valid values for M_{ds} specified in clause D.5.3.

The control parameter *DTA_min_*M_{ds} shall be set to the same value as the DPU-MIB configuration parameter DTA_MIN_Mds.

D.5.7.3 Maximum M_{ds} for DTA (*DTA_max_*M_{ds})

The control parameter *DTA_max_*M_{ds} provides the maximum number of FDS symbol periods M_{ds} in a PDX frame the DRA is allowed to request using a DTA update procedure. *DTA_max_*M_{ds} shall be within the range of valid values for M_{ds} specified in clause D.5.3.

The control parameter *DTA_max_*M_{ds} shall be set to the same value as the DPU-MIB configuration parameter DTA_MAX_Mds.

D.5.7.4 Maximum net data rate for DTA (*DTA_NDR_max*)

The control parameter *DTA_NDR_max* provides the value of the maximum *NDR* if DTA operation is enabled, and is defined for downstream and upstream direction separately. The bit loading for the downstream shall be determined such that the downstream *NDR* (as specified in clause D.5.8.2.1) does not exceed *DTA_NDR_max_ds*. The bit loading for the upstream shall be determined such that the upstream *NDR* (as specified in clause D.5.8.2.1) does not exceed *DTA_NDR_max_us*.

The valid values and coding for *DTA_NDR_max* shall be the same as for *NDR_max* as specified in clause 11.4.2.2.

The control parameter *DTA_NDR_max* is derived by the DRA from the DPU-MIB configuration parameter DTA_MAXNDR.

D.5.7.5 Maximum net data rate (*NDR_max*)

The value of *NDR_max* shall be ignored if DTA operation is enabled.

D.5.7.6 Minimum expected throughput (*ETR_min*)

The value of *ETR_min* shall be ignored if DTA operation is enabled, except for the purpose of comparing *ETR* against *ETR_min_eoc*, as specified in clauses D.5.9 and D.5.10.

D.5.8 Transceiver related DTA status parameters

The following status parameters indicate the state of DTA and Annex D operation at the transceiver level:

- Annex D operation enabled (*Annex_D_enabled*);

The following status parameters, specified in clause D.5.8.2, are used for data rate reporting if DTA is enabled:

- Net data rate (*NDR*);
- Attainable net data rate (*ATTNDR*);
- Expected throughput (*ETR*);
- Attainable expected throughput (*ATTETR*).

D.5.8.1 Annex D operation enabled (*Annex_D_enabled*)

The status parameter *Annex_D_enabled* indicates whether Annex D operation is enabled. The *Annex_D_enabled* value is reported as ANNEX_D_ENABLED in the DPU-MIB.

D.5.8.2 Data rate reporting if DTA is enabled

D.5.8.2.1 Net data rate (*NDR*)

If DTA is enabled, the status parameter net data rate (*NDR*) shall be calculated as defined in Table 9-27, assuming:

$$M_{ds} = DTA\_max\_M_{ds}$$

$$M_{us} = M_F - 1 - DTA\_min\_M_{ds}$$

The *NDR* updates, valid values, representation and DPU-MIB reporting shall be as specified in clause 11.4.1.1.1.

NOTE – The NDR equations presented in this clause do not account for the fact that in some cases the actual maximum M_{ds} is smaller than the one defined in the MIB ($Act\_max\_M_{ds} < DTA\_max\_M_{ds}$) and the actual minimum M_{ds} is larger than the one defined in the MIB ($Act\_min\_M_{ds} > DTA\_min\_M_{ds}$), as defined in clause T.2.7.

D.5.8.2.2 Attainable net data rate (*ATTNDR*)

If DTA is enabled, the status parameter attainable net data rate (*ATTNDR*) is defined as the *NDR* that would be achieved if control parameter *DTA_NDR_max* were configured at the maximum valid value of *DTA_NDR_max* (see clause D.5.7.4), while other control parameters remain at the same value.

The *ATTNDR* updates, valid values, representation and DPU-MIB reporting shall be as specified in clause 11.4.1.1.2.

D.5.8.2.3 Expected throughput (*ETR*)

If DTA is enabled, the status parameter expected throughput (*ETR*) shall be derived from the *NDR* (as specified in clause D.5.8.2.1) and the *RTxOH* (as defined in Table 9-27), as *ETR* = (1 – *RTxOH*) x *NDR*.

The *ETR* updates, valid values, representation and DPU-MIB reporting shall be as specified in clause 11.4.1.1.3.

D.5.8.2.4 Attainable expected throughput (*ATTETR*)

If DTA is enabled, the status parameter attainable expected throughput (*ATTETR*) shall be derived from the *ATTNDR* (as specified in clause D.5.8.2.2) and the *RTxOH* (as defined in Table 9-27), as *ATTETR* = (1 – *RTxOH*) x *ATTNDR*.

The *ATTETR* updates, valid values, representation and DPU-MIB reporting shall be as specified in clause 11.4.1.1.4.

D.5.8.2.5 All NOI with Data symbols EFTR with DTFO enabled (*ANDEFTR*)

If DTA is enabled, the parameter All NOI with Data symbols EFTR with DTFO enabled (*ANDEFTR*) shall be calculated as defined in clause 11.4.1.1.17 according to the derived framing parameters given in Table 9-27, assuming:

$$M_{ds} = DTA\_max\_M_{ds}$$

$$M_{us} = MF - 1 - DTA\_min\_M_{ds}$$

ANDEFTR as defined in this clause shall be used to derive the performance monitoring parameters minimum All NOI with Data symbols EFTR (*ANDEFTR_min*), All NOI with Data symbols EFTR (*ANDEFTR_max*), and maximum sum All NOI with Data symbols EFTR (*ANDEFTR_sum*) as defined in clauses 11.4.1.1.18, 11.4.1.1.19 and 11.4.1.1.20.

D.5.8.2.6 All NOI with Data symbols EFTR with DTFO disabled (*ANDEFTR0*)

If DTA is enabled, the parameter All NOI with Data symbols EFTR with DTFO disabled (*ANDEFTR0*) shall be calculated as defined in clause 11.4.1.1.17.1 according to the derived framing parameters given in Table 9-27, assuming:

$$M_{ds} = DTA\_max\_M_{ds}$$

$$M_{us} = MF - 1 - DTA\_min\_M_{ds}$$

ANDEFTR0 as defined in this clause shall be used to derive the performance monitoring parameters minimum All NOI with Data symbols EFTR (*ANDEFTR0_min*), All NOI with Data symbols EFTR (*ANDEFTR0_max*), and maximum sum All NOI with Data symbols EFTR (*ANDEFTR0_sum*) as defined in clauses 11.4.1.1.18.1, 11.4.1.1.19.1, and 11.4.1.1.20.1.

D.5.9 Channel initialization policy for DTA

The channel initialization policy for DTA shall be as specified in clause 12.3.7, except for the following two constraints:

1) $ETR_0 \geq ETR\_min\_eoc$, where ETR_0 shall be calculated as specified in clause 9.8.2.4 using the data symbol rate corresponding to the value of hs_M_{ds}.

   NOTE – This implies that for the purpose of verifying that $ETR_0 \geq ETR\_min\_eoc$, the *ETR* and *ETR_min_eoc* are calculated as if DTA were disabled, i.e., $Mds = hs\_Mds$.

2) $NDR \leq NDR\_max$, where

   a) The *NDR* for the downstream direction shall be calculated using the value $M_{ds} = DTA\_max\_M_{ds}$ (see clause D.5.7.3).

   b) The *NDR* for the upstream direction shall be calculated using the value $DTA\_min\_M_{ds}$ (see clause D.5.7.2).

   c) The *NDR_max* shall be replaced with the value determined by the control parameter *DTA_NDR_max* (see D.5.7.4).

D.5.10 High_BER event for DTA

The High_BER event for DTA shall be as specified in clause 12.1.4.3.4, except for the definition of the ETR, which for DTA, and for the purpose of verifying that $ETR0 \geq ETR\_min\_eoc$, shall be as specified in clause D.5.9.

D.5.11 RMC commands

RMC commands for use with DTA are shown in Table D.4.

Table D.4 – RMC commands for use with DTA

Command name	Command ID	Description/comments	Reference
DTA update	14_{16}	Indicates a request for DTA update. May be included in any downstream RMC message.	See Table D.5

Table D.5 – DTA update command (sent by the MTU-O only)

Field name	Format	Description
Command header	1 byte: [00 aaaaaa]	aaaaaa = 14_{16}
DTA update parameters	Two bytes: byte 0 [a_7 ... a_0] byte 1 [b_7... b_0]	$a_4a_3a_2a_1a_0$ = the actual number of FDS symbol periods in the PDX frame – 3, represented as an unsigned integer. $b_1b_0a_7a_6a_5$ = the updated number of FDS symbol periods in the PDX frame – 3, represented as an unsigned integer. b_3b_2 = reserved by ITU T. $b_7b_6b_5b_4$ = The logical frame down count (DTAFDC) to implementation of the DTA update, represented as an unsigned integer. (Note)
NOTE – this down count is reused for indicating the PDX frame to switch to the new US RMC symbol position in case b_3b_2 = 2, see clause D.5.6.		

If, during the transition in the downstream $M_{ds}(n+1) > M_{ds}(n)$, there are two downstream RMC symbols present in the ACK window (see Figure D.3), the MTU-R shall acknowledge the most recent RMC symbol, while ignoring the status of the older one. The MTU-O shall assume that the older one was not received correctly.

NOTE – Since the status of the RMC commands in the older symbol are ignored by the MTU-R, the MTU-O should avoid sending different commands in the two RMC symbols that rely on the same ACK.

If, during the transition in the downstream $M_{ds}(n+1) < M_{ds}(n)$, there are no downstream RMC symbols present in the ACK window (see Figure D.3), the MTU-R shall set the bit b (b = acknowledgement of the RMC message) in the corresponding upstream RMC command to 1 (positive acknowledgement).

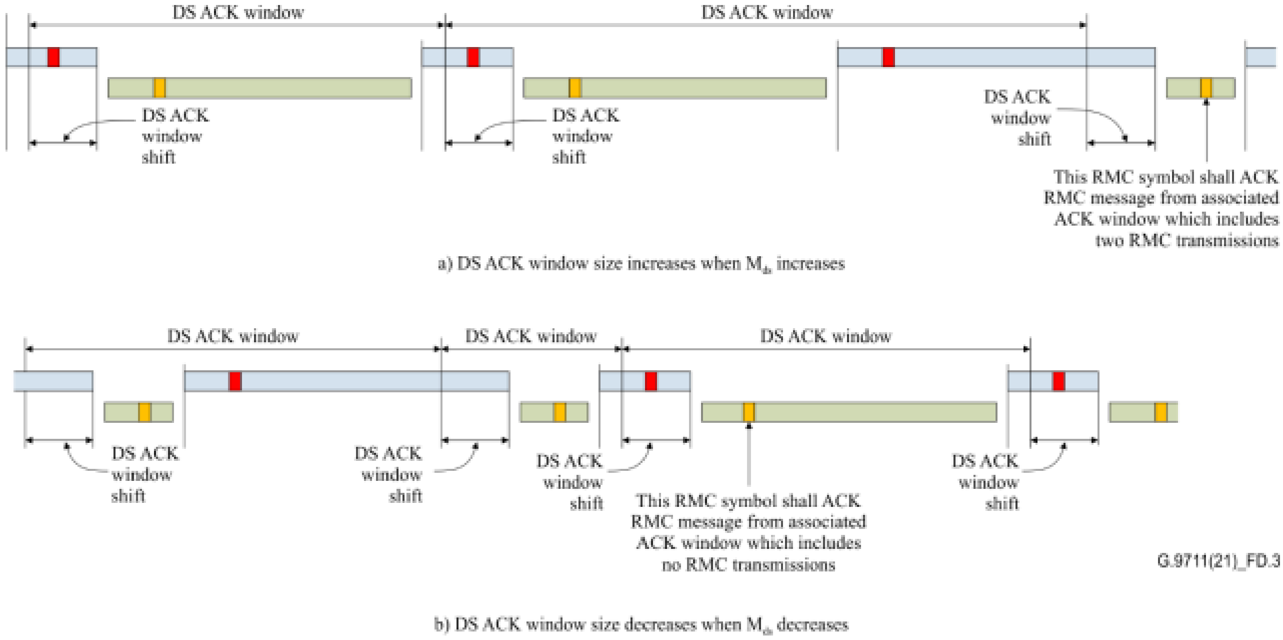


Figure D.3 – Cases of 2 RMC symbols in DS ACK window (a) and no RMC symbols in DS ACK window (b)

D.5.12 eoc commands

In addition to the high priority eoc commands listed in Table 11-4 the command given in Table D.6 is defined.

Table D.6 – Near high priority commands and responses

Command and response type and assigned OPCODE	Direction of command	Command content	Response content	Support	Reference
min used initial DTAFDC 0000 1011_2	From MTU-O to MTU-R.	Update 'min used initial DTAFDC'	Acknowledgement	Mandatory if this Annex is supported	See clause D.5.12.1

D.5.12.1 Update 'min used initial DTAFDC'

Leaving and joining of additional MTU-Rs may require the update of the 'min used initial DTAFDC' value. The MTU-O shall use the update 'min used initial DTAFDC' command to inform the MTU-R about the new 'min used initial DTAFDC' value.

The first byte of the command and response shall be the assigned value for the min used initial DTAFDC command type, as shown in Table D.6. The subsequent bytes of the command and response shall be as shown in Tables D.6 and D.7, respectively.

Table D.7 – Update 'min used initial DTAFDC' command (MTU-O to MTU-R)

Name	Length (Bytes)	Byte	Content
min used initial DTAFDC	3	2	08_{16} (Note)
		3	New minimum used initial value of the DTA frame down count (DTAFDC) represented as an unsigned 8-bit integer. Valid values are from 2 to 15.
NOTE – All other values are reserved by ITU-T.			

The MTU-R shall respond to the update 'min used initial DTAFDC' command by using the response message defined in Table D.8. The new value of 'min used initial DTAFDC' shall be applied immediately after the MTU-O has received the response from the MTU-R.

Table D.8 – Update 'min used initial DTAFDC' response (MTU-R to MTU-O)

Name	Length (Bytes)	Byte	Content
Acknowledge min used initial DTAFDC	2	2	84_{16} (Note)
NOTE – All other values are reserved by ITU-T.			

NOTE – The update 'min used initial DTAFDC' does not require a synchronisation mechanism between MTU-O and MTU-R. However, a synchronization across the vectored group may be necessary. In case the value is being reduced, the MTU-Os are allowed to continue with their current larger value until all MTU-Rs have acknowledged the reception of the new reduced value. In case the value is being increased, since 'min used initial DTAFDC' is a minimum value, the MTU-O may apply a larger value immediately and does not have to wait for a response.

D.6 Initialization messages

D.6.1 Channel analysis and exchange phase

D.6.1.1 O-MSG 1

See clause 12.3.4.2.1. The Annex D parameter field in O-MSG 1 is shown in Table D.9.

Table D.9 – Annex D parameter field

Field name	Format	Description
DTA_enabled	One byte	Indicate if DTA procedure is enabled. Valid values are 00_{16} (DTA disabled) and 01_{16} (DTA enabled)
DTA_NDR_max_us	Two bytes	Indicates the maximum NDR for the upstream if DTA operation is enabled (as specified in clause D.5.7.4), coded as an unsigned integer in multiples of 96 kbit/s. If DTA is disabled, the field shall be set to 0.
DTA_min_Mds	One byte	Indicates the minimum number of downstream symbol periods M_{ds} in a PDX frame the DRA is allowed to request, coded as an unsigned integer. The valid values are specified in clause D.5.7.2. If DTA is disabled, the field shall be set to 0.

D.6.1.2 R-MSG 2

See clause 12.3.4.2.2. The Annex D parameter field in R-MSG 2 is shown in Table D.10.

Table D.10 – Annex D parameter field

Field name	Format	Description
Min initial DTAFDC	One byte	Minimum initial value of the DTA frame down count (DTAFDC) supported by the MTU-R coded as an unsigned integer. Valid values are from 2 to 5. If DTA is disabled (see Table D.9), all bits of the field shall be set to 0.

D.6.1.3 O-PMS

See clause 12.3.4.2.5. The Annex D parameter field in O-PMS is shown in Table D.11.

Table D.11 – Annex D parameter field

Field name	Format	Description
DTA_max_M_{ds}	One byte	Indicates the upper bound to the maximum number of downstream symbol periods M_{ds} in a PDX frame the DRA is allowed to request, coded as an unsigned integer. The valid values are specified in clause D.5.3. If DTA is disabled, all bits of the field shall be set to 0.
DTA_NDR_max_ds	Two bytes	Indicates the maximum *NDR* for the downstream if DTA operation is enabled (as specified in clause D.5.7.4), coded as an unsigned integer in multiples of 96 kbit/s. If DTA is disabled, all bits of the field shall be set to 0.
Min used initial DTAFDC	One byte	Minimum used initial value of the cDTA frame down count (DTAFDC) selected by the DRA coded as an unsigned integer. Valid values are from 2 to 15. If DTA is disabled, all bits of the field shall be set to 0.

Annexes E to O

Annexes E to O are intentionally left blank.

Annex P

Adaptation to the twisted pair medium

(This annex forms an integral part of this Recommendation.)

P.1 Scope

This annex specifies operations of ITU-T G.9711 transceiver in a twisted pair scenario. In the twisted pair scenario, the MTU-O and the peer MTU-R is connected via a twisted pair.

P.2 Definitions

This annex does not define any new terms

P.3 Abbreviations and acronyms

This annex does not define any new abbreviations or acronyms.

P.4 Reference models

P.5 Profiles

P.5.1 Profiles for operation over twisted pairs

ITU-T G.9711 transceivers for operation over twisted pairs shall comply with at least one profile specified in Table P.1. Compliance with more than one profile is allowed.

Table P.1 – Profiles for the twisted pair medium

Profile name	P424a	P424amp	P424d	P424dmp	P848a	Reference
Parameter	**Parameter value for profile (Note 1)**					
PSD type (Note 3)	424 MHz	424 MHz	424 MHz	424 MHz	848 MHz	
Duplexing mode	TDD	TDD	FDX (Note 7)	FDX (Note 7)	For further study	Clause 7.1
P2MP operation	No	Yes	No	Yes		
Maximum number of MTU-Rs in P2MP mode	Not applicable	4 (Note 5)	Not applicable	4 (Note 5)		Clause 5.1
Maximum aggregate downstream transmit power (dBm)	+4	+4	+4	+4		
Maximum aggregate upstream transmit power (dBm)	+4	+4	+4	+4		
Subcarrier spacing (kHz)	51.75	51.75	51.75	51.75		
Precoding type	Linear	Linear	Linear	Linear		
Aggregate net data-rate (ANDR) capability	4000 Mbit/s (Note 6)	4000 Mbit/s (Note 6)	8000 Mbit/s (Note 6)	8000 Mbit/s (Note 6)		
Maximum number of FEC codewords in one DTU (Q_{max})	16	16	16	16		Clause 8.2
Parameter $(1/S)_{max}$ downstream	48	48	48	48		(Note 4)

Table P.1 – Profiles for the twisted pair medium

Profile name	P424a	P424amp	P424d	P424dmp	P848a	Reference
Parameter	**Parameter value for profile (Note 1)**					
Parameter $(1/S)_{max}$ upstream	48	48	48	48		(Note 4)
Index of the lowest supported downstream data-bearing subcarrier (lower band-edge frequency (informative))	43 (2.22525 MHz)	43 (2.22525 MHz)	43 (2.22525 MHz)	43 (2.22525 MHz)		(Note 2)
Index of the lowest supported upstream data-bearing subcarrier (lower band-edge frequency (informative))	43 (2.22525 MHz)	43 (2.22525 MHz)	43 (2.22525 MHz)	43 (2.22525 MHz)		(Note 2)
Index of the highest supported downstream data-bearing subcarrier (upper band-edge frequency (informative))	8191 (423.88425 MHz)	8191 (423.88425 MHz)	8191 (423.88425 MHz)	8191 (423.88425 MHz)		(Note 2)
Index of the highest supported upstream data-bearing subcarrier (upper band-edge frequency (informative))	8191 (423.88425 MHz)	8191 (423.88425 MHz)	8191 (423.88425 MHz)	8191 (423.88425 MHz)		(Note 2)
Maximum number of eoc bytes per direction per logical frame period	M_F = 36: 6000 M_F = 23: 4400	M_F = 36: 6000 M_F = 23: 4400	M_F = 36: 8000 M_F = 23: 6000	M_F = 36: 8000 M_F = 23: 6000		

NOTE 1 – Other profiles are for further study.

NOTE 2 – The allowed frequency band is further determined by applicable PSD mask requirements defined in [ITU-T G.9710], constrained by the capabilities guaranteed by the profile(s) that the implementation supports. The band-edge frequency in MHz appears in parentheses below the subcarrier index (informative).

NOTE 3 – The PSD type is specified in [ITU-T G.9710].

NOTE 4 – The value of 1/S is the number of FEC codewords transmitted during one symbol period and shall be computed as the total number of data bytes loaded onto a DMT symbol, which is equal to the maximum of B_D and B_{DR} divided by the applied FEC codeword size N_{FEC} (see clauses 9.3 and 9.5). Parameter $(1/S)_{max}$ defines the maximum value of 1/S.

NOTE 5 – Support of a larger number of MTU-Rs (up to 16) is optional.

NOTE 6 – This ANDR number represents the highest ANDR theoretically possible within this Recommendation assuming support of only the mandatory functionalities and an ideal AFE. The actual ANDR capability may be lower with a practical AFE implementation. Achievable aggregate net data rate further depends on channel conditions and system configurations.

NOTE 7 – If operation in FDX mode is discovered to be not beneficial from the performance perspective, the transmission line may fall back to the TDD mode during initialization (see clause 12.3.3).

P.5.2 Profile compliance

See clause 6.2 for rules regarding profile compliance.

Annex Q

Adaptation to the coaxial medium

(This annex forms an integral part of this Recommendation.)

Q.1 Scope

This annex specifies operations of ITU-T G.9711 transceiver in a coaxial cable scenario. In the coaxial cable scenario, the MTU-O and the peer MTU-R is connected via a coaxial cable.

Q.2 Definitions

This annex does not define any new terms.

Q.3 Abbreviations and acronyms

This annex does not define any new abbreviations or acronyms.

Q.4 Reference models

Q.5 Profiles

Q.5.1 Profiles for operation over coaxial cables

ITU-T G.9711 transceivers for operation over coaxial cables shall comply with at least one profile specified in Table Q.1. Compliance with more than one profile is allowed.

Table Q.1 – Annex Q profiles for operation over coaxial cables

Profile name	Q424c	Q424cmp	Q424d	Q424dmp	Q848c	Reference
Parameter	**Parameter value for profile (Note 1)**					
PSD type (Note 3)	424 MHz	424 MHz	424 MHz	424 MHz	848 MHz	
Duplexing mode	TDD	TDD	FDX (Note 5)	FDX (Note 5)		
P2MP operation	No	Yes	No	Yes		
Maximum number of MTU-Rs in P2MP mode	Not applicable	4 (Note 6)	Not applicable	4 (Note 6)		Clause 5.1
Maximum aggregate downstream transmit power (dBm)	+2	+2	+2	+2		
Maximum aggregate upstream transmit power (dBm)	+2	+2	+2	+2		
Precoding type	Not applicable	Not applicable	Not applicable	Not applicable	For further study	
Subcarrier spacing (kHz)	51.75	51.75	51.75	51.75		
Aggregate net data-rate (ANDR) capability	4000 Mbit/s (Note 7)	4000 Mbit/s (Note 7)	8000 Mbit/s (Note 7)	8000 Mbit/s (Note 7)		
Maximum number of FEC codewords in one DTU (Q_{max})	16	16	16	16		Clause 8.2
Parameter $(1/S)_{max}$ downstream	48	48	48	48		(Note 4)
Parameter $(1/S)_{max}$	48	48	48	48		(Note 4)

Table Q.1 – Annex Q profiles for operation over coaxial cables

Profile name	Q424c		Q424cmp		Q424d		Q424dmp		Q848c	Reference
Parameter	**Parameter value for profile (Note 1)**									
upstream										
Index of the lowest supported downstream data-bearing subcarrier (lower band-edge frequency (informative))	43 (2.22525 MHz)		43 (2.22525 MHz)		43 (2.22525 MHz)		43 (2.22525 MHz)			(Note 2)
Index of the lowest supported upstream data-bearing subcarrier (lower band-edge frequency (informative))	43 (2.22525 MHz)		43 (2.22525 MHz)		43 (2.22525 MHz)		43 (2.22525 MHz)			(Note 2)
Index of the highest supported downstream data-bearing subcarrier (upper band-edge frequency (informative))	8191 (423.88425 MHz)		8191 (423.88425 MHz)		8191 (423.88425 MHz)		8191 (423.88425 MHz)			(Note 2)
Index of the highest supported upstream data-bearing subcarrier (upper band-edge frequency (informative))	8191 (423.88425 MHz)		8191 (423.88425 MHz)		8191 (423.88425 MHz)		8191 (423.88425 MHz)			(Note 2)
Maximum number of eoc bytes per direction per logical frame period	M_F = 36	M_F = 23	M_F = 36	M_F = 23	M_F = 36	M_F = 23	M_F = 36	M_F = 23		
	6000	4400	6000	4400	6000	4400	6000	4400		

NOTE 1 – Other profiles are for further study.

NOTE 2 – The allowed frequency band is further determined by applicable PSD mask requirements defined in [ITU-T G.9710], constrained by the capabilities guaranteed by the profile(s) that the implementation supports. The band-edge frequency in MHz appears in parentheses below the subcarrier index (informative).

NOTE 3 – The PSD type is specified in ITU-T G.9710.

NOTE 4 – The value of 1/S is the number of FEC codewords transmitted during one symbol period and shall be computed as the total number of data bytes loaded onto a DMT symbol, which is equal to the maximum of B_D and B_{DR} divided by the applied FEC codeword size N_{FEC} (see clauses 9.3 and 9.5). Parameter $(1/S)_{max}$ defines the maximum value of 1/S.

NOTE 5 – If operation in FDX mode is discovered to be not beneficial from the performance perspective, the transmission line may fall back to the TDD mode during initialization (see clause 12.3.3).

NOTE 6 – Support of a larger number (up to 16) of MTU-Rs is optional.

NOTE 7 – This ANDR number represents the highest ANDR theoretically possible within this Recommendation assuming support of only the mandatory functionalities and an ideal AFE. The actual ANDR capability may be lower with a practical AFE implementation. Achievable aggregate net data rate further depends on channel conditions and system configurations.

Q.5.2 Profile compliance

See clause 6.2 for rules regarding profile compliance.

Q.6 Discontinuous operation

For Annex Q operations, the same requirements as defined in clause X.8 shall be applied.

Q.7 Requirements specific to FDX mode

For Annex Q operations, the same requirements as defined in X.9 shall be applied.

Q.8 Adaptation to the coaxial cable medium

Q.8.1 Application reference model

See clause 5.2.

Q.8.2 Termination impedance

See clause Q.2 of [ITU-T G.9710].

Q.8.3 Maximum aggregate transmit power

See clause Q.3 of [ITU-T G.9710] and Table Q.1.

Q.8.4 MDU coaxial cable configurations (informative)

See clause X.12.4 [b-ITU-T G.9701].

Annex R

Annex R is intentionally left blank.

Annex S

NT software upgrade

(This annex forms an integral part of this Recommendation.)

S.1 Scope

This annex provides means to upgrade the software of a network termination (NT) where the executable software can be upgraded with a single vendor-specific image file. The executable software may exist in multiple parts of the equipment (e.g., DSP firmware and higher layer application software). Two images are maintained at the NT so that one can be upgraded while the other one is executed. The contents of this software image file and the upgrade of individual components of an NT are beyond the scope of this annex.

This annex is beyond the scope of transceiver functionality and is optional for system implementations.

S.2 References

[ITU-T I.363.5] Recommendation ITU-T I.363.5 (1996), *B-ISDN ATM Adaptation Layer specification: Type 5 AAL*.

[IETF RFC 1321] IETF RFC 1321 (1992), *The MD5 Message-Digest Algorithm*.

S.3 Reference model

The reference model for the NT software upgrade is shown in Figure S.1. It contains the associated OAM entities of the DPU and NT. The DPU entity contains the software image management function as a part of the ME-O. The ME-O will act as a master for the software image upgrades at the ME-R, which contains two instances of software images (0 and 1). Those two instances of software images at the NT are managed independently by the software management function of the DPU. Additional vendor specific files may be managed (see clause S.4.2).

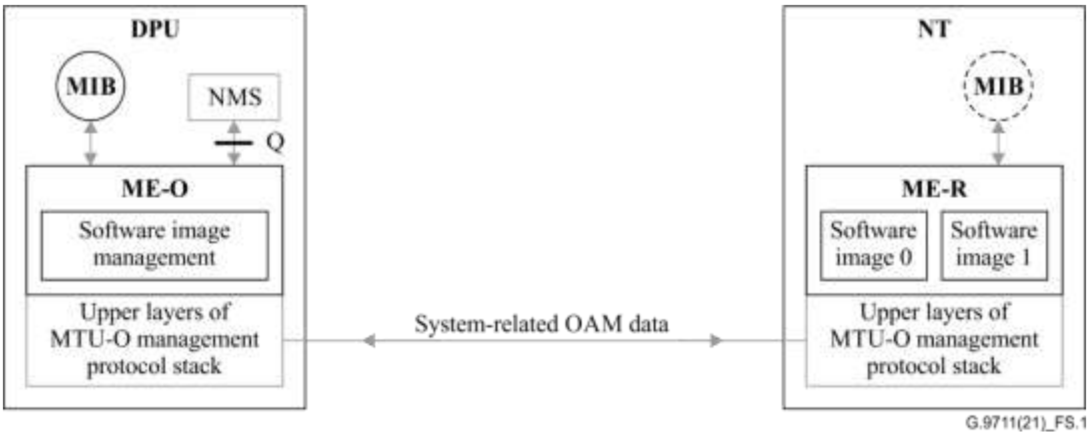


Figure S.1 – Software image management reference model

The status of each software image at the ME-R is reflected in DPU-MIB. The ME-O and ME-R use a transparent communication channel to exchange software management commands and data between them as system-related OAM data. The clauses of this annex describe the software image management process and the details of messages exchanged.

S.4 Software image management process

The ME-O manages executable software images stored in the NT (documented here as its fundamental usage, clause S.4.1). This process may also be used to manage vendor-specific files at the NT (documented here as vendor-specific usage, see clause S.4.2).

S.4.1 Fundamental usage

The NT contains two software image instances, each independently manageable.

Some pluggable equipment might not contain software. Others may contain software that is intrinsically bound to the NT's own software image. No software image can be managed for such equipment, though it may be convenient for the NT to support the retrieval of attributes of the software image. In this case, the ME-R would support only the 'get software image' action.

S.4.1.1 Software images attributes for fundamental usage

The following manageable attributes are specified for each software image instance:

Managed software image: This attribute distinguishes between the two software image instances (0, 1). (mandatory) (1 byte)

Version: This string attribute identifies the version of the software. (mandatory) (14 bytes)

Is committed: This attribute indicates whether the associated software image is committed (1) or uncommitted (0). By definition, the committed software image is loaded and executed upon reboot of the NT. Normally, one of the two software images is committed, while the other is uncommitted. Under no circumstances are both software images allowed to be committed at the same time. On the other hand, both software images could be uncommitted at the same time if both were invalid. Upon NT first time start-up, instance 0 is initialized to committed, while instance 1 is initialized to uncommitted (that is, the NT ships from the factory with image 0 committed). (mandatory) (1 byte)

Is active: This attribute indicates whether the associated software image is active (1) or inactive (0). By definition, the active software image is one that is currently loaded and executing in the NT. Normally, one of the two software images is active while the other is inactive. Under no circumstances are both software images allowed to be active at the same time. On the other hand, both software images could be inactive at the same time if both were invalid. (mandatory) (1 byte)

Is valid: This attribute indicates whether the associated software image is valid (1) or invalid (0). By definition, a software image is valid if it has been verified to be an executable code image. The verification mechanism is vendor discretionary; however, it should include at least a data integrity (e.g., CRC) check of the entire code image. Upon software download completion, the NT validates the associated code image and sets this attribute according to the result. (mandatory) (1 byte)

Product code: This attribute provides a way for a vendor to indicate product code information on a file. It is a character string, padded with trailing nulls if it is shorter than 25 bytes. (optional) (25 bytes)

Image hash: This attribute is an MD5 hash of the software image. It is computed as specified in [IETF RFC 1321] at completion of the end download action (optional) (16 bytes).

S.4.1.2 Actions supporting the software upgrade process

All of the following actions are mandatory for NTs with remotely manageable software.

Get software image: Retrieve attributes of a software image instance. This action is valid for all software image instances.

Start download: Initiate a software download sequence. This action is valid only for a software image instance that is neither active nor committed.

Download section: Download a section of a software image. This action is valid only for a software image instance that is currently being downloaded (image 1 in state S2, image 0 in state S2' as shown in Figure S.3).

End download: Signal the completion of a download image sequence, providing CRC for final verification. This action is valid only for a software image instance that is currently being downloaded (image 1 in state S2, image 0 in state S2' as shown in Figure S.3).

Activate image: Load/execute a software image. When this action is applied to a software image that is currently inactive, execution of the current code image is suspended, the associated software image is loaded from non-volatile memory, and execution of this new code image is initiated (that is, the associated entity reboots on the previously inactive image). When this action is applied to a software image that is already active, a soft restart is performed. The software image is not reloaded from non-volatile memory; the current volatile code image is simply restarted. Set the *is active* attribute value to 1 for the target software image instance and set the *is active* attribute value to 0 for the other software image. This action is only valid for a valid software image.

Commit image: Set the *is committed* attribute value to 1 for the target software image instance and set the *is committed* attribute value to 0 for the other software image. This causes the committed software image to be loaded and executed by the boot code upon subsequent start-ups. This action is only applicable when the target software image is valid.

NOTE – Software upgrade process using the above actions is exemplified in clause S.6.

S.4.2 Vendor-specific usage

In this application, the software image management is flexible, in keeping with the needs of particular vendors and applications. The distinction between fundamental and vendor-specific usage is that the managed software image instance shall not be a value that could be used in the fundamental usage application. That is, this byte shall be neither 00_{16} nor 01_{16}.

The NT automatically instantiates as many software image instances as it is prepared to support.

- In its vendor-specific usage, the support of attributes of the software image instances are optional.
- The actions are optional.
- Files might or might not exist in versioned pairs (previous revision, next revision).

S.4.2.1 File attributes for the vendor-specific usage

Each software image instance has the following manageable attributes:

Managed software image: This attribute distinguishes between software image instances, and in vendor-specific usage is required to have neither the value 00_{16} nor the value 01_{16}. It is suggested that the software image be numbered consecutively beginning from 2 (mandatory) (1 byte).

Version: If this attribute is supported, its meaning is the same as that of the fundamental usage application (optional) (14 bytes).

Is committed: This attribute indicates whether the associated file is committed (1) or uncommitted (0). Vendor-specific instances might or might not exist in pairs, and might or might not support the concept of a commit (optional) (1 byte).

Is active: This attribute indicates whether the associated file is active (1) or inactive (0). Vendor-specific instances might or might not support the concept of an active state (optional) (1 byte).

Is valid: This attribute indicates whether the associated file is valid (1) or invalid (0). Vendor-specific instances might or might not include a way to determine their validity (optional) (1 byte).

Product code: This attribute provides a way for a vendor to indicate product code information on a file. It is a character string, padded with trailing nulls if it is shorter than 25 bytes (optional) (25 bytes).

Image hash: This attribute is an MD5 hash of the software image. It is computed at completion of the end download action (optional) (16 bytes).

S.4.2.2 Actions for vendor-specific usage and download process

The following actions are available for vendor-specific use, but optional. If the NT does not support a given action, it should respond with a reason code indicating "command not supported".

Get software image: Retrieve attributes of a software image instance. This action is valid for all software image instances.

Start download: Initiate a software download sequence.

Download section: Download a section of a file.

End download: Signal the completion of a file download, providing CRC and version information for final verification, if supported. This action causes the file to be stored in the NT's non-volatile memory.

NOTE – The download mechanism supports downloading of a zero-byte file to the NT. This is done using a start download command specifying an image size of zero, followed by an immediate end download, with a zero CRC and also specifying an image size of zero. The action the NT takes from this messaging is beyond the scope of this annex. It is vendor discretionary whether the NT recognizes downloading a file of size zero as a file delete operation, or as a file replace operation, or as any other vendor discretionary operation.

Activate image: Effectuate the file, for example by loading its contents into NT hardware. If appropriate, the hardware or application may be reinitialized. Set the *is active* attribute value to 1 for the target file instance.

Commit image: Set the *is committed* attribute value to 1 for the target file instance, if supported. The semantics of this operation are vendor-specific; there is no de-commit action.

S.4.3 OAM data for software management

The OAM data for software management process is transparently exchanged between ME-O and ME-R. The messages described in the subsequent section are to be included in the payload of a datagram eoc command (see clause 11.2.2.4.2). Each message in clause S.5 sent from ME-O to ME-R or from ME-R to ME-O is included as payload of exactly one datagram eoc command without additional data or protocol. The message size is limited by the maximum payload size of the datagram eoc command (up to 1018 bytes in length).

Support of the datagram eoc command (see Table 11-7) is mandatory for Annex S.

Some of the messages in clause S.5 require a response. The response shall be sent within 300 ms. The sending ME shall consider the message as lost if the corresponding response is not received within 400ms.

S.4.3.1 Transaction correlation identifier

The transaction correlation identifier is used to associate a request message with its response message. For request messages, the DPU shall select a transaction identifier that avoids the possibility of ambiguous responses from NTs. A response message carries the transaction identifier of the message to which it is responding.

S.4.3.2 Message type field

The message type field is subdivided into four parts. These are shown in Figure S.2.

Bit 7	6	5	4	0
0	AR	AK	MT	

Figure S.2 – Message type field subdivision

Bit 7, the most significant bit, is reserved for future use by ITU-T. It shall be set to 0 by the transmitter and ignored by the receiver.

Bit 6, acknowledge request (AR), indicates whether or not the message requires an acknowledgement. An acknowledgement is a response to an action request. If an acknowledgement is expected, this bit shall be set to 1. If no acknowledgement is expected, this bit shall be set to 0. In messages sent by the NT, this bit shall be set to 0.

Bit 5, acknowledgement (AK), indicates whether or not this message is an acknowledgement to an action request. If a message is an acknowledgement, this bit shall be set to 1. If the message is not an acknowledgement, this bit shall be set to 0. In messages sent by the DPU, this bit shall be set to 0.

Bits 4..0, message type (MT), indicate the message type, as defined in Table S.1. Values not shown in the table are reserved by ITU-T.

Table S.1 – NT software management message types

MT	Type	Purpose	AR	AK
30	Get software image	DPU requests one or more attributes of a managed software image instance from the NT.	1	0
	Get software image response	NT provides the attributes of a managed software image instance requested by the DPU	0	1
19	Start software download	DPU requests to start a software download	1	0
	Start software download response	NT acknowledges that a software download may start	0	1
20	Download section	Download a section of a software image	Note	No
	Download section response	NT acknowledges reception of last section within a window	0	1
21	End software download	End of a software download action	1	0
	End software download response	NT informs the DPU whether the download command was successful or not	0	1
22	Activate software	DPU requests the NT to activate the indicated software image under the provided condition	1	0
	Activate software response	NT informs the DPU whether the activate software command was successful or not	0	1

Table S.1 – NT software management message types

MT	Type	Purpose	AR	AK
23	Commit software	DPU requests the NT to commit the indicated software image	1	0
	Commit software response	NT informs the DPU whether the commit software command was successful or not	0	1
NOTE – The download section action is acknowledged only for the last section within a window. See clause S.6.				

S.4.3.3 Get software image and get software image response messages

The get software image and get software image response messages are used to transfer attributes of software image instances from the NT to the DPU.

For an attribute mask, a bit map is used in the get software image and get software image response messages. This bit map indicates which attributes are requested (in the case of get software image) or provided (in the case of get software image response). The bit map is composed as given in Table S.2.

Table S.2 – NT software image attributes

Byte	Bit							
	7	6	5	4	3	2	1	0
1	Attribute 1	Attribute 2	Attribute 3	Attribute 4	Attribute 5	Attribute 6	Attribute 7	Attribute 8
2	Attribute 9	Attribute 10	Attribute 11	Attribute 12	Attribute 13	Attribute 14	Attribute 15	Attribute 16

The attribute numbers in Table S.2 correspond to the specific attributes as given in Table S.3. An attribute is 'set' if the corresponding bit in the attribute mask is equal to 1 and is not set if the bit is 0.

Table S.3 – NT software image attributes

Attribute number	Description
1	Version
2	Is committed
3	Is active
4	Is valid
5	Product code
6	Image hash
7..16	Reserved

S.5 Message set

S.5.1 Get software image

The format of the Get software image message is described in Table S.4.

Table S.4 – Get software image message

Field	Byte	7	6	5	4	3	2	1	0	Comments
Datagram protocol identifier	1	0	0	0	0	0	0	0	1	NT software management = 01_{16}
Transaction correlation identifier	2-3									
Message type	4	0	1	0	1	1	1	1	0	AR = 1, AK = 0, MT = 30 Action = get software image
Managed software image instance	5									Software image instance 0 instance 0 1 instance 1 2..254 vendor-specific use 255 reserved by ITU-T
Message contents length	6-7									Length of message contents field in bytes = 2 (Note)
Message contents	8-9									Attribute mask
NOTE – This field shall be coded as an unsigned integer on 16 bits [b_{15} … b_0], where b_0 is the least significant bit (LSB). Byte 6 shall represent [b_{15} … b_8] and byte 7 shall represent [b_7 … b_0].										

S.5.2 Get software image response

The format of the Get software image response is described in Table S.5

Table S.5 – Get software image response message

Field	Byte	7	6	5	4	3	2	1	0	Comments
Datagram protocol identifier	1	0	0	0	0	0	0	0	1	NT software management = 01_{16}
Transaction correlation identifier	2-3									
Message type	4	0	0	1	1	1	1	1	0	AR = 0, AK = 1, MT = 30 Action = get software image response.
Managed software image instance	5									Software image instance 0 instance 0 1 instance 1 2..254 vendor-specific use 255 reserved by ITU-T
Message contents length	6-7									Length of message contents field in bytes, variable for this message type (Note).
Message contents	8	0	0	0	0	x	x	x	x	Result, reason 0000 command processed successfully 0001 command processing error 0010 command not supported 0011 parameter error 0100 reserved by ITU-T 0101 unknown managed software image instance 0110 device busy 1001 attribute(s) failed or unknown
	9-10									Attribute mask
	11-12									Optional-attribute mask, used with 1001 encoding: 0 default 1 unsupported attribute
	13-14									Attribute execution mask, used with 1001 encoding: 0 default 1 failed attribute
	15-n									Value of first attribute included (size depending on the type of attribute)
										…
										Value of last attribute included
NOTE – This field shall be coded as an unsigned integer on 16 bits [b_{15} … b_0], where b_0 is the LSB. Byte 6 shall represent [b_{15} … b_8] and byte 7 shall represent [b_7 … b_0].										

Bytes 11-14 are allocated for the optional-attribute and attribute execution masks; however, the contents of these bytes are only valid in conjunction with result code 1001 used to indicate failed or unknown attributes. When the result code is not 1001, these bytes shall be set to 0 by the NT transmitter and ignored by the DPU receiver.

S.5.3 Start software download

The format of the Start software download message is described in Table S.6.

Table S.6 – Start software download message

Field	Byte	7	6	5	4	3	2	1	0	Comments
Datagram protocol identifier	1	0	0	0	0	0	0	0	1	NT software management = 01_{16}
Transaction correlation identifier	2-3									
Message type	4	0	1	0	1	0	0	1	1	AR = 1, AK = 0, MT = 19 Action = start software download.
Managed software image instance	5									Software image instance 0 instance 0 1 instance 1 2..254 vendor-specific use 255 reserved by ITU-T
Message contents length	6-7									Length of message contents field in bytes = 5 (Note 1).
Message contents	8									Window size (represented as a number of sections) minus one (Note 2)
	9-12									Image size in bytes (Note 3)

NOTE 1 – This field shall be coded as an unsigned integer on 16 bits [b_{15} … b_0], where b_0 is the LSB. Byte 6 shall represent [b_{15} … b_8] and byte 7 shall represent [b_7 … b_0].

NOTE 2 – This value shall be coded as an unsigned integer on 8 bits [b_7 … b_0], where b_0 is the LSB.

NOTE 3 – This value shall be coded as an unsigned integer on 32 bits [b_{31} … b_0], where b_0 is the LSB. Byte 9 shall represent [b_{31} … b_{24}] and byte 12 shall represent [b_7 … b_0].

S.5.4 Start software download response

The format of the Start software download response is described in Table S.7.

The response contains a result code in byte 8, and a window size counter-proposal (which may be the same as that suggested by the DPU in the original request) in byte 9.

Table S.7 – Start software download response message

Field	Byte	7	6	5	4	3	2	1	0	Comments
Datagram protocol identifier	1	0	0	0	0	0	0	0	1	NT software management = 01_{16}
Transaction correlation identifier	2-3									
Message type	4	0	0	1	1	0	0	1	1	AR = 0, AK = 1, MT = 19 bits 5-1: action = start software download response.
Managed software image instance	5									Software image instance 0 instance 0 1 instance 1 2..254 vendor-specific use 255 reserved by ITU-T
Message contents length	6-7									Length of message contents field in bytes = 2 (Note 1)
Message contents	8	0	0	0	0	x	x	x	x	Result, reason 0000 command processed successfully 0001 command processing error 0010 command not supported 0011 parameter error 0100 reserved by ITU-T 0101 unknown managed software image instance 0110 device busy
	9									Window size (represented as a number of sections) minus one (Note 2)
NOTE 1 – This field shall be coded as an unsigned integer on 16 bits [$b_{15} \dots b_0$], where b_0 is the LSB. Byte 6 shall represent [$b_{15} \dots b_8$] and byte 7 shall represent [$b_7 \dots b_0$]. NOTE 2 – This value shall be coded as an unsigned integer on 8 bits [$b_7 \dots b_0$], where b_0 is the LSB.										

S.5.5 Download section

The format of the Download section message is described in Table S.8.

Table S.8 – Download section message

Field	Byte	7	6	5	4	3	2	1	0	Comments
Datagram protocol identifier	1	0	0	0	0	0	0	0	1	NT software management = 01_{16}
Transaction correlation identifier	2-3									
Message type	4	0	x	0	1	0	1	0	0	AR = x, AK = 0, MT = 20 x = 0 no response expected (section within a window) x = 1 response expected (last section of a window) Action = download section
Managed software image instance	5									Software image instance 0 instance 0 1 instance 1 2..254 vendor-specific use 255 reserved by ITU-T
Message contents length	6-7									Length of message contents field in bytes, variable for this message type (Note 1)
Message contents	8									Download section number (Note 2)
	9-n									Software image data

NOTE 1 – This field shall be coded as an unsigned integer on 16 bits [$b_{15} \dots b_0$], where b_0 is the LSB. Byte 6 shall represent [$b_{15} \dots b_8$] and byte 7 shall represent [$b_7 \dots b_0$].

NOTE 2 – This value shall be coded as an unsigned integer on 8 bits [$b_7 \dots b_0$], where b_0 is the LSB.

S.5.6 Download section response

The format of the Download section response message is described in Table S.9.

Table S.9 – Download section response message

Field	Byte	7	6	5	4	3	2	1	0	Comments
Datagram protocol identifier	1	0	0	0	0	0	0	0	1	NT software management = 01_{16}
Transaction correlation identifier	2-3									
Message type	4	0	0	1	1	0	1	0	0	AR = 0, AK = 1, MT = 20 Action = download section response
Managed software image instance	5									Software image instance 0 instance 0 1 instance 1 2..254 vendor-specific use 255 reserved by ITU-T
Message contents length	6-7									Length of message contents field in bytes = 2 (Note 1)
Message contents	8	0	0	0	0	x	x	x	x	Result, reason 0000 command processed successfully 0001 command processing error 0010 command not supported 0011 parameter error 0100 reserved by ITU-T 0101 unknown managed software image instance 0110 device busy
	9									Download section number (Note 2)
NOTE 1 – This field shall be coded as an unsigned integer on 16 bits [b_{15} … b_0], where b_0 is the LSB. Byte 6 shall represent [b_{15} … b_8] and byte 7 shall represent [b_7 … b_0]. NOTE 2 – This value shall be coded as an unsigned integer on 8 bits [b_7 … b_0], where b_0 is the LSB.										

S.5.7 End software download

The format of this command is similar to that of the start software download message. See Table S.10.

Table S.10 – End software download message

Field	Byte	7	6	5	4	3	2	1	0	Comments
Datagram protocol identifier	1	0	0	0	0	0	0	0	1	NT software management = 01_{16}
Transaction correlation identifier	2-3									
Message type	4	0	1	0	1	0	1	0	1	AR = 1, AK = 0, MT = 21 Action = end software download
Managed software image instance	5									Software image instance 0 instance 0 1 instance 1 2..254 vendor-specific use 255 reserved by ITU-T
Message contents length	6-7									Length of message contents field in bytes = 8 (Note 1)
Message contents	8-11									CRC-32, computed over all bytes of the software image, as specified in [ITU-T I.363.5]
	12-15									Image size in bytes (Note 2)

NOTE 1 – This field shall be coded as an unsigned integer on 16 bits [b_{15} … b_0], where b_0 is the LSB. Byte 6 shall represent [b_{15} … b_8] and byte 7 shall represent [b_7 … b_0].

NOTE 2 – This value shall be coded as an unsigned integer on 32 bits [b_{31} … b_0], where b_0 is the LSB. Byte 12 shall represent [b_{31} … b_{24}] and byte 15 shall represent [b_7 … b_0].

S.5.8 End software download response

The response message informs the DPU whether the download command was successful. Byte 8 reports the result of the process and indicates the "device busy" reason code (0110) in response to any received end software download command as long as the instance is busy writing the image to a non-volatile store. Once the NT has stored all images successfully, it responds to continued end software download commands with a 0 in Byte 8. See Table S.11.

Table S.11 – End software download response message

Field	Byte	7	6	5	4	3	2	1	0	Comments
Datagram protocol identifier	1	0	0	0	0	0	0	0	1	NT software management = 01_{16}
Transaction correlation identifier	2-3									
Message type	4	0	0	1	1	0	1	0	1	AR = 0, AK = 1, MT = 21 Action = end software download response.
Managed software image instance	5									Software image instance 0 instance 0 1 instance 1 2..254 vendor-specific use 255 reserved by ITU-T
Message contents length	6-7									Length of message contents field in bytes = 1 (Note).
Message contents	8	0	0	0	0	x	x	x	x	Result, reason 0000 command processed successfully (CRC correct) 0001 command processing error (CRC incorrect, in addition to the normal criteria) 0010 command not supported 0011 parameter error 0100 reserved for use by ITU-T 0101 unknown managed software image instance 0110 device busy 1000 CRC correct and image stored in volatile memory
NOTE – This field shall be coded as an unsigned integer on 16 bits [b_{15} … b_0], where b_0 is the LSB. Byte 6 shall represent [b_{15} … b_8] and byte 7 shall represent [b_7 … b_0].										

S.5.9 Activate image

The format of the Activate image message is described in Table S.12.

Table S.12 – Activate image message

Field	Byte	7	6	5	4	3	2	1	0	Comments
Datagram protocol identifier	1	0	0	0	0	0	0	0	1	NT software management = 01_{16}
Transaction correlation identifier	2-3									
Message type	4	0	1	0	1	0	1	1	0	AR = 1, AK = 0, MT = 22 Action = activate image.
Managed software image instance	5									Software image instance 0 first instance 1 second instance 2..254 vendor-specific use
Message contents length	6-7									Length of message contents field in bytes = 1 (Note 1).
Flags	8	0	0	0	0	0	0	F	F	Bits FF: 00 Activate image unconditionally 01 Activate image only if no POTS/VoIP calls are in progress 10 Activate image only if no emergency call is in progress (Note 2) 11 Reserved If the NT denies the activate image command because of the FF field, it returns result, reason code 0110, device busy.

NOTE 1 – This field shall be coded as an unsigned integer on 16 bits [b_{15} … b_0], where b_0 is the LSB. Byte 6 shall represent [b_{15} … b_8] and byte 7 shall represent [b_7 … b_0].

NOTE 2 – The NT determines the presence of an originating emergency call on a vendor discretionary basis.

S.5.10 Activate image response

The format of the Activate image response message is described in Table S.13.

Table S.13 – Activate image response message

Field	Byte	7	6	5	4	3	2	1	0	Comments
Datagram protocol identifier	1	0	0	0	0	0	0	0	1	NT software management = 01_{16}
Transaction correlation identifier	2-3									
Message type	4	0	0	1	1	0	1	1	0	AR = 0, AK = 1, MT = 22 Action = activate image response.
Managed software image instance	5									Software image instance 0 first instance 1 second instance 2..254 vendor-specific use
Message contents length	6-7									Length of message contents field in bytes = 1 (Note).
Message contents	8	0	0	0	0	x	x	x	x	Result, reason 0000 command received successfully, activation of new image will follow according to clause S.6.3 0001 command processing error 0010 command not supported 0011 parameter error 0100 reserved by ITU-T 0101 unknown managed software image instance 0110 device busy
NOTE – This field shall be coded as an unsigned integer on 16 bits [b_{15} … b_0], where b_0 is the LSB. Byte 6 shall represent [b_{15} … b_8] and byte 7 shall represent [b_7 … b_0].										

S.5.11 Commit image

The format of the Commit image message is described in Table S.14.

Table S.14 – Commit image message

Field	Byte	7	6	5	4	3	2	1	0	Comments
Datagram protocol identifier	1	0	0	0	0	0	0	0	1	NT software management = 01_{16}
Transaction correlation identifier	2-3									
Message type	4	0	1	0	1	0	1	1	1	AR = 1, AK = 0, MT = 23 Action = commit image.
Managed software image instance	5									Software image instance 0 first instance 1 second instance 2..254 vendor-specific use
Message contents length	6-7									Length of message contents field in bytes = 0 (Note).
NOTE – This field shall be coded as an unsigned integer on 16 bits [b_{15} … b_0], where b_0 is the LSB. Byte 6 shall represent [b_{15} … b_8] and byte 7 shall represent [b_7 … b_0].										

S.5.12 Commit image response

The format of the Activate image response message is described in Table S.15.

Table S.15 – Commit image response message

Field	Byte	7	6	5	4	3	2	1	0	Comments
Datagram protocol identifier	1	0	0	0	0	0	0	0	1	NT software management = 01_{16}
Transaction correlation identifier	2-3									
Message type	4	0	0	1	1	0	1	1	1	AR = 0, AK = 1, MT = 23 Action = commit image response
Managed software image instance	5									Software image instance 0 first instance 1 second instance 2..254 vendor-specific use
Message contents length	6-7									Length of message contents field in bytes = 1 (Note)
Message contents	8	0	0	0	0	x	x	x	x	Result, reason 0000 command processed successfully 0001 command processing error 0010 command not supported 0011 parameter error 0100 reserved by ITU-T 0101 unknown managed software image instance

Table S.15 – Commit image response message

										0110 device busy
NOTE – This field shall be coded as an unsigned integer on 16 bits [b_{15} … b_0], where b_0 is the LSB. Byte 6 shall represent [b_{15} … b_8] and byte 7 shall represent [b_7 … b_0].										

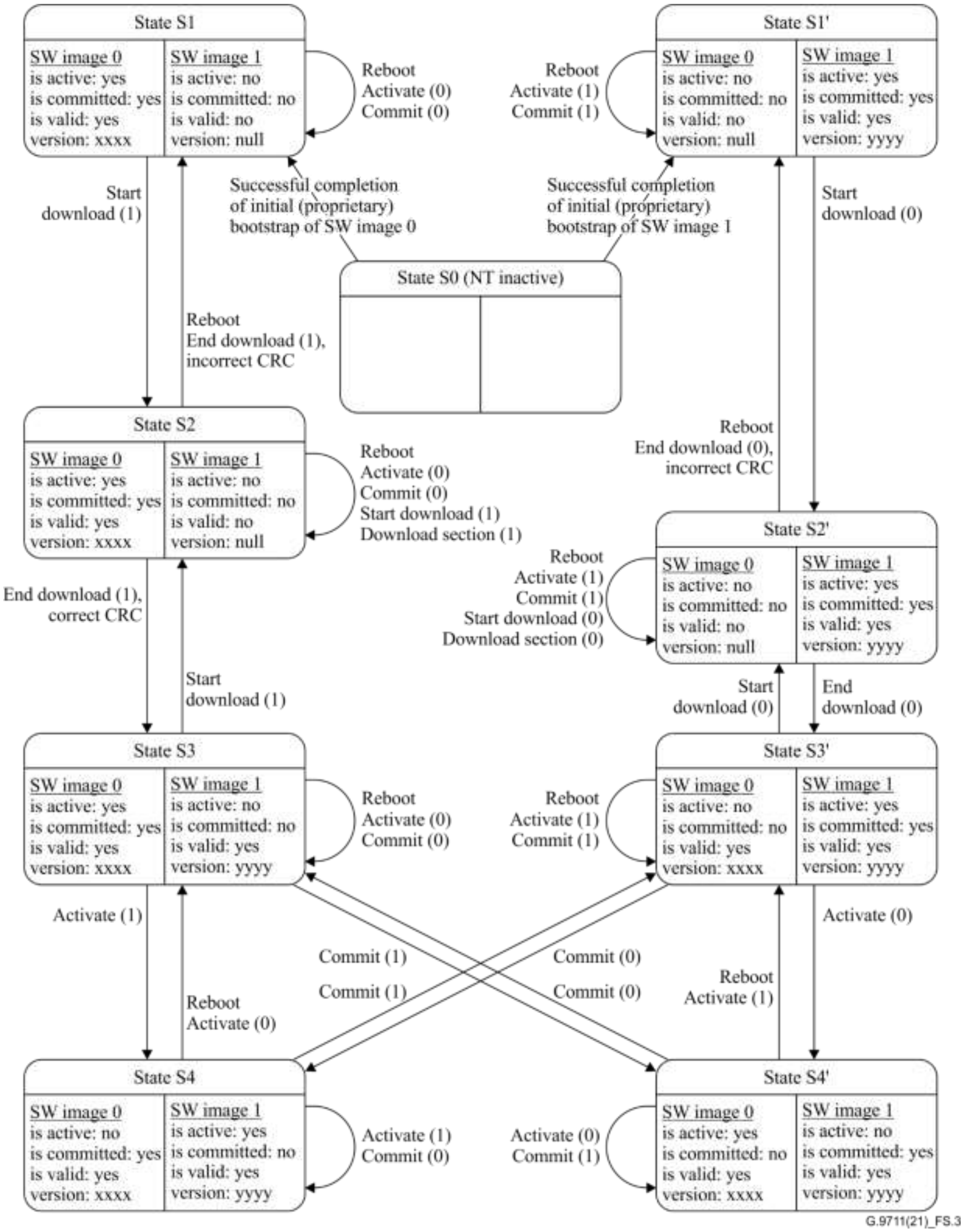
S.6 Software upgrade (informative)

S.6.1 Overview

The software image management is specified in clause S.4. The NT creates two software image instances, 0 and 1. Each image has three Boolean attributes: committed, active and valid. An image is valid if the contents have been verified to be an executable code image. An image is committed if it will be loaded and executed upon reboot of the NT. An image is active if it is currently loaded and executing in the NT. At any given time, at most one image may be active and at most one image may be committed.

An NT goes through a series of states to download and activate a software image as shown in Figure S.3. Each state is determined by the status of both software images. For example, S3 is the state where both images are valid but only image 0 is committed and active. State S0 is a conceptual initialization state.

The DPU controls the state of the NT through a series of commands specified in clause S.4. For example, an NT in state S3 will transition to state S4 upon receipt of the activate (1) command. The specified commands are start download, download section, end download, activate image and commit image.



NOTE 1 – In Figure S.3, states S1 and S2 (and S1' and S2') are distinguished only for convenience in understanding the flow. Upon receipt of a start download message, and particularly when the NT reboots, any partial downloads in progress are discarded.
NOTE 2 – In Figure S.3, state transitions occur when any of the listed actions occur.

Figure S.3 – Software image state diagram

S.6.2 Software image download

The software image download operation is a file transfer from the DPU to the NT.

The atomic unit of file transfer is the section, the amount of data that can be transferred in a single download section message. The maximum size of the section is limited by the maximum payload size of the datagram eoc command (see clause 11.2.2.4.2). The DPU may send smaller sections at will, including the final section of a file transfer. Because the message format allows for variable length, software image sections are never padded.

A number of sections comprise a so-called window. A window shall not exceed 256 sections. Figure S.4 illustrates the relationship between a software image and its decomposition into windows and sections.

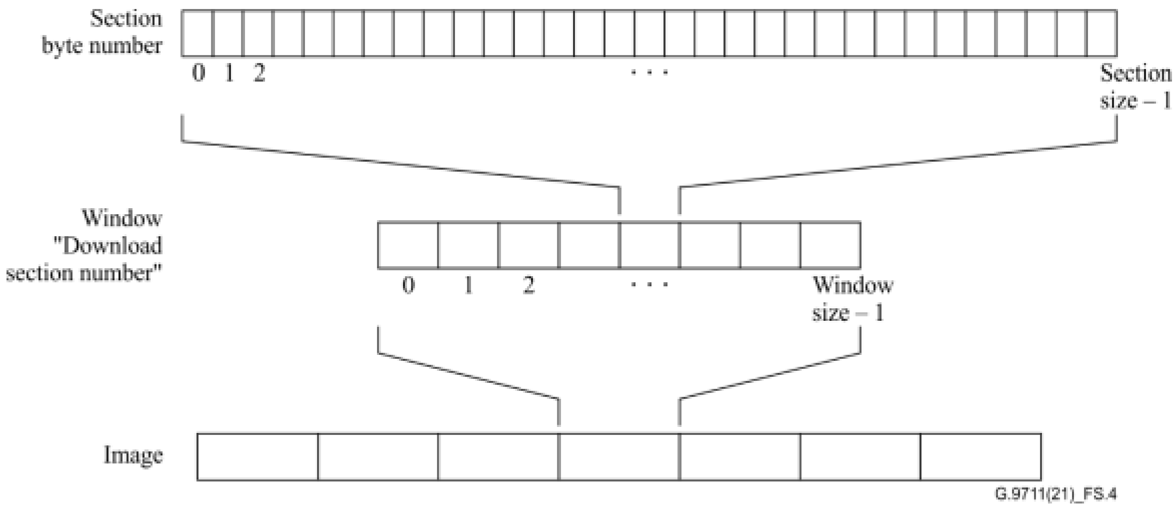


Figure S.4 – Relationship between image, windows and sections

During the initial software download message exchange, the DPU proposes a maximum window size, but a lower value can be stipulated by the NT, which shall be accepted by the DPU. The DPU may send windows with fewer sections than this negotiated maximum, but shall not exceed the maximum. Though it is not a preferred choice, the DPU may send all windows at the full negotiated maximum size, with the final window of the download operation with download section messages containing only null bytes.

Each download section message contains a sequence number, which begins anew at 0 with each window. By tracking the incrementing sequence numbers, the NT can confirm that it has in fact received each section of code.

In the message type field of the last download section message of each window, the DPU indicates the end of the window by setting the AR (acknowledgement request) bit – prior download section messages are unacknowledged. If the NT has not received the entire window correctly, i.e., if it misses a sequence number, it acknowledges with a command processing error result, whereupon the DPU falls back to the beginning of the window and tries again. To improve the chance of successful transmission, the DPU may choose to reduce the size of the window on its next attempt.

When the final window has been successfully downloaded, the DPU sends an end software download message whose contents include the size of the downloaded image in bytes, along with a CRC-32 computed according to [ITU-T I.363.5], across the entire image. If the NT agrees with both of these values, it updates the software image validity attribute to indicate that the newly downloaded image is valid. Figure S.5 illustrates this process.

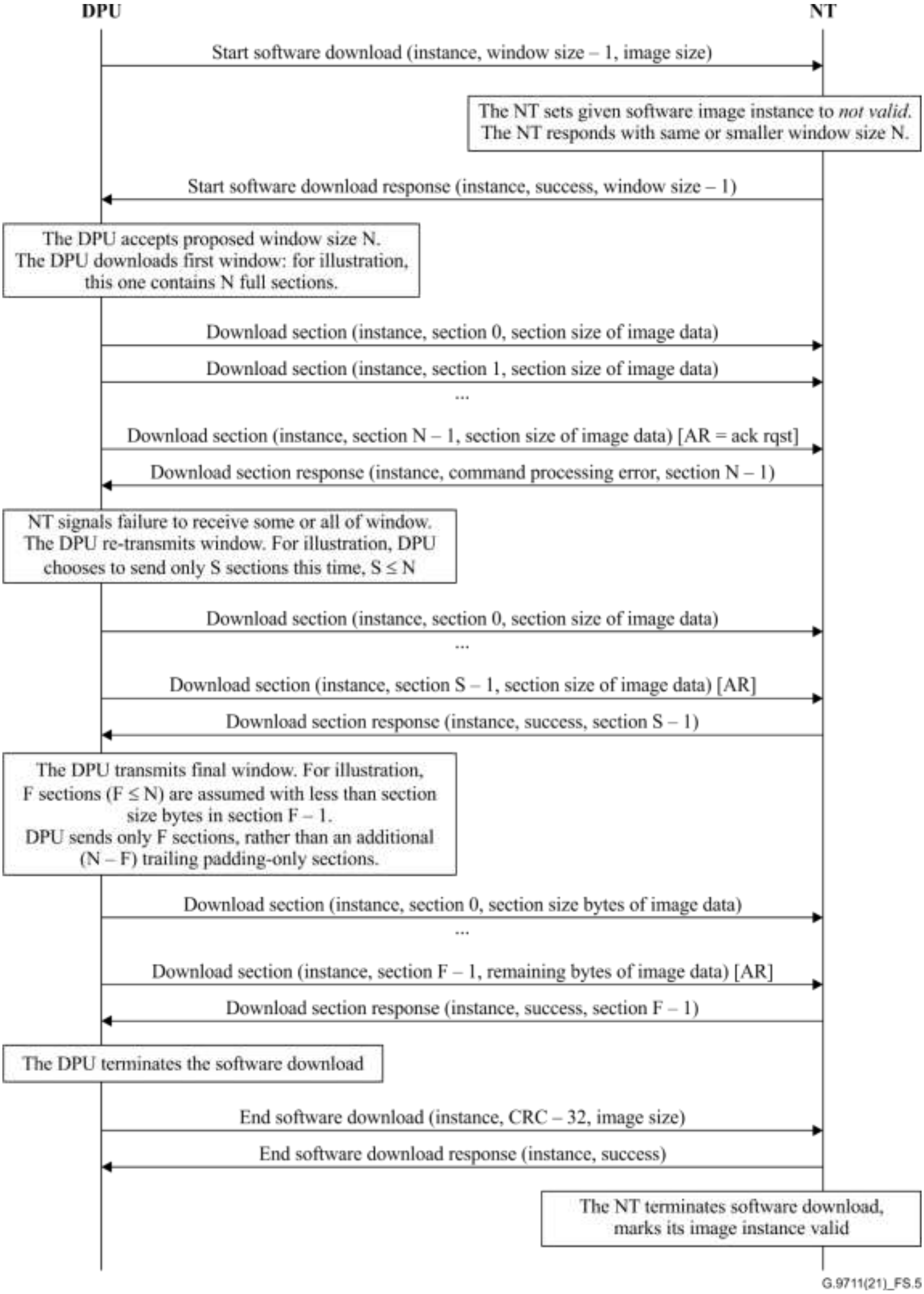


Figure S.5 – Software download

The NT positively acknowledges an end download message only after it has performed whatever operations may be necessary – such as storage in non-volatile memory – to accept an immediate activate or commit message from the DPU. As illustrated in Figure S.6, the NT responds with a device busy result code until these operations are complete, and the DPU periodically retries the end download command. The DPU includes a timeout to detect an NT that never completes the download operation.

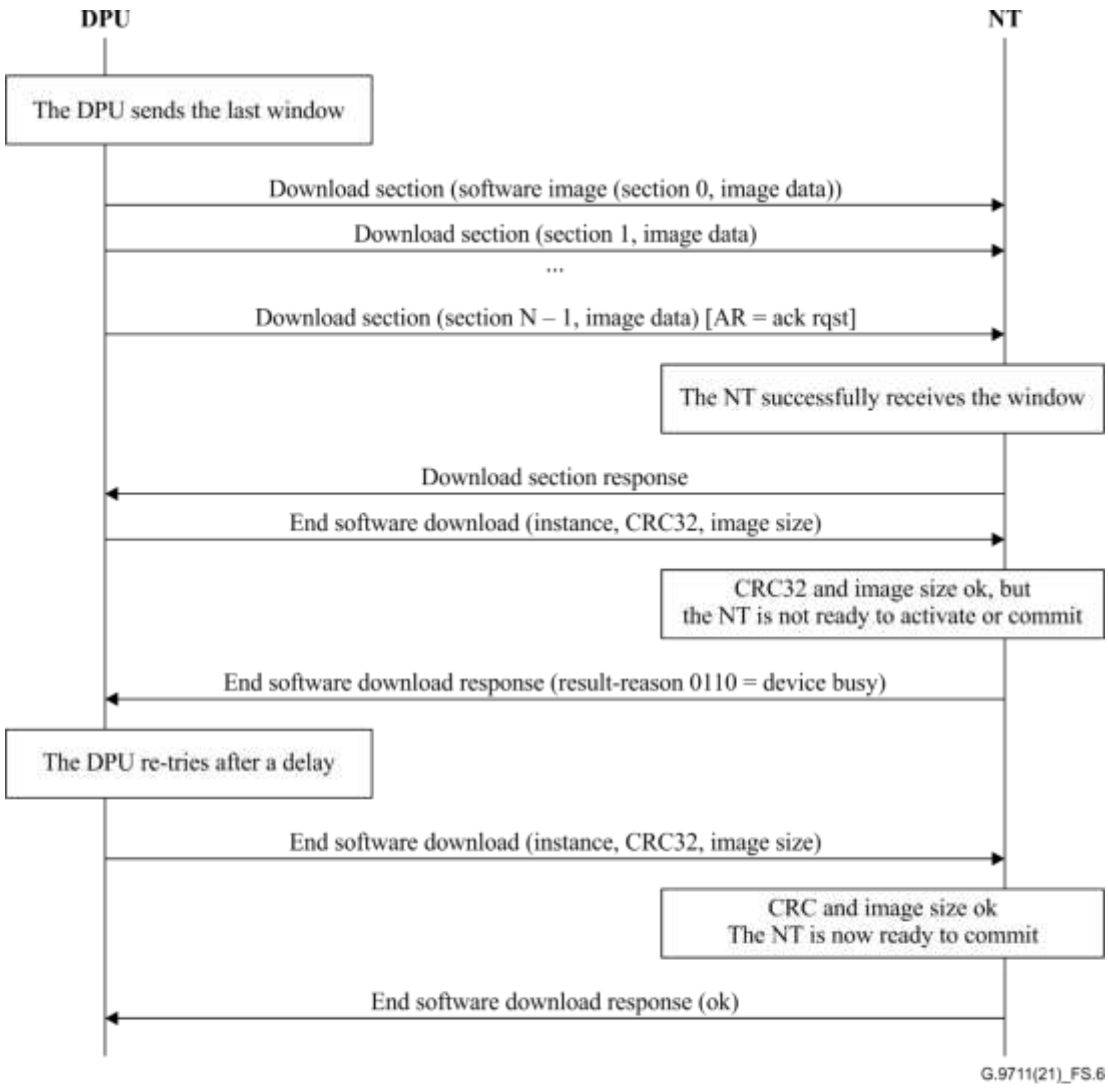


Figure S.6 – Busy response handling

The nested state machines in the DPU and NT can conceivably get out of step in a number of unspecified ways; nor is it specified how to escape from a loop of transmission failure and retry. As a recovery mechanism from detectable state errors, it is recommended that the NT reply with command processing error result codes to both the acknowledged download section and the end software download commands, and that the DPU send a final end software download command with a known bad CRC and image size (e.g., all 0), whereupon both the DPU and the NT reset to the state in which no download is in progress, that is, state S1/S1' of Figure S.3. Likewise, the DPU can abort the download operation at any time by sending an end software download message with invalid CRC and image size.

S.6.3 Software image activate and commit

Figure S.7 shows the details of software image activate and commit. When the NT has downloaded and validated a new image, that image is initially not-committed and not-activated. The DPU may then send the activate image command. After the NT sends a positive activate image response, the NT loads and executes the new software image, but without changing the committed state of either image. The DPU may then send the commit image command, causing the NT to set the commit state true for the new image, and false for the previous image. The time between the download, activate and commit phases is not specified.

If there is a problem with the newly activated image that causes the NT to fail (e.g., watchdog timeout), the NT may do a soft restart on the (other) committed image. Activating prior to committing may thereby allow for automatic failure recovery by the NT.

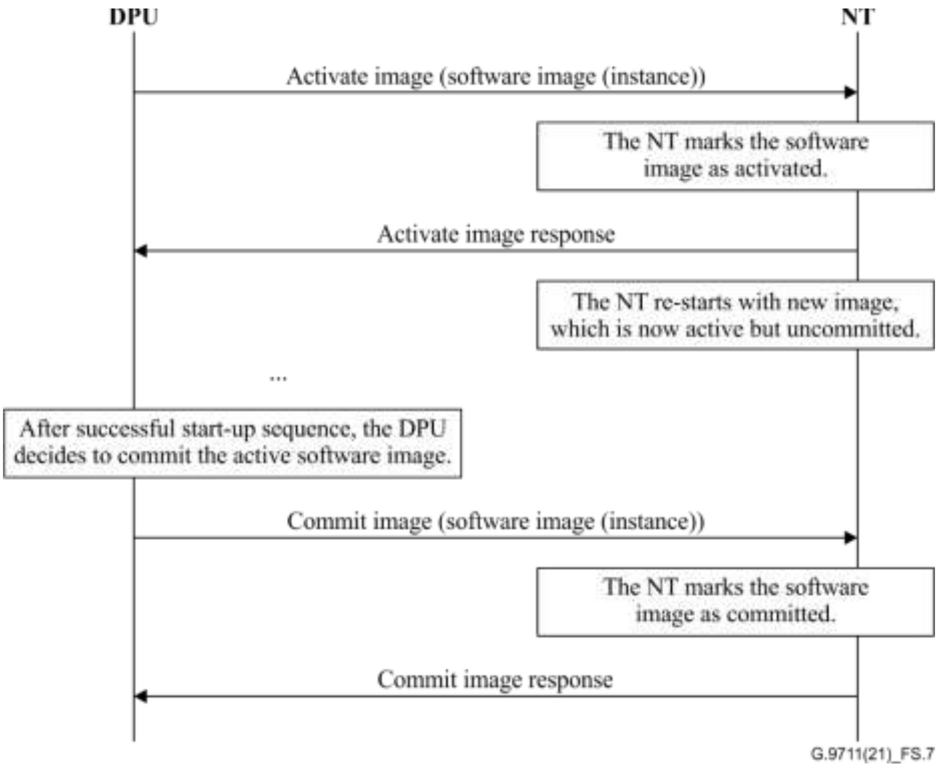


Figure S.7 – Software activate and commit

Annex T

Dynamic time assignment (DTA) – higher-layer control aspects

(This annex forms an integral part of this Recommendation.)

T.1 Scope

This annex specifies the cross-layer control aspects of dynamic time assignment (DTA). According to Annex D, the DRA block monitors traffic-related information and decides when to make changes in the PDX frame configuration of each MTU-O. The update of the PDX frame configuration is done using the DTA procedure described in clause D.5.2. This annex specifies the parameters to control the behaviour of the DRA functionality that determines DTA. If not stated otherwise, the requirements and definitions specified in this Annex are applicable to independent DTA (iDTA) and to coordinated DTA (cDTA). The specified parameters are individual to each transmission line managed by the DRA.

T.2 DTA control parameters

The DRA control parameters that facilitate iDTA and cDTA operations according to Annex D are shown in Table T.1.

Table T.1 – DTA control parameters

Parameter name	Description	Reference
DTA_allowed	Allow DTA	Clause T.2.1
hs_M_{ds}	Handshake M_{ds}	Clause T.2.2
$DTA\_pref\_M_{ds}$	Preferred M_{ds} for DTA	Clause T.2.3
DTA_SMax	Maximum step size for DTA changes	Clause T.2.4
$DTA\_min\_M_{ds}$	Minimum M_{ds} for DTA	Clause T.2.5
$DTA\_max\_M_{ds}$	Maximum M_{ds} for DTA	Clause T.2.6
DTA_ETR_min	Minimum expected throughput for DTA	Clause T.2.7
DTA_NDR_max	Maximum net data rate for DTA	Clause T.2.8
DTA_Min_Time	Minimum time between DTA updates	Clause T.2.9

T.2.1 DTA allowed (*DTA_allowed*)

See clause D.5.7.1.

T.2.2 Handshake M_{ds} (hs_M_{ds})

The control parameter hs_M_{ds} represents the value of M_{ds} selected during the ITU-T G.994.1 handshake phase of initialization (see Table 11.70.3 of [ITU-T G.994.1]) but revises the definition of the NPar(3) bits associated with the SPar(2) bit "Number of downstream symbol positions in PDX frame" as specified in Table 12-11. If DTA is enabled (see clauses T.2.7, D.5.9), it provides the number of FDS symbol positions in a PDX frame during initialization and from the time the MTU-O enters showtime until the first DTA update. During a fast retrain, the value of M_{ds} shall be set to hs_M_{ds} regardless of the value of M_{ds} used in the previous L0 link state.

NOTE – The setting of this parameter for cDTA is assumed to be the same for all active lines of a vectored group.

T.2.3 Preferred *Mds* for DTA ($DTA\_pref\_M_{ds}$)

The control parameter $DTA\_pref\_M_{ds}$ represents the preferred M_{ds} value.

On transmission lines where iDTA operation is enabled, the value of $DTA\_pref\_M_{ds}$ provides the number of FDS symbol periods in a PDX frame requested by the DRA in a first DTA update after the MTU-O enters showtime: if $Act\_min\_M_{ds} \leq DTA\_pref\_M_{ds} \leq Act\_max\_M_{ds}$ (see clause T.2.7), the DRA shall request a DTA update (using the DTA.request primitive, see clause D.5.1) with the value of *DTA_pref_Mds* at the first opportunity after the MTU-O enters showtime.

On transmission lines where cDTA operation is enabled, the DRA shall consider the demand for upstream and downstream traffic of all other transmission lines that are part of a vectored group to select a suitable M_{ds} value, which may be different from the value of $DTA\_pref\_M_{ds}$. However, if the value of $DTA\_pref\_M_{ds}$ is suitable, that value shall be selected. The DRA shall request a DTA update (using the cDTA request primitives cDTA.request, see clause D.5.1) with the selected value of M_{ds} at the first opportunity after the MTU-O enters showtime.

$DTA\_pref\_M_{ds}$ shall be within the valid range specified for M_{ds} in clause D.5.3. $DTA\_pref\_M_{ds}$ shall be greater than or equal to $DTA\_min\_M_{ds}$ and less than or equal to $DTA\_max\_M_{ds}$.

NOTE 1 – The preferred M_{ds} value ($DTA\_pref\_M_{ds}$) may also be used by DTA control algorithms to return to that value in case of low traffic. In case of iDTA the DRA may decide to request DTA updates to apply the preferred M_{ds} value if the demand for upstream and downstream traffic on the considered transmission line can be fulfilled with an M_{ds} value equal to $DTA\_pref\_M_{ds}$. In case of cDTA the DRA has to consider the traffic demands of other transmission lines. Only if the demand for upstream and downstream traffic of all transmission lines that are part of a vectored group can be fulfilled with an M_{ds} value equal to $DTA\_pref\_M_{ds}$, DTA updates may be requested to apply this value.

The control parameter $DTA\_pref\_M_{ds}$ shall be set to the same value as the DPU-MIB configuration parameter DTA_PREF_Mds.

NOTE 2 – The setting of this parameter for cDTA is assumed to be the same for all active lines of a vectored group.

T.2.4 Maximum step size for DTA changes (*DTA_SMax*)

The control parameter *DTA_SMax* represents the maximum step size for DTA changes and is the maximum change in M_{ds} that the DRA is allowed to request for a single DTA update (see clause D.5.2). The absolute value of the difference between the number of FDS symbol periods M_{ds} in a PDX frame just prior to and immediately after any DTA update shall be less than or equal to *DTA_SMax*.

In order to speed up the transition to hs_M_{ds} due to a joining line in case of cDTA (see clause D.5.2), the constraint *DTA_SMax* shall not apply during this transition.

The valid values for *DTA_SMax* are all integers between 1 and 25 for $M_F = 36$ and between 1 and 12 for $M_F = 23$.

The control parameter *DTA_Smax* shall be set to the same value as the DPU-MIB configuration parameter DTA_SMAX.

NOTE – If the *ETR* falls below *DTA_ETR_min*, the DRA is required to initiate DTA updates in order to increase this rate above *DTA_ETR_min* (see clause T.2.7). Setting *DTA_Min_time* (see clause T.2.9) to a high value or *DTA_SMax* to a low value or both, might result in a slow return to an *ETR* value above *DTA_ETR_min*, in such a case.

T.2.5 Minimum M_{ds} for DTA ($DTA\_min\_M_{ds}$)

See clause D.5.7.2.

T.2.6 Maximum M_{ds} for DTA ($DTA\_max\_M_{ds}$)

See clause D.5.7.3.

T.2.7 Minimum expected throughput for DTA (DTA_ETR_min)

The control parameter *DTA_ETR_min* represents the minimum expected throughput for DTA and provides a target minimum ETR that the DRA should meet when DTA operation is enabled.

In order to meet the *DTA_ETR_min* configured value for the downstream direction, the DRA shall calculate the number of downstream symbols min_M_{ds} needed to provide an expected throughput of at least *DTA_ETR_min*. This shall be done according to the derived framing parameters given in Table 9-27 such that *ETR* would be greater than or equal to the downstream *DTA_ETR_min* assuming a downstream data symbol rates in PSF and NPSF as calculated in section 9.8.2.4 by using $M_{ds}=min\_M_{ds}$ and, $M_{us}=M_F$-1-min_M_{ds}:

For the upstream direction the DRA shall calculate the maximum value max_M_{ds} such that at least an expected throughput of the upstream *DTA_ETR_min* will be available. This shall be done according to the derived framing parameters given in Table 9-27 such that *ETR* would be greater than or equal to the upstream *DTA_ETR_min* assuming an upstream data symbol rates in PSF and NPSF as calculated section 9.8.2.4 by using $M_{ds}=min\_M_{ds}$ and, $M_{us}=M_F$-1-min_M_{ds}:

The calculated minimum and maximum values min_M_{ds} and max_M_{ds} shall further constrain the dynamic range of M_{ds} given by $DTA\_max\_M_{ds}$ and $DTA\_min\_M_{ds}$ using the following definitions:

$$Act\_min\_M_{ds} = \max(min\_M_{ds}, DTA\_min\_M_{ds})$$

$$Act\_max\_M_{ds} = \min(max\_M_{ds}, DTA\_max\_M_{ds})$$

In case of iDTA, the DRA shall select an M_{ds} value such that $Act\_min\_M_{ds} \leq M_{ds} \leq Act\_max\_M_{ds}$. If $Act\_min\_M_{ds} > Act\_max\_M_{ds}$, the value of hs_M_{ds} shall be used by the DRA for the PDX frame configuration. In this case, the *ETR* is lower than *DTA_ETR_min* but is still greater than or equal to *ETR_min*.

In case of cDTA, the DRA shall select a common M_{ds} value for all active lines of the vectoring group such that, for each active line, the condition $Act\_min\_M_{ds} \leq M_{ds} \leq Act\_max\_M_{ds}$ is valid.

NOTE 1 – Act_min_Mds and Act_max_Mds may differ between transmission lines.

Upon completion of an OLR occurring on the transmission line, the values of min_M_{ds}, max_M_{ds}, $Act\_min\_M_{ds}$ and $Act\_max\_M_{ds}$ shall be updated by the DRA. If the *ETR* falls below *DTA_ETR_min* after an OLR procedure, the DRA shall recalculate the values of min_M_{ds}, max_M_{ds}, $Act\_min\_M_{ds}$ and $Act\_max\_M_{ds}$. If, as a result of this recalculation, a change of M_{ds} is needed to increase the rate above *DTA_ETR_min*, the DRA shall request a change from the MTU-O, in compliance with the configured value of *DTA_SMax* and *DTA_Min_Time*. If the needed change cannot be accomplished with one request, the DRA shall make the necessary number of requests. The valid values and coding for *DTA_ETR_min* shall be the same as for *ETR_min* as specified in clause 11.4.2.1.

The control parameter *DTA_ETR_min* is derived by the DRA from the DPU-MIB configuration parameter for the minimum expected throughput for DTA (DTA_MINETR).

If in the DPU-MIB configuration operation according to Annex D is preferred or forced, i.e., iDTA or cDTA is allowed, the value of MINETR shall be configured to a value greater than or equal to DTA_MINETR for each direction of transmission and the value of M_{ds} in the DPU-MIB, which is equal to the value of the control parameter hs_M_{ds}, shall be configured within the range from DTA_MIN_Mds to DTA_MAX_Mds. This constraint ensures that $Act\_min\_M_{ds} \leq hs\_M_{ds} \leq Act\_max\_M_{ds}$.

NOTE 2 – To comply with the requirement *ETR* ≥ *DTA_ETR_min* in the upstream, under unfavourable loop conditions, the *Act_max_Mds* might be lower than *DTA_max_Mds*. In this case the DRA will report in the DPU-MIB a GDRds (see clause 7.11.1.3 of [ITU-T G.997.3]) that is lower than the NDRds, even in case the DRA or L2+ functions do not have any intrinsic throughput capability limitations.

NOTE 3 – To comply with the requirement *ETR* ≥ *DTA_ETR_min* in the downstream, under unfavourable loop conditions, the A*ct_min_Mds* might be higher than *DTA_min_Mds*. In this case the DRA will report in the DPU-MIB a GDRus (see clause 7.11.1.3 of [ITU-T G.997.3]) that is lower than the NDRus, even in case the DRA or L2+ functions do not have any intrinsic throughput capability limitations.

T.2.8 Maximum net data rate for DTA (*DTA_NDR_max*)

See clause D.5.7.4.

T.2.9 Minimum time between DTA updates (*DTA_Min_Time*)

This is the minimum time between any two successive DTA updates. The DRA shall not send a DTA request primitive (DTA.request) to the MTU-O within *DTA_Min_Time* after the previous DTA update has been completed (see clause D.5.6).

For Annex D, in order to speed up the transition to *hs_Mds* due to a joining line (see clause D.5.2), the constraint *DTA_Min_Time* shall not apply during this transition.

The valid range of *DTA_Min_time* shall be from 0 to 163.83 seconds in steps of 0.01 second.

NOTE – If the *ETR* falls below *DTA_ETR_min*, the DRA is required to initiate DTA updates in order to increase this rate above *DTA_ETR_min* (see clause T.2.7). Setting *DTA_Min_time* to a high value or *DTA_SMax* (see clause T.2.4) to a low value or both, might result in a slow return to an *ETR* value above *DTA_ETR_min,* in such a case.

T.3 Coordination between the link state request and the DTA request

The DRA shall only send DTA request primitives DTA.request (see clause D.5.1) if in case of iDTA the current link state is L0 or if in case of cDTA the current link state is L0 for all active lines of the vectored group.

Moreover, the DRA shall not send DTA request primitives after a LinkState.Request is sent by the DRA to the MTU-O until the corresponding LinkState.Confirm is received by the DRA.

T.4 Diagnostics and monitoring of DTA

T.4.1 Successful DTA primitive

The following primitive is defined at the MTU-O:

- Successful DTA (*success_DTA*): This primitive occurs after a successful completion of a DTA procedure. This occurs when the MTU-O concludes the completion of the DTA update procedure when it switched to the new M_{ds} value and receives an upstream transmission from the MTU-R according to the new M_{ds} value, with US RMC symbol at the correct position.

Support of this primitive is optional.

T.4.2 Downstream utilization (*utilization_ds*)

Support of the performance parameter *utilization_ds* is optional.

If supported, it shall be measured in showtime by the MTU-O in every non-overlapping 1 second interval, taking into account all complete logical frames within this interval. The downstream utilization is defined as the ratio, expressed in percent, between:

– The total number of bits of the data and eoc packets (see clause 8.2.2) transmitted during that interval increased by an additional 16 bits per packet to approximate the overhead of the DTU frame header (see clause 8.3.1).

– A counter of bits reset at the beginning of the interval and incremented for each transmitted downstream logical frame by the value:

$$L_{frame} \times \frac{K_{FEC}}{N_{FEC}} \times (1 - DTUFramingOH)$$

where K_{FEC} and N_{FEC} are the actual values used in that logical frame and Lframe is the total number of data bits that the logical frame would contain, using the actual bit allocations, if:

- $TTR_{ds} = M_{ds}$, $TTR_{NPSFds} = M_{us}$ where M_{ds} and M_{us} are the actual value in that logical frame and;
- $TBUDGET_{ds} = M_{ds}+M_{us}$ in FDX mode or $TBUDGET_{ds}=M_{ds}$ in TDD mode and;
- if DTFO is enabled, the Band 1 is active at the same symbol position as those indicated in the actual frame setting of that logical frame.

NOTE – With the assumed logical frame parameters, all symbols with Band 1 active are located in the NOI.

For example, if DTFO is enabled and TCM is used,

$$L_{frame} = L_{DR0} + M' \times L_{D0,PSF} + M'' \times L_{D0,NPSF} + T_{DTFO} \times L_{D1,PSF,NOI}$$

where

- T_{DTFO} is the number of data_data plus RMC_data symbols transmitted on DTFO active symbols positions in the logical downstream frame using the band 1 in the NOI or DOI,
- M' is equal to M_{ds}-2 if a sync symbol is present in PSF of the downstream logical frame, otherwise, M' is equal to M_{ds}-1,
- M'' is equal to M_{us}-1 if a sync symbol is present in NPSF of the downstream logical frame, otherwise, M'' is equal to M_{us}.

For every second where the *utilization_ds* is above the DTA_HUS_THRESHOLDds configured in the MIB, a downstream High Utilization Second (DTA_HUS) shall be declared. The count of downstream DTA_HUS in 15min and 24h interval shall be reported in the MIB as a far-end value (CURR/PREV_FE_15/24_DTA_HUS).

T.4.3 Upstream utilization (*utilization_us*)

Support of the performance parameter *utilization_us* is optional.

If supported, it shall be measured in showtime by the MTU-O in every non-overlapping 1 second interval, taking into account all complete logical frames within this interval. The upstream utilization is defined as the ratio, expressed in percent, between:

– The total number of bits of the data and eoc packets (see clause 8.2.2) received during that interval increased by an additional 16 bits per packet to approximate the overhead of the DTU frame header (see clause 8.3.1).

– A counter of bits reset at the beginning of the interval and incremented for each received upstream logical frame by the value:

$$L_{frame} \times \frac{K_{FEC}}{N_{FEC}} \times (1 - DTUFramingOH)$$

where K_{FEC} and N_{FEC} are the actual values used in that logical frame and Lframe is the total number of data bits that the logical frame would contain, using the actual bit allocations, if:

- $TTR_{us} = M_{us}$, $TTR_{NPSFus} = M_{ds}$ where M_{ds} and M_{us} are the actual value in that logical frame and;
- $TBUDGET_{us} = M_{ds}+M_{us}$ in FDX mode or $TBUDGET_{us}=M_{us}$ in TDD mode and;

– if DTFO is enabled, the Band 1 is active at the same symbol position as those indicated in the actual frame setting of that logical frame.

NOTE – With the assumed logical frame parameters, all symbols with Band 1 active are located in the NOI.

For example, if DTFO is enabled and TCM is used,

$$L_{frame} = L_{DR0} + M' \times L_{D0,PSF} + M'' \times L_{D0,NPSF} + T_{DTFO} \times L_{D1,PSF,NOI}$$

where

– T_{DTFO} is the number of data_data plus RMC_data symbols transmitted on DTFO active symbols positions in the logical downstream frame using the band 1 in the NOI or DOI,

– M' is equal to M_{us}-2 if a sync symbol is present in PSF of the upstream logical frame, otherwise, M' is equal to M_{us}-1,

  M'' is equal to M_{ds}-1 if a sync symbol is present in NPSF of the upstream logical frame, otherwise, M'' is equal to M_{ds}.

– The values L_{DR0}, $L_{D0,PSF}$, $L_{D0,NPSF}$, M_{ds}, M_{us}, K_{FEC}, N_{FEC} are the actual values used in that logical frame. $L_{D1,PSF,NOI}$ is equal to the actual values of $L_{D1,PSF}$ in that logical frame during the NOI.

For every second where the *utilization_us* is above the DTA_HUS_THRESHOLDus configured in the MIB, an upstream High Utilization Second (DTA_HUS) shall be declared. The count of upstream DTA_HUS in 15min and 24h interval shall be reported in the MIB as a near-end value (CURR/PREV_NE_15/24_DTA_HUS).

Annexes U to W

Annexes U to W are intentionally left blank.

Annex X

Operation without multi-line coordination intended for a crosstalk-free environment

(This annex forms an integral part of this Recommendation.)

X.1 Scope

This annex specifies operation of ITU-T G.9711 transceivers in a crosstalk free environment. In a crosstalk free environment, vectoring is not used and synchronization between transmission lines is not needed. The annex is applicable for either twisted-pair or coaxial cables.

Unless otherwise and specifically stated in this annex, all definitions and requirements specified in the main body and other Annexes of this Recommendation are applicable for transceivers compliant with this annex.

X.2 Definitions

This annex defines no new terms.

X.3 Abbreviations and acronyms

This annex defines no new abbreviations or acronyms.

X.4 Reference model(s)

The reference model of a DPU intended for operation in a crosstalk-free environment is given in Figure X.1. The reference model in Figure X.1 is consistent with the one in Figure 5-2, except that it has no ε-c-1 and ε-1-n signal exchanges. The VCE is still present to support test parameters (see clause 11.4.1.2).

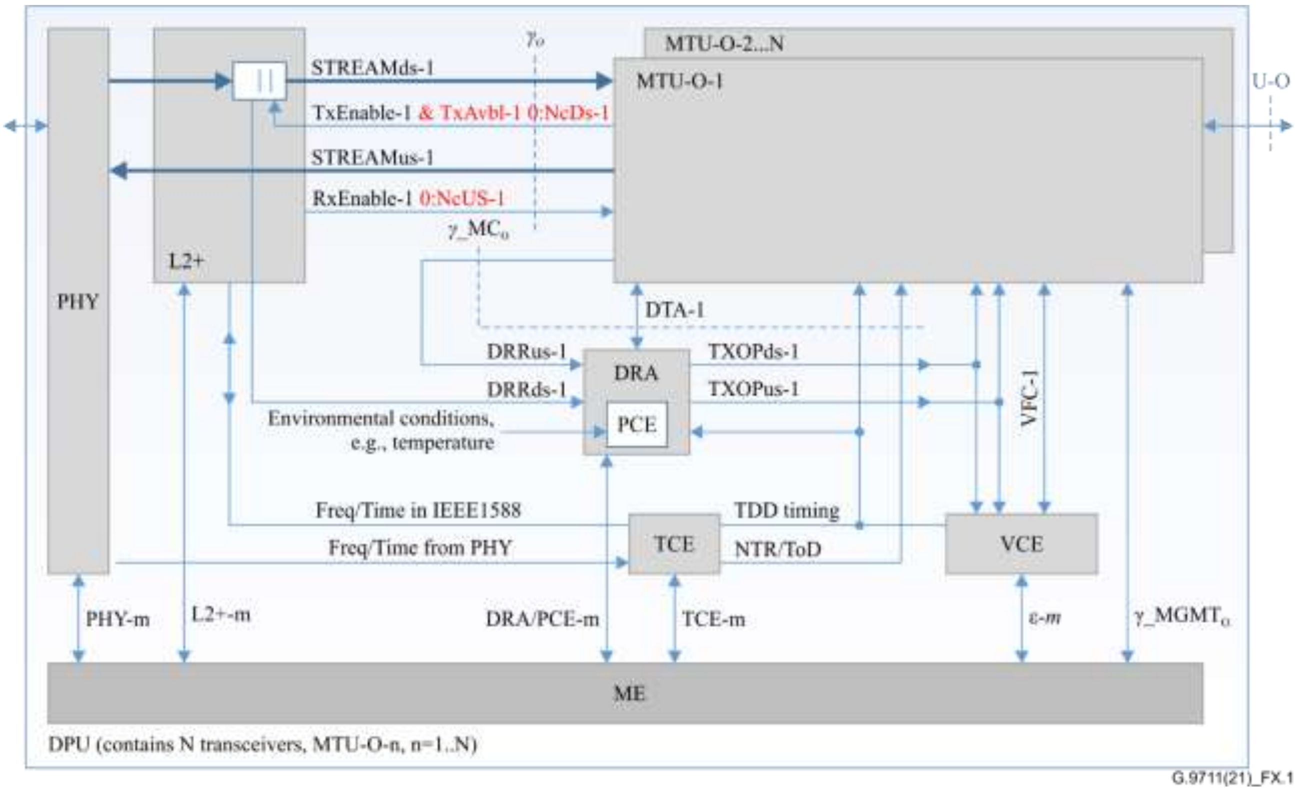


Figure X.1 – Reference model of a DPU intended for operation in a crosstalk-free environment

X.5 Profiles

X.5.1 Profiles for operation over coaxial cables in a crosstalk-free environment

ITU-T G.9711 transceivers for operation over coaxial cables in a crosstalk-free environment shall comply with at least one profile specified in Table Q.1. Compliance with more than one profile is allowed. The rules regarding profile compliance are defined in clause Q.5.1.

X.5.2 Profiles for operation over twisted-pair cables in a crosstalk-free environment

ITU-T G.9711 transceivers for operation over twisted-pair cables in a crosstalk-free environment shall comply with at least one profile specified in Table P.1 except that precoding is not applicable. Compliance with more than one profile is allowed. The rules regarding profile compliance are defined in clause P.5.1.

X.5.3 Profile compliance

See clauses P.5.1 and Q.5.1 for rules regarding profile compliance.

X.6 On-line reconfiguration

For Annex X operation, the MTU-O shall not use OLR Request Type 3 (see clause 11.2.2.5) and the MTU-R shall reject any received OLR Request Type 3.

X.7 Initialization

Annex X operation involves no vectoring, which reduces the expected duration of initialization.

NOTE – Messages associated with vectoring: O-P-VECTOR 1, R-P-VECTOR 1, O-P-VECTOR 1-1, R-P-VECTOR 1-1, O-P-VECTOR 2 can be of minimum duration.

X.8 Discontinuous operation

X.8.1 Discontinuous operation in P2P mode

This clause specifies the additional requirement on the discontinuous operation for Annex X operation in P2P mode.

All DTFO blocks in both directions shall be either inactive or disabled.

The use of Band 1 shall be disabled during initialization.

All logical frame configurations shall be set with $TTR_{ds} = M_{ds}$, $TTR_{us} = M_{us}$, i.e., the size of the DOI is zero symbol periods in both directions of transmission.

NOTE – Power savings can be achieved by using idle symbols during the NOI (with *IDF* set to 0) and by limiting the overall transmission time during the logical frame by appropriate settings of *TBUDGET*.

In addition, if an FDX mode is selected, $TTR_{NPSFds}=M_{us}$, $TTR_{NPSFus}=M_{ds}$.

X.8.2 Discontinuous operation in P2MP mode

This clause specifies the additional requirement on the discontinuous operation for Annex X operation in P2MP mode.

All logical frame configurations shall be set with $TTR_{ds} = M_{ds}$, $TTR_{us} = M_{us}$, i.e., the size of the DOI is zero symbol periods in both directions of transmission.

In addition, if an FDX mode is selected, $TTR_{NPSFds}=M_{us}$, $TTR_{NPSFus}=M_{ds}$ and the Band 1 may be used in NOI_{NPSF}.

The data_data symbols in the PSF and NPSF shall be constructed using the same active bit-loading table and coding parameters. The content of the preamble part of the data_preamble in the PSF and NPSF shall be identical.

A bitmap, the DTFOBitmap (see Tables X-2 and X-3) represents the list of active DTFO symbols in the NOI_{PSF} and NOI_{NPSF} of the logical frame. Each bit with value 1 of the DTFOBitmap indicates on which symbol position a DTFO symbol shall be transmitted. Each bit with value 0 of the DTFOBitmap indicates on which symbol position no DTFO symbol shall be transmitted. The first bit of the DTFO bitmap indicates the position of RMC, and the next bit, the next symbol of the logical frame, and so on. In FDX, the bitmap covers both the PSF and NPSF. The use of the DTFOBitmap shall replace the use of the *TA_B1* and *T_B1* parameter to configure the NOI_{PSF} DTFO block for all framing mode if Annex X and P2MP mode are selected.

If Annex X and P2MP mode are selected, the MTU-O may select a mode during initialization through the DTFOBitmap mode field of the O-MSG 1 where a single bitmap is specified for both directions. The bitmap shall apply simultaneously to both upstream and downstream. The bitmap shall be transmitted in the field DTFOBitmapds of the MTU-O DTFO command. The field DTFOBitmapus shall not be present in the MTU-O and MTU-R DTFO commands. The first bit of the bitmap, b_0, shall indicate the downstream RMC position of the next logical frame. The symbol position represented by the remaining bits depends on the framing mode. They are as followed:

– In FDXC and FDXZ framing modes (see Figure X-2 and X-3):

- b_0 to $b_{Mds\text{-}DRMCds\text{-}1}$: In downstream, symbol position starting at the RMC position of the next downstream logical frame. For upstream, symbol positions of the NPSF aligned with the downstream ones.
- $b_{Mds\text{-}DRMCds}$ to $b_{Mds+Mus\text{-}DRMCds\text{-}1}$. In downstream, symbol positions starting at the first symbol of the NPSF of the next downstream logical frame. For upstream symbol positions of the PSF aligned with the downstream ones.
- $b_{Mds+Mus\text{-}DRMCds}$ to $b_{Mds+Mus\text{-}1}$: For downstream, symbol positions starting at the first symbol position of the next PDX frame. For upstream, symbol positions of the NPSF aligned with the downstream ones.

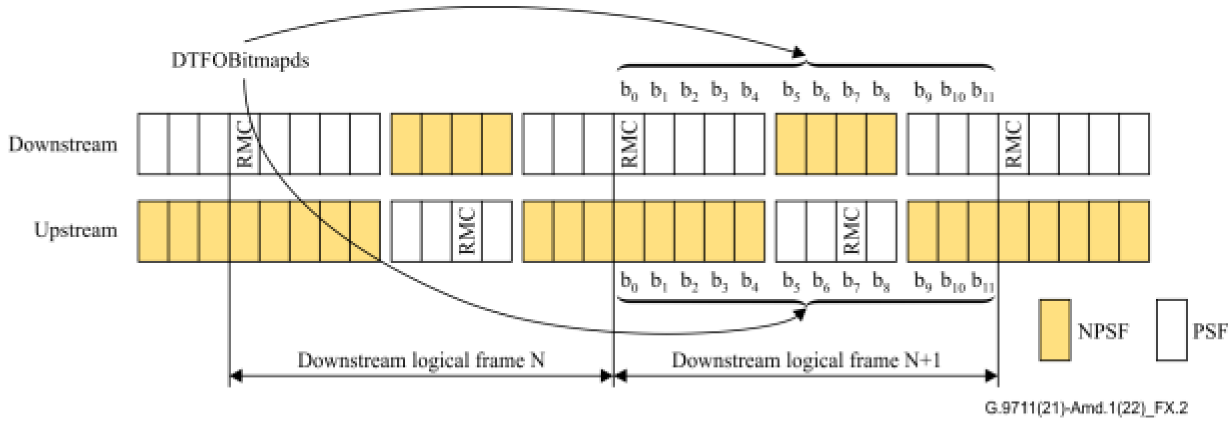


Figure X-2 – Signification of bits in DTFOBitmapds for FDXC framing mode with M_{ds}=8, M_{us}=4 and $DRMC_{ds}$ = 3

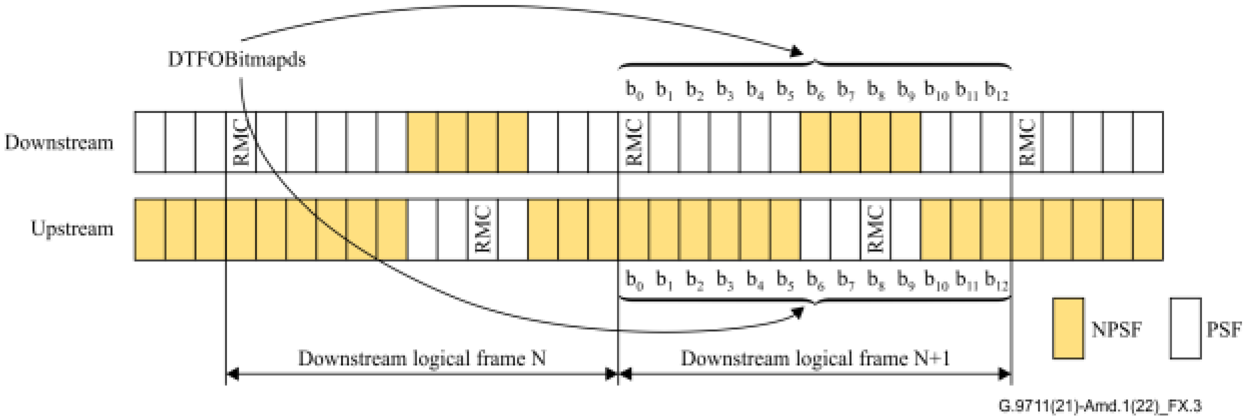


Figure X-3 – Signification of bits in DTFOBitmapds for FDXZ framing mode with M_{ds}=9, M_{us}=4 and $DRMC_{ds}$ = 3

– In TDD framing mode (see Figure X-4):

- b_0 to $b_{Mds\text{-}DRMCds\text{-}1}$: In downstream, symbol position starting at the RMC of the next downstream logical frame. Not used in upstream.
- $b_{Mds\text{-}DRMCds}$ to $b_{Mds+Mus\text{-}DRMCds\text{-}1}$: For upstream, symbol positions starting at the first upstream symbol of the PDX frame. Not used in downstream.
- $b_{Mds+Mus\text{-}DRMCds}$ to $b_{Mds+Mus\text{-}1}$: For downstream, symbol positions starting at the first symbol position of the next PDX frame. Not used in upstream.

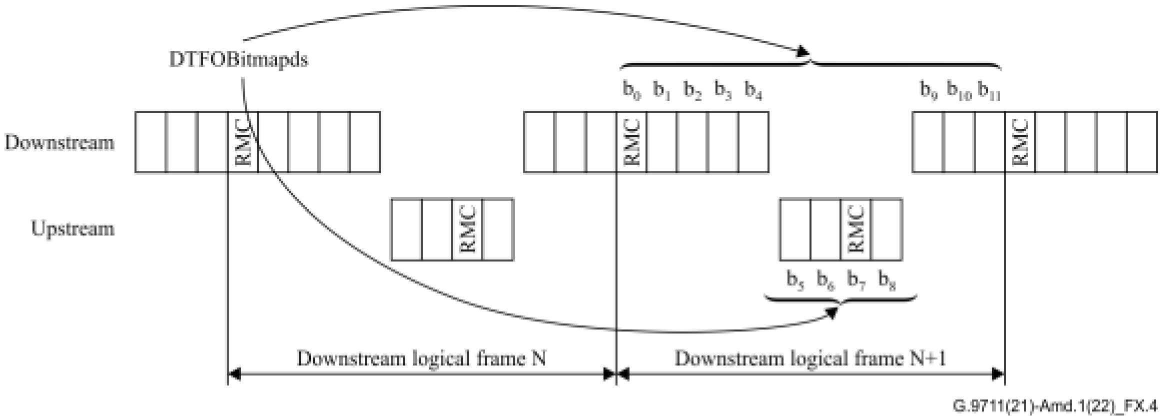


Figure X-4 – Signification of bits in DTFOBitmapds for TDD framing mode with M_{ds}=8, M_{us}=4 and $DRMC_{ds}$ = 3

– In TDDZ framing modes (see Figure X-5):

- b_0 to $b_{Mds\text{-}DRMCds\text{-}1}$: In downstream, symbol position starting at the RMC of the next downstream logical frame. Not used in upstream.
- $b_{Mds\text{-}DRMCds}$: Not used.
- $b_{Mds\text{-}DRMCds+1}$ to $b_{Mds+Mus\text{-}DRMCds}$. For upstream, symbol positions starting at the first upstream symbol of the PDX frame. Not used in downstream.
- $b_{Mds+Mus\text{-}DRMCds+1}$ to $b_{Mds+Mus}$: For downstream, symbol positions starting at the first symbol position of the next PDX frame. Not used in upstream.

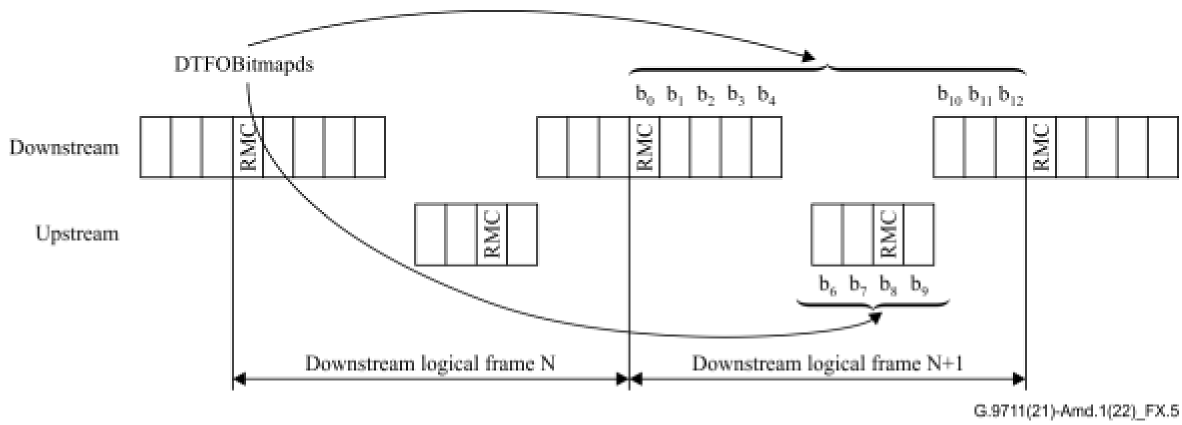


Figure X-5 – Signification of bits in DTFOBitmapds for TDDZ framing mode with M_{ds}=8, M_{us}=4 and $DRMC_{ds}$ = 3 (bit b_5 is unused)

NOTE – In FDX mode, all DTFO symbols are transmitted in full duplex in that mode.

Tables X-1 and Table X-4 define the MTU-O and MTU-R DTFO commands, respectively.

Table X-1 – MTU-O DTFO command (sent by MTU-O only)

Field name	Format	Description
Command header	One byte: [00 aaaaaa]	aaaaaa = $0B_{16}$
$DTFO_{ds}$	Five bytes	Downstream DTFO configuration parameters. See Table X-2
$DTFOreq_{us}$	Five bytes or 1 byte	Upstream NOI & DOI DTFO configuration parameters request. See Table X-3
NOTE – The absence of the MTU-O DTFO command in the RMC message shall be interpreted by the MTU-R as: • the downstream DTFO is disabled (as when downstream DTFO enable bit is 0) and upstream DTFO is disabled. • the $DTFObitmap_{ds}$ is 0 • the $DTFObitmap_{us}$ values shall be set to 0		

Table X-2 – Downstream NOI & DOI DTFO configuration parameters

Field name	Format	Description
DTFOBitmap$_{ds}$	4 bytes byte 0: [a_7 ... a_0] byte 1: [a_{15}... a_8] byte 2: [a_{23} ... a_{16}] byte 3: [a_{31} ... a_{24}]	Bitmap indicating in which position of the downstream logical frame DTFO symbols using the Band 1 are active. Bit is set to 1 if DTFO symbol is active and set to 0 if it is inactive. The bit a_0 indicates the RMC symbol and the bit a_k indicates the kth active symbol following the RMC symbol counting all active symbols in both the PSF and NPSF.
DTFOcontrol$_{ds}$	One byte: [cb00 $a_{35}a_{34}a_{33}a_{32}$]	$a_{35}a_{34}a_{33}a_{32}$: Last 4 bits of the DTFObitmap$_{ds}$. b = Downstream DTFO enable bit (*DTFOEnable$_{ds}$*) (Note 1) 0 – Downstream DTFO is disabled. 1 – Downstream DTFO is enabled. c = DTFO restoration indicator (*TxPreamble*): 0 – non-preamble symbols in all active DTFO symbols. Allowed non-preamble symbol types are specified in section 10.7. 1 – preamble symbol in all active DTFO symbols; valid if at least one DTFO symbol is active in the next logical frame.

Table X-3– Upstream NOI & DOI DTFO configuration parameters request

Field name	Format	Description
DTFOBitmap$_{us}$	4 bytes byte 0: [a_7 ... a_0] byte 1: [a_{15}... a_8] byte 2: [a_{23} ... a_{16}] byte 3: [a_{31} ... a_{24}]	Bitmap indicating in which position of the upstream logical frame DTFO symbols using the Band 1 are active. Bit is set to 1 if DTFO symbol is active and set to 0 if it is inactive. The bit a_0 indicates the RMC symbol and the bit a_k indicates the kth active symbol following the RMC symbol counting all active symbols in both the PSF and NPSF. (Note 1)
DTFOcontrol$_{us}$	One byte: [0b00 $a_{35}a_{34}a_{33}a_{32}$]	$a_{35}a_{34}a_{33}a_{32}$: Last 4 bits of the DTFObitmap$_{us}$. b = DTFO restoration request (*ReqPreamble*): 0 – default (no restoration). 1 – request of upstream preamble for active DTFO symbols.
NOTE 1 – That field shall not be present if the single DTFOBitmap mode is enabled in O-MSG1. NOTE 2 – The remaining bits of the DTFObitmap$_{us}$ shall be set to 0 if the single DTFOBitmap mode is enabled in O-MSG1.		

Table X-4 – MTU-R DTFO command (sent by the MTU-R only)

Field name	Format	Description
Command header	One byte: [00 aaaaaa]	aaaaaa = $0C_{16}$ (Note 1)
DTFOBitmap$_{us}$	4 bytes byte 0: [a_7 ... a_0] byte 1: [a_{15}... a_8] byte 2: [a_{23} ... a_{16}] byte 3: [a_{31} ... a_{24}]	Bitmap indicating in which position of the downstream logical frame DTFO symbols using the Band 1 are active. Bit is set to 1 if DTFO symbol is active and set to 0 if it is inactive. The bit a_0 indicates the RMC symbol and the bit a_k indicates the kth active symbol following the RMC symbol counting all active symbols in both the PSF and NPSF. (Note 2)
DTFOcontrol$_{us}$	One byte: [cb00 $a_{35}a_{34}a_{33}a_{32}$]	$a_{35}a_{34}a_{33}a_{32}$: Last 4 bits of the DTFObitmap$_{us}$. (Note 3) b = DTFO restoration indicator (*TxPreamble*): 0 – non-preamble symbol in all active DTFO symbols. Allowed non-preamble symbol types are specified in section 10.7. 1 – preamble symbol in all active DTFO symbols. c = DTFO restoration request (*ReqDTFORestoration*): 0 – default (no restoration). 1 – request for downstream DTFO symbols restoration.
NOTE 1 – This command shall be sent if and only if the MTU-O DTFO command was present in the last received RMC message. NOTE 2 – That field shall not be present if the single DTFO bitmap mode is enabled in O-MSG1. NOTE 3 – The remaining bits of the DTFObitmap$_{us}$ shall be set to 0 if the single DTFO bitmap mode is enabled in O-MSG1.		

X.9 Requirements specific to FDX mode

X.9.1 In showtime

For Annex X operations, the requirements in this clause shall apply in showtime.

Per direction, the transmit PSD in PSF and NPSF shall be the same. Specifically:

– the MREFPSDus shall be the same as MREFPSD_NPus.

– per direction, the *gi* tables in PSF and NPSF shall be identical.

Per direction, the active bit loadings in PSF and NPSF shall be identical at any time.

Per direction, in case of TCM, the pre-ordered tone-ordering table *t1* for NPSF shall be generated following the rules specified for the NOI_{PSF} (see clause 10.2.1.2.1). Therefore, the pre-ordered tone-ordering tables in PSF and NPSF are the same at any time. In case of PCS-LCM, the re-ordered tone-ordering table *t'* for NPSF shall be generated following the rules specified for the NOI_{PSF} (see clause 10.2.1.3.2). Therefore, the re-ordered tone-ordering tables of PSF and NPSF are the same at any time.

The SRA and FRA procedures shall be initiated for PSF only. The modifications done by those procedures in PSF shall apply also to NPSF. SPA procedure shall not be initiated.

X.9.2 In initialization

For Annex X operations, the requirement in this clause shall apply during initialization.

If an FDX profile is selected and the FDXMASKds or FDXMASKus contains masked subcarriers in the MIB, the link shall fall back to TDD or TDDZ framing mode during initialization.

The same PSD in NPSF and PSF shall be applied during initialization. Specifically:

– In O-EC-PRM message, the value of STARTCB_NPus shall be set to 0 dB.

– In O-UPDATE message, the value of CDCB_NPus shall be set to 0 dB.

– In O-EC-PRM 1 message, the value of CDCBUPDATE_NPus shall be set to 0dB.

– In O-SNR message, the field CDPSDMASK_NPus shall contain a PSD descriptor with ZERO breakpoint. The value of CDPSDMASK_NPus shall be equal to CDPSDMASKus.

– In R-SNR message, the CDPSD_NP2us field shall contain a PSD descriptor with ZERO breakpoints and the value of CDPSD_NP2us shall be equal to CDPSDus.

– In O-PRM message, the MREFPSDMASK_NPus field shall contain a PSD descriptor with ZERO breakpoints and the value of MREFPSDMASK_NPus shall be equal to MREFPSDMASKus.

– In O-PRM message, the TONEMASK_NPus shall be set to a "Band descriptor" with ZERO bands.

– In R-PRM message, the field MREFPSD_NPus shall contain a PSD descriptor with ZERO breakpoint. The value of MEREFPSD_NPus shall be equal to MREFPSDus.

The bits, gains and PCS-LCM parameters shall be exchanged for the PSF only. Specifically, the O-PMD-NPSF 1 message shall not be sent and the R-PMD-NPSF 1 message shall not be sent. The exchanged values of bits, gains, and PCS-LCM coding parameters for PSF of a particular transmission direction shall be applied also to NPSF of this transmission direction.

X.10 Initialization messages

X.10.1 Channel discovery phase

X.10.1.1 O-SIGNATURE

See clause 12.3.3.2.1. If a P2MP profile is selected, the field 28 "DTFO Band 1 symbol assignment" shall be replaced by the field described in Table X.5.

Table X.5 – DTFO Band 1 symbol assignment

<table>
<tr><th>Field name</th><th>Byte</th><th>Bits</th><th>Description</th></tr>
<tr><td rowspan="2">Upstream DTFO Band 1 symbol assignment</td><td>1-5</td><td></td><td>[$a_{35}…a_0$]: Bitmap indicating in which position of the upstream logical frame DTFO symbols using the Band 1 are active. This uses the same coding as the RMC DTFO command (see X.8.2) when separate DTFO bitmaps per direction are used and assuming an FDX framing (NOTE).
byte 1: [a_7 ... a_0]
byte 2: [a_{15}... a_8]
byte 3: [a_{23} ... a_{16}]
byte 4: [a_{31} ... a_{24}]
byte 5: [0000 $a_{35}a_{34}a_{33}a_{32}$]</td></tr>
<tr><td rowspan="2">6-8</td><td>[23:12]</td><td>Logical frames with Band 1 active in the upstream defined as a bit map:
– Bit 12 corresponds to the first logical frame of the superframe;
– Bit 19 corresponds to the last logical frame of the superframe (M_F=36);
– Bit 23 corresponds to the last logical frame of the superframe (M_F=23).</td></tr>
<tr><td>Downstream DTFO Band 1 symbol</td><td>[11:0]</td><td>Logical frames with Band 1 active in the downstream defined as a bit map:
– Bit 0 corresponds to the first logical frame of the superframe;</td></tr>
</table>

Table X.5 – DTFO Band 1 symbol assignment

Field name	Byte	Bits	Description
assignment			– Bit 7 corresponds to the last logical frame of the superframe (M_F=36); – Bit 11 corresponds to the last logical frame of the superframe (M_F=23).
	9-13		[a_{35}…a_0]: Bitmap indicating in which position of the downstream logical frame DTFO symbols using the Band 1 are active. This uses the same coding as the RMC DTFO command (see X.8.2) when separate DTFO bitmaps per direction are used and assuming an FDX framing (NOTE). byte 1: [a_7 ... a_0] byte 2: [a_{15}... a_8] byte 3: [a_{23} ... a_{16}] byte 4: [a_{31} ... a_{24}] byte 5: [0000 $a_{35}a_{34}a_{33}a_{32}$]
NOTE – If the system falls back to TDD or TDDZ framing mode, DTFO Band 1 symbols shall be transmitted only on the remaining active symbols at the corresponding symbol positions.			

X.10.2 Channel analysis and exchange phase

X.10.2.1 O-MSG 1

See clause 12.3.4.2.1. The Annex X parameter field in O-MSG 1 is shown in Table X.6.

Table X.6 – Annex X parameter field

Field name	Format	Description
DTFOBitmap mode	One byte	Indicate if separate DTFO bitmaps are used per direction or if a single DTFO bitmap is used for both directions. The field shall be set to 00_{16} if separate DTFO bitmap are used and set to 01_{16} if a single DTFO bitmap is used for both directions.

Annex Y

Upstream dynamic resource reports

(This annex forms an integral part of this Recommendation.)

An upstream dynamic resource report (DRRus) shall represent the total amount of data in each of the QoS queues located in the NT in terms of reporting *blocks*. The size of reporting blocks shall be configured and updated via a DRR configuration request eoc command (see Table 11-52 and the DRRdata for DRR configuration request field of Table Y.2).

The number of QoS queues supported by the NT shall be represented by *NQ*, with $1 \leq NQ \leq 8$. Queues shall be numbered starting from QID=0 up to QID=*NQ-1*. An eoc response message shall indicate the value *NQ*. The MTU-R reports the value of *NQ* as part of the DRR configuration data at initialization (R-MSG1) and during showtime in the reply to the eoc DRR configuration command (Table 11-53), field "DRRdata for DRR configuration confirm" defined in Table Y.2. The value *NQ* is implementation dependent but shall not change until the next initialization.

The resource metric shall consist of *NQ* bytes, a single byte per queue, transmitted in the order of ascending QID. Each byte shall represent the queue fill. The queue fill for QID 0 shall be transmitted first.

The queue fill, expressed in reporting blocks, shall be obtained by rounding up the corresponding value in bytes. If *k* packets with lengths L_i bytes ($i = 1,...,k$) are stored in the queue, the queue fill, *R*, shall be calculated as follows.

$$R = \text{ceiling}\left(\frac{1}{B}\sum_{i=1}^{k} L_i\right)$$

where *B* is the reporting block size in bytes.

For DRRus, the queue fill value R shall be encoded into a fixed-size single byte field. This non-linear encoding shall be as specified in Table Y.1.

Table Y.1 – Encoding of queue fill in blocks

Queue fill, R, in blocks	Binary input (MTU-R)	Encoding in upstream RMC message	Binary output (MTU-O)
0 – 127	00000000abcdefg	0abcdefg	00000000abcdefg
128 – 255	00000001abcdefx	10abcdef	00000001abcdef1
256 – 511	0000001abcdexxx	110abcde	0000001abcde111
512 – 1023	000001abcdxxxxx	1110abcd	000001abcd11111
1 024 – 2 047	00001abcxxxxxxx	11110abc	00001abc1111111
2 048 – 4 095	0001abxxxxxxxxx	111110ab	0001ab111111111
4 096 – 8 191	001axxxxxxxxxxx	1111110a	001a11111111111
8 191 – 16 383	01xxxxxxxxxxxxx	11111110	011111111111111
>16 383	1xxxxxxxxxxxxxx	11111111	111111111111111

The format of the DRRdata field in the DRR configuration request for the MTU-O (Table 11-52) and the DRR configuration confirm for the MTU-R (Table 11-53) shall be as defined in Table Y.2.

Table Y.2 – DRRdata field sent by MTU

Name	Length (bytes)	Byte	Content
DRRdata for DRR configuration request (MTU-O only) (Note 2)	9	1	01_{16} (Note 1)
		2	One byte for the reporting block size for QID 0 (B0)
		3	One byte for the reporting block size for QID 1 (B1)
		4	One byte for the reporting block size for QID 2 (B2)
		5	One byte for the reporting block size for QID 3 (B3)
		6	One byte for the reporting block size for QID 4 (B4)
		7	One byte for the reporting block size for QID 5 (B5)
		8	One byte for the reporting block size for QID 6 (B6)
		9	One byte for the reporting block size for QID 7 (B7)
DRRdata for DRR configuration confirm (MTU-R only) (Note 2)	2	1	81_{16} (Note 1)
		2	Number of QoS queues supported by the NT (NQ)
NOTE 1 – Byte 1 is used as a message identifier for the DRRdata type. All other values for this byte are reserved by ITU-T. NOTE 2 – The sizes of the reporting blocks are given in bytes. The reporting block size in the DRR configuration request message for QIDs that are not supported by the NT shall bet set to zero			

The DRR configuration data sent during the initialization in R-MSG1 shall be identical to the two-byte DRR configuration confirm data in Table Y.2. The DRA determines the size of the DRRus resources metric (N_{RM}) in the upstream RMC as one byte per QID with $NQ \leq N_{RM} \leq 8$. The size of the resource metric N_{RM} is conveyed from the DRA to the MTU-O in the DRRus.request (see Table 8-4) and from the MTU-O to the MTU-R in the DRR configuration commands (see clause 11.2.2.16).

Appendix I

Copper pair wiring topologies and reference loops

(This appendix does not form an integral part of this Recommendation.)

I.1 Wiring topologies

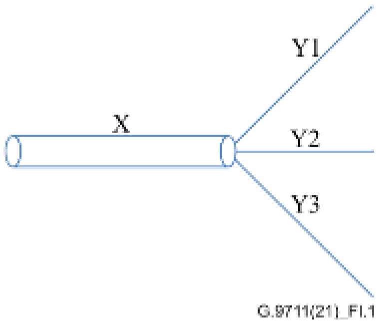


Figure I.1 – Modified star wiring topology

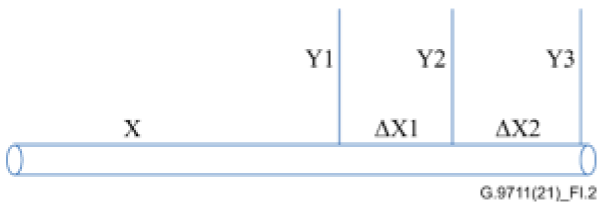


Figure I.2 – Distributed wiring topology

I.2 Reference loops

I.2.1 The final drop

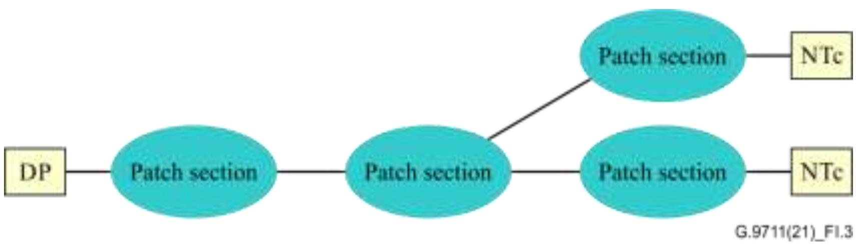


Figure I.3 – Overview of the final drop

I.2.2 In-premises wiring

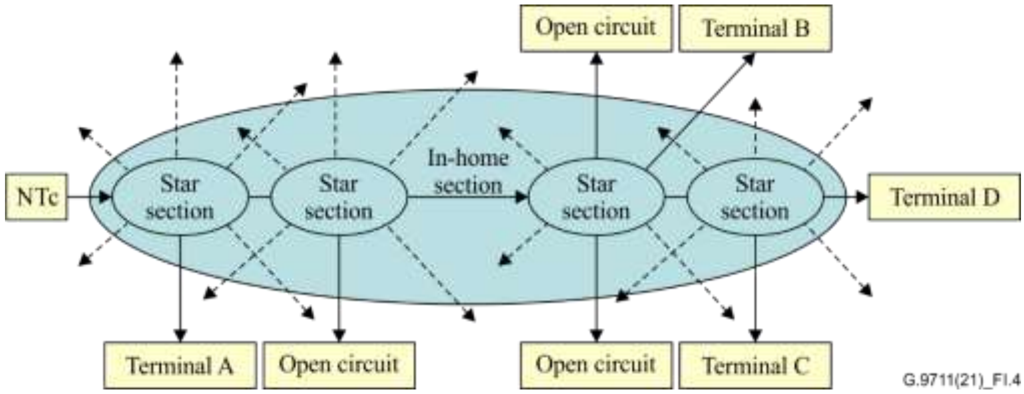


Figure I.4 – Overview of the in-premises wiring

I.2.4 Wire types

NOTE – The high-frequency crosstalk environment is currently not properly specified. The crosstalk coupling functions, including their dependence at high frequencies on length, frequency and number of disturbers, is for further study.

Table I.1 – Wire types

Short name	Type	Reference
I51	Un-twisted double wire cable consisting of 0.8mm PVC insulated copper wires	Clause I.2.5.2
I83	Low quality twisted pair cable consisting of 0.6mm PVC insulated copper wires, no cover	Clause I.2.5.2
U72	Single-quad cable consisting of 4 twisted 0.5mm PVC insulated copper wires, LSZH cover, un-shielded	Clause I.2.5.2
Cat3	Unshielded twisted pair cable used in telephone wiring defined in ANSI/TIA-568, designed for 16MHz performance	Clause I.2.5.2
Cat5e	Twisted pair cable commonly used in computer networks defined in ANSI/TIA-568, designed for 100MHz performance	Clause I.2.5.2
Cat6	Twisted pair cable commonly used in computer networks defined in ANSI/TIA-568, designed for 250MHz performance	Clause I.2.5.2

I.2.5 Examples of use cases

I.2.5.1 FTTB example

The following figure illustrates a possible cable configuration for a fibre-to-the-building (FTTB) scenario. Figure I.5 illustrates a P2P scenario where the DPU is in the basement of a building (multi-dwelling unit, MDU) and the pairs to each customer share a common cable duct (vertical riser). This leads to a situation where there is a progressive reduction in the cross-talk as the branches of the tree structure spread out. The pairs in the riser could be in a single cable containing a pair connected to each customer or in separate cables, one cable per customer bundled together in the duct. In addition, there may be bridged taps in the wiring each apartment after the common cable duct.

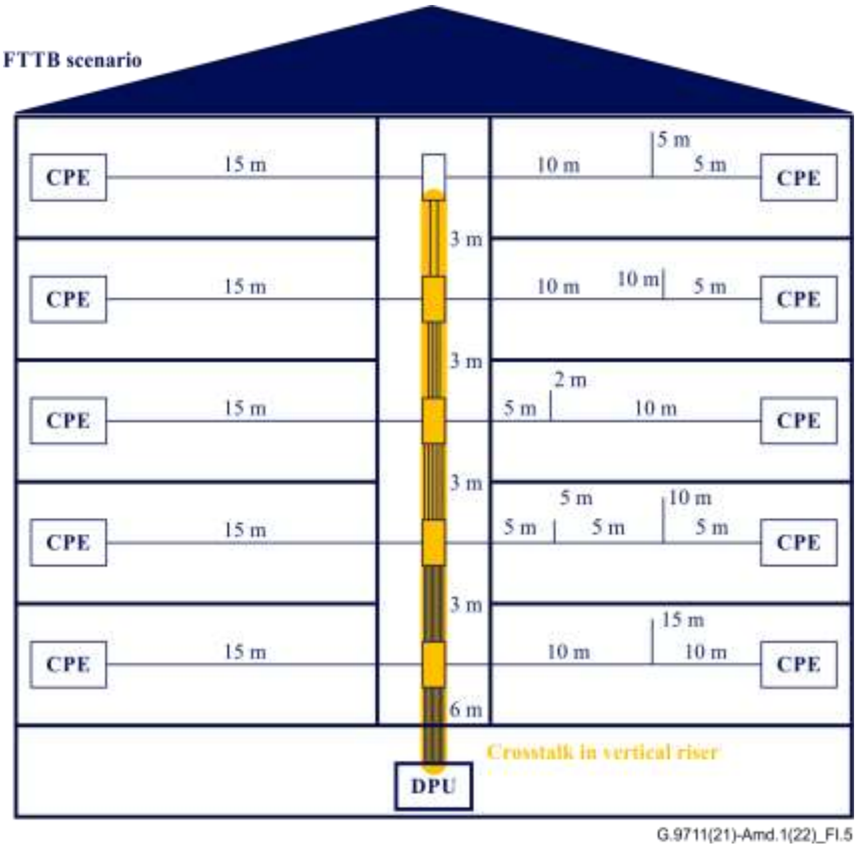


Figure I.5 – Illustration of cabling configuration in an MDU

I.2.5.1.1 FTTB with P2MP example

This example has the same topology described in Figure I.5 with the addition of CPE on one or more of the bridged taps in each premise.

I.2.5.2 FTTdp examples

The following figures illustrate possible cable configurations for an overhead FTTdp scenario.

Each scenario may be P2P or P2MP. A single MTU-O serves a single DPU port. In the P2MP case there are one or more CPE on the bridged taps in a home, each home is served by a separate DPU port.

Figure I.6 illustrates an overhead FTTdp scenario where the DPU is in the underground at the base of an overhead pole and the pairs to each customer share a common vertical cable up the pole. There is crosstalk between the pairs in the common cable. The pairs pass through the Distribution Point (DP, a passive cross connect at the pole top) to radial overhead cables to each home. Typically, there is reduced crosstalk in the radial distribution section. In addition, there may be bridged taps in the wiring in each home after the radial distribution cable.

Figure I.7 illustrates an overhead FTTdp scenario where the DPU is underground at the base of a pole and compared to Figure I.6 serves an additional DP through a multi-pair aerial cable with crosstalk.

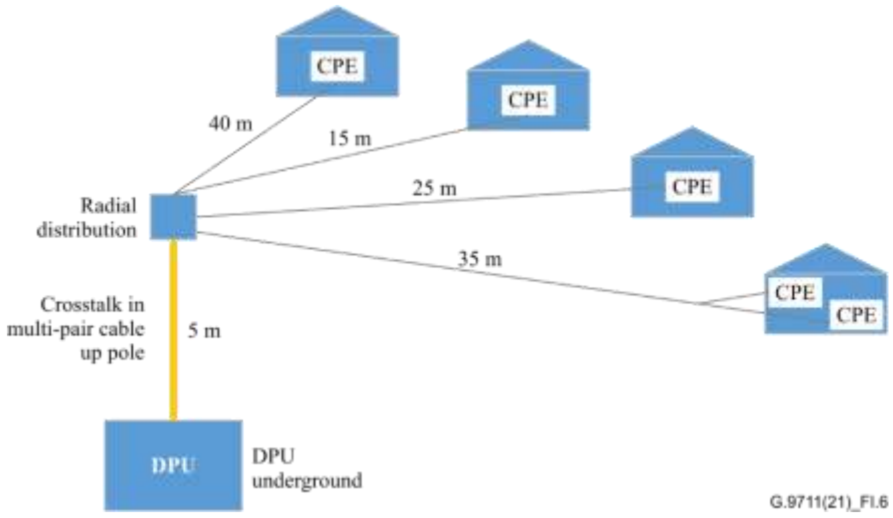


Figure I.6 – FTTdp overhead single DP example

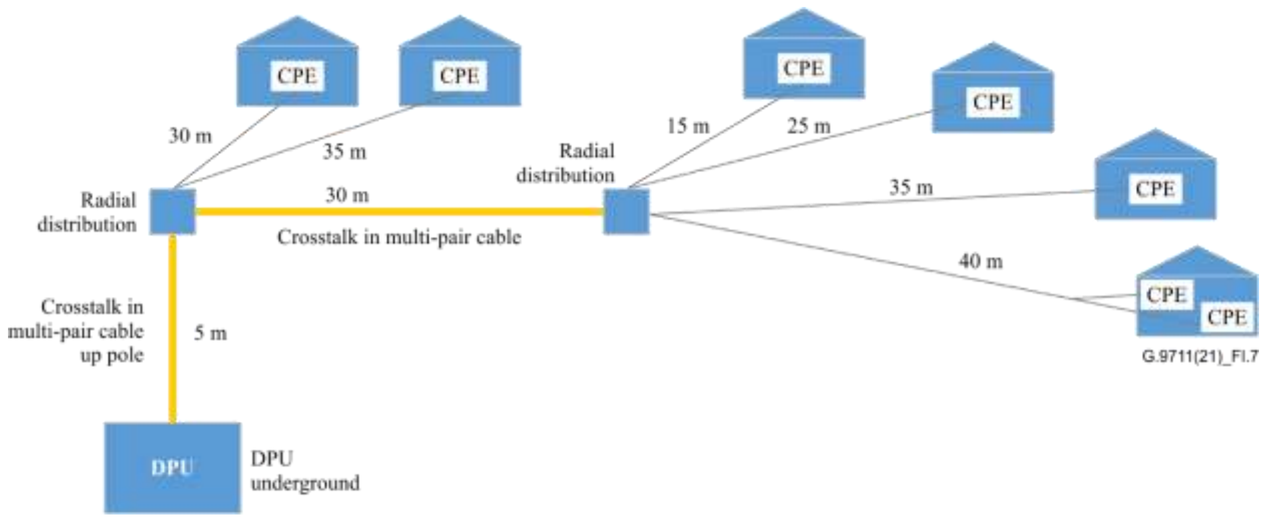


Figure I.7 – FTTdp overhead multiple DP example

I.2.5.3 Single MTU-O (logical port) to multiple premises, P2MP example

Figure I.8 illustrates a Point-to-Multi-Point (P2MP) scenario where a single MTU-O serves a single DPU logical port, with multiple hardware ports per logical port and where each DPU hardware port serves one CPE.

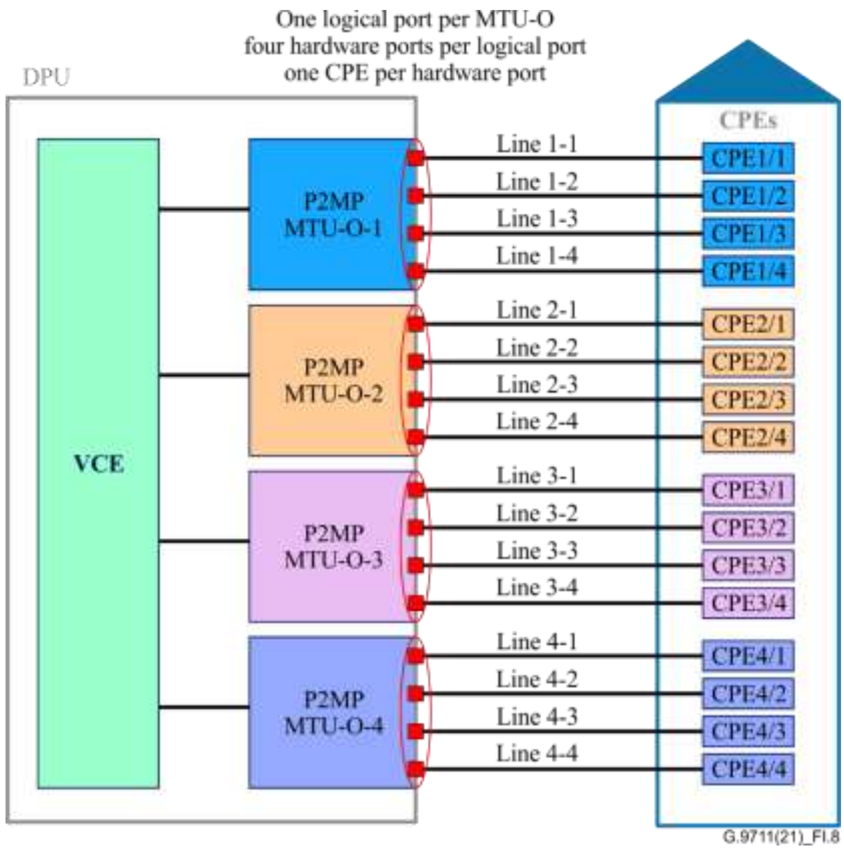


Figure I.8 – Illustration P2MP resource sharing in the DPU (multiple hardware ports per logical port in the DPU)

I.2.6 Loop sets for simulation and testing

Figure I.9 illustrates the loop types in conjunction with FTTB scenarios.

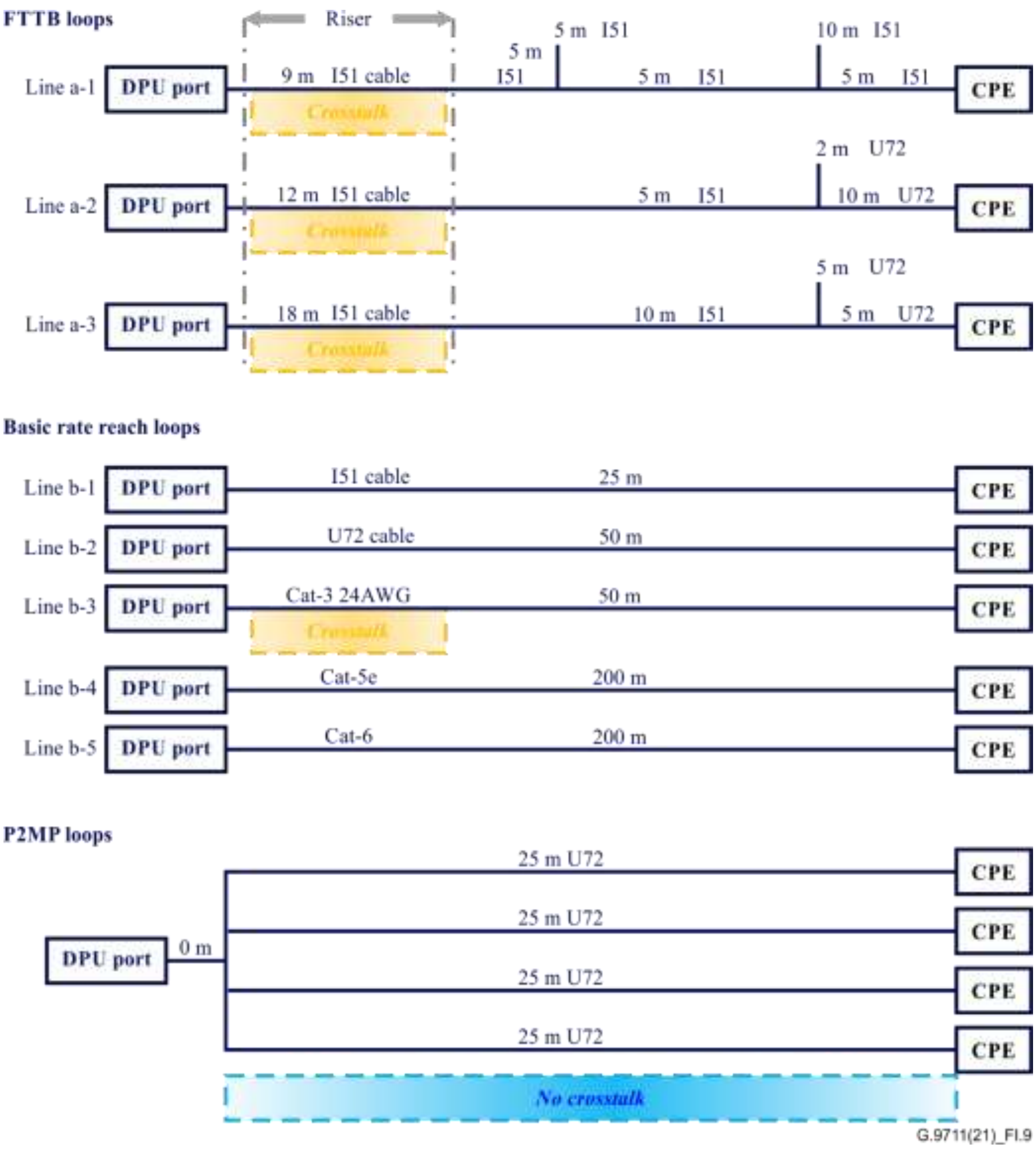


Figure I.9 – Loops for simulation and testing

Appendix II

Coaxial cable wiring topologies and reference loops

(This appendix does not form an integral part of this Recommendation.)

II.1 Reference loops

Figures II.1 and II.2 illustrate possible coaxial cable configurations for a typical deployment of P2P MGfast in MDU with and without satellite TV service using coaxial cable. Cable types include RG-6, RG-11 and RG-59. In this scenario there are no splitters or bridge taps in the MGfast path. Also, no in-line amplification devices in the MGfast or satellite signal path. The details of those coaxial cable characteristic is referred to [BBF document TR-285, Amendment 1].

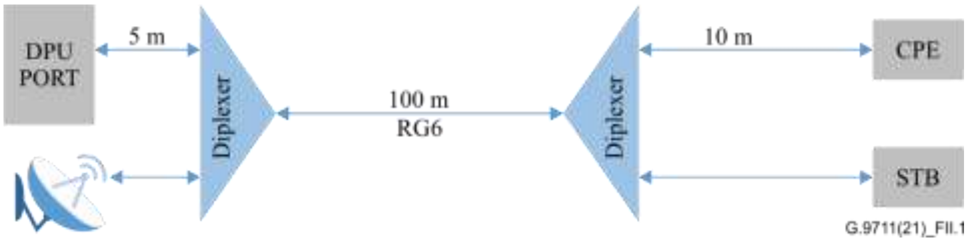


Figure II.1 – Illustration of coaxial cabling configuration with satellite TV in an MDU

Figure II.2 – Illustration of coaxial cabling configuration without satellite TV in an MDU

II.2 Wire types

Table II.1 – Wire types

Short name	Type	Reference
RG-6	1.024 mm outer diameter of the core conductor, 4.7 mm inner diameter of the shield, used for cable television, satellite television and cable modems	Clause II.1
RG-11	1.63 mm outer diameter of the core conductor, 7.25 mm inner diameter of the shield, used for cable television, satellite television for long drops and underground conduit	Clause II.1
RG-59	0.58 mm outer diameter of the core conductor, 3.7 mm inner diameter of the shield, used for baseband video in closed-circuit television	Clause II.1

Appendix III

Example OLR use cases

(This appendix does not form an integral part of this Recommendation.)

III.1 Transmitter initiated gain adjustment (TIGA)

This clause includes a number of examples of the use of TIGA in a vectoring configuration.

For a P2P deployment case, interactions between an MTU-O and an MTU-R on a single transmission line are described as well as the interactions between the MTU-Os on multiple transmission lines and the VCE.

The possible flows in a TIGA procedure are illustrated in Figure 13-8. The TIGA procedure ends with an SRA-R with four possible SCCC values, as explained below.

The normal flow of a TIGA procedure includes the following steps:

– First, the VCE initiates a TIGA request. The VCE may initiate a TIGA request when a precoder coefficient update is scheduled. The VCE instructs the MTU-O to send a TIGA command to the MTU-R.
– After TIGA-ACK received by the MTU-O, the VCE gives instruction to the MTU-O to proceed further by waiting for reception of the TIGARESP.
– After TIGARESP is received: Upon instruction from the VCE, the MTU-O sends an SRA-R RMC response, with the SCCC value indicated in the received TIGARESP, to execute the TIGA.

There are two potential disruptions causing exception cases to the procedure:

1) In the case of TIGA-ACK is not received,
– the VCE may decide to initiate a new TIGA command, to have another try, or
– the VCE may decide to not uphold the whole vectored group due to this transmission line and proceed with sending an SRA-R RMC command with SCCC= 1101 (special value) indicating that the MTU-O will enable only the precoder update corresponding with the TIGA command, but will not modify the bit-loading tables, as defined in TIGA request.

2) In the case of TIGA-ACK is received, but TIGARESP is not received,
– the VCE may decide to initiate a new TIGA command, to have another try, or
– the VCE may decide to not uphold the whole vectored group due to this transmission line and proceed with sending an SRA-R RMC command with SCCC= 1110 (special value) indicating that the MTU-O will enable only the precoder update corresponding to the TIGA command, but will not modify the bit-loading tables, as defined in TIGA request (e.g., in case the VCE knows that bit-loading table indicated in TIGA request may not be sufficiently accurate), or
– the VCE may decide to not uphold the whole vectored group due to this transmission line and proceed with sending an SRA-R RMC command with SCCC= 1111 (special value) indicating that the MTU-O will enable both the precoder and the bit-loading table updates corresponding to the TIGA command (e.g., in case the VCE knows that bit-loading table in TIGA request is an accurate proposal).

The goals of introducing the mentioned exceptions and indicating special values i.e., SCCC=1111/1110/1101, are the following:

In case of "TIGA-ACK is received, but TIGARESP is not received":

The advantage of indicating SCCC=1111/1110 to the MTU-R, is that it may be able to "live with" the proposed TIGA values of bit loading, despite it preferred the TIGARESP values. Thus, the MTU-R will be able to continue showtime with the updated TIGA gains and bit-loading values, and later further adapt the bit loading using autonomous SRA.

In case of "TIGA-ACK is not received":

One possibility is that the TIGA request was not received by the MTU-R. In this case, the advantage of indicating SCCC=1101 to the MTU-R, is that it gets warned about a precoder change, but without change of bit-loading tables. This avoids de-synchronization in the bit-loading tables between the MTU-O and MTU-R. Nevertheless, the MTU-R's FEQ values may not be correct anymore (on some or all tones), and therefore SNRM loss and possibly constellation decision errors may occur. The MTU-R may be able to continue showtime by lowering the bit loading via an FRA procedure (which may be further followed by autonomous SRA to optimize the bit loading).

Another possibility is that the TIGA request was received by the MTU-R but the TIGA-ACK got lost (e.g., due to impulse noise). In principle, in this case the MTU-R knows the settings indicated in TIGA command, however the VCE/MTU-O cannot be sure of it. Therefore, using SCCC=1101 is a prudent approach, avoiding de-synchronization in the bit-loading tables between the MTU-O and MTU-R.

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