International Telecommunication Union

ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

G.998.4
(01/2015)

SERIES G: TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

Digital sections and digital line system – Metallic access networks

---

Improved impulse noise protection for digital subscriber line (DSL) transceivers

Recommendation ITU-T G.998.4

ITU-T

ITU-T G-SERIES RECOMMENDATIONS

TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

INTERNATIONAL TELEPHONE CONNECTIONS AND CIRCUITS	G.100–G.199
GENERAL CHARACTERISTICS COMMON TO ALL ANALOGUE CARRIER-TRANSMISSION SYSTEMS	G.200–G.299
INDIVIDUAL CHARACTERISTICS OF INTERNATIONAL CARRIER TELEPHONE SYSTEMS ON METALLIC LINES	G.300–G.399
GENERAL CHARACTERISTICS OF INTERNATIONAL CARRIER TELEPHONE SYSTEMS ON RADIO-RELAY OR SATELLITE LINKS AND INTERCONNECTION WITH METALLIC LINES	G.400–G.449
COORDINATION OF RADIOTELEPHONY AND LINE TELEPHONY	G.450–G.499
TRANSMISSION MEDIA AND OPTICAL SYSTEMS CHARACTERISTICS	G.600–G.699
DIGITAL TERMINAL EQUIPMENTS	G.700–G.799
DIGITAL NETWORKS	G.800–G.899
DIGITAL SECTIONS AND DIGITAL LINE SYSTEM	G.900–G.999
General	G.900–G.909
Parameters for optical fibre cable systems	G.910–G.919
Digital sections at hierarchical bit rates based on a bit rate of 2048 kbit/s	G.920–G.929
Digital line transmission systems on cable at non-hierarchical bit rates	G.930–G.939
Digital line systems provided by FDM transmission bearers	G.940–G.949
Digital line systems	G.950–G.959
Digital section and digital transmission systems for customer access to ISDN	G.960–G.969
Optical fibre submarine cable systems	G.970–G.979
Optical line systems for local and access networks	G.980–G.989
Metallic access networks	**G.990–G.999**
MULTIMEDIA QUALITY OF SERVICE AND PERFORMANCE – GENERIC AND USER-RELATED ASPECTS	G.1000–G.1999
TRANSMISSION MEDIA CHARACTERISTICS	G.6000–G.6999
DATA OVER TRANSPORT – GENERIC ASPECTS	G.7000–G.7999
PACKET OVER TRANSPORT ASPECTS	G.8000–G.8999
ACCESS NETWORKS	G.9000–G.9999

For further details, please refer to the list of ITU-T Recommendations.

Recommendation ITU-T G.998.4

Improved impulse noise protection for digital subscriber line (DSL) transceivers

Summary

Recommendation ITU-T G.998.4 specifies techniques beyond those defined in the existing ITU-T digital subscriber line (DSL) Recommendations ITU-T G.992.3, ITU-T G.992.5 and ITU T G.993.2 to provide enhanced protection against impulse noise or to increase the efficiency of providing impulse noise protection (INP).

This version of this Recommendation integrates all of the previous amendments and corrigenda with the 2010 version of Recommendation ITU-T G.998.4.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
1.0	ITU-T G.998.4	2010-06-11	15	11.1002/1000/10418
1.1	ITU-T G.998.4 (2010) Cor. 1	2010-11-29	15	11.1002/1000/11017
1.2	ITU-T G.998.4 (2010) Cor. 2	2011-04-13	15	11.1002/1000/11132
1.3	ITU-T G.998.4 (2010) Amd. 1	2011-06-22	15	11.1002/1000/11131
1.4	ITU-T G.998.4 (2010) Cor. 3	2011-12-16	15	11.1002/1000/11399
1.5	ITU-T G.998.4 (2010) Amd. 2	2012-04-06	15	11.1002/1000/11505
1.6	ITU-T G.998.4 (2010) Cor. 4	2012-06-13	15	11.1002/1000/11646
1.7	ITU-T G.998.4 (2010) Cor. 5	2013-03-16	15	11.1002/1000/11894
1.8	ITU-T G.998.4 (2010) Amd. 3	2014-01-13	15	11.1002/1000/12092
1.9	ITU-T G.998.4 (2010) Amd. 4	2015-05-22	15	11.1002/1000/12377
2.0	ITU-T G.998.4	2015-01-13	15	11.1002/1000/12376

* To access the Recommendation, type the URL http://handle.itu.int/ in the address field of your web browser, followed by the Recommendation's unique ID. For example, http://handle.itu.int/11.1002/1000/11830-en.

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.

INTELLECTUAL PROPERTY RIGHTS

ITU draws attention to the possibility that the practice or implementation of this Recommendation may involve the use of a claimed Intellectual Property Right. ITU takes no position concerning the evidence, validity or applicability of claimed Intellectual Property Rights, whether asserted by ITU members or others outside of the Recommendation development process.

As of the date of approval of this Recommendation, ITU had received notice of intellectual property, protected by patents, 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 TSB patent database at http://www.itu.int/ITU-T/ipr/.

Table of Contents

Recommendation ITU-T G.998.4

Improved impulse noise protection for digital subscriber line (DSL) transceivers

1 Scope

This Recommendation specifies techniques beyond those defined in the existing ITU-T digital subscriber line (DSL) [ITU-T G.992.3], [ITU-T G.992.5] and [ITU-T G.993.2] to provide enhanced protection against impulse noise or to increase the efficiency of providing impulse noise protection (INP).

Impulse noise is a noise event of limited duration that can degrade one or more transmitted symbols. Unlike the various types of continuous noise found on DSLs, impulse noise has a short duration and may repeat, either randomly or periodically. Impulse noise that does not appear to repeat periodically but occurs as unpredictable events is termed SHINE (single high impulse noise event). Impulse noise caused by noise from electrical mains and that thus repeats at a constant period related to the local AC power frequency is termed REIN (repetitive electrical impulse noise).

Impulse noise protection techniques are, in general, techniques used by a DSL transceiver to protect against the effects of impulse noise on the transmitted signal. Existing ITU-T DSL Recommendations specify techniques to ameliorate impulse noise effects. Among these methods are the use of forward error correction (FEC) coding and interleaving.

This Recommendation specifies a physical layer retransmission method for enhancing INP, with annexes specifically providing the details required for implementation of these techniques for transceivers supporting [ITU-T G.992.3], [ITU-T G.992.5] and [ITU-T G.993.2]. Methods for enhancing INP by techniques other than physical layer retransmission are for further study.

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.992.3] Recommendation ITU-T G.992.3 (2009), *Asymmetric digital subscriber line transceivers 2 (ADSL2)*.

[ITU-T G.992.5] Recommendation ITU-T G.992.5 (2009), *Asymmetric digital subscriber line 2 transceivers (ADSL2) – Extended bandwidth ADSL2 (ADSL2plus)*.

[ITU-T G.993.2] Recommendation ITU-T G.993.2 (2015), *Very high speed digital subscriber line transceivers 2 (VDSL2)*.

[ITU-T G.993.5] Recommendation ITU-T G.993.5 (2015), *Self-FEXT cancellation (vectoring) for use with VDSL2 transceivers*.

3 Definitions

This Recommendation defines the following terms:

3.1 aggregate data rate (ADR): This is the sum of aggregate data rates per latency over all latency paths and over the retransmission return channel (RRC). If retransmission is enabled, the aggregate data rate in the latency path #1 is the sum of the net data rate plus the overhead rate due to the data transfer unit (DTU) framer and the aggregate data rate in the latency path #0 is the overhead rate. The aggregate data rate of the RRC is the rate excluding the overhead of the Golay code. The aggregate data rate is the rate at the A-reference point.

3.2 expected throughput (ETR): This is the rate available in Showtime at the α/β-reference point, assuming full protection against an impulse noise environment corresponding to the impulse noise environment as described by parameters in the MIB.

3.3 forward direction: This is the direction of transmission of the DTUs.

3.4 impulse noise protection (INP): This is the number of consecutive DMT symbols as seen at the δ-reference point, for which errors can be completely corrected by the retransmission function, regardless of the number of errors within the errored discrete multi-tone (DMT) symbols.

3.5 impulse protection against repetitive electrical impulse noise (INP_REIN): This is the number of consecutive DMT symbols that are corrupted by REIN, as seen at the δ-reference point, for which errors can be completely corrected by the retransmission function, regardless of the number of errors within the errored DMT symbols.

3.6 line rate (LR): This is the data rate at the U-interface**.**

3.7 net data rate (NDR): This is the data rate at the α/β-reference point of the bearer channel mapped in latency path #1, assuming that no retransmissions occur.

3.8 overhead rate (OR): This is the rate assigned to the overhead channel carried in latency path #0.

3.9 repetitive electrical impulse noise (REIN): This is a type of electrical noise encountered on digital subscriber lines. It is evident as a continuous and periodic stream of short impulse noise events. Individual REIN impulses commonly have durations of less than 1 millisecond. REIN is commonly coupled from electrical power cable appliances drawing power from the AC electrical power network, having a repetition rate of twice the AC power frequency (100 or 120 Hz).

3.10 return direction: This is the direction of transmission of acknowledgements (in the RRC) of received DTUs.

3.11 single high impulse noise event (SHINE): This is a type of electrical noise encountered on digital subscriber lines. SHINE generally arises as a periodic stream of impulses with effectively random inter-arrival time and impulse length both inversely related to intensity. Generally the term SHINE is associated with large impulses with durations in the range of milliseconds to seconds.

3.12 total data rate (TDR): This is the sum of total data rate per latency over all latency paths and the rate of the RRC including its forward error correction (FEC) overhead (Golay). This is the rate at the C-reference point.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

ATM Asynchronous Transfer Mode

ATTNDR Attainable Net Data Rate

ATU-C Central office ADSL2/ADSL2plus Transceiver Unit

ATU-R	Remote ADSL2plus Transceiver Unit
CRC	Cyclic Redundancy Check
DMT	Discrete Multi-Tone
DTU	Data Transfer Unit
EFTR	Error-free Throughput Rate
ETR	Expected Throughput
eoc	embedded operations channel
FEC	Forward Error Correction
LSB	Least Significant Bit
MIB	Management Information Base
MTBE	Mean Time Between error Events
NDR	Net Data Rate
NMS	Network Management System
PMD	Physical Media Dependent
PMS-TC	Physical Media Specific Transmission Convergence
PSD	Power Spectral Density
PTM	Packet Transfer Mode (64/65-octet encapsulation)
REIN	Repetitive Electrical Impulse Noise
RRC	Retransmission Return Channel
SDO	Scheduled Discontinuous Operation
SHINE	Single High Impulse Noise Event
SID	Sequence Identifier
TC	Transmission Convergence
TPS-TC	Transmission Protocol Specific Transmission Convergence
TS	Time Stamp
VTU-O	VDSL2 Transceiver Unit – Optical side
VTU-R	VDSL2 Transceiver Unit – Remote side

5 Overview

This Recommendation shall be implemented in conjunction with one of the following ITU-T Recommendations, referred as "associated Recommendations": [ITU-T G.992.3] (ADSL2), [ITU-T G.992.5] (ADSL2plus), or [ITU-T G.993.2] (VDSL2).

The main body specifies the elements that are independent of the associated Recommendation that include:

– Data path and the retransmission return channel for the transmission direction for which retransmission is enabled.

– Management and control of the retransmission function.

The annexes specify the elements that are dependent on the associated Recommendation that include:

– Requirements on the data path specific to the associated Recommendation.

– Changes to the initialization of the associated Recommendation.

– Changes to the embedded operations channel (eoc) messages.

A transceiver compliant with this Recommendation shall support the main body, one of the associated Recommendations and the respective annex.

6 Functional reference model

Figure 6-1 shows the functional reference model for the case where retransmission is enabled in both transmission directions.

In the forward direction, only one bearer channel (#0) is active. Octets from the bearer channel are encapsulated in data transfer units (DTUs). DTUs are stored in a retransmission queue after transmission. A DTU multiplexer will select either a new DTU or a DTU from the retransmission queue for transmission over the α2-reference point.

The PMS-TC contains two latency paths and a retransmission request channel (RRC). Latency path 0 contains only overhead data, while latency path 1 contains only DTUs (i.e., octets coming over the α2-reference point). The RRC carries acknowledgments for received DTUs. The latency paths are scrambled and encoded using a Reed-Solomon code. The RRC is encoded using an extended Golay code. The output bits from the latency paths and the RRC are multiplexed into a data frame that is transferred to the PMD over the δ-reference point.

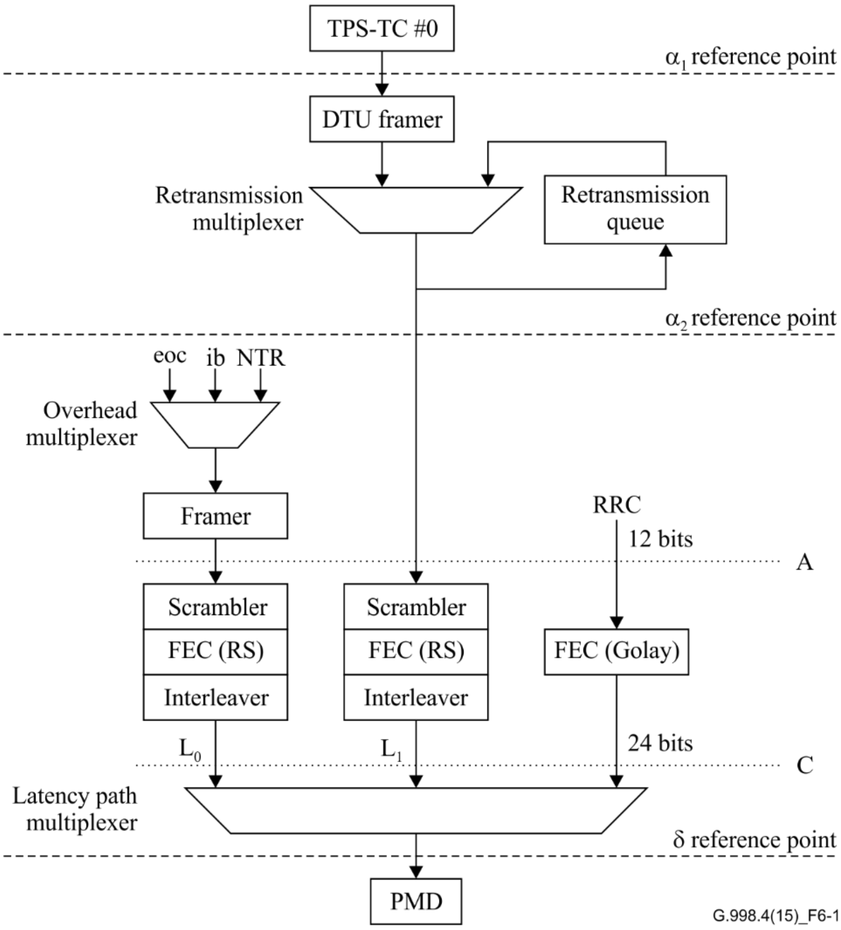


Figure 6-1 – Reference model when retransmission is enabled in both directions

Figure 6-2 shows the functional reference model in the forward direction when retransmission is enabled in a single direction. This functional reference model is identical to the one described in Figure 6-1, with the exception that there is no RRC.

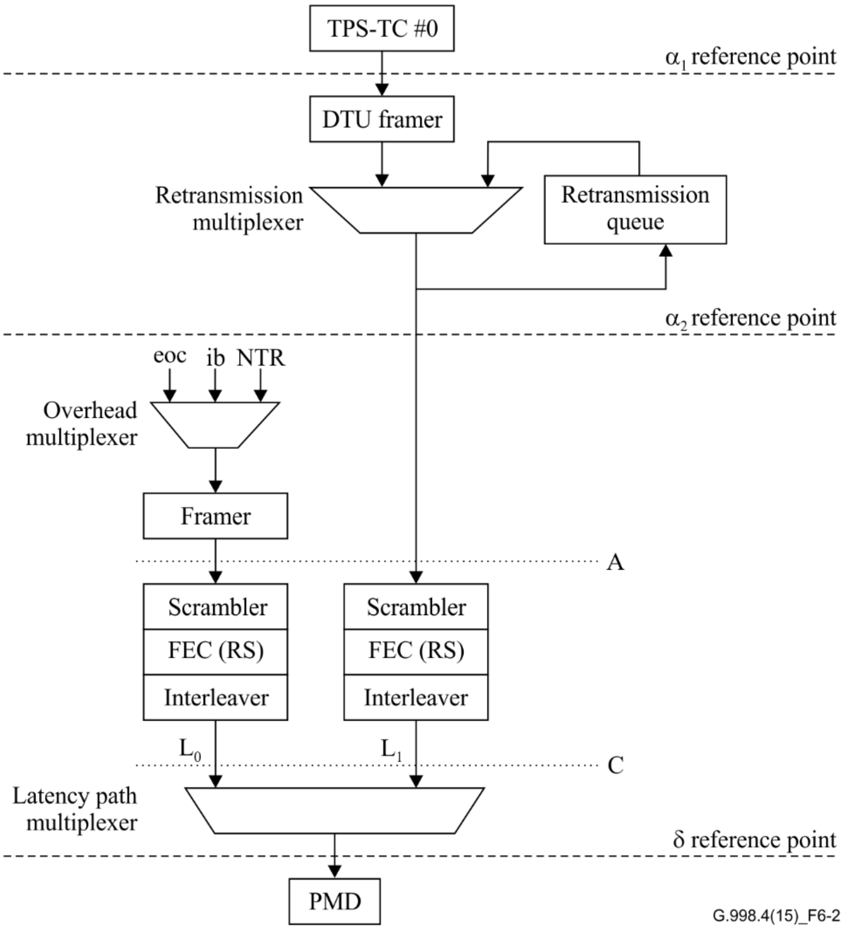


Figure 6-2 – Reference model in the forward direction when retransmission is enabled in a single direction

Figure 6-3 shows the functional reference model in the return direction when retransmission is enabled in a single direction. The functional reference model for the TPS-TC is identical to the TPS-TC functional model in the applicable associated Recommendation ([ITU-T G.992.3], [ITU-T G.992.5] or [ITU-T G.993.2]). The PMS-TC consists of one latency path and the RRC. The functional model of the latency paths is identical to that in the applicable associated Recommendation ([ITU-T G.992.3], [ITU-T G.992.5] or [ITU-T G.993.2]). The RRC is multiplexed with the output of the latency paths into a data frame that is transferred to the PMD over the δ-reference point.

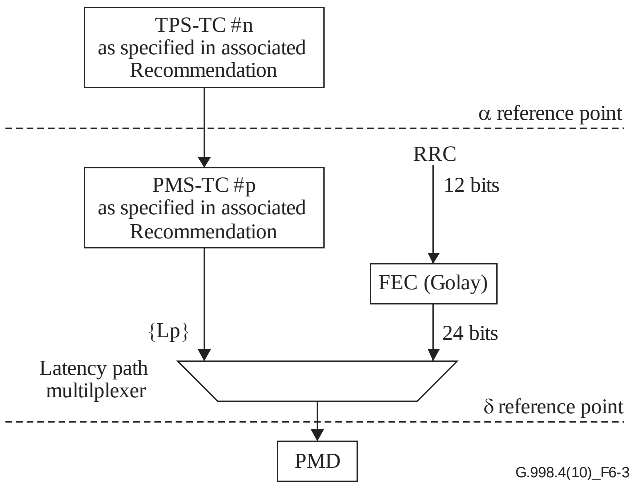


Figure 6-3 – Reference model in the return direction when retransmission is enabled in a single direction

In the reference model of Figure 6-1 and Figure 6-2, the retransmission queue is shown to be located between the TPS-TC and scrambler only for the purpose of defining the data transmission unit (DTU) frame structure that is described in clause 8 below. It is noted that the DTU frame structure is defined such that it is transparent to the location of the retransmission queue where the queue may be placed at one layer in the transceiver structure and interoperate with another device having the queue located in a different layer.

7 TPS-TC function

Transceivers complying with this Recommendation shall support either the ATM TC or PTM TC with 64/65-octet encapsulation or both.

7.1 ATM TPS-TC

The ATM TC shall be as specified in the associated ITU-T Recommendation related to ADSL2, ADSL2plus or VDSL2 with the exception that the ATM payload scrambler as defined in clause K.2.8 of [ITU-T G.992.3] and [ITU-T G.993.2] shall be disabled and with the inclusion of control parameters as specified in the following clauses. Modifications to the control parameters of the associated ITU-T Recommendations are specified in Annexes A, B and C.

7.1.1 Control parameters specific to ITU-T G.998.4

The ATM TPS-TC control parameters specific to ITU-T G.998.4 are defined in Table 7-1.

Table 7-1 – Control parameters of the ATM TPS-TC

Parameter	Definition
ETR_min	Minimum allowed value for ETR in kbit/s.
ETR_max	Maximum allowed value for ETR in kbit/s.
net_max	Maximum allowed value for NDR in kbit/s.
INP_min	Minimum impulse noise protection (INP) against SHINE in DMT symbols.
SHINEratio	The loss of rate in a 1 second interval expressed as a fraction of NDR due to a SHINE impulse noise environment expected by the operator to occur at a probability acceptable for the services.

Table 7-1 – Control parameters of the ATM TPS-TC

Parameter	Definition
INP_min_rein	Minimum impulse protection against electrical repetitive impulse noise (REIN) in DMT symbols.
iat_rein_flag	Configuration flag indicating the inter-arrival time of REIN. The flag shall be set to 0 if the inter-arrival time is derived from a REIN at 100 Hz. The flag shall be set to 1 if the inter-arrival time is derived from a REIN at 120 Hz. (Notes 1, 2).
delay_max	Maximum delay (see clause 8.1.6) in ms.
delay_min	Minimum delay (see clause 8.1.6) in ms.
leftr_thresh	The threshold used to declare leftr defects (see clause 11.3.3) expressed in a fraction of the NDR. The value 0 is a special value to indicate that the receiver shall use a special value for declaring leftr defect. The minimum valid threshold to declare leftr is ETR/2. The receiver shall ignore threshold values that are less than the minimum and shall use ETR/2 for declaring leftr defect instead (see clause 11.3.3).
CIpolicy	The channel initialization policy used for this bearer channel.
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 equally spaced impulses per AC cycle of 50 Hz or 60 Hz. Consideration of cases where the 2 impulses are not equally spaced is for further study.	

7.1.2 Valid configurations

A valid configuration of the ATM TPS-TC shall consist of the configuration of each control parameter with one of their valid values specified in Table 7-2.

Table 7-2 – Valid configurations of ATM TPS-TC

Parameter	Capability
ETR_min	The valid values are all multiples of 8 from 0 to the maximum of the valid values of the minimum net data rate specified in the associated Recommendation.
ETR_max	The valid values are all multiples of 8 from 0 to the maximum of the valid values of the maximum net data rate specified in the associated Recommendation.
net_max	The valid values are all multiples of 8 from 0 to the maximum of the valid values of the maximum net data rate specified in the associated Recommendation.
INP_min	The valid values are all integers from 0 to 63 for system with a sub-carrier spacing of 4.3125 kHz. The valid values are all integers from 0 to 127 for system with a sub-carrier spacing of 8.625 kHz.
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 7 for system with a sub-carrier spacing of 4.3125 kHz. The valid values are all integers from 0 to 13 for system with a sub-carrier spacing of 8.625 kHz.
iat_rein_flag	The valid values are 0 and 1.

Table 7-2 – Valid configurations of ATM TPS-TC

Parameter	Capability
delay_max	The valid values are all integers from 1 to 63.
delay_min	The valid values are all integers from 0 to 63.
leftr_thresh	The valid values are all multiples of 0.01 from 0.01 to 0.99.
CIpolicy	The valid value is 0.

7.1.3 Mandatory configurations

The mandatory configurations of the TPS-TC 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 7-3.

Table 7-3 – Mandatory configurations of ATM TPS-TC

Parameter	Capability
ETR_min	The mandatory values shall be all multiples of 8 from 0 to the maximum of the mandatory values of the minimum net data rate specified in the associated Recommendation.
ETR_max	The mandatory values shall be all multiples of 8 from 0 to the maximum of the mandatory values of the maximum net data rate specified in the associated Recommendation.
net_max	The mandatory values shall be all multiples of 8 from 0 to the maximum of the mandatory values of the maximum net data rate specified in the associated Recommendation.
INP_min	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.
delay_min	All valid values shall be supported.
leftr_thresh	All valid values shall be supported.
CIpolicy	All valid values shall be supported.

7.2 PTM TPS-TC with 64/65-octet encapsulation

The PTM TC with 64/65-octet encapsulation shall be as specified in the associated ITU-T Recommendation with the inclusion of control parameters as specified in the following clauses. Modifications to the control parameters of the associated ITU-T Recommendations are specified in Annexes A, B and C.

7.2.1 Control parameters specific to ITU-T G.998.4

The control parameters of the PTM TPS-TC specific to ITU-T G.998.4 are the same as for the ATM TPS-TC (see Table 7-1).

7.2.2 Valid configurations

The valid configurations of the control parameters of the PMS TPS-TC specific to ITU-T G.998.4 shall be the same as for the ATM TPS-TC (see Table 7-2).

7.2.3 Mandatory configurations

The mandatory configurations of the control parameters of the PMS TPS-TC specific to ITU-T G.998.4 shall be the same as for the ATM TPS-TC (see Table 7-3).

8 Retransmission functions

8.1 DTU framer

Each DTU shall contain an integer number of 53-byte ATM cells (data or idle cells) or an integer number of 64/65-octet PTM codewords and the following octets:

– One octet containing the sequence identifier (SID).

– One octet containing the time stamp (TS).

– *W* octets containing overhead for an 8-bit CRC.

– *V* octets containing the padding bytes.

The content of the SID and TS are specified in clause 8.1.5 and clause 8.1.6. The content of the *W* octets to insert the 8-bit CRC are specified in the clauses on the DTU framing. The content of the padding octets is vendor discretionary. The number of padding octets per DTU, *V*, shall be chosen by the receiver during initialization.

The DTU shall be mapped into and synchronized with, an integer number, *Q*, of RS codewords. Therefore, the following general relationship between the number of payload octets per Reed-Solomon codeword, *H* (see Table 9-2), and the number of RS codewords per DTU, *Q*, holds:

$$\left(Q*H-2-V-W\right)=A*53\text{ for ATM}$$
$$\left(Q*H-2-V-W\right)=A*65\text{ for PTM}$$

A is the integer number of ATM cells or PTM codewords.

The transmitter shall support the framing structure without a CRC as described in clause 8.1.1.

In addition, the transmitter shall indicate during initialization support of one of the DTU structures described in clauses 8.1.2, 8.1.3 and 8.1.4 The DTUs structures described in clauses 8.1.2, 8.1.3 and 8.1.4 contain an additional 8-bit CRC to facilitate detection of errors at the TPS-TC. W is the number of bytes that are inserted when a CRC is added to the DTU.

During initialization, the receiver shall select either the DTU structure without CRC or the DTU structure with CRC that was indicated as being supported by the transmitter during initialization.

The DTU size in DMT symbols is *S***Q*. For operation with the line in the L0 state, both transmitter and receiver shall support all *S***Q* values in the range 0.5 to 4.

The valid configuration structures are described in clauses 8.1.1, 8.1.2, 8.1.3 and 8.1.4.

8.1.1 DTU framer without CRC-8 (Framing type 1)

DTU Framing type 1 shall not contain an 8-bit CRC (W=0). The SID, TS, and padding octets shall be mapped first in this order followed by the *A* ATM cells or 64/65-octet codewords. The SID octet shall be mapped into the first octet of a RS codeword. The following relationship between the number of payload octets per Reed-Solomon codeword, *H*, and the number of RS codewords per DTU, *Q*, holds:

$$(Q * H - 2 - V) = A * 53 \text{ for ATM}$$
$$(Q * H - 2 - V) = A * 65 \text{ for PTM}$$

Figure 8-1 outlines the assembly of a DTU with Framing type 1 and its synchronization with RS codewords.

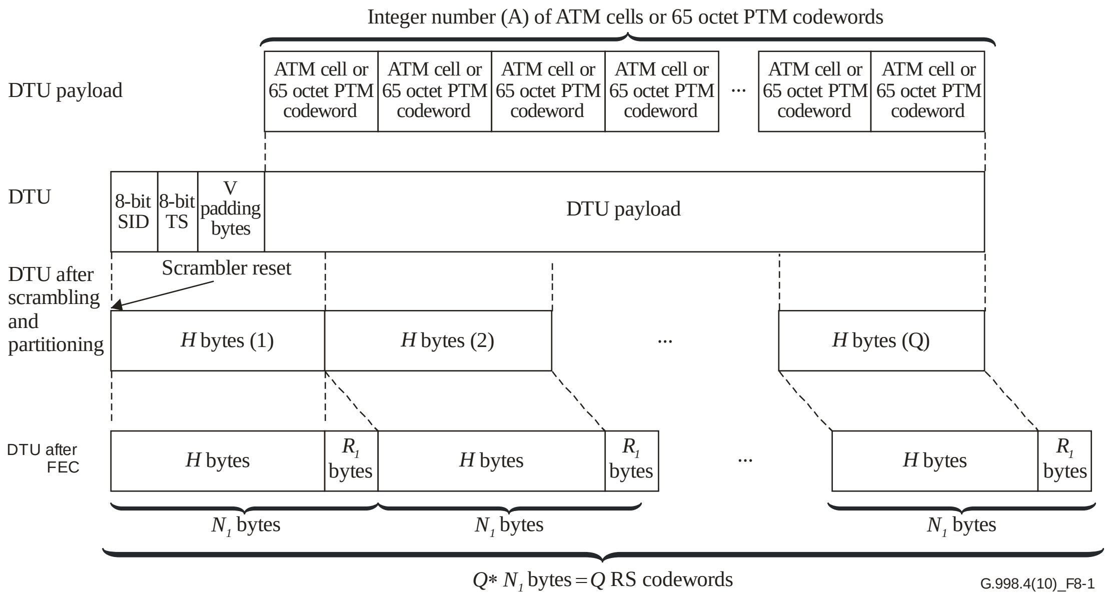


Figure 8-1 – Structure of DTU without CRC (Framing type 1) and synchronization with RS codewords

8.1.2 DTU framer with CRC-8 (Framing type 2)

In this mode, the DTU structure is the same as in clause 8.1.1 with an additional 8-bit CRC inserted at the end of the DTU (i.e., W=1). This CRC shall be computed before the scrambling over the payload octets, the SID, the TS and the padding octets of the DTU. The 8-bit CRC shall be generated as the CRC of the PMS-TC defined in clause 9.5.2.3 of [ITU-T G.993.2]. The SID shall be mapped into the first octet of a Reed-Solomon codeword. Figure 8-2 outlines the assembly of a DTU with Framing type 2 and its synchronization with RS codewords.

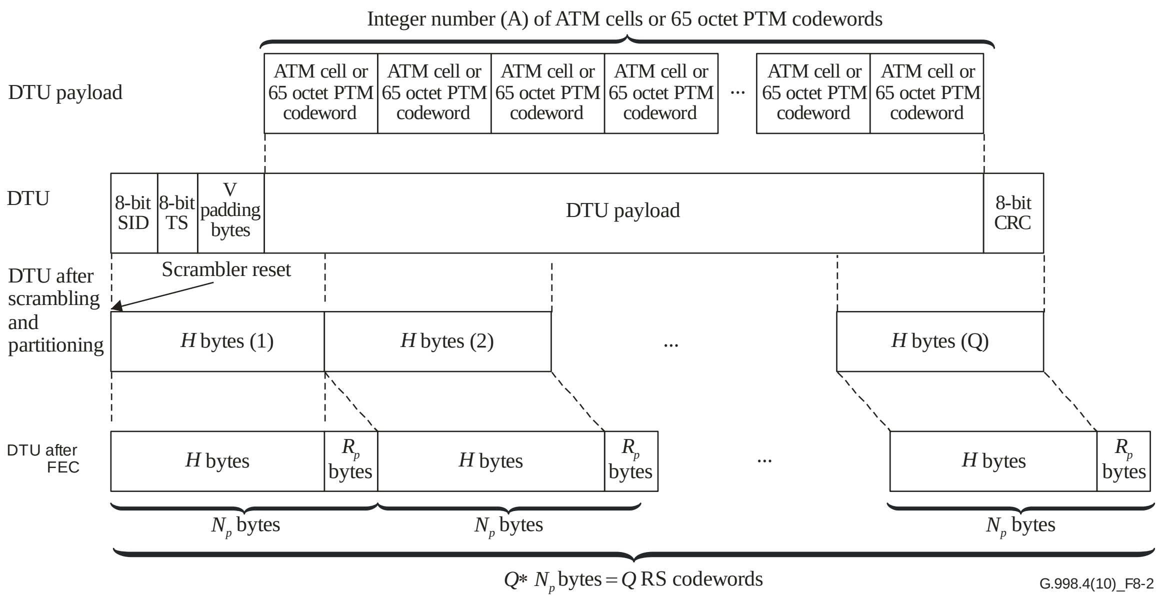


Figure 8-2 – Structure of DTU with CRC at the tail (Framing type 2) and synchronization with RS codewords

The following relationship holds between the Q, H, A and V for the DTU structure with CRC (W=1).

$$(Q*H-3-V)=A*53 \text{ for ATM}$$
$$(Q*H-3-V)=A*65 \text{ for PTM}$$

8.1.3 DTU framer with CRC-8 (Framing type 3)

In this mode, the DTU structure is that described in clause 8.1.1 with an 8-bit CRC inserted as the first octet of the DTU. This CRC shall be computed before scrambling over the payload octets, the SID, the TS and padding octets of the DTU previously transferred across the α2/β2-reference point. The 8-bit CRC shall be generated as the CRC of the PMS-TC defined in clause 9.5.2.3 of [ITU-T G.993.2]. The 8-bit CRC shall be mapped into the first octet of a Reed-Solomon codeword.

The bytes following the CRC byte shall be the SID, TS and padding octets followed by the sequence of *A* ATM cells or 64/65-octet codewords.

Figure 8-3 outlines the assembly of a DTU with Framing type 3 and its synchronization with RS codewords.

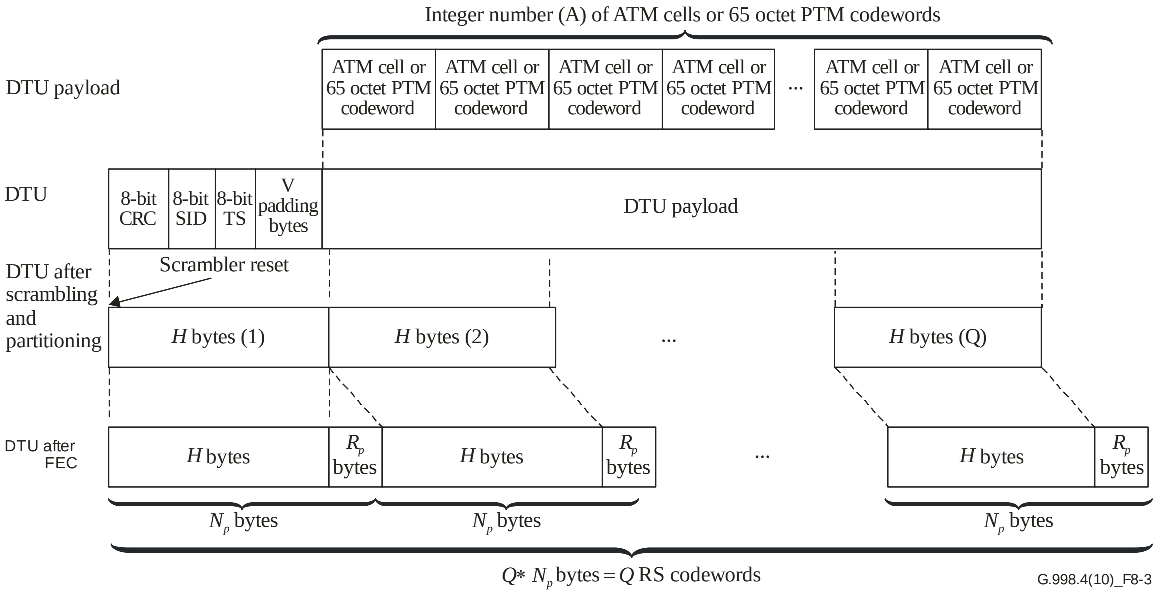


Figure 8-3 – Structure of DTU with CRC at the head (Framing type 3) and synchronization with RS codewords

The following relationship holds between the *Q*, *H*, *A* and *V* for the DTU structure with CRC.

$$(Q*H-3-V)=A*53 \text{ for ATM}$$
$$(Q*H-3-V)=A*65 \text{ for PTM}$$

8.1.4 DTU framer with CRC-8 (Framing type 4)

In this mode, the DTU structure is that described in clause 8.1.1 with an 8-bit CRC inserted as the first byte of the DTU. The CRC shall be computed before scrambling over the payload octets, the SID, the TS and the padding octets of the DTU previously transferred across the α2/β2-reference point. The 8-bit CRC shall be generated as the CRC of the PMS-TC defined in clause 9.5.2.3 of [ITU-T G.993.2]. The 8-bit CRC shall be mapped into the first octet of a Reed-Solomon codeword. The number of octets that are inserted per DTU by this method is SEQ_1. The framing parameters shall be chosen such that they meet the following constraints:

– $W = SEQ_1$, with $SEQ_1 = 2$ for ADSL and $SEQ_1 = 8$ for VDSL,

– $M_1 \times Q \times G_1 = T_1 \times SEQ_1$, with:

- $G_1 = 1$ if $SEQ_1=2$,
- T_1/M_1 an integer if $SEQ_1=8$

– $H = M_1 \times (B_{10}+\lceil G_1 / T_1 \rceil)$, with $G_1=1$ if $SEQ_1=2$

where SEQ_1, M_1, G_1, and T_1 correspond to the SEQ_p, M_p, G_p, T_p in the associated Recommendation for latency path $p=1$, B_{10} corresponds to the B_{pn} in the associated Recommendation for latency path $p=1$ and frame bearer n=0, and $\lceil x \rceil$ denotes ceiling of x.

With the above framer settings, additional W-1 octets are inserted into the DTU. The value of the additional octets shall be FF_{16}. W shall be equal to 2 if the associated Recommendation is [ITU-T G.992.3] or [ITU-T G.992.5] and shall be equal to 8 if the associated Recommendation is [ITU-T G.993.2]. When $G_1=1$, the extra bytes are inserted at equal distance.

The octets following the 8-bit CRC are the SID, TS and padding octets followed by the sequence of A ATM cells or 64/65-octet codewords with the FF_{16} octets inserted in proper locations in the DTU. The distribution of the W octets among T_1 MDFs shall be executed according to clause 9.5.2.1 of [ITU-T G.993.2] with $G_1=1$ if $W=2$. The DTU with CRC and corresponding FF_{16} octet is mapped into and synchronized with Q RS codewords as depicted in Figure 8-4 for $W=2$, $Q=2$, $M_1=2$.

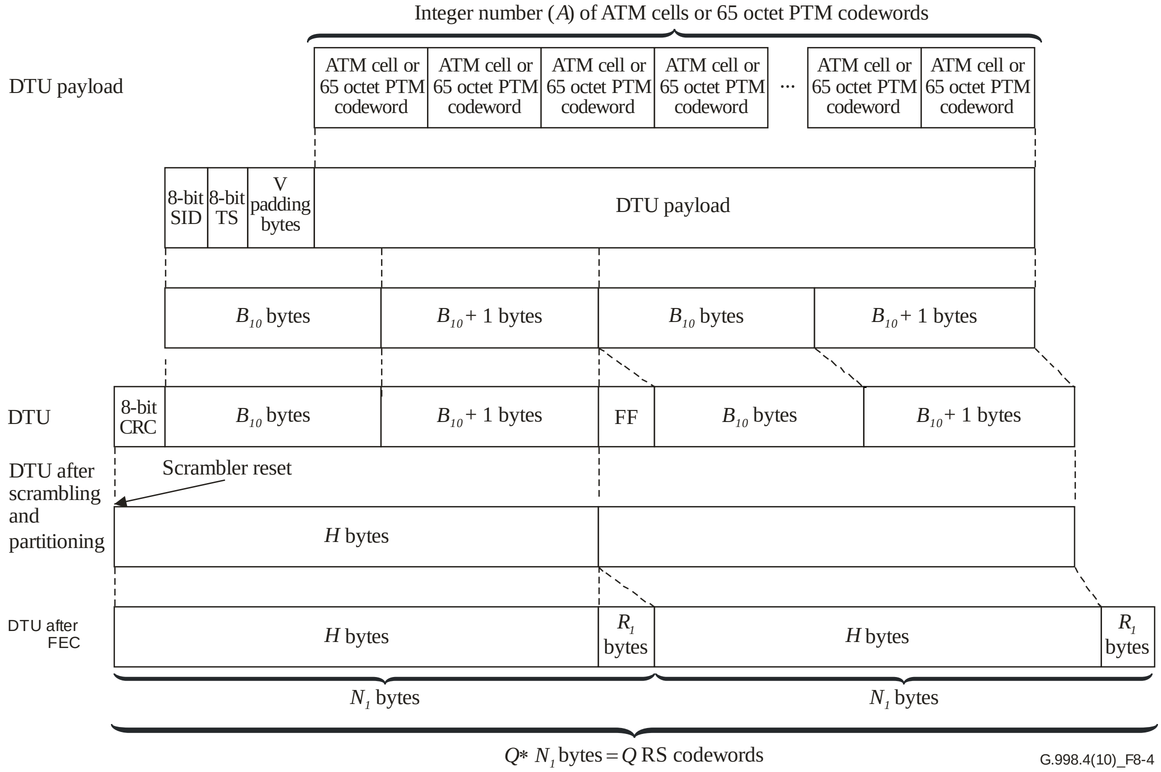


Figure 8-4 – Example of structure of DTU with CRC at the head (Framing type 4, W=2) and synchronization with RS codewords [M_1=2, T_1=Q=2, SEQ_1 = 2, and B_{10} = (H/2) – 1]

The following relationship holds between the Q, H, A, V, *and* W for the DTU structure with CRC.

$$(Q*H-2-W-V)=A*53 \text{ for ATM}$$

$$(Q*H-2-W-V)=A*65 \text{ for PTM}$$

NOTE – The location of the W=8 bytes is chosen such that they coincide with the location of the bytes in a VDSL2 OH frame carrying OH frame type 2, when the OH frame coincides with the DTU. The location of the W=2 bytes is chosen such that they coincide with the location of the bytes in an ADSL2 OH frame according to Table 7-14 with SEQ_1=2, when the OH frame coincides with the DTU.

8.1.5 Sequence identifier (SID)

The SID octet in each DTU identifies the DTU in the transmission sequence. The transmitter increments the SID for every newly framed DTU. Retransmitted DTUs shall have the same SID as for their first transmission. The SID octet shall be initialized to 00_{16} and this shall be the SID of the first DTU transmitted in Showtime. Upon reaching an SID value of FF_{16}, the following SID value shall be 00_{16}.

8.1.6 Time stamp

The time stamp is used in two functionalities:

1. The time stamp shall be used to control the α1-β1 delay of the DTU and its associated data payload.
2. The time stamp may be used to reduce the delay jitter between the transmitter and receiver γ interfaces.

The time reference (also referred to as the DMT Symbol ID) is the count of all DMT symbols, i.e., data symbols and sync symbols, transmitted over the line after entering Showtime.

The time stamp byte of a DTU shall contain the value of the time reference modulo 255 of the DMT symbol that shall contain the first bit of this DTU, assuming that no retransmission event occurs between the framing of the DTU and its transmission over the line.

The value FF_{16} (255) in the TS octet is reserved.

1. In general, the time stamp byte (TS) in each DTU is used both for lines in a bonding group and for lines without bonding:

To control the maximum α1-β1 delay of the DTU and its associated data payload, the configuration parameter *delay_max* shall be the upper limit for the delay that is added to the transmission delay only caused by retransmissions. Here the receiver and/or the transmitter shall identify and discard all DTUs whose payload cannot be transferred over the β1-reference point at the receiver without violating the *delay_max* limit. The time stamp shall be the criterion for discarding the DTUs.

The processing delay between the U-interface and the retransmission sub-layer of the receiver (β2-reference point) in the retransmission data path direction shall be excluded from consideration for *delay_max* in the retransmission data path direction.

NOTE 1 – Consequently, the end-to-end delay between the α1-reference point and the β1-reference point may exceed the value of delay_max by the amount of the processing delay in the transmitter and receiver.

To reduce the delay variation from the γ-interface on the transmit side to the γ-interface at the receiver:

1. Outlet shaping in the receiver shall be supported.
2. The delay between the γ-interface and α1-reference point and the delay between the β1-reference point and γ-interface shall be independent of the retransmissions of DTUs.

The configuration parameter *delay_min* shall be the lower limit for the delay that is added to the transmission delay caused by retransmissions only. The time stamp shall be used by the outlet shaping function to determine when the payload of the DTU shall be sent to the β1-reference point to meet the delay limits. The outlet shaping function shall minimize the additional delay that may be introduced above *delay_min* , and shall never exceed *delay_max*.

NOTE 2 – Due to limited receiver retransmission queue memory (see clauses A.1.1, B.1.1 and C.1.1) an XTU may need to limit the net data rate in order to comply with the *delay_min* limit.

2. If the XTU is configured as part of a bonding group, it is required that the differential delay in the physical layer between all the bonded lines in one group remains bounded.

NOTE 3 – The differential delay requirements of the governing bonding specification (e.g., ITU-T G.998.1 for ATM Bonding or ITU-T G.998.2 for PTM bonding) need to be met on all lines in a bonded group.

8.2 Retransmission multiplexer

Every H*Q bytes (as related to the aggregate data rate of latency path #1), a DTU shall be transferred across the α2-reference point. The retransmission multiplexer selects the kind of DTU to be transferred. The DTU shall be either a new DTU taken from the DTU framer or a previously transmitted DTU taken from the retransmission queue. The control of the selection is done by a transmitter retransmission state machine based on the content of the RRC and on the requirements of INP and delays configured on the bearer transported in the latency path.

8.3 Transmitter retransmission state machine

In the transmitter any DTU that is not acknowledged shall be retransmitted if the constraint of the maximal delay is met. The exact time when a DTU is retransmitted is implementation specific but the transmitter shall ensure that at least NRET (see clause 8.6.4) retransmissions of the same DTU are possible without violating the maximal delay constraint. DTUs that have been acknowledged need not be retransmitted again, even if requested by the receiver.

8.4 Retransmission return channel (RRC)

The retransmission return channel is used to acknowledge the DTUs. It consists of 24 bits multiplexed with the latency paths every data frame. The RRC payload contains three fields:

1. A field of 5 bits, AbsoluteDTUCountLsbs, that contains the least significant bits (LSBs) of the absolute number of the last received DTU. The absolute number of a DTU is the count of all DTUs (new or retransmitted, with or without error) received prior to this DTU since entering Showtime. For the first received DTU upon entering Showtime, AbsoluteDTUCountLsbs shall be zero.
2. A field of 2 bits, Nack[k] (k=0,1), that indicates the status of the two last received DTUs. Nack[0] indicates the status of the last received DTU and Nack[1] indicates the status of the penultimate received DTU. Nack[k]=0 if the DTU is acknowledged, otherwise Nack[k]=1.
3. A field of 5 bits, ConsecutiveGoodDTUs, that indicates:
   – if Nack[1]=0, this field indicates the number of DTUs prior to the penultimate received DTU that are acknowledged. If the number is greater than 31, this field shall be set to 31.
   – if Nack[1]=1, this field indicates the number of consecutive DTUs acknowledged, where the consecutive DTUs are counted starting from *lb* (see clause 8.6) DTUs preceding the penultimate received DTU.

Those fields are protected by 12 bits of redundancy. The overall structure is depicted in Figure 8-5.

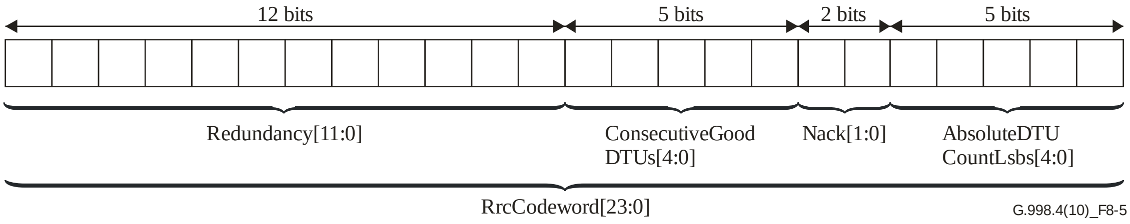


Figure 8-5 – Structure and content of the RRC codeword

The data is transported in the RRC codeword LSB first, i.e.:

RrcCodeword[4:0] = AbsoluteDTUCountLsbs[4:0]

RrcCodeword[6:5] = Nack[1:0]

RrcCodeword[11:7] = ConsecutiveGoodDTUs[4:0]

RrcCodeword[23:12] = Redundancy[11:0]

NOTE – With a 4 kHz symbol rate, the rate of the RRC is 96 kbit/s.

Examples of evaluations of ConsecutiveGoodDtus are shown in Figure 8-6.

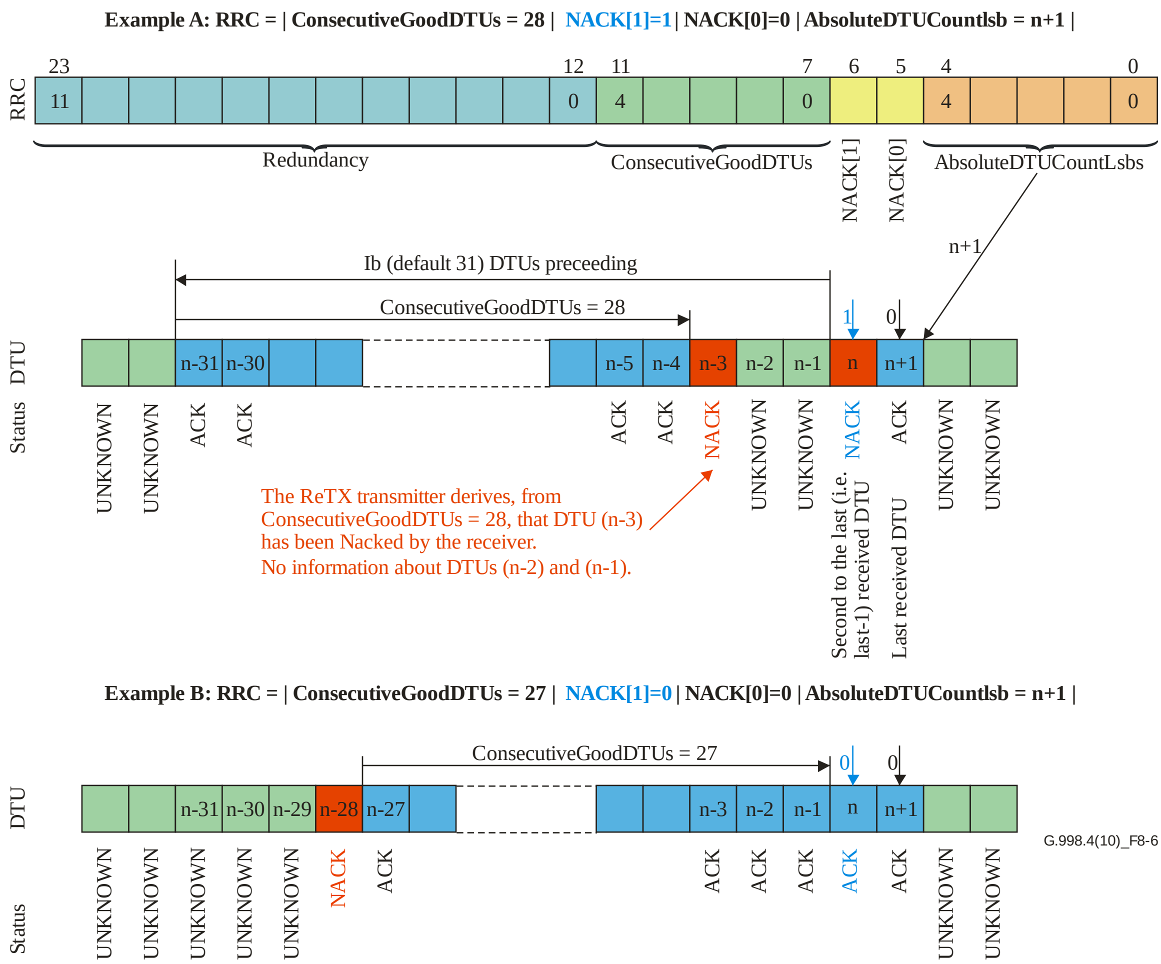


Figure 8-6 – Examples for evaluation of ConsecutiveGoodDtus with *lb* = 31

8.4.1 RRC field initialization

A virtual extension shall be created for the received DTUs where it is assumed that 33 DTUs have been received correctly before entering Showtime, without the need for retransmission.

8.4.2 Extended Golay Code Description

The redundancy bits of the RRC codeword, [b_{12} b_{13} ... b_{23}], shall contain the check bits of the modified extended (24,12) Golay code.

For a 12-bit data message transmitted RRC frame, the Golay redundancy bits [b_{13} b_{14} ... b_{23}] shall be computed using the following operation in GF(2):

$$C(D) = M(D) \times D^{11} \text{ modulo } G(D),$$

where D is the delay operator, and

$$M(D) = b_0D^{11} + b_1D^{10} + \ldots + b_{10}D + b_{11}$$

is the data message polynomial,

$$G(D) = D^{11} + D^9 + D^7 + D^6 + D^5 + D + 1$$

is the generator polynomial,

$$C(D) = b_{17}D^{10} + b_{18}D^9 + b_{22}D^8 + b_{21}D^7 + b_{14}D^6 + b_{19}D^5 + b_{23}D^4 + b_{13}D^3 + b_{20}D^2 + b_{15}D + b_{16}$$

is the parity check polynomial.

The bit b_{12} is the overall parity bit computed in GF(2) as:

$$b_{12} = \sum_{k=0}^{11} b_k + \sum_{k=13}^{23} b_k$$

8.5 Roundtrip

The roundtrip in each direction is split into two parts: one due to the transmitter of the DTUs, called the transmitter half-roundtrip and noted as HRT_{tx}, and one due to the receiver of the DTUs, called the receiver half roundtrip and noted as HRT_{rx}. Both half roundtrips have a part expressed in DMT symbol noted as HRT_{tx}^S and HRT_{rx}^S and a part computed in DTU noted as HRT_{tx}^D and HRT_{rx}^D.

The symbol part of the receiver half roundtrip, HRT_{rx}^S, is defined as the maximal time in DMT symbol measured at the U-interface between the last received bit of the DTU with absolute number $k+HRT_{rx}^D$ and the transmission of the first RRC containing information on the DTU with absolute number k. The value is rounded up to the nearest integer.

The symbol part of the transmitter half roundtrip, HRT_{tx}^S, is defined as the maximal time in DMT symbol measured at the U-interface between the reception of the first RRC containing the request for retransmission of the DTU with absolute number k and the first bit of the DTU transmitted HRT_{tx}^D DTUs before the actual retransmission of the DTU transmitted with the absolute number k. This value assumes that the retransmitted DTU is sent as soon as possible, i.e., is not delayed by the transmit state machine, and is not delayed by the transmission of the current DTU over the U-interface. The value is rounded up to the nearest integer.

Both HRT_{rx}^S and HRT_{tx}^S values are computed assuming that no sync symbol is transmitted in any direction from the transmission of the DTU with absolute number k and its retransmission.

From the definition of the half roundtrips, the minimal size of the transmit queue $Q_{tx,min}$ is computed as:

$$Q_{tx,\min} = \left\lceil \frac{HRT_{tx}^S + HRT_{rx}^S + 1}{Q \times S_1} \right\rceil + HRT_{tx}^D + HRT_{rx}^D + 1$$

This relationship is illustrated in the Figure 8-7.

NOTE – The additional symbol in the round up function takes into account the potential mis-alignment of the sync symbols between the upstream and downstream direction. This extra symbol could be removed if the sync symbols in the direction of DTU transmission are aligned with the sync symbols in the RRC direction in a range from $-HRT_{rx}^S + \left\lfloor \left(HRT_{rx}^D + 1\right) \times Q \times S_1 \right\rfloor$ to $HRT_{tx}^S + \left\lfloor HRT_{tx}^D \times Q \times S_1 \right\rfloor - 1$ DMT symbols, where a positive value indicates that the sync symbol in the direction of DTU transmission is sent after the sync symbol in the RRC direction.

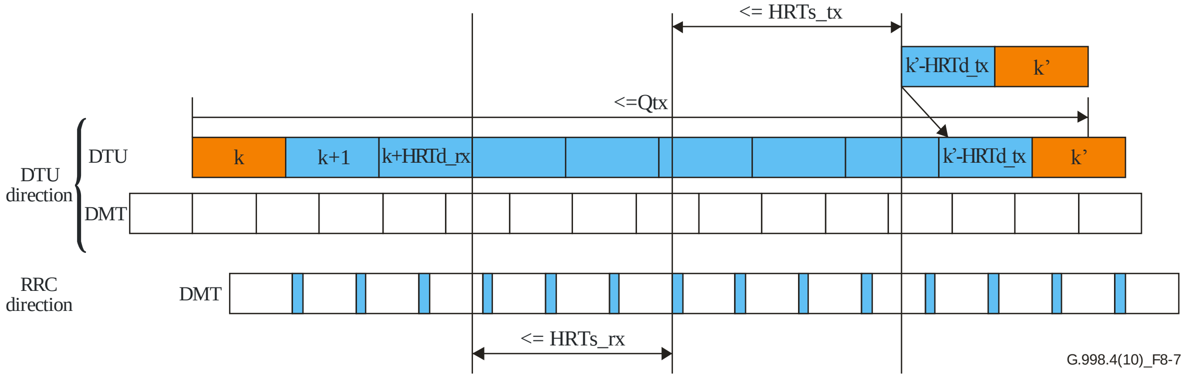


Figure 8-7 – Relationship between half roundtrip definition and minimal Q_{tx}

The full roundtrip time (RTT) including the receiver and transmitter contribution, expressed in milliseconds, is given by:

$$RTT = \frac{Q_{tx,\min} \times Q \times S_1}{f_s}$$

where f_s is the data symbol rate expressed in ksymbols/s.

8.6 Retransmission control parameters

8.6.1 Control parameters

The retransmission control parameters are defined in Table 8-1.

Table 8-1 – Control parameters of the retransmission function

Parameter	Definition
FramingType	Type of DTU framing.
Q	Number of Reed-Solomon codewords per DTU.
V	Number of padding octets per DTU.
HRT_{tx}^{S}	The symbol part of the transmitter half roundtrip expressed in DMT symbols as defined in clause 8.5.
HRT_{tx}^{D}	The DTU part of the transmitter half roundtrip expressed in DTUs as defined in clause 8.5.
HRT_{rx}^{S}	The symbol part of the receiver half roundtrip expressed in DMT symbols as defined in clause 8.5.
HRT_{rx}^{D}	The DTU part of the receiver half roundtrip expressed in DMT symbols as defined in clause 8.5.
Q_{tx}	Delay in DTU between two consecutive transmissions of the same DTU assumed by the receiver for the reference state machine.
lb	Look back value (see clause 8.4).

8.6.2 Valid configurations

A valid configuration of the retransmission function shall consist in the configuration of each control parameter with one of their valid values specified in the Table 8-2.

Table 8-2 – Valid configuration of the retransmission function

Parameter	Capability
FramingType	The valid values are 1, 2, 3 and 4.
HRT_{tx}^{S}	The valid values are any integer from 0 to 15 if the associated Recommendation is [ITU-T G.992.3], [ITU-T G.992.5] or [ITU-T G.993.2] except for profile 30a. The valid values are all multiple of 2 from 0 to 30 if the associated Recommendation is [ITU-T G.993.2] with profile 30a.
HRT_{tx}^{D}	The valid values are any integer from 0 to 2
HRT_{rx}^{S}	The valid values are any integer from 1 to 16 if the associated Recommendation is [ITU-T G.992.3], [ITU-T G.992.5] or [ITU-T G.993.2] except for profile 30a. The valid values are all multiple of 2 from 2 to 32 if the associated Recommendation is [ITU-T G.993.2] with profile 30a.
HRT_{rx}^{D}	The valid values are any integer from 0 to 2.
Q_{tx}	The valid values are any integer from 1 to 63. Valid configuration shall be compatible with the memory as defined in the associated annex.
lb	The valid values are any integer from 1 to 31. Valid configuration shall be such that $lb \leq \min(31, Q_{tx})$.

8.6.3 Mandatory configurations

The mandatory configurations of the retransmission function to be supported are a subset of the valid configurations. They shall consist in the configuration of each control parameter with one of their mandatory values specified in the Table 8-3.

Table 8-3 – Mandatory configuration of the retransmission function

Parameter	Capability
FramingType	The transmitter shall support *FramingType* 1 and at least one of the *FramingType* 2, 3, and 4.
Q_{tx}	All valid values shall be supported.
lb	All valid values shall be supported.

8.6.4 Selection of parameter values

A reference transmit state machine is defined to allow the receiver to derive the settings of the retransmission path (*H*, *Q*, *V*, *R*, *L*) and the queue delay (Q_{tx}). Those settings are based on the following constraints:

– The constraints on the delays: *delay_min*, *delay_max*.

– The constraints on the impulse noise: *INP_min*, *INP_min_rein* and *iat_rein_flag*.

– The constraints on the noise: SNR_margin.

– The constraints on the rate.

NOTE – The receiver should take precautions to be robust against non-stationary RFI.

The reference transmit state machine retransmits any unacknowledged DTU as a fixed number of DTUs, Q_{tx}, after the last transmission of the same DTU. An unacknowledged DTU is not retransmitted after the first transmission of the same DTU plus *delay_max*. Consequently, no more than $NRET = \left\lfloor \frac{delay\_\max \times f_s}{Q_{tx} \times Q \times S} \right\rfloor$ retransmissions of the same DTU are possible with the reference transmit state machine.

The actual INP reported by the transmitter depends on the actual transmitter state machine. The actual transmitter state machine may retransmit DTUs at intervals different from Q_{tx} DTUs. Examples of these state machines can be found in Appendix I. They may differ from the values computed from the formula derived from the reference state machine. The value of the actual INP reported in the MIB shall be that derived by the transmitter.

9 PMS-TC function

The PMS-TC functional model consists of two latency paths. However, the multiplexing of overhead data and user data shall be restricted as described below.

Latency path #0 shall contain only the overhead channel and no user data (i.e., B_{0n}=0). This latency path supports FEC and interleaving. Only a reduced number of combinations of L, N, R, and D shall be allowed for this latency path. These combinations are specified in the respective annexes.

Latency path #1 shall carry user data only for bearer #0 (i.e., B_{1n}=0 for n≠0) and shall be protected by retransmission. Latency path #1 shall use the DTU framing as described in clauses 8.1 and 8.2.

Clause 9.3 describes the multiplexing of the two latency paths and the RRC.

9.1 Scrambler

The PMS-TC scrambler for the latency path #1 shall be identical to the PMS-TC scrambler specified in the associated Recommendation (clause 9.2 of [ITU-T G.993.2], clause 7.7.1.3 of [ITU-T G.992.3]) but its state shall be reset to all ZEROS at the first bit of each DTU. The scrambler is reset so that the first two octets of each DTU are identical before or after scrambling. For DTU with Framing type 1 and 2, this allows decoding of the SID and TS at the receiver before descrambling.

9.2 FEC

For operation per Annex A, the FEC shall be the same as in [ITU-T G.992.3]. The interleaving used on Latency path #0 shall be the same convolutional interleaving as defined in [ITU-T G.992.3].

For operation per Annex B, the FEC shall be the same as in [ITU-T G.992.5]. The interleaving used on Latency path #0 shall be the same convolutional interleaving as defined in [ITU-T G.992.5].

For operation per Annex C, the FEC shall be the same as in [ITU-T G.993.2]. The interleaving used on Latency path #0 shall be the same convolutional interleaving as defined in [ITU-T G.993.2].

The interleaving used on Latency path #1 shall be a block interleaving. The interleaving block shall have a size of $D_1 \times N_{FEC}$ bytes, with N_{FEC} being the length of the RS codeword, and D_1 being the interleaving depth. If D_1=1, then an interleaving block equals an RS codeword. If D_1=Q (the number of RS codewords per DTU) then an interleaving block equals a DTU. Each byte B_k within an interleaving block (input at position k, with index k in the interval 0 to $D_1 \times N_{FEC} - 1$) shall be located at the output of the interleaving function at position l given by $l = i \times D_1 + j$, where $i = k$ MOD N_{FEC} and j = floor(k / N_{FEC}). The block interleaver is illustrated in Figure 9-1a.

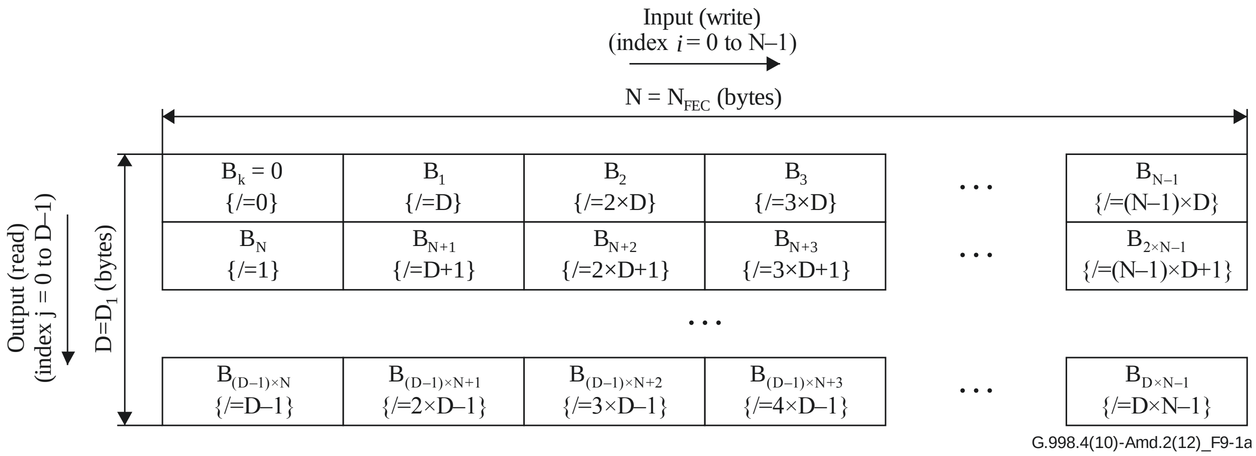


Figure 9-1a – Illustration of the block interleaver

9.3 Latency paths multiplexer

The RRC shall be mapped first on the data frame. Then, the latency paths shall be mapped with the order compliant with the associated Recommendation. The multiplexing of the RRC and latency paths is depicted in Figure 9-1 for [ITU-T G.993.2] and Figure 9-2 for [ITU-T G.992.3] and [ITU-T G.992.5].

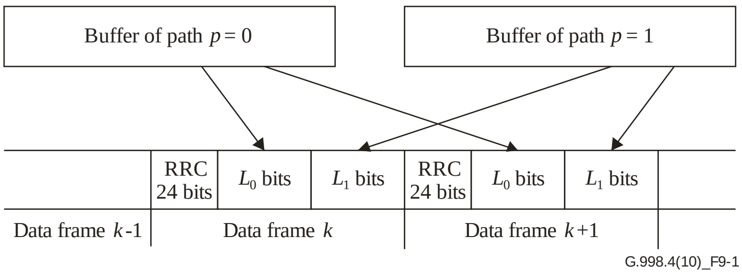


Figure 9-1 – Multiplexing of RRC and latency paths for ITU-T G.993.2

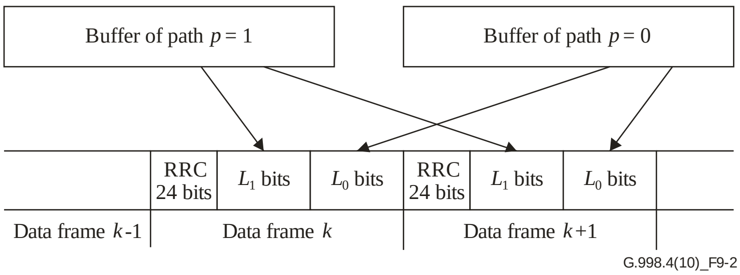


Figure 9-2 – Multiplexing of RRC and latency paths for ITU-T G.992.3 and ITU-T G.992.5

9.4 Framing parameters

The framing parameters for the two latency paths are given in the sections below. Two types of framing parameters are defined:

– Primary framing parameters: the parameters that are exchanged during initialization.

– Derived framing parameters: parameters that can be computed using the primary parameters as input. The derived parameters can be used to verify data rates or additional constraints on the validity of the primary parameters.

9.4.1 Primary parameters

The primary parameters are shown in Table 9-1.

Table 9-1 – Primary framing parameters

Parameter	Definition
B_{pn}	The number of octets per MDF from bearer channel n in latency path p. The actual number of octets in an MDF in latency path 1 can vary between B_{1n}-V-W-2 and B_{1n} +1, depending on the DTU framing type.
FramingType	The DTU framing structure (Note 1).
Q	The number of RS codewords per DTU (Note 1).
D_1	The interleaving depth for latency path #1
V	The number of padding bytes per DTU (Note 1).
R_p	The number of redundancy octets per Reed-Solomon codewords in the latency path #*p* (Note 2).
M_p	Number of MDFs per Reed-Solomon codeword (Note 2).
L_p	The number of bits from latency path #*p* transmitted in each data symbol (Note 2).
G_p	The total number of overhead octets in an OH sub-frame (Note 3).
T_p	The number of MDFs that carry G_p overhead octets.
NOTE 1 – This parameter only applies to latency path #1. NOTE 2 – Latency path #0 contains only overhead traffic. The valid values of this parameter in latency path #0 shall be restricted as described in the annexes. NOTE 3 – This parameter is undefined if the associated Recommendation is [ITU-T G.992.3] or [ITU-T G.992.5]. In this case, the equivalent parameter assumes a special value of 0 or 1 (see Table 9-3).	

9.4.2 Derived parameters

The derived parameters are shown in Table 9-2.

Table 9-2 – Derived framing parameters

Parameter	Definition
W	DTU overhead octets related to CRC insertion: – *W*=0 for *FramingType* = 1 – *W*=1 for *FramingType* = 2 or 3 – *W*=2 for *FramingType* = 4 when the associated Recommendation is [ITU-T G.992.3] or [ITU-T G.992.5] – *W*=8 for *FramingType* = 4 when the associated Recommendation is [ITU-T G.993.2]
N_{FECp}	The Reed-Solomon codeword size: $$N_{FEC1} = M_1 \times \left(B_{10} + \left\lceil \frac{G_1}{T_1} \right\rceil \right) + R_1$$ $$N_{FEC0} = M_0 \times \left\lceil \frac{G_0}{T_0} \right\rceil + R_0$$ by convention, $\left\lceil \frac{G_1}{T_1} \right\rceil$ is equal to 1 if $G_1 = T_1 = 0$.
H	The number of payload bytes per Reed-Solomon codeword in a DTU: $H = N_{FEC1} - R_1$

Table 9-2 – Derived framing parameters

Parameter	Definition
S_p	The number of data symbols per Reed-Solomon codeword for latency path p: $$S_p = \frac{8 \times N_{FECp}}{L_p}$$
DTUframingOH	The relative overhead due to the DTU framing: $$\frac{V + W + 2}{Q \times H}$$
f_{DMT}	The rate of transmission of DMT symbols in kHz. – f_{DMT} = 4.3125*16/17 kHz if the associated Recommendation is [ITU-T G.992.3] or [ITU-T G.992.5]. – f_{DMT} is as specified in clause 10.4.4 of [ITU-T G.993.2] if the associated Recommendation is [ITU-T G.993.2].
f_s	The rate of transmission of data symbols in kHz. – f_s = 4 kHz if the associated Recommendation is [ITU-T G.992.3] or [ITU-T G.992.5]. – f_s is as specified in clause 10.4.4 of ITU-T G.993.2 if the associated Recommendation is [ITU-T G.993.2].
TDR_p	The total data rate per latency path in kbit/s: $$TDR_p = L_p \times f_s$$
TDR	The total data rate in kbit/s: $TDR = \sum_p TDR_p + 24 \times f_s$ if the RRC is present in this direction. $TDR = \sum_p TDR_p$ if the RRC is absent in this direction.
NDR_p	The net data rate per latency path: If retransmission is enabled, $NDR_1 = L_1 \times f_s \times \frac{H}{N} \times (1 - DTUframingOH)$, and NDR_0 = 0. If retransmission is disabled, the net data rate per latency is defined in the associated Recommendation.
OR_p	The overhead rate per latency path: If retransmission is enabled, $OR_0 = 8 \times f_s \times \frac{G_0 \times M_0}{S_0 \times T_0}$, and OR_1 = 0. If retransmission is disabled, the overhead rate per latency path is defined in the associated Recommendation.
ADR_p	The aggregate data rate per latency path: $ADR_p = NDR_p + OR_p$ kbit/s.
ADR	The aggregate data rate: $ADR = \sum_p ADR_p + 12 \times f_s$ kbit/s if the RRC is present in this direction. $ADR = \sum_p ADR_p$ kbit/s if the RRC is absent in this direction.

Table 9-2 – Derived framing parameters

Parameter	Definition
RTxOH	The retransmission overhead needed to protect against the worst-case impulse noise environment as configured in the MIB and stationary noise. $$RTxOH = REIN\_OH + SHINE\_OH + STAT\_OH$$ with If *INP_min_rein* >0: $REIN\_OH = \left(\frac{INP\_min\_rein}{Q \times S_1} + 1\right) \times Q \times S_1 \times \left(\left\lfloor \frac{f_{DMT}}{f_{REIN}} \right\rfloor\right)^{-1}$ with f_{REIN}, the repetition frequency of REIN in kHz. If *INP_min_rein*=0 then *REIN_OH*=0 $SHINE\_OH = SHINEratio$ $STAT\_OH = 10^{-4}$
ETRu	The unlimited version of expected throughput in kbit/s: $(1 - RTxOH) \times NDR$
ETR	The expected throughput in kbit/s: $ETR = \min(ETRu, ETR\_\max)$

9.4.3 Valid configurations

The valid values of the framing parameters and any additional constraints are shown in Table 9-3.

Table 9-3 – Valid configurations of framing parameters

Parameter	Definition
B_{pn}	The valid values of B_{10} are any integer from 0 to 254. The valid value of B_{00}, B_{01}, B_{11} is 0.
FramingType	The valid values are 1, 2, 3 or 4, corresponding to Framing types 1 to 4 (see clause 8.1.1-clause 8.1.4).
Q	The valid values of *Q* are any integer from 1 to 64 if the associated Recommendation is [ITU-T G.993.2]. The valid values of *Q* are any integer from 1 to 16 if the associated Recommendation is [ITU-T G.992.3] or [ITU-T G.992.5]. Furthermore, valid configurations of *Q* shall be such that $0.5 \le Q \times S_1 \le 4$ in L_0 state.
D_1	The only valid value of D_1 is 1 if the associated Recommendation is [ITU-T G.992.3] or [ITU-T G.992.5]. The valid values of D_1 are any integer from 1 to 64 if the associated Recommendation is [ITU-T G.993.2], but restricted to the set of values advised by the remote transmitter (see clauses C.2.1.1 and C.2.2.1). Furthermore, valid values of D_1 shall be such that D_1 = Q or D_1 = 1.
V	The valid values of *V* are any integer from 0 to 15.
R_p	The valid values of R_1 are 0, 2, 4, 8, 10, 12, 14 or 16. The valid values of R_0 are defined in Annexes A, B and C.
M_p	The valid value of M_1 is 1 for FramingType = 1, 2, or 3. The valid value of M_1 is specified in clause 8.1.4 for FramingType = 4.
L_p	The valid values of L_1 are the same as the valid values of the latency path #0 specified in the associated Recommendation.

Table 9-3 – Valid configurations of framing parameters

Parameter	Definition
	The valid values of L_0 are defined in Annexes A, B and C.
G_p	The valid values of G_0 are defined in Annex C if the associated Recommendation is ITU-T G.993.2. The valid value of G_0 is 1 if the associated Recommendation is [ITU-T G.992.3] or [ITU-T G.992.5]. The valid value of G_1 is 0 for *FramingType* = 1, 2, 3. The valid values of G_1 are defined in clause 8.1.4 for FramingType=4.
T_p	The valid values of T_0 are defined in Annexes A, B and C. The valid value of T_1 is 0 for *FramingType* = 1, 2, or 3. The valid values of T_1 are defined in clause 8.1.4 for FramingType = 4.
N_{FECp}	The valid values of N_{FEC1} are any integer from 1 to 255 if the associated Recommendation is [ITU-T G.992.3] or [ITU-T G.992.5]. The valid values of N_{FEC1} are any integer from 32 to 255 if the associated Recommendation is [ITU-T G.993.2] The valid values of N_{FEC0} are defined in Annexes A, B and C.
S_1	The valid values are the same as the valid values of the latency path #0 specified in the associated Recommendation.

9.4.4 Mandatory configurations

The mandatory values of the framing parameters are shown in Table 9-4. Mandatory applies to support at the transmitter.

Table 9-4 – Mandatory configurations of the framing parameters

Parameter	Capability
B_{pn}	All valid values shall be supported.
FramingType	For a transmitter, *FramingType*=1 shall be supported, as well as at least one of the other *FramingType* values (2, 3 or 4). For a receiver, either Framing type 1 or all of Framing types 2, 3, and 4 shall be supported.
Q	All valid values shall be supported
D_1	The only mandatory value of D_1 is 1.
V	All valid values shall be supported
R_p	All valid values shall be supported
M_p	All valid values shall be supported
L_p	All valid values of L_0 shall be supported The mandatory values of L_1 shall be the same as the mandatory values of the latency path #0 specified in the associated Recommendation.
G_p	All valid values shall be supported
T_p	All valid values shall be supported
N_{FECp}	All valid values shall be supported
S_1	The mandatory values shall be the same as the mandatory values specified of the latency path #0 specified in the associated Recommendation.

9.5 Impulse noise protection

During initialization, the receiver shall select values for the framing parameters that guarantee protection against the worst-case impulse noise environment defined by the associated MIB parameters.

These MIB parameters are:

– *INP_min*: Minimum impulse noise protection against SHINE impulses, expressed in DMT symbols at the δ-reference point;

– *INP_min_rein*: Minimum impulse noise protection against REIN impulses, expressed in DMT symbols at the δ-reference point;

– f_{REIN}: the repetition frequency of REIN expressed in kHz. Only two values (0.1 and 0.12 kHz) are possible 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* or *INP_min_rein* DMT symbols depending on the type of impulse);

– SHINE impulses are assumed to be isolated.

To derive the framer settings, the receiver shall assume the transmitter reference model described in clause 8.6.4 and the worst case impulse noise environment.

The following clauses list the constraints on the framing parameters that have to be met to meet the required condition. The constraints will be different depending on whether the impulse noise environment consists of a single type of impulse (either REIN or SHINE) or an impulse noise environment consisting of both REIN and SHINE.

9.5.1 SHINE-only or REIN-only impulse noise environment

When the noise environment consists of only a single type of impulse, the framing parameters shall meet the constraints given below. In these formulas, *INP_min* should be interpreted as either *INP_min* (describing the SHINE INP) or *INP_min_rein* (describing the REIN INP), depending on the type of noise environment.

1. Retransmission transmit queue roundtrip constraint:

$$Q_{tx} \geq \left\lceil \frac{HRT_{tx}^{S} + HRT_{Rx}^{S} + 1}{S_1 \times Q} \right\rceil + HRT_{Tx}^{DTU} + HRT_{Rx}^{DTU} + 1$$

2. Retransmission rescheduling FIFO at receiver. There shall be an integer $Nret \geq 1$ such that the two following constraints are met:

a. $$Nret \times Q_{tx} \times S_1 \times Q \leq \lfloor delayMax \times f_{DMT} \rfloor - \lfloor delayMax \times f_{sync} \rfloor$$

b. $$Nret \times Q_{tx} \geq \left\lceil \frac{INP\_\min}{S_1 \times Q} \right\rceil + 1$$

3. If *INP_min_REIN* is greater than 0, an additional REIN constraint is included:

$$Nret \times Q_{tx} \leq \left\lfloor \left(\left\lfloor \frac{f_{DMT}}{f_{REIN}} - INP\_\min\_rein \right\rfloor - \left\lceil \left(\frac{1}{f_{REIN}} - \frac{INP\_\min\_rein}{f_{DMT}} \right) \times f_{sync} \right\rceil \right) \times \frac{1}{S_1 \times Q} \right\rfloor - 1$$

In the above equations, f_{sync} is the repetition rate of the sync symbol in kHz.

NOTE – The retransmission provides a correction to SHINE pulses of length INP_min with an inter-arrival greater than $delay\_max + (S_1 \times Q \times Q_{tx})/f_s$.

9.5.2 Mixed SHINE and REIN impulse noise environment

When the noise environment consists of a mix of REIN and SHINE impulse noise, the framing parameters shall meet the constraints given below.

1. Retransmission transmit queue roundtrip constraint:

$$Q_{tx} \geq \left\lceil \frac{HRT_{tx}^{S} + HRT_{Rx}^{S} + 1}{S_1 \times Q} \right\rceil + HRT_{Tx}^{DTU} + HRT_{Rx}^{DTU} + 1$$

2. Retransmission rescheduling FIFO at receiver. There shall be an integer Nret ≥ 2 and an integer k ≥ 1 such that the following two constraints are met:

   a. $Nret \times Q_{tx} \times S_1 \times Q \leq \lfloor delayMax \times f_{DMT} \rfloor - \lceil delayMax \times f_{sync} \rceil$

   b. $\left(Nret \times Q_{tx} + \left\lceil \frac{INP\_min\_rein}{S_1 \times Q} \right\rceil + 1 \right) \times S_1 \times Q \leq \left\lfloor \frac{k \times f_{DMT}}{f_{REIN}} \right\rfloor - \left\lceil \frac{k \times f_{sync}}{f_{REIN}} \right\rceil$ and

   c. $Nret \times Q_{tx} \geq \left\lceil \left(\left\lceil \frac{(k-1) \times f_{DMT}}{f_{REIN}} + INP\_min\_rein \right\rceil - \left\lfloor \left(\frac{(k-1)}{f_{REIN}} + \frac{INP\_min\_rein}{f_{DMT}} \right) \times f_{sync} \right\rfloor \right) \times \frac{1}{S_1 \times Q} \right\rceil + 1$

3. Reference transmit state machine REIN constraint:

$$\left(Q_{tx} + \left\lceil \frac{INP\_min\_rein}{S_1 \times Q} \right\rceil + 1 \right) \times S_1 \times Q \leq \left\lfloor \frac{f_{DMT}}{f_{REIN}} \right\rfloor - \left\lceil \frac{f_{sync}}{f_{REIN}} \right\rceil$$

Reference transmit state machine SHINE constraint:

$$\left\lceil \frac{INP\_min}{S_1 \times Q} \right\rceil + 1 \leq (Nret - 1) \times Q_{tx}$$

In the above equations, f_{sync} is the repetition rate of the sync symbol in kHz.

NOTE – The retransmission provides a correction to SHINE pulses of length INP_min with an inter-arrival greater than $delay\_max + (S_1 \times Q \times Q_{tx})/f_s$.

10 PMD function

The PMD function shall be compliant with the associated Recommendation, except for the provisions given below.

10.1 Definition of 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.

In stationary noise, one can assume that each error event consist of a single corrupted DTU. In that case, 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 DTUs that are detected in error at the receiver and have not been corrected by a retransmission. (See DTU counter rtx-uc in clause 12)

f_s: is the data symbol rate in ksymbols/s.

This calculation is only valid under the assumption of stationary noise.

10.2 General definition of signal-to-noise ratio margin

If retransmission is used in a given direction, the reference MTBE is defined at the 1 dB signal-to-noise ratio margin working point.

Therefore, the signal-to-noise ratio margin is equal to 1 dB plus the maximum increase (scalar gain, in dB) of the reference noise power spectral density (PSD) at all relevant frequencies, for which the MTBE of the active TPS-TC stream is not lower than the minimum MTBE (MTBE_min, see clause 10.3) specified for this TPS-TC stream, without any change of PMD parameters (e.g., bits and gains) and PMS-TC parameters (e.g., L_p, FEC parameters) and with EFTR (see clause 11.2.2) ≥ ETR. The MTBE is referenced to the output of the PMS-TC function after retransmission (i.e., the α1/β1-reference point).

During testing of the signal-to-noise ratio margin, only stationary noise shall be applied (i.e., no impulse noise shall be present).

The definition of the reference noise PSD depends on the control parameter SNRM_MODE as defined in [ITU-T G.992.3], [ITU-T G.992.5] or [ITU-T G.993.2], respectively.

10.3 Definition of MTBE_min

The minimum MTBE (MTBE_min) is defined as 14 400 seconds (corresponding to an average of one error event in four hours).

NOTE – This value is taken from Broadband Forum [b-TR-126], corresponding to HDTV quality.

10.4 Accelerated testing of MTBE

In order to facilitate testing, a special test mode is defined, in which retransmissions shall not be requested by the receiver nor sent autonomously by the transmitter. This test shall be performed in the presence of stationary noise only. The remote side shall enter the test mode upon eoc request (see clauses A.3.1.3.1 and C.3.1.3.1).

The test mode shall be selected with setting RTX_ENABLE = RTX_TESTMODE. The remote end shall be forced into this state by sending a diagnostic command through the eoc.

P_{DTU} is defined as the probability that a DTU-container is corrupted, i.e., a DTU is not received correctly in a single transmission. In this test mode it can be calculated 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 DTUs that are detected in error at the receiver and as a consequence of absence of retransmission are detected as uncorrected. Therefore, the *Number_of_uncorrected DTUs* equals the *Number_of_errored DTUs*.

In this accelerated test, the requirement for P_{DTU} is:

$$P_{DTU} \le \frac{8.3333 \times 10^{-3}}{\sqrt{f_s}} \times \left(T_{DTU\_in\_DMT}\right)^{1/2}$$

where f_s is the symbol rate in Hz.

NOTE – Appendix II provides the calculations motivating this requirement.

11 Operation, administration and maintenance (OAM) management function

11.1 Configuration parameters

11.1.1 Minimum expected throughput (MINETR_RTX)

The MINETR_RTX is a configuration parameter used to derive the control parameter *ETR_min* which specifies the minimum allowed value for the expected throughput rate *ETR* (see clause 7).

It is used in the channel initialization policy and on-line reconfiguration procedures.

The downstream and upstream values of MINETR_RTX shall be configured in the CO-MIB.

The values range from 0 to the highest valid value of the minimum net data rate specified in the associated Recommendation, in steps of 1000 bit/s.

The control parameter *ETR_min* is derived by rounding up MINETR_RTX to the next multiple of 8 kbit/s.

11.1.2 Maximum expected throughput (MAXETR_RTX)

The MAXETR_RTX is a configuration parameter used to derive the control parameter *ETR_max* which specifies the maximum allowed value for the expected throughput rate *ETR* (see clause 7).

It is used in the definition of ETR as a limiting value.

The downstream and upstream values of MAXETR_RTX shall be configured in the CO-MIB.

The values range from 0 to the highest valid value of the maximum net data rate specified in the associated Recommendation, in steps of 1000 bit/s.

The control parameter *ETR_max* is derived by rounding down MAXETR_RTX to the next multiple of 8 kbit/s if $ETR\_min \leq ETR\_max$ after rounding for the corresponding direction. Otherwise, *ETR_max* is set to $ETR\_max = ETR\_min$.

11.1.3 Maximum net data rate (MAXNDR_RTX)

The MAXNDR_RTX is a configuration parameter used to derive the control parameter *net_max* which specifies the maximum allowed value for the net data rate *NDR* (see clause 7).

It is used in the channel initialization policy and on-line reconfiguration procedures.

The downstream and upstream values of MAXNDR_RTX shall be configured in the CO-MIB.

The values range from 0 to the highest valid value of the maximum net data rate specified in the associated Recommendation, in steps of 1000 bit/s.

The value of MAXNDR_RTX is rounded down to the next multiple of 8 kbit/s to obtain *net_max*.

11.1.4 Maximum delay (DELAYMAX_RTX)

The DELAYMAX_RTX is a configuration parameter used to derive the control parameter *delay_max* which specifies the maximum allowed delay for retransmission (see clause 7).

It is used in the channel initialization policy and on-line reconfiguration procedures.

The downstream and upstream values of DELAYMAX_RTX shall be configured in the CO-MIB.

The values range from 1 to 63 ms in steps of 1 ms.

The control parameter *delay_max* shall be set to the same value as the configuration parameter DELAYMAX_RTX.

11.1.5 Minimum delay (DELAYMIN_RTX)

The DELAYMIN_RTX is a configuration parameter used to derive the control parameter *delay_min* which specifies the minimum allowed delay for retransmission (see clause 7).

It is used in the channel initialization policy and on-line reconfiguration procedures.

The downstream and upstream values of DELAYMIN_RTX shall be configured in the CO-MIB.

The values range from 0 to 63 ms in steps of 1 ms.

The control parameter *delay_min* shall be set to the same value as the configuration parameter DELAYMIN_RTX.

11.1.6 Minimum impulse noise protection against SHINE for systems using 4.3125 kHz subcarrier spacing (INPMIN_SHINE_RTX)

The INPMIN_SHINE_RTX is a configuration parameter that, for the case of subcarrier spacing of 4.3125 kHz, is used to derive the control parameter *INP_min* which specifies the minimum impulse noise protection against SHINE (see clause 7).

It is used in the channel initialization policy and on-line reconfiguration procedures.

The downstream and upstream values of INPMIN_SHINE_RTX shall be configured in the CO-MIB.

The values range from 0 to 63 DMT symbols of 4.3125 kHz in steps of 1 DMT.

The control parameter *INP_min* shall be set to the same value as the configuration parameter INPMIN_SHINE_RTX.

11.1.7 Minimum impulse noise protection against SHINE for systems using 8.625 kHz subcarrier spacing (INPMIN8_SHINE_RTX)

The INPMIN8_SHINE_RTX is a configuration parameter that, for the case of subcarrier spacing of 8.625 kHz, is used to derive the control parameter *INP_min* which specifies the minimum impulse noise protection against SHINE (see clause 7).

It is used in the channel initialization policy and on-line reconfiguration procedures.

The downstream and upstream values of INPMIN8_SHINE_RTX shall be configured in the CO-MIB.

The values range from 0 to 127 DMT symbols of 8.625 kHz in steps of 1 DMT.

The control parameter *INP_min* shall be set to the same value as the configuration parameter INPMIN8_SHINE_RTX.

11.1.8 SHINERATIO_RTX

The SHINERATIO_RTX is a configuration parameter used to derive the control parameter *SHINEratio*, which is used in the definition of the expected throughput rate (*ETR*) (see clause 7).

The downstream and upstream values shall be configured in the CO-MIB.

The 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.

The control parameter *SHINEratio* shall be set to the same value as the configuration parameter SHINERATIO_RTX.

11.1.9 Minimum impulse noise protection against REIN for systems using 4.3125 kHz subcarrier spacing (INPMIN_REIN_RTX)

The INPMIN_REIN_RTX is a configuration parameter that, for the case of subcarrier spacing of 4.3125 kHz, is used to derive the control parameter *INP_min* which specifies the minimum impulse noise protection against REIN (see clause 7).

It is used in the channel initialization policy and on-line reconfiguration procedures.

The downstream and upstream values of INPMIN_REIN_RTX shall be configured in the CO-MIB.

The values range from 0 to 7 DMT symbols of 4.3125 kHz in steps of 1 DMT.

The control parameter *INP_min* shall be set to the same value as the configuration parameter INPMIN_REIN_RTX.

11.1.10 Minimum impulse noise protection against REIN for systems using 8.625 kHz subcarrier spacing (INPMIN8_REIN_RTX)

The INPMIN8_REIN_RTX is a configuration parameter that, for the case of subcarrier spacing of 8.625 kHz, is used to derive the control parameter *INP_min* which specifies the minimum impulse noise protection against REIN (see clause 7).

It is used in the channel initialization policy and on-line reconfiguration procedures.

The downstream and upstream values of INPMIN8_REIN_RTX shall be configured in the CO-MIB.

The values range from 0 to 13 DMT symbols of 8.625 kHz in steps of 1 DMT.

The control parameter *INP_min* shall be set to the same value as the configuration parameter INPMIN8_REIN_RTX.

11.1.11 REIN Inter-arrival time for retransmission (IAT_REIN_RTX)

The IAT_REIN_RTX is a configuration parameter that is used to derive the control parameter *iat_rein_flag* which specifies the REIN inter-arrival time (see clause 7).

It is used in the channel initialization policy and on-line reconfiguration procedures.

The downstream and upstream values of IAT_REIN_RTX shall be configured in the CO MIB.

The values are 0 and 1.

The control parameter *iat_rein_flag* shall be set to the same value as the configuration parameter IAT_REIN_RTX.

11.1.12 Threshold for declaring *"leftr"* defect (LEFTR_THRESH)

The LEFTR_THRESH is a configuration parameter that is used to derive the control parameter *leftr_thresh*, which specifies the fraction of *NDR* that shall be used as the threshold for declaring *leftr* defects (see clause 7).

The downstream and upstream values of LEFTR_THRESH shall be configured in the CO-MIB.

The valid range for LEFTR_THRESH is from 0.01 to 0.99 with a granularity of 0.01 and a special value indicating that ETR shall be used as the threshold for declaring *leftr* detects.

The control parameter *leftr_thresh* shall be set to the same value as the configuration parameter LEFTR_THRESH. The special value of LEFTR_THRESH shall be mapped to *leftr_thresh* = 0.

The minimum valid threshold for declaring *leftr* defect is *ETR*/2. The receiver shall use *ETR*/2 in the case the threshold is configured to a value less than *ETR*/2 by the operator.

11.1.13 Retransmission mode (RTX_MODE)

The RTX_MODE is a configuration parameter used to control activation of retransmission during initialization.

This parameter has 4 valid values:

0: RTX_FORBIDDEN: ITU-T G.998.4 retransmission not allowed.

1: RTX_PREFERRED: ITU-T G.998.4 retransmission is preferred by the operator.

(i.e., if ITU-T G.998.4 RTX capability is supported by both XTU's, the XTU's shall select ITU-T G.998.4 operation for this direction).

2: RTX_FORCED: Force the use of the ITU-T G.998.4 retransmission.

(i.e., if ITU-T G.998.4 RTX capability in this direction is not supported by both XTU's or not selected by the XTU's, an initialization failure shall result).

NOTE – Due to the optionality of ITU-T G.998.4 retransmission in upstream direction, the use of RTX_FORCED in upstream may lead to initialization failure, even if the XTU is supporting ITU-T G.998.4 (in downstream).

3: RTX_TESTMODE: Force the use of the ITU-T G.998.4 retransmission in the test mode described in clause 10.4.

(i.e., if ITU-T G.998.4 RTX capability is not supported by both XTU's or not selected by the XTU's, an initialization failure shall result).

11.2 Test parameters

A number of general ITU-T G.998.4 specific test parameters are specified in the following clauses.

The test parameters are calculated/measured by the transmit or receive function and shall be reported on request to the near-end management entity. The near-end management entity shall send the test parameter value to the far-end management entity on request during Showtime, using the test parameter read eoc commands defined in the annexes.

The following test parameters shall be passed on request from the receive PMS-TC function to the near-end ME:

– Expected throughput (*ETR*).

– Actual delay of retransmission (*delay_act_RTX*).

The following test parameters shall be passed on request from the transmit PMS-TC function to the near end ME:

– Actual impulse noise protection against SHINE (*INP_act_SHINE*).

– Actual impulse noise protection against REIN (*INP_act_REIN*).

11.2.1 Expected throughput (*ETR*)

The test parameter expected throughput (*ETR*) is defined in Table 9-2 as:

$$ETR = \min(ETRu, ETR\_\max) \text{ kbit/s}$$

where:

ETRu: is the unlimited version of *ETR* given by

$$ETRu = (1 - RTxOH) \times NDR$$

It shall be calculated by the receiver during initialization and updated upon OLR.

The RTxOH (see Table 9-2) is the expected rate loss, expressed as a fraction of net data rate (NDR), due to the combined effect of:

– impulse noise protection against worst-case REIN impulses as described by the configuration parameters INPMIN_REIN_RTX and IAT_REIN_RTX in the CO-MIB;
– impulse noise protection against worst-case SHINE as described by the configuration parameters INPMIN_SHINE_RTX and SHINERATIO_RTX in the CO-MIB;
– overhead due to correction of stationary noise errors.

The valid values are all integers from 0 to the maximum of the valid values of the maximum net data rate specified in the associated Recommendation values.

The test-parameter *ETR* shall be represented as a 32-bit unsigned integer expressing the value of *ETR* in kbit/s. This data format supports a granularity of 1 kbit/s.

The test parameter *ETR* shall be mapped on the reporting parameter "Actual Data Rate". The downstream and upstream values shall be reported in the CO-MIB.

11.2.2 Error-free throughput (*EFTR*)

The error-free throughput (*EFTR*) is defined as the average bit-rate, calculated during a 1-second time window, at the β1-reference point, of bits originating from DTUs that have been detected to contain no error at the moment of crossing the β1-reference point. The 1-second time windows are consecutive and non-overlapping. As a result of this definition, $EFTR \leq NDR$.

The *EFTR* shall be calculated in Showtime by the receiver.

The *EFTR* shall be calculated for every complete second the xTU is in the Showtime state. Only for these seconds, the *EFTR* is defined.

The *EFTR* is not a test parameter directly reported to the ME, but is indirectly used in the definition of related parameter *EFTRmin* and *leftr* defects.

11.2.3 Actual INP against SHINE (*INP_act_SHINE*)

The test parameter *INP_act_SHINE* is defined as the actual INP against SHINE of the latency path with retransmission under following specific conditions:

Assuming impulse noise protection against REIN equal to *INPmin_rein*

Assuming $EFTR \geq ETR$

NOTE 1 – If the reference transmit state machine is used by the transmitter (clause 8.6.4), the actual INP against SHINE of the latency path with retransmission is the greatest value of *INP_min* that is compatible with the constraints defined in clause 9.5.1 or clause 9.5.2 and the above specific conditions.

It shall be calculated by the transmitter during initialization and updated upon OLR.

The test parameter *INP_act_SHINE* shall be represented as a 16-bit unsigned integer expressing the value in fractions of DMT symbols with a granularity of 0.1 symbols.

The valid range is from 0 to 204.6. The special value 204.7 indicates a value of 204.7 or higher.

NOTE 2 – The linear format is chosen for simplicity reason and does not imply any future accuracy requirements.

The test parameter *INP_act_SHINE* shall be mapped on the reporting parameter ACTINP. The downstream and upstream values shall be reported in the CO-MIB.

11.2.4 Actual INP against REIN (*INP_act_REIN*)

The test parameter *INP_act_REIN* is defined as the minimum of

1) the actual INP against REIN of the latency path with retransmission under the following specific conditions:
   – Assuming impulse noise protection against SHINE equal to *INP_min_SHINE*.

– Assuming $EFTR \geq ETR$; and

NOTE 1 – If the reference transmit state machine is used by the transmitter (clause 8.6.4), the actual INP against REIN of the latency path with retransmission is the greatest value of *INP_min_rein* that is compatible with the constraints defined in clause 9.5.1 or clause 9.5.2 and the above specific conditions.

2) the actual INP in the latency path carrying the overhead channel.

It shall be calculated by the transmitter during initialization and updated upon OLR.

The test parameter *INP_act_REIN* shall be represented as an 8-bit unsigned integer expressing the value. It is coded in fractions of DMT symbols with a granularity of 0.1 symbols.

The range is from 0 to 25.4. The special value 25.5 indicates a value of 25.5 or higher.

NOTE 2 – The linear format is chosen for reasons of simplicity and does not imply any future accuracy requirements.

The test parameter *INP_act_REIN* shall be mapped on the reporting parameter ACTINP_REIN. The downstream and upstream values shall be reported in the CO-MIB.

11.2.5 Actual delay RTX (*delay_act_RTX)*

If retransmission is used in a given transmit direction, the test parameter *delay_act_RTX* is defined as the actual value of the time-independent component of the delay between the α1 and β1-reference points due to the retransmission functionality. This can be calculated as the minimum possible instantaneous delay between the α1 and β1-reference points, based on the actual settings of the framing parameters.

It shall be calculated by the receiver during initialization and updated upon OLR.

The test parameter *delay_act_RTX* is coded in ms (rounded to the nearest ms) and shall be represented as an 8-bit unsigned integer. Valid values are between 0 and 63 ms.

The test parameter *delay_act_RTX* shall be mapped on the reporting parameter "Actual Delay". The downstream and upstream values shall be reported in the CO-MIB.

11.3 OAM line-related primitives

11.3.1 Near-end anomalies

The following near-end anomalies are redefined with respect to the definition in the associated Recommendations. They are only defined for the latency path #1 carrying the DTUs:

– Forward error correction *fec-p* (with p=1): A *fec-p* anomaly occurs on any received Reed-Solomon codewords corrected by the FEC even if this Reed-Solomon codeword is part of the DTU that is discarded or corrected by a retransmission. This anomaly is not asserted if errors are detected and are not correctable.

– Cyclic redundancy check *crc-p* (with p=1): As there is no CRC on the latency path carrying the DTUs, the *crc-p* anomaly is redefined by the detection of at least one uncorrected DTU per 17 ms time interval.

NOTE 1 – *crc-p* should not be confused with CRC-8 in DTU Framing types 2, 3 and 4.

NOTE 2 – The CV and ES are derived as per the associated Recommendation from the redefined *crc-p* anomaly and other anomalies or defects. The SES is derived as per the associated Recommendation from the redefined *crc-p* anomaly and other anomalies or defects, with the addition of ITU-T G.998.4 *seftr* defect.

No defect, anomaly and failure are defined for the latency path carrying the overhead channel.

11.3.2 Far-end anomalies

No far-end anomalies are defined in this Recommendation.

11.3.3 Near-end defects

The low error-free throughput rate "(*leftr*)" defect is defined as follows:

For seconds in which the *EFTR* is defined:

– When *leftr_thresh* is set to the value different from 0:

  A *leftr* defect occurs when $EFTR < \max(leftr\_thresh * NDR, ETR/2)$

  A *leftr* defect terminates when $EFTR \geq \max(leftr\_thresh * NDR, ETR/2)$

– When *leftr_thresh* is set to the special value of 0:

  A *leftr* defect occurs when $EFTR < 0.998 \times ETR$

  A *leftr* defect terminates when $EFTR \geq 0.998 \times ETR$

For seconds in which the *EFTR* is not defined, *leftr* defect shall terminate or remain in the off state.

The severe loss of error-free throughput rate (*seftr*) defect is defined as follows:

For seconds in which the *EFTR* is defined, *seftr* defect occurs when $EFTR<ETR/2$ and terminates when $EFTR \geq ETR/2$.

For seconds in which the *EFTR* is not defined, *seftr* defect shall terminate or remain in the off state.

11.3.4 Far-end defects

No far-end defects are defined in this Recommendation.

11.4 Performance monitoring parameters

A number of general ITU-T G.998.4 specific performance monitoring parameters are specified in the following clauses.

The performance monitoring parameters are measured by the receive function and shall be reported on request to the near-end management entity. The near-end management entity shall send the parameter value to the far-end management entity on request during Showtime, using the management counter read eoc command defined in the annexes.

The following performance monitoring parameters shall be passed on request from the receive PMS-TC function to the near-end ME:

– Two counters
  - *leftr* defect seconds counter
  - Error-free bits counter
– One parameter
  - Minimum error-free throughput (*EFTR_min*) parameter.

11.4.1 "*leftr*" defect seconds counter

This is a near-end counter of seconds with a near-end "*leftr*" defect present.

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 CO-MIB as a near-end value.

The downstream value shall be reported in the CO-MIB as a far-end value.

11.4.2 Error-free bits counter

This is a near-end counter counting the number of error-free bits passed over the β1-reference point, divided by 2^{16}. Error-free bits are bits originating from DTU's that have been detected to contain no error at the moment of crossing the β1-reference point.

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 CO-MIB as a near-end value.

The downstream value shall be reported in the CO-MIB as a far-end value.

11.4.3 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 the values of *EFTR* are less than *ETR*/2;
– seconds in which *EFTR* is not defined;
– the single second preceding a second with *seftr* defect;
– the single second following a second with *seftr* defect.

The *EFTR_min* shall be measured in Showtime by the receiver. Reading by the xTU-C management entity (i.e., VME for [ITU-T G.993.2]) of the far-end *EFTR_min* shall be via an eoc command over the U-interface. Reading by the xTU-C management entity of the near-end *EFTR_min* shall be from the near-end receive PMS-TC over the MPS-TC (i.e., over the γ_O-interface for [ITU-T G.993.2]).

The valid values are all integers from *ETR*/2 to the maximum of the valid values of the maximum NDR specified in the associated Recommendations.

The performance monitoring parameter *EFTR_min* shall be represented as a 32-bit unsigned integer expressing the value of *EFTR_min* in kbit/s. This data format supports a granularity of 1 kbit/s. For the observation periods in which *EFTR* is either not defined or always less than *ETR*/2, or both, over the complete observation period, the value of *EFTR_min* shall be set to a special 32-bit value of $0xFFFFFFFF_{16}$.

The previous value of *EFTR_min* shall be reported if no *EFTR* measurement has been done since the last reading of *EFTR_min*.

NOTE 1 – The above requirement covers the case where two retrievals of *EFTR_min* over the eoc take place in less than 1 second, and in which no new *EFTR* measurement is available, since the *EFTR* is only updated on 1 second interval.

Although this parameter *EFTR_min* is reported via the management counter read eoc command, this performance monitoring parameter is not a counter. Therefore, the requirements of [ITU-T G.992.3], [ITU-T G.993.2] and [ITU-T G.997.1] applicable to counters in general do not apply to this parameter.

The parameter reported to the CO-MIB over the Q-interface, MINEFTR, is defined as the minimum of the retrieved *EFTR_min* values observed over the 15 min or 24 hour accumulation periods.

The XTU-C management entity shall retrieve the far-end *EFTR_min*, to calculate the far-end MINEFTR as defined on the Q interface. The xTU-C management entity shall retrieve the near-end *EFTR_min* to calculate the near-end MINEFTR, as defined on the Q interface.

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 MINEFTR value shall be reported to the CO-MIB as a near-end value.

The downstream MINEFTR value shall be reported to the CO-MIB as a far-end value.

11.5 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 total data rate provided by the local PMD, the selected values shall meet all of the constraints communicated by the transmitter prior to the channel analysis and exchange phase, including:

– Message overhead data rate ≥ Minimum message overhead data rate.

– *ETR* ≥ *ETR_min*.

– Impulse noise protection at least against a combined threat of worst-case REIN impulses as described by the CO-MIB parameters *INPmin_REIN* and *IAT_REIN_flag* and of worst-case SHINE impulses as described by the CO-MIB parameter *INPmin*.

– Minimum delay ≤ Delay ≤ Maximum delay.

– SNR Margin ≥ TARSNRM.

If within these constraints, the receiver is unable to select a set of configuration parameters, then the transmitter shall enter the SILENT state instead of the Showtime state at the completion of the initialization procedures.

Within those constraints, the receiver shall select the values as to optimize in the priority given in the priority list below. The channel initialization policy applies only for the selection of the values exchanged during initialization, and does not apply during Showtime.

The following channel initialization policy is defined:

– Policy ZERO if $CIpolicy_n$=0, then:

1) Maximize the *ETR* until a limit of *ETR_max*
2) Maximize the *NDR* until a limit of *net_max*
3) Maximize margin until MAXSNRM
4) Minimize excess margin with respect to the maximum SNR margin MAXSNRM through gain adjustments (see clause 10.3.4.2 of [ITU-T G.993.2]). Other control parameters may be used to achieve this (e.g., MAXMASK, see clause 7.2.3 of [ITU-T G.993.2]).

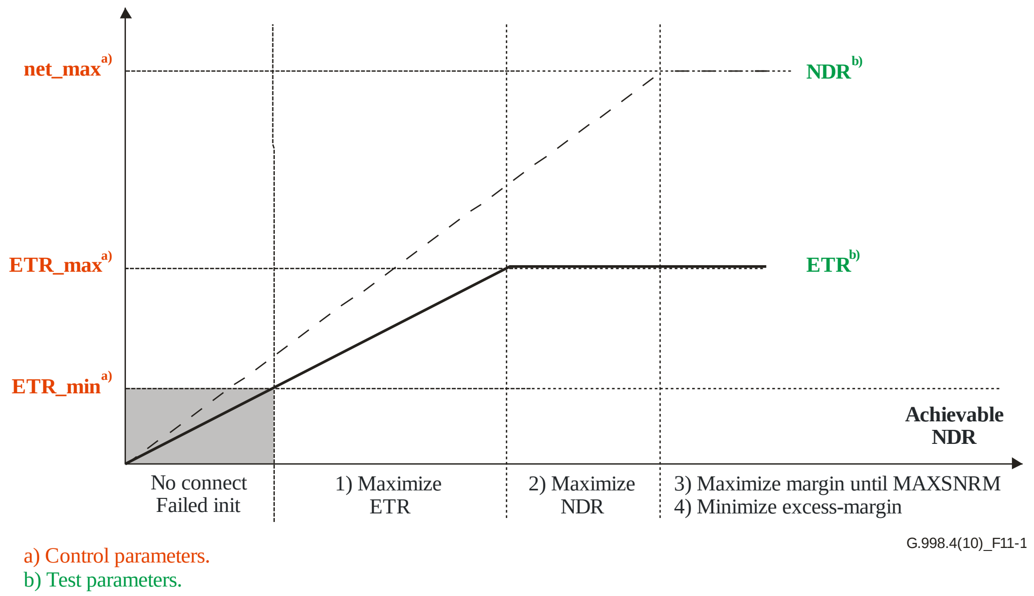


Figure 11-1 – Illustration of *CIpolicy*=0

Support of channel initialization policy 0 is mandatory.

The $CIpolicy_n$ parameter values other than 0 are reserved for use by the ITU-T.

12 DTU counters

For trouble-shooting and testing of the retransmission functionality, three DTU counters are defined to monitor the retransmissions:

– counter of uncorrected DTU (rtx-uc): this is a counter that is incremented each time a DTU is detected in error and has not been corrected by one or more retransmissions within the *delay_max* constraint;

– counter of corrected DTU (rtx-c): this is a counter that is incremented each time a DTU has been detected in error and has been successfully corrected by a retransmission;

– counter of retransmitted DTU by the transmitter (rtx-tx): this is a counter that is incremented each time a DTU has been retransmitted by the transmitter. Multiple retransmission of the same DTU is counted as many times as it has been retransmitted.

Those counters are 32-bit values with wrap-around and shall be maintained by the xTU. They shall be available upon request over the eoc. The counters shall be reset at power-on. The counters shall not be reset upon a link state transition and shall not be reset when read.

13 On-line reconfiguration (OLR)

Any on-line reconfiguration (OLR) that is not defined in the following subclauses is for further study.

13.1 Bit swapping

Bit swapping using type 1 OLR overhead channel messages shall be as specified in the associated Recommendation: [ITU-T G.992.3], [ITU-T G.992.5] or [ITU-T G.993.2].

13.2 Seamless rate adaptation (SRA)

SRA shall use modified type 5 OLR overhead channel messages as specified in the associated annex of Recommendation ITU-T G.998.4 (this Recommendation).

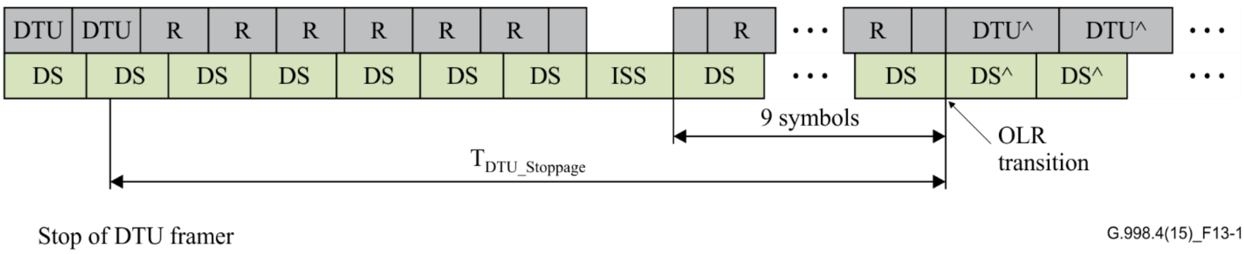
13.3 SOS

SOS shall use modified type 6 OLR overhead channel messages as specified in the associated annex of Recommendation ITU-T G.998.4 (this Recommendation).

NOTE – Type 6 is not supported in association with [ITU-T G.992.3] and [ITU-T G.992.5].

13.4 Transition mechanism for type 5 and type 6 modified OLR commands

When the retransmission transmitter has received an SRA request via a type 5 OLR or an SOS request via a type 6 OLR overhead channel message from the retransmission receiver, the procedure shall be as depicted in Figure 13-1 and further defined in this clause.



DS Data Symbol before SRA/SOS transition execution
ISS Inverted sync symbol at regular location of a sync symbol with respect to sync symbol period
DS^ Data symbol after SRA/SOS transition execution with applied new framing
DTU DTU before SRA/SOS transition
R DTU before SRA/SOS transition, transmitted from retransmission buffer
DTU^ DTU after SRA/SOS transition

Figure 13-1 – Transition mechanism to new OLR configuration parameters

The DTU framer shall stop for a period of time, $T_{DTU\text{-stoppage}}$, prior to ending the transmission of the transition primitive.

$T_{DTU\text{-stoppage}}$ shall be the greatest of the following durations:

– the minimum stoppage time required to satisfy the *INP_min* and *INP_min_rein* configurations; and

– the minimal delay as configured by *delay_min*.

NOTE – In case one uses the reference state machine in the transmitter, the minimum stoppage time required to satisfy the *INP_min* and *INP_min_rein* configuration is equal to $Nret*Q_{tx}*T_{DTU}$, where *Nret* is the smallest integer that meets the constraints specified in clause 9.5.

When the DTU framer is stopped, DTUs from the retransmission buffer shall be transferred to the retransmission multiplexer. In case a transmitter uses a transmit state machine other than the reference state machine, the transmitted DTUs during the stoppage time may include positively acknowledged DTUs.

The transition primitive is comprised of the inverted sync symbol, ISS marker, as defined within [ITU-T G.992.3], [ITU-T G.992.5] and [ITU-T G.993.2], followed by 9 transitory DMT symbols before transmission of data symbols with the new framing parameters is commenced.

The first DMT symbol after the transition primitive shall carry the first DTU with the changed framing. The alignment between start of DTU and start of the DMT data symbol shall be identical to the alignment at Showtime entry.

The absoluteDTUcounts shall be reset to 0 for the first DTU with the changed framing. The RRC in the reverse direction relative to the direction associated with the framing change shall be reset with the conditions specified in clause 8.4.1 when the first DTU with the changed framing is acknowledged.

The SID octet shall be reset to 0 for the first DTU with the changed framing, as is the case at Showtime entry.

The TS octet shall not be reset upon application of the new framing, but shall keep its significance across the framing change, such that it can still be used to reduce the delay jitter between the transmitter and receiver γ interfaces after the OLR transition period.

Annex A

Support of ITU-T G.998.4 with ITU-T G.992.3

(This annex forms an integral part of this Recommendation.)

A.1 Specific requirements

For [ITU-T G.992.3], retransmission is defined only for the downstream direction (i.e., DTUs are transmitted only in the downstream direction and the RRC is transmitted only in the upstream direction).

A.1.1 Memory

The size of the transmit retransmission queue in the CO is limited to the half of the downstream interleaver delay in bytes, i.e.:

$$Q_{tx} * Q * H \leq 8001 \text{ octets for [ITU-T G.992.3]}$$

where Q_{Tx} is the length of the transmit retransmission queue in DTUs.

The minimum memory for the receiver retransmission queue shall be identical to the amount of the memory for the related transmit queue.

The maximal DTU size in octets ($Q*H$) shall be 1024.

A.1.2 Overhead channel access (supplements clause 7.8.2 of ITU-T G.992.3)

The overhead channel shall be included in the latency path #0 as specified in [ITU-T G.992.3] for MSG_{LP}=0 with the additional constraints on the latency path #0:

– L_0 shall be a multiple of 8.

– $T_0 = 1$.

– B_{0n} shall be equal to 0.

– R_0 shall be equal to 16. $N_{FEC,0}$ shall be greater or equal to 32.

– Valid D_0 shall be 1, 2, or 4.

– The INP_0 (INP of the latency path as defined in Table 7-7 of [ITU-T G.992.3]) shall be at least 7.

– The following relationship shall hold between N_0, D_0 and L_0 to insure robustness to REIN at 120 Hz.

$$\frac{8 \times N_{FEC,0} \times D_0}{L_0} \leq \left\lfloor \frac{f_{DMT}}{120Hz} \right\rfloor - 1 = 32 \text{ with } f_{DMT} \text{ the symbol rate } 4312.5*16/17 \text{ Hz.}$$

A.1.3 Multiplexing

If the ROC is enabled then the RRC and L_0 (ROC) bits may share a common sub-carrier. The same SNR margin offset (SNRMOFFSET-ROC) shall be applied to the RRC and the L0 (ROC).

A.2 Initialization

A.2.1 ITU-T G.994.1 phase (replaces clause K.x.10 of ITU-T G.992.3)

This clause describes the change to the ITU-T G.994.1 messages of [ITU-T G.992.3] to support ITU-T G.998.4 in conjunction with [ITU-T G.992.3].

During the ITU-T G.994.1 phase, only the selection of the ATM TPS-TC function is made. The ATM TPS-TC shall be configured during the channel analysis phase via the C/R-MSG1 messages and during the exchange phase via the C/R-PARAMS messages.

During the ITU-T G.994.1 phase, only the selection of the PTM TPS-TC function is made, together with the configuration for use of pre-emption and short packets. The remaining parameters of the PTM TPS-TC shall be configured during the channel analysis phase via the C-MSG1/R-MSG1 messages and during the exchange phase via the C-PARAMS/R-PARAMS messages.

A.2.1.1 ITU-T G.994.1 capability list message

A SPar(2) bit downstream ATM TPS-TC #0 RETX is added to each of the operating mode Annexes A/L, B, I, J, and M of [ITU-T G.992.3] to indicate support of retransmission in the downstream direction for ATM TPS-TC #0.

A SPar(2) bit downstream PTM TPS-TC #0 RETX is added to each of the operating mode Annexes A/L, B, I, J, and M of [ITU-T G.992.3] to indicate support of retransmission in the downstream direction for PTM TPS-TC #0.

The ATU-C shall set the Spar(2) bit "Downstream ATM TPS-TC #0 RETX" to ONE in the CL message to indicate the CO-MIB enables retransmission in the downstream direction and the ATU-C supports ATM retransmission in the downstream direction.

The ATU-C shall set the Spar(2) bit "Downstream PTM TPS-TC #0 RETX" to ONE in the CL message to indicate the CO-MIB enables retransmission in the downstream direction and the ATU-C supports PTM retransmission in the downstream direction.

The ATU-R shall set the Spar(2) bit "Downstream ATM TPS-TC #0 RETX" to ONE in the CLR message to indicate the ATU-R supports ATM retransmission in the downstream direction.

The ATU-R shall set the Spar(2) bit "Downstream PTM TPS-TC #0 RETX" to ONE in the CLR message to indicate the ATU-R supports PTM retransmission in the downstream direction.

This information for an ATM-TC function is represented using a block of ITU-T G.994.1 information as shown in Table A.1.

Table A.1 – Format for an ATM-TC CL and CLR message

Spar(2) bit	Definition of related Npar(3) octets
Downstream ATM TPS-TC #0 RETX	A block of Npar(3) octets as defined below describing the capabilities of the downstream ATM-TC function #0, if present.
	Definition of the parameter block of Npar(3) octets
	A parameter block of 1 octet reserved by the ITU-T.

This information for a PTM-TC function is represented using a block of ITU-T G.994.1 information as shown in Table A.2.

Table A.2 – Format for a PTM-TC CL and CLR message

Spar(2) bit	Definition of related Npar(3) octets
Downstream PTM TPS-TC #0 RETX	A block of Npar(3) octets as defined below describing the capabilities of the downstream PTM-TC function #0, if present.
	Definition of the parameter block of Npar(3) octets
	A parameter block of 1 octet indicating the support for pre-emption and short packets.

A.2.1.2 ITU-T G.994.1 Mode select message

If and only if the "Downstream ATM TPS-TC #0 RETX" Spar(2) bit is set to ONE in the last previous CL and CLR message, may the "Downstream ATM TPS-TC #0 RETX" Spar(2) bit be set to ONE in the MS message. It shall be set to ZERO otherwise.

If and only if the "Downstream PTM TPS-TC #0 RETX" Spar(2) bit is set to ONE in the last previous CL and CLR message, may the "Downstream PTM TPS-TC #0 RETX" Spar(2) bit be set to ONE in the MS message. It shall be set to ZERO otherwise.

No more than one of the "Downstream ATM TPS-TC #0 RETX" and "Downstream PTM TPS-TC #0 RETX" Spar(2) bits shall be set to ONE. If both bits are set in both the last previous CL message and the last previous CLR message, the selection of setting either the "Downstream ATM TPS-TC #0 RETX" or the "PTM-TC DS #0 RETX" Spar(2) bit to ONE is made by the entity transmitting the MS message.

If the "Downstream ATM TPS-TC #0 RETX" or the "Downstream PTM TPS-TC #0 RETX" Spar(2) bit is set to ONE in the MS message, then all "Downstream STM TPS-TC #*n*", "Downstream ATM TPS-TC #*n*" and "Downstream PTM TPS-TC #*n*" Spar(2) bits (for n = 0, 1, 2, and 3) shall be set to ZERO in the MS message.

If the "Downstream PTM TPS-TC #0 RETX" Spar(2) bit is set to ONE, then the PTM TPS-TC shall operate according to Annex N of [ITU-T G.992.3], with use of short packets and pre-emption enabled if and only if the related Downstream PTM TPS-TC #0 RETX" Npar(3) bit is set ONE.

A.2.1.2.1 ATU-C behaviour in case of RTX_ENABLE = FORCED

If the parameter RTX_ENABLE is set to the value "FORCED" in the CO-MIB and in the ITU-T G.994.1 mode select message both the downstream ATM TPS-TC #0 RETX and the downstream PTM TPS-TC #0 RETX Spar(2) bits are set to ZERO, then the ATU-C transmitter shall enter the C-SILENT1 state upon completion of the ITU-T G.994.1 phase.

This is to be considered as an initialization failure. The initialization failure count shall be incremented and an initialization failure cause value 6 shall be indicated in the MIB. This failure code shall be generated by the ATU-C.

A.2.2 TPS-TC configuration in the channel analysis phase (replaces clause 6.6.2 of ITU-T G.992.3)

This clause describes the change to the channel analysis messages of the initialization of [ITU-T G.992.3] to support ITU-T G.998.4 in conjunction with [ITU-T G.992.3].

The C-MSG1 message shall include the TPS-TC information specified in Table A.3. The TPS-TC information contains the requirement on the configuration of the downstream bearer #0 mapped into the retransmission path.

Table A.3 – Format for TPS-TC C-MSG1 information

Octet number [i]	PMS-TC format bits [8 × I + 7 to 8 × I + 0]	Description
Octet 0	[aaaa aaaa] bit 7 to 0	The bits aaaa aaaa give the LSB of the minimum throughput rate of the downstream bearer #0 (*ETR_min*) expressed as a multiple of 8 kbit/s.
Octet 1	[aaaa aaaa] bit 15 to 8	The bits aaaa aaaa give the MSB of the minimum throughput rate of the downstream bearer #0 (*ETR_min*) expressed as a multiple of 8 kbit/s.
Octet 2	[bbbb bbbb] bit 7 to 0	The bits bbbb bbbb give the LSB of the maximum throughput rate of the downstream bearer #0 (*ETR_max*) expressed as a multiple of 8 kbit/s.
Octet 3	[bbbb bbbb] bit 15 to 8	The bits bbbb bbbb give the MSB of the maximum throughput rate of the downstream bearer #0 (*ETR_max*) expressed in multiple of 8 kbit/s.
Octet 4	[cccc cccc] bit 7 to 0	The bits cccc cccc give the LSB of the maximum net data rate of the downstream bearer #0 (*net_max*) expressed as a multiple of 8 kbit/s.
Octet 5	[cccc cccc] bit 15 to 8	The bits cccc cccc give the MSB of the maximum net data rate of the downstream bearer #0 (*net_max*) expressed as a multiple of 8 kbit/s.
Octet 6	[00dd dddd] bit 7 to 0	The bits dd dddd give the minimal impulse noise protection (INPmin) of the downstream bearer #0 (*INP_min*) expressed in DMT symbols.
Octet 7	[eeee eeee] bit 7 to 0	The bits eeee eeee give the value of the *SHINEratio* expressed as a unit of 0.001.
Octet 8	[000f 0ggg] bit 7 to 0	The bits ggg give the minimal impulse noise protection against REIN of the downstream bearer #0 (*INP_min_rein*) expressed in DMT symbols. The bit f contain the periodicity of REIN of the bearer #0 (*iat_rein_flag*). If f equals 0, the periodicity of REIN is 100Hz. If f equals 1, the periodicity of REIN is 120 Hz.
Octet 9	[00hh hhhh] bit 7 to 0	The bits hh hhhh gives the maximum delay of the downstream bearer #0 (*delay_max*) expressed in ms.
Octet 10	[00ii iiii] bit 7 to 0	The bits ii iiii gives the minimum delay of the downstream bearer #0 (*delay_min*) expressed in ms.
Octet 11	[0jjj jjjj] bit 7 to 0	The bits jjj jjjj give the leftr threshold value for down stream bearer #0 (*leftr_thresh*) expressed in one hundredth multiples of NDR.
Octet 12	[0000 00kk] bit 7 to 0	The bits kk give the CI policy for downstream bearer #0.
NOTE – When retransmission is enabled (in the downstream), only one bearer channel shall be supported in the downstream and upstream directions.		

A.2.3 PMS-TC configuration in channel analysis phase (replaces clause 7.10.2 of ITU-T G.992.3)

A.2.3.1 C-MSG1 message

The format of the PMS-TC information transmitted in the C-MSG1 message shall be as described in Table A.4.

Table A.4 – Format for PMS-TC C-MSG1 information

Octet number [i]	PMS-TC format bits [8 × I + 7 to 8 × I + 0]	Description
Octet 0	[0000 00aa]	The bits aa give the supported DTU framing type with CRC-8 by the ATU-C: aa = 00 Reserved by ITU-T aa = 01 indicates support of DTU framing type 2 (see clause 8.1.2). aa = 10 indicates support of DTU framing type 3 (see clause 8.1.3). aa = 11 indicates support of DTU framing type 4 (see clause 8.1.4).
Octet 1	[00dd ssss] bit 7 to 0	The bits ssss and dd give the transmitter half roundtrip of the ATU-C. The bits ssss contain the part in DMT symbols coded as integer from 0 to 15 and the bits dd contain the part in DTU coded as integer from 0 to 3.
Octet 2	[0000 bbbb] bit 7 to 0	The bits bbbb contain the transmitter supported maximum 1/*S* value for the latency path with retransmission function. This maximum 1/*S* shall equal (n+1), with n coded as an unsigned 4-bit value bbbb, in the 0 to 15 range. When retransmission is enabled, this value supersedes the maximum 1/*S* value exchanged with the "S_{1min}" field in the PMS-TC capabilities list in ITU-T G.994.1.

A.2.3.2 R-MSG1 message

The format of the PMS-TC information transmitted in the R-MSG1 message shall be as described in Table A.5.

Table A.5 – Format for PMS-TC R-MSG1 information

Octet number [i]	PMS-TC format bits [8 × I + 7 to 8 × I + 0]	Description
Octet 0	[0add ssss] bit 7 to 0	The bits ssss and dd give the receiver half roundtrip of the ATU-R. The bits ssss contain the part in DMT symbols coded as integer from 0 to 15 and the bits dd contain the part in DTU coded as integer from 0 to 3. The bit a indicates the value of *CPARAMS_INP_FLAG*. *CPARAMS_INP_FLAG* =1 indicates that the C-PARAMS symbols are repeated (2 × *INP_min_rein + 1*) times. *CPARAMS_INP_FLAG* =0 indicates no repetition.

A.2.4 PMS-TC configuration in exchange phase (supplements clause 7.10.3 of ITU-T G.992.3)

A.2.4.1 R-PARAMS message

The format of the PMS-TC information transmitted in the R-PARAMS message (Table 7-21 of [ITU-T G.992.3]) shall be replaced by the format described in Table A.6. The length of the PMS-TC information transmitted in the R-PARAMS message is not changed.

Table A.6 – Format for PMS-TC R-PARAMS information

Octet number [i]	PMS-TC format bits [8 × I + 7 to 8 × I + 0]	Description
Octet 0	[p fff 0000] bit 7 to 0	The bits fff encode the initialization success/failure code as defined in clause 7.10.3 of [ITU-T G.992.3]. The bit p is the probing bit. A value 1 indicates that the current initialization is used for automode probing. A value 0 indicates that the current initialization is normal initialization.
Octet 1	[0001 1111] bit 7 to 0	Reserved by ITU-T
Octet 2	[1111 1111] bit 7 to 0	Reserved by ITU-T
Octet 3	[gggg gggg] bit 7 to 0	The bits gggggggg encode the value of MSG_C, the number of octets in the message based portion of the overhead structure. The latency path #0 is used to transport the message based overhead information.
Octet 4	[hhhh hhhh] bit 7 to 0	The bits hhhhhhhh give the number of octets from bearer #0 per Mux Data frame being transported in latency path #1 with retransmission function, B_{10}.
Octet 5-7	[0000 0000] bit 7 to 0	Reserved by ITU-T
Octet 8	[0mmm mmmm] bit 7 to 0	The bits mmmmmmm give the value of M_p for latency path #0. They are always present.
Octet 9	[tttt tttt] bit 7 to 0	The bits ttttttt give the value of T_p for latency path #0. They are always present.
Octet 10	[rrrr 0DDD] bit 7 to 0	The bits rrrr0DDD give the value of R_p and D_p for latency path #0. The rrrr and DDD bits are coded as defined in Table 7-18. They are always present.
Octet 11	[llll llll] bit 7 to 0	The bits llllllll give the LSB of the value of L_p for latency path #0. They are always present.
Octet 12	[llll llll] bit 15 to 8	The bits llllllll give the MSB of the value of L_p for the latency path #0. These are always present.
Octet 13	[0mmm mmmm] bit 7 to 0	The bits mmmmmmm give the value of M_p for latency path #1. They are always present. The value shall be set to 1 for DTU Framing type 1, 2 and 3.
Octet 14	[tttt tttt] bit 7 to 0	The bits ttttttt give the value of T_p for latency path #1. They are always present. It shall be set to zero in case of DTU framing type 1, 2 and shall be set to Q in case of DTU framing type 3.
Octet 15	[rrrr 0DDD] bit 7 to 0	The bits rrrr0DDD give the value of R_p and D_p for latency path #1. The rrrr and DDD bits are coded as defined in Table 7-18. They are always present.

Table A.6 – Format for PMS-TC R-PARAMS information

Octet number [i]	PMS-TC format bits [8 × I + 7 to 8 × I + 0]	Description
Octet 16	[llll llll] bit 7 to 0	The bits llllllll give the LSB of the value of L_p for latency path #1. They are always present.
Octet 17	[llll llll] bit 15 to 8	The bits llllllll give the MSB of the value of L_p for the latency path #1. These are always present.
Octet 18	[0000 00aa] bit 7 to 0	The bits aa gives the selected DTU framing type. It shall be coded as: The selected DTU framing type, it shall be coded as aa=00, DTU Framing type 1 (see clause 8.1.1) aa=01, DTU Framing type 2 (see clause 8.1.2) aa=10, DTU Framing type 3 (see clause 8.1.3) aa=11, DTU Framing type 4 (see clause 8.1.4) The receiver shall select a framing type supported by the transmitter.
Octet 19	[0qqq qqqq] bits 7 to 0	The number of Reed-Solomon codeword per DTU. $1 \leq Q \leq 16$.
Octet 20	[0000 vvvv] bits 7 to 0	The number of padding octets per DTU. $0 \leq V \leq 15$.
Octet 21	[jjjj jjjj] bits 7 to 0	Delay in DTU between two consecutive transmissions of a DTU used by the receiver in the reference state machine. $1 \leq Q_{Tx} \leq 63$.
Octet 22	[000n nnnn] bit 7 to 0	The bits nnnnn encode the value of the look back value (*lb*) of the RRC channel.
Octets 23-27	[0000 0000] bit 7 to 0	Reserved by ITU-T

A.2.4.2 C-PARAMS message

Octets 18-27 of the PMS-TC information transmitted in the C-PARAMS message (Table 7-21 of [ITU-T G.992.3]) shall be set as described in Table A.7. The length of the PMS-TC information transmitted in the C-PARAMS message is not changed.

Table A.7 – Format for modified PMS-TC C-PARAMS information

Octet number [i]	PMS-TC format bits [8 × I + 7 to 8 × I + 0]	Description
Octets 18-22	[0000 0000] bit 7 to 0	Reserved by ITU-T
Octets 23-27	[0000 0000] bit 7 to 0	Reserved by ITU-T

Furthermore, Octet 0 bits fff (see Table 7-21 of [ITU-T G.992.3]), which encodes the initialization success/failure code, shall be based on the channel initialization policies defined in this Recommendation instead of the policies of [ITU-T G.992.3].

Additionally, if *delay_max* is lower than the actual roundtrip (see clause 8.6), then an initialization failure shall be indicated by setting the initialization status to 010_2 (configuration not feasible on the line). The actual roundtrip depends on line independent XTU-C and XTU-R characteristics and on line dependent DTU sizes and data rates.

If a non-zero success/failure code is set by one of the ATUs:

– the initialization failure count shall be incremented,

– the other bits in the PMS-TC PARAMS information shall be set to 0, and

– the transmitter shall enter the SILENT state (see Annex D of [ITU-T G.992.3]) instead of the Showtime state at the completion of the initialization procedures.

A.2.5 Initialization messages

A.2.5.1 C-MSG1 (supplements clause 8.13.5.1.1 of ITU-T G.992.3)

Table 8-37 of [ITU-T G.992.3] shall be replaced with Table A.8.

Table A.8 – C-MSG1 prefix, message and CRC length

Part of message	Length (bits or symbols)
Prefix	32
Npmd	160
Npms	24
Ntps	104
Nmsg	288
CRC	16
LEN_C-MSG1 (symbols)	336

A.2.5.2 R-MSG1 (supplements clause 8.13.5.2.3 of ITU-T G.992.3)

Table 8-38 of [ITU-T G.992.3] shall be replaced with Table A.9.

Table A.9 – R-MSG1 prefix, message and CRC length

Part of message	Length (bits or symbols)
Prefix	32
Npmd	32
Npms	8
Ntps	0
Nmsg	40
CRC	16
LEN_R-MSG1 (symbols)	88

A.2.5.3 C-PARAMS (replaces clause 8.13.6.1.4 of ITU-T G.992.3)

The C-PARAMS state is of fixed length. In this state, the ATU-C shall transmit *LEN_C-PARAMS* C-PARAMS symbols to modulate the C-PARAMS message and CRC at (2 × *NSC_C-PARAMS*) bits per symbol. The value *NSC_C-PARAMS* shall be defined as the number of subcarriers to be used for modulation of the C-PARAMS message as indicated by the ATU-R in the R-MSG2 message. The impulse noise protection of the C-PARAMS message shall be equal to *INP_CPARAMS*= *INP_min_rein*× *CPARAMS_INP_FLAG*, where the *CPARAMS_FLAG* is as indicated by the ATU-R in the R-MSG2 message. The value *LEN_C-PARAMS* shall be defined as (length of the C-PARAMS message and CRC in bits) multiplied by (2 × *INP_CPARAMS* +1), divided by (2 × *NSC_C-PARAMS*) and rounded to the higher integer.

Table A.10 lists the length of the C-PARAM message summed over TPS-TC, PMS-TC and PMD layers. The TPS-TC, PMS-TC and PMD bits each correspond to an even number of octets.

Table A.10 – C-PARAMS message and CRC length

Part of message	Length (bits or symbols)
Npmd	96 + 24 × *NSCus*
Npms	224
Ntps	0
Nmsg	320 + 24 × *NSCus*
CRC	16
LEN_C-PARAMS (state length in symbols)	$\left\lceil \frac{336 + 24 \times NSCus}{2 \times NSC\_C\text{-}PARAMS} \right\rceil \times (2 \times INP\_CPARAMS + 1)$
NOTE – $\lceil x \rceil$ denotes rounding to the next higher integer.	

The C-PARAMS message, *m*, is defined by:

$$m = \{tps_{Ntps-1}, \ldots , tps_0, pms_{Npms-1}, \ldots , pms_0, pmd_{Npmd-1}, \ldots , pmd_0\} = \{m_{Nmsg-1}, \ldots , m_0\}$$

The C-PARAMS message conveys 3 sets of parameters, related to TPS-TC, PMS-TC and PMD configuration. TPS-TC parameters are conveyed in the bits tps_{Ntps-1} to tps_0 and are defined in clause 6. PMS-TC parameters are conveyed in the bits pms_{Npms-1} to pms_0 and are defined in clause 7. PMD parameters are conveyed in the bits pmd_{Npmd-1} to pmd_0 and are defined in clause 8.

PMS-TC parameters include the framer configuration parameters. PMD parameters include the bits and gains table for the upstream subcarriers.

A CRC shall be appended to the message. The 16 CRC bits shall be computed from the Nmsg message *m* bits in the same way as the CRC bits are calculated for the C-MSG-FMT message.

If the number of the message and CRC bits to be transmitted is not an integer multiple of the number of bits per symbol (i.e., not a multiple of 2 × *NSC_C-PARAM*), then the message and CRC bits shall be further padded with zero bits such that the overall number of bits to be transmitted is equal to (2 × *NSC_C-PARAM* × *LEN_C-PARAM*) / (2 × *INP_CPARAMS* + 1).

The C-PARAMS message bits (along with the CRC bits and the padding bits) shall be scrambled using the following equation:

$$d'_n = d_n \oplus d'_{n-18} \oplus d'_{n-23}$$

where d_n is the *n*-th input to the scrambler (first input is d_1);

and d'_n is the *n*-th output from the scrambler (first output is d'_1);

and the scrambler is initialized to $d'_n = 1$ for $n < 1$.

The bits to be transmitted shall be input into the scrambler equation with the least significant bit first (m_0 first and m_{Nmsg-1} last, followed by c_0 first and c_{15} last, followed by padding bits, if present). By construction of the scrambler, the scrambler output bits d'_n to d'_{18} are equal to m_0 to m_{17} respectively.

The output of the scrambler shall be transmitted at (2 × *NSC_C-PARAM*) bits per C-PARAMS symbol (the first bit output of the scrambler is transmitted first, and so on). Bit pairs shall be mapped onto subcarriers in ascending order of subcarrier index and using the same 4-QAM modulation as defined in Table 8-36 of [ITU-T G.992.3] for C-REVERB symbols. Each C-PARAMS symbol shall be repeated and transmitted (2 × *INP_CPARAMS* + 1) times.

The C-PARAMS symbol shall contain only the *NSC_C-PARAM* subcarriers (carrying the message bits) and the C-TREF pilot tone. The other subcarriers shall be transmitted at no power (i.e., $X_i = Y_i = 0$).

The C-TREF pilot may be part of the set of *NSC-PARAMS* subcarriers (carrying the message bits). In this case, the C-TREF pilot shall be modulated with message bits. Otherwise, it shall be modulated with the fixed {0, 0} 4-QAM constellation point.

The C-PARAMS state shall be followed by the C-REVERB7.

A.3 Management plane procedures

A.3.1 Test parameter read commands (supplements clause 9.4.1.10 of ITU-T G.992.3)

Four test parameters are added to Table 9-30 of [ITU-T G.992.3] as described in Table A.11.

The parameter with ID=41_{16} contains the actual INP against SHINE as derived by the far-end transmitter. It is represented as an unsigned 16-bit integer in multiple of 0.1. This parameter shall be available from the ATU-C through a single read command.

The parameter with ID=42_{16} contains the actual INP against REIN as derived by the far-end transmitter. It is represented as an unsigned 8-bit integer in multiple of 0.1. This parameter shall be available from the ATU-C through a single read command.

The parameter with ID=43_{16} contains the actual ETR as derived by the far-end receiver. It is represented as an unsigned 32-bit integer in multiple of 1 kbit/s. This parameter shall be available from the ATU-R through a single read command.

The parameter with ID=44_{16} contains the actual delay as derived by the far-end receiver. It is represented as an unsigned 8-bit integer in multiple of 1 ms. This parameter shall be available from the ATU-R through a single read command.

Table A.11 – Additional PMD test parameter ID values

Test parameter ID	Test parameter name	Length for single read	Length for multiple read	Length for block read
41_{16}	Far-end RTX Transmitter Actual Impulse Noise protection against SHINE (INP_act_SHINE)	2 octets	n/a	n/a
42_{16}	Far-end RTX Transmitter Actual Impulse Noise protection against REIN (*INP_act*_REIN)	1 octet	n/a	n/a
43_{16}	RTX Receiver Expected Throughput (*ETR*)	4 octets	n/a	n/a
44_{16}	RTX Receiver Actual Delay (*delay_act_RTX*)	1 octet	n/a	n/a

A.3.2 Management counter read commands (supplements clause 9.4.1.6 of ITU-T G.992.3)

Replace Table 9-19 of [ITU-T G.992.3] and Table 9-20 of [ITU-T G.992.3] with Table A.12 and Table A.13, respectively.

The field "*EFTR_min*" contains the *EFTR_min* as derived by the far-end receiver. It is represented as an unsigned 32-bit integer in multiple of 1 kbit/s. This field shall be present in the response from the ATU-R if retransmission is enabled in the downstream direction. Although this parameter is reported via the management counter eoc commands, this performance monitoring parameter is not a counter. Therefore, the requirements of [ITU-T G.992.3] and [ITU-T G.997.1] applicable to counters in general do not apply to this parameter.

Table A.12 – Management counter read command transmitted by the responder

Message length (Octets)	Element name (Command)
2 + 4 × *Nc* for PMS-TC and variable for TPS-TC	81_{16} followed by: all the PMS-TC counter values, followed by all the TPS-TC counter values. All other octet values are reserved by ITU-T.
NOTE – *Nc* is the number of counters related to the PMS-TC, *Nc*=14 in the report on the downstream direction and *Nc*=8 in the report on the upstream direction.	

Table A.13 – ATU management counter values

PMD & PMS-TC
Counter of the FEC-0 anomalies (Note 1)
Counter of the FEC-1 anomalies (Note 1)
Counter of the CRC-0 anomalies (Note 1)
Counter of the CRC-1 anomalies (Note 1)
Counter of rtx-tx (Note 3)
Counter of rtx-c (Note 2)
Counter of rtx-uc (Note 2)
FEC errored seconds counter
Errored seconds counter
Severely errored seconds counter
LOS errored seconds counter
Unavailable errored seconds counter
Counter of "leftr" defect seconds (Note 2)
Counter of error free bits (Note 2)
EFTR_min (Note 2)
TPS-TC
Counters for TPS-TC #0
NOTE 1 – The ATU-R shall include the fields of the FEC and CRC anomalies for the latency path #0 and #1; the FEC and CRC of the latency path #0 shall be vendor discretionary. The ATU-C shall include only the fields of the FEC and CRC anomalies for the latency path #0. NOTE 2 – These counters shall be included only in the ATU-R to ATU-C report on the downstream direction. NOTE 3 – This counter shall be included only in the ATU-C to ATU-R report on the upstream direction.

A.3.3 Diagnostic commands and responses (supplements clause 9.4.1.2 of ITU-T G.992.3)

Replace Table 9-10 of [ITU-T G.992.3] with the Table A.14.

Table A.14 – eoc commands transmitted by the ATU-C

Message length (Octets)	Element name (Command)
2	01_{16} Perform Self Test
2	02_{16} Update Test Parameters
2	03_{16} Start TX Corrupt CRC
2	04_{16} End TX Corrupt CRC
2	05_{16} Start RX Corrupt CRC
2	06_{16} End RX Corrupt CRC
2	07_{16} Enter RTX TESTMODE
2	08_{16} Leave RTX TESTMODE
2	80_{16} ACK
All other octet values are reserved by the ITU-T.	

A.3.3.1 Retransmission test mode

A special test mode is defined for accelerated testing of the MTBE (see clause 10.4). A diagnostic command is defined to enter or leave the mode during Showtime.

Upon reception of the Enter RTX_TESTMODE command, the ATU-R shall acknowledge it with an ACK response. Afterwards, the ATU-R shall acknowledge all received DTUs.

Upon reception of the Leave RTX_TESTMODE command, the ATU-R shall resume its normal behaviour of retransmission.

A.3.4 On-line reconfiguration command

For the support of seamless rate adaptation with retransmission, an additional OLR request (Type 5) is defined. This OLR request shall replace the OLR request Type 02_{16} and the OLR request type 03_{16} of Table 9-7 of [ITU-T G.992.3].

The format of the OLR type 5 command transmitted by the initiating receiver is described in Table A.15. Upon reception of this command, the transceiver shall either trigger a reconfiguration of its transmitter as described in clause 13.2 or generate an OLR reply. The format of the OLR type 5 command transmitted by the responding transmitter is described in Table A.16. The reason code is defined in clause 9.4.1.1 of [ITU-T G.992.3]. All reason codes are applicable to OLR type 5.

In every OLR request of type 5, the new framer settings shall be selected such that all configuration constraints are met.

Table A.15 – Additional on-line reconfiguration commands transmitted by the initiating receiver

Message length (octets)	Element name (command)
$2 + 10 + 3 \times N_f$	05_{16} Request type 5 followed by: 2 octets containing the new L_1 value 1 octet containing the new B_{10} value 1 octet containing the new M_1 value 1 octet containing the new R_1 value 1 octet containing the new Q value 1 octet containing the new V value 1 octet containing the new Q_{tx} value 1 octet containing the new lb value 1 octet for the number of subcarriers N_f $3 \times N_f$ octets describing subcarrier parameter field for each subcarrier

Table A.16 – Additional on-line reconfiguration commands transmitted by the responding transmitter

Message length (octets)	Element name (command)
3	84_{16} Reject type 3 request followed by: 1 octet for reason code

A.3.5 Power management commands (replaces clause 9.4.1.7 of ITU-T G.992.3)

For further study.

NOTE – The low power mode L2 in conjunction with ITU-T G.998.4 is not supported. So, L2 request should not be sent by the ATU-C when retransmission is enabled. Support of L2 in conjunction with ITU-T G.998.4, including improvements to the functionalities of the low power mode, is for further study.

A.4 OLR timing of changes in control parameters

This clause specifies the timing of changes for the parameters included in OLR type 5. The timing of the changes in the values of the various control parameters shall be done per the procedure defined in clause 13.

NOTE – After the change in RS and DTU parameters, DTUs that were encoded with the old parameter values can no longer be retransmitted. The modems should try to ensure that all DTUs that were encoded with the old framing parameters have been correctly received before the changes in framing parameters are executed. This may be done by temporarily interrupting the transmission of new DTUs over the α_1 interface and autonomously retransmitting only DTUs from the retransmission queue for a suitable period of time. This period of time shall not exceed $T_{dtu\text{-}stoppage}$.

A change in the b_i and g_i values of one or more subcarriers is implemented by changing the corresponding PMD control parameter (see Table 8-4 of [ITU-T G.992.3]).

Annex B

Support of ITU-T G.998.4 with ITU-T G.992.5

(This annex forms an integral part of this Recommendation.)

B.1 Specific requirements

For [ITU-T G.992.5], retransmission is defined only for the downstream direction (i.e., DTUs are transmitted only in the downstream direction and the RRC is transmitted only in the upstream direction).

B.1.1 Memory

The size of the transmit retransmission queue in the CO is limited to the half of the downstream interleaver delay in bytes, i.e.:

– If the ATU-C indicates in C-MSG1 support of a transmit retransmission queue size up to 12000 octets (see clause B.3.1), then the ATU-R shall select Q_{TX}, Q and H such that:

$$Q_{tx} * Q * H \leq 12000 \text{ octets for ITU-T G.992.5,}$$

– Otherwise, the ATU-R shall select Q_{TX}, Q and H such that:

$$Q_{tx} * Q * H \leq 8001 \text{ octets for ITU-T G.992.5,}$$

where Q_{tx} is the length of the transmit retransmission queue in DTUs.

The minimum memory for the receiver retransmission queue shall be identical to the amount of the memory for the related transmit queue.

The maximal DTU size in octet (Q*H) shall be 1024.

B.1.2 Overhead channel

The overhead channel shall be configured as specified in clause A.1.2.

B.1.3 Multiplexing

If the ROC is enabled then the RRC and L_0 (ROC) bits may share a common sub-carrier. The same SNR margin offset (SNRMOFFSET-ROC) shall be applied to the RRC and the L0 (ROC).

B.2 Initialization

This clause describes the change to the messages of the initialization of ITU-T G.992.5 to support ITU-T G.998.4 in conjunction with ITU-T G.992.5.

The messages of the initialization shall be modified as specified in clause A.2 except that the octet 2 of Table A.4 shall be replaced by the octet 2 of Table B.1. The length of the C-MSG1 (LEN_C_MSG1) is 336+ *NSCds*/4 or 336 depending, respectively, on whether or not windowing is applied.

Table B.1 – Format for PMS-TC C-MSG1 information

Octet number [i]	PMS-TC format bits [8 × I + 7 to 8 × I + 0]	Description
Octet 2	[c000 bbbb] bit 7 to 0	The bits bbbb contain the transmitter supported maximum 1/*S* value for the latency path with retransmission function. This maximum 1/*S* shall equal (n+1), with n coded as an unsigned 4-bit value bbbb, in the 0 to 15 range. When retransmission is enabled, this value supersedes the maximum 1/*S* value exchanged with the "S_{1min}" field in the PMS-TC capabilities list in: ITU-T G.994.1. The bit c gives the maximum supported size of the transmit retransmission queue. It is coded to 0 if a maximal size of 8001 bytes is supported and is coded to 1 if a maximal size of 12000 bytes is supported.

B.3 Management plane procedures

Management plane procedures shall be as specified in clause A.3 except for clause A.3.4, which shall be replaced by the contents of clauses B.3.4 and B.3.5.

B.3.1 Intentionally left blank

B.3.2 Intentionally left blank

B.3.3 Intentionally left blank

B.3.4 On-line reconfiguration command

For the support of seamless rate adaptation with retransmission, an additional OLR request (Type 5) is defined. This OLR request shall replace the OLR request Type 02_{16} and the OLR request type 03_{16} of Table 9-7 of [ITU-T G.992.5].

The format of the OLR type 5 command transmitted by the initiating receiver is described in Table B.2. Upon reception of this command the transceiver shall either trigger a reconfiguration of its transmitter as described in clause 13.2 or generate an OLR reply. The format of the OLR type 5 command transmitted by the responding transmitter is described in Table B.3. The reason code is defined in clause 9.4.1.1 of [ITU-T G.992.3]. All reason codes are applicable to OLR type 5.

In every OLR request of type 5, the new framer settings shall be selected such that all configuration constraints are met.

Table B.2 – Additional on-line reconfiguration commands transmitted by the initiating receiver

Message length (octets)	Element name (command)
2 + 11 + 4 × N_f	05_{16} Request type 5 followed by: 2 octets containing the new L_1 value 1 octet containing the new B_{10} value 1 octet containing the new M_1 value 1 octet containing the new R_1 value 1 octet containing the new Q value 1 octet containing the new V value 1 octet containing the new Q_{tx} value 1 octet containing the new lb value 2 octets for the number of subcarriers N_f 4 × N_f octets describing subcarrier parameter field for each subcarrier

Table B.3 – Additional on-line reconfiguration commands transmitted by the responding transmitter

Message length (octets)	Element name (command)
3	84_{16} Reject type 3 request followed by: 1 octet for reason code

B.3.5 Power management commands (replaces clause 9.4.1.7 of ITU-T G.992.5)

For further study.

NOTE – The low power mode L2 in conjunction with ITU-T G.998.4 is not supported. So, L2 request should not be sent by the ATU-C when retransmission is enabled. Support of L2 in conjunction with ITU-T G.998.4, including improvements to the functionalities of the low power mode, is for further study.

B.4 OLR timing of changes in control parameters

Timing of changes in control parameters shall be as specified in clause A.4.

Annex C

Support of ITU-T G.998.4 with ITU-T G.993.2

(This annex forms an integral part of this Recommendation.)

C.1 Specific requirements

C.1.1 Memory

The following definitions shall apply:

$$delay\_octet_{DS,0} = (D_{DS,0} - 1) \times (I_{DS,0} - 1)$$

$$delay\_octet_{US,0} = (D_{US,0} - 1) \times (I_{US,0} - 1).$$

If retransmission is enabled in the downstream direction,

then $delay\_octet_{DS,1} = 2 \times Q_{tx,DS} \times Q_{DS} \times H_{DS}$

otherwise $delay\_octet_{DS,1} = (D_{DS,1} - 1) \times (I_{DS,1} - 1)$

If retransmission is enabled in the upstream direction,

then $delay\_octet_{US,1} = 2 \times Q_{tx,US} \times Q_{US} \times H_{US}$

otherwise $delay\_octet_{DS,1} = (D_{US,1} - 1) \times (I_{US,1} - 1)$

The following constraint shall apply:

$$delay\_octet_{DS,0} + delay\_octet_{DS,1} + delay\_octet_{US,0} + delay\_octet_{US,1} \leq MAXDELAYOCTET,$$

where MAXDELAYOCTET is the parameter "aggregate interleaver and de-interleaver delay", in octets, specified in Table 6-1 of [ITU-T G.993.2] for the profile.

The VTU-O and VTU-R shall support all values of ($delay\_octet_{DS,0}$ + $delay\_octet_{DS,1}$ + $delay\_octet_{US,0}$ + $delay\_octet_{US,1}$) up to the maximum of MAXDELAYOCTET. The minimum amount of memory required in a transceiver (VTU-O or VTU-R) to meet this requirement is MAXDELAYOCTET/2 octets. The actual amount of memory used is implementation specific.

The minimum memory for the receiver retransmission queue shall be identical to the amount of the memory for the related transmit queue of the same direction.

The maximal DTU size in octets ($Q \times H$) shall be equal to the value given in Table C.1 depending on the profile and direction.

Table C.1 – Maximal DTU size

Profile	Maximal DTU size ($Q \times H$)	
	Downstream	Upstream
8a,8b,8c,8d	2048 bytes	512 bytes
12a	2048 bytes	1536 bytes
17a	3072 bytes	1536 bytes
30a	3072 bytes	3072 bytes

The MAXDELAYOCTET-split (MDOSPLIT) configuration parameter shall be applied in ITU-T G.998.4. With $delay\_octet_{x,p}$ (with x = DS or US and p = 0 or 1) as defined in this clause, the sum of the max_delay_octet values specified in O-PMS (see clause C.2.1.3) shall be limited to (see clause 11.4.2.7 of [ITU-T G.993.2]):

$$max\_delay\_octet_{DS,0} + max\_delay\_octet_{DS,1} \leq MAXDELAYOCTETS\_DS$$

$max\_delay\_octet_{US,0} + max\_delay\_octet_{US,1} \leq MAXDELAYOCTETS\_US$

C.1.2 Overhead channel

If the ROC is enabled in O-TPS, single latency with ROC mode (see clause 9.1 of [ITU-T G.993.2]) shall be used and the overhead channel shall use the ROC as specified in [ITU-T G.993.2].

If ROC is disabled in O-TPS or is not supported by either the VTU-O or the VTU-R, single latency with ROC mode (see clause 9.1 of [ITU-T G.993.2]) shall be used and the overhead channel shall use the framing parameters as they are derived for the ROC (see framer constraint limitations in Table 12-47 of [ITU-T G.993.2]) with the following configuration:

– SNRMOFFSET-ROC = 0 dB,

– INPMIN-ROC = max(INPMIN_REIN, 2),

with the exception that sub-carriers loaded with the bits of the overhead channel may share sub-carriers loaded with the bits of the latency path #1.

C.1.3 Multiplexing

If the ROC is enabled then the RRC and L_0 (ROC) bits may share a common sub-carrier. The same SNR margin offset (SNRMOFFSET-ROC) shall be applied to the RRC and the L_0 (ROC).

C.1.4 Attainable net data rate (ATTNDR)

See clause 11.4.1.1.7 of [ITU-T G.993.2].

NOTE – The calculation of the ATTNDR in loop diagnostics uses an SNRGAP value that is defined for a 10^{-7} bit error ratio on 4-QAM (no coding gain, no retransmission, INP_min_0=0).

C.1.4.1 The basic attainable net data rate method

See clause 11.4.1.1.7.1 of [ITU-T G.993.2].

C.1.4.2 The improved attainable net data rate method

Support of the improved attainable net data rate method is optional.

The attainable net data rate is the maximum net data rate that the receive PMS-TC and PMD functions are designed to support, assuming the conditions of the basic attainable net data rate method (see clause 11.4.1.1.7.1) and the following conditions:

– If the control parameter *attndr_method* is set to a value of 1, the VTU-O and VTU-R shall use the impulse noise protection limit INP_min_0 with value as indicated in O-TPS (see clause C.2.1.2);

– If the control parameter *attndr_method* is set to a value of 2, the VTU-O and VTU-R shall use an impulse noise protection limit $INP\_min_0 = 0$;

– Use of erasure decoding or not is identical to usage on the bearer channels;

– Taking into account the framing limitations;

– Latency not less than the minimum latency configured for the bearer channel ($delay\_act_0 \geq delay\_min_0$);

– Taking into account the value of the ATTNDR_MDOSPLIT parameter;

– Net data rate is neither limited by the configured maximum net data rate, nor by the configured maximum ETR;

– Taking into account the actual half roundtrip delay of the VTU-O and VTU-R;

– Channel initialization policy CIP = 0;

– Transmit PSD is equal to MREFPSD for all sub-carriers for which gi ≠ 0.

NOTE 1 – The ATTNDR value may be lower due to possible transmit power reductions, as a consequence of configured MAXMARGIN setting, configured MAXNDR setting and vendor discretionary transmit power reductions (e.g., subcarriers with $g_i = 0$, due to AFE dynamic range, …).

NOTE 2 – The basic method does not specify a number of conditions to calculate ATTNDR, which leads to vendor discretionary behaviour in the reported ATTNDR values. The improved method defines additional conditions to reduce variation of reported ATTNDR values over implementations.

When the ATTNDR value is reported during Showtime for a direction in which retransmission is disabled, the following parameters used in the calculation of the ATTNDR shall also be reported over the eoc with the ATTNDR value (see clause 11.4.1.1.7.2 and Table 11-28a of [ITU-T G.993.2]) and also be reported in the CO-MIB with the ATTNDR value (see clauses 7.5.1.19 and 7.5.1.20 of [ITU-T G.997.1]):

– $ATTNDR\_INP\_act_0$ (see clauses 7.5.1.41.2 and 7.5.41.3 of [ITU-T G.997.1]);

– $ATTNDR\_delay\_act_0$ (see clauses 7.5.1.41.6 and 7.5.41.7 of [ITU-T G.997.1]).

When the ATTNDR value is reported during Showtime for a direction in which retransmission is enabled, the following parameters used in the calculation of the ATTNDR shall also be reported over the eoc with the ATTNDR value (see Table C.1a) and also be reported in the CO-MIB with the ATTNDR value (see clauses 7.5.1.19 and 7.5.1.20 of [ITU-T G.997.1]):

– $ATTNDR\_INP\_act\_SHINE_0$ (see clauses 7.5.1.41.2 and 7.5.41.3 of [ITU-T G.997.1]);

– $ATTNDR\_INP\_act\_REIN_0$ (see clauses 7.5.1.41.4 and 7.5.41.5 of [ITU-T G.997.1]);

– $ATTNDR\_delay\_act\_RTX_0$ (see clauses 7.5.1.41.6 and 7.5.41.7 of [ITU-T G.997.1]).

The parameter $ATTNDR\_INP\_act\_SHINE_0$ is the SHINE far-end actual impulse noise protection used in the calculation of the ATTNDR. The actual impulse noise protection $ATTNDR\_INP\_act\_SHINE_0$ shall be represented as a 16-bit unsigned integer $attndr\_inp\_act\_shine_0$, with the value of $ATTNDR\_INP\_act\_SHINE_0$ defined as $ATTNDR\_INP\_act\_SHINE_0 = attndr\_inp\_act\_shine_0 / 10$ DMT symbols. This data format supports an $ATTNDR\_INP\_act\_SHINE_0$ granularity of 0.1 DMT symbol. The range is from 0 DMT symbols (represented as 0) to 204.6 DMT symbols (represented as 2046). The value 2047 is a special value indicating an $ATTNDR\_INP\_act\_SHINE_0$ higher than 204.6 DMT symbols.

The parameter $ATTNDR\_INP\_act\_REIN_0$ is the far-end REIN actual impulse noise protection used in the calculation of the ATTNDR. The actual impulse noise protection $ATTNDR\_INP\_act\_REIN_0$ shall be represented as an 8-bit unsigned integer $attndr\_inp\_act\_REIN_0$, with the value of $ATTNDR\_INP\_act\_rein_0$ defined as $ATTNDR\_INP\_act\_REIN_0 = attndr\_inp\_act\_rein_0 / 10$ DMT symbols. This data format supports an $ATTNDR\_INP\_act\_REIN_0$ granularity of 0.1 DMT symbol. The range is from 0 DMT symbols (represented as 0) to 25.4 DMT symbols (represented as 254). The value 255 is a special value indicating an $ATTNDR\_INP\_act\_REIN_0$ higher than 25.4 DMT symbols.

The parameter $ATTNDR\_delay\_act\_RTX_0$ is the far-end actual delay used in the calculation of the ATTNDR. The actual delay $ATTNDR\_delay\_act\_RTX_0$ shall be represented as an 8-bit unsigned integer $attndr\_delay\_ac\_rtxt_0$, with the value of $ATTNDR\_delay\_act\_RTX_0$ defined as $ATTNDR\_delay\_act\_RTX_0 = attndr\_delay\_act\_rtx_0 / 10$ ms. This data format supports an $ATTNDR\_delay\_act\_RTX_0$ granularity of 0.1 ms. The range is from 0 ms (represented as 0) to 25.4 ms (represented as 254). The value 255 is a special value indicating an $ATTNDR\_DELAY\_act\_RTX_0$ higher than 25.4 ms.

C.1.4.3 ATTNDR_MAXDELAYOCTET-split (ATTNDR_MDOSPLIT)

See clause 11.4.2.8 of [ITU-T G.993.2].

C.1.4.4 ATTNDR test parameter read commands and responses

See clause 11.2.3.11 of [ITU-T G.993.2], with the ATTNDR test parameter defined as shown in Table C.1a.

Table C.1a – ATTNDR test parameter

Octet number	Basic method	Improved method (retransmission disabled)	Improved method (retransmission enabled)
1 - 4	*ATTNDR*	*ATTNDR*	*ATTNDR*
5	N/A	Reserved and set to 00_{16}	$\mathit{ATTNDR\_INP\_act\_SHINE}_0$
6	N/A	$\mathit{ATTNDR\_INP\_act}_0$	
7	N/A	Reserved and set to 00_{16}	$\mathit{ATTNDR\_INP\_act\_REIN}_0$
8	N/A	$\mathit{ATTNDR\_delay\_act}_0$	$\mathit{ATTNDR\_delay\_act\_RTX}_0$
NOTE – The format of the fields is defined in clause 11.4.1.1.7.			

C.2 Initialization

Support of ITU-T G.998.4 in VDSL2 is realized through the "ITU-T G.998.4 extensions" codepoints in ITU-T G.994.1 and the "ITU-T G.998.4 parameter field" in the various VDSL2 initialization messages, as specified in [ITU-T G.993.2]. This clause defines the contents of the "ITU-T G.998.4 extensions" codepoints in ITU-T G.994.1 and the ITU-T G.998.4 parameter field for the relevant initialization messages. When an initialization message is not included in the subsections below, the ITU-T G.998.4 parameter field for that message shall be a single byte with value 00_{16}.

C.2.0 ITU-T G.994.1 handshake phase

The initialization procedure starts with the ITU-T G.994.1 handshake phase. During this phase, the VTU-O and the VTU-R shall exchange their ITU-T G.998.4 extensions capabilities in addition to the parameters communicated in a regular handshake phase, as defined in [ITU-T G.993.2]. Based on these capabilities, the final set of ITU-T G.998.4 extensions is determined during the ITU-T G.994.1 handshake phase of initialization (see Table 11.68.0.1 and Table 11.68.11 of [ITU-T G.994.1] and Tables C.1.1, C.1.2, C.1.3, and C.1.4).

Table C.1.1 – VTU-O CL message Npar(3) bit definitions

ITU-T G.994.1 Npar(3) Bit	Definition of Npar(3) bits
ITU-T G.998.4 Annex D support	If set to ONE, this bit indicates that the VTU-O supports ITU-T G.998.4 Annex D. This bit may only be set to ONE if the VTU-O transceiver is ITU-T G.993.5 capable, but the bit "ITU-T G.993.5" is set to ZERO in the Spar(2) octet 2 of ITU-T G.993.2; otherwise this bit shall be set to ZERO. NOTE – In earlier versions of ITU-T G.998.4, support of Annex D was indicated implicitly by support of ITU-T G.993.5 (i.e., the bit "ITU-T G.993.5" is set to ONE in the Spar(2) octet 2 of ITU-T G.993.2).

Table C.1.2 – VTU-O MS message Npar(3) bit definitions

ITU-T G.994.1 Npar(3) Bit	Definition of Npar(3) bits
ITU-T G.998.4 Annex D support	This bit shall be set to ONE, if and only if, set to ONE in both the last previous CL message and the last previous CLR message. If set to ONE, this bit indicates that operation in ITU-T G.998.4 Annex D is selected, even if this MS message does not indicate the selection of ITU-T G.993.5. If set to ZERO, this bit indicates that operation in ITU-T G.998.4 Annex D is not selected.

Table C.1.3 – VTU-R CLR message Npar(3) bit definitions

ITU-T G.994.1 Npar(3) Bit	Definition of Npar(3) bits
ITU-T G.998.4 Annex D support	If set to ONE, this bit indicates that the VTU-R supports ITU-T G.998.4 Annex D. This bit may only be set to ONE if the bit "ITU-T G.993.5" is also set to ONE in the Spar(2) octet 2 of ITU-T G.993.2; otherwise this bit shall be set to ZERO. NOTE – In earlier versions of ITU-T G.998.4, support of Annex D was indicated implicitly by support of ITU-T G.993.5 (i.e., the bit "ITU-T G.993.5" is set to ONE in the Spar(2) octet 2 of ITU-T G.993.2).

Table C.1.4 – VTU-R MS message Npar(3) bit definitions

ITU-T G.994.1 Npar(3) Bit	Definition of Npar(3) bits
ITU-T G.998.4 Annex D support	This bit shall be set to ONE if and only if set to ONE in both the last previous CL message and the last previous CLR message. If set to ONE, this bit indicates that operation in ITU-T G.998.4 Annex D is selected, even if this MS message does not indicate selection of ITU-T G.993.5. If set to ZERO, this bit indicates that operation in ITU-T G.998.4 Annex D is not selected.

C.2.1 VTU-O messages

C.2.1.1 O-MSG 1

The O-MSG 1 message contains the capabilities of the VTU-O. The ITU-T G.998.4 parameter field for O-MSG 1 shall be structured as shown in Table C.2.

Table C.2 – ITU-T G.998.4 parameter field for O-MSG1

	Field contents	Format	Description
1	Parameter field length	1 byte	Total number of data bytes in ITU-T G.998.4 parameter field.
2	Retransmission support	1 byte [0000 000u]	Indicates support of upstream retransmission at the VTU-O.
3	DTU options	1 byte [0000 0cba]	Indicates the optional framing types supported by the VTU-O transmitter.
4	VTU-O Half-roundtrip Tx	1 byte [00ddssss]	VTU-O transmitter half-roundtrip delay.
5	VTU-O half-roundtrip Rx	1 byte [00ddsssss]	VTU-O receiver half roundtrip delay.
6	DS $(1/S)_{max}$	1 byte [0eeeeeee]	Maximum 1/*S* value supported by the VTU-O in the downstream direction when retransmission is enabled.
7	US $(1/S)_{max}$	1 byte [0eeeeeee]	Maximum 1/*S* value supported by the VTU-O in the upstream direction when retransmission is enabled.
8	Downstream D_1 values supported	1 byte [edddddddd]	Indicates the optional block interleaving depth values supported by the VTU-O transmitter
9	Support of LPMode Annex E	1 byte [0000 00ab]	Indicates the enabling of LPMode link sub-states L2.1 and L2.2 in the downstream direction: ab=00 if both L2.1 and L2.2 are disabled ab=01 is reserved for use by the ITU-T ab=10 if L2.1 is enabled and L2.2 is disabled ab=11 if both L2.1 and L2.2 are enabled

Field #1 "Parameter field length" indicates the number of data bytes in the ITU-T G.998.4 parameter field. The data bytes are the bytes following this length indicator byte (i.e., all bytes in the ITU-T G.998.4 parameter field counting from the penultimate byte). This byte is included to allow CPEs that do not support ITU-T G.998.4 to still correctly parse O-MSG1.

Field #2 "Retransmission support" indicates the upstream retransmission capability of the VTU-O. The field shall be coded as a single byte [0000 000u], where:

– u = 0 indicates that retransmission is not supported in the upstream direction.

– u = 1 indicates that retransmission is supported in the upstream direction.

Note that support for downstream retransmission is implied if the VTU-O includes an ITU-T G.998.4 parameter field that has a non-zero number of data bytes in it.

Field #3 "DTU options" indicates which of the optional DTU framing types are supported by the VTU-O transmitter. The field shall be coded as a single byte [0000 0abc], where:

– a = 1 indicates support of DTU framing type 2 (see clause 8.1.2).

– b = 1 indicates support of DTU framing type 3 (see clause 8.1.3).

– c = 1 indicates support of DTU framing type 4 (see clause 8.1.4).

At least one of the bits a, b or c shall be set to 1 when retransmission is supported in the downstream direction.

Field #4 "VTU-O Half-roundtrip Tx" contains the half-roundtrip delay of the VTU-O transmitter. The field shall be coded as a single byte [00ddssss], where:

– ssss is a four-bit number indicating the part of the delay in DMT symbols for the profiles with 4.3125 kHz sub-carrier spacing or in multiple of 2 DMT symbols for the profiles with 8.625 kHz sub-carrier spacing.

– dd is a two-bit number indicating the part of the delay in DTU.

Field #5 "VTU-O Half-roundtrip Rx" contains the half-roundtrip delay of the VTU-O receiver. The field shall be coded as a single byte [00ddssss], where:

– ssss is a four-bit number indicating the part of the delay in DMT symbols for the profiles with 4.3125 kHz sub-carrier spacing or in multiple of 2 DMT symbols for the profiles with 8.625 kHz sub-carrier spacing.

– dd is a two-bit number indicating the part of the delay in DTU.

Field #6 "DS $(1/S)_{max}$ with RTX" contains the maximal $1/S$ value supported by the VTU-O in the downstream direction when retransmission is enabled in this direction downstream. The field shall be coded as an unsigned 8-bit value with a range from 1 to 64 in steps of 1. When retransmission is enabled in downstream, this value supersedes the value of "DS $(1/S)_{max}$" exchanged in the PMS-TC capabilities field of O-MSG 1.

Field #7 "US $(1/S)_{max}$ with RTX" contains the maximal $1/S$ value supported by the VTU-O in the upstream direction when retransmission is enabled in upstream. The field shall be coded as an unsigned 8-bit value with a range from 1 to 64 in steps of 1. When retransmission is enabled in upstream, this value supersedes the value of "US $(1/S)_{max}$" exchanged in the PMS-TC capabilities field of O-MSG 1.

Field #8 "Downstream D_1 values supported" contains the description of the set of downstream block interleaving depth values supported by the VTU-O transmitter on the latency path #1. The field shall be coded as a single byte [eddddddd], where:

– ddddddd is a seven-bit unsigned integer indicating the maximum interleaving depth D_1 value supported;

– e is set to 1 to indicate that the VTU-O only supports D_1 values that are an integer power of 2, and set to 0 otherwise.

Field #9 "Support of LPMode Annex E" indicates whether or not the LPMode link sub-states L2.1 and L2.2 (as defined in Annex E) are enabled in the downstream direction. The value ab depends on the CO-MIB enabling and the VTU-O supporting the LPMode link sub-states L2.1 and L2.2 in the downstream direction.

When retransmission is enabled, all other parameter values exchanged in the remainder of O-MSG 1 shall keep their original meaning (as defined in [ITU-T G.993.2]), unless indicated otherwise above.

C.2.1.2 O-TPS

The O-TPS message conveys the TPS-TC configuration for both the upstream and the downstream directions. It is based on the capabilities that were indicated in O-MSG 1 and R-MSG 2. The ITU-T G.998.4 parameter field for O-TPS shall be structured as shown in Table C.3.

Table C.3 – ITU-T G.998.4 parameter field for O-TPS

	Field contents	Format	Description
1	Parameter field length	1 byte	Total number of data bytes in ITU-T G.998.4 parameter field.
2	Retransmission enabled	1 byte [0000 00ud]	Indicates whether retransmission is enabled or disabled (per transmission direction).
3	Downstream *ETR_max*	2 bytes	Extension of the bearer channel descriptor containing the maximum ETR in the downstream direction.
4	Downstream *ETR_min*	2 bytes	Extension of the bearer channel descriptor containing the minimum ETR in the downstream direction.
5	Downstream minimum delay	1 byte	Extension of bearer channel descriptor containing the downstream minimum delay requirement for the downstream bearer channel (Note).
6	Downstream *INP_min_REIN* and *iat_REIN_flag*	1 byte [f00mmmmm]	Extension of bearer channel descriptor containing the downstream minimum INP against REIN and REIN inter-arrival time in the downstream direction.
7	Downstream *SHINEratio*	1 byte	Value of the downstream SHINEratio.
8	Upstream minimum delay	1 byte	Extension of bearer channel descriptor containing the upstream minimum delay requirement for the upstream bearer channel (Note).
9	Upstream *INP_min_REIN* and *iat_REIN_flag*	1 byte [f00mmmmm]	Extension of bearer channel descriptor containing the upstream minimum INP against REIN and REIN inter-arrival time in the downstream direction.
10	Downstream *leftr_thresh*	1 byte [0iii iiii]	The bits iii iiii gives leftr_thresh value for downstream.
11	CI policy	1 byte [0000 000p]	Downstream channel initialization policy.
12	ITU-T G.998.4 LPMode parameter field	Variable length	Control parameters for the LPMode defined in Annex E.
NOTE – When retransmission is enabled in either downstream or upstream or both, only one bearer channel shall be supported in upstream and downstream.			

Field #1 "Parameter field length" indicates the number of data bytes in the ITU-T G.998.4 parameter field. The data bytes are the bytes following this length indicator byte (i.e., all bytes in the ITU-T G.998.4 parameter field counting from the penultimate byte). This byte is included to allow CPEs that do not support ITU-T G.998.4 to still correctly parse O-TPS.

Field #2 "Retransmission enabled" indicates whether retransmission is enabled in the upstream and downstream directions. The field shall be coded as a single byte [0000 00ud], where:

– u = 0 indicates that retransmission is not enabled in the upstream direction.

– u = 1 indicates that retransmission is enabled in the upstream direction.

– d = 0 indicates that retransmission is not enabled in the downstream direction.

– d = 1 indicates that retransmission is enabled in the downstream direction.

If retransmission is not enabled in the downstream direction, the remaining bytes of the ITU-T G.998.4 parameter field that pertain to downstream transmission shall be set to zero at the transmitter and ignored at the receiver.

If retransmission is not enabled in the upstream direction, the bytes of the ITU-T G.998.4 parameter field that pertain to upstream transmission shall be set to zero at the transmitter and ignored at the receiver.

Field #3 "Downstream *ETR_max*" contains the *ETR_max* as defined in clause 7 for the downstream bearer channel. The field shall be coded as a 16-bits unsigned integer with the data rate in multiple of 8 kbit/s.

Field #4 "Downstream *ETR_min*" contains the *ETR_min* as defined in clause 7 for the downstream bearer channel. The field shall be coded as a 16-bits unsigned integer with the data rate in multiple of 8 kbit/s.

Field #5 "Downstream minimum delay" contains the minimum delay requirement (*delay_min*) for the downstream bearer channel. The field shall be coded as a single byte. Valid values are defined in Table 7-2.

Field #6 "Downstream *INP_min_REIN* and *iat_REIN_flag*" contains the minimum INP and the inter-arrival time that shall be assumed for REIN protection in the downstream direction. The field shall be coded as a single byte [f00m mmmm], where:

– mmmmm is a five-bit number containing the minimum required INP protection against REIN pulses in the downstream direction (*INP_min_REIN*). Valid values are defined in Table 7-2.

– f is a flag that indicates the frequency of the REIN pulses, where:
  - f = 0 indicates a repetition frequency of REIN of 100 Hz (*iat_REIN_flag* = 0).
  - f = 1 indicates a repetition frequency of REIN of 120 Hz (*iat_REIN_flag* = 1).

Field #7 "*SHINEratio*" contains the *SHINEratio* for downstream transmission. The value of *SHINEratio* is obtained by multiplying the 8-bit value with 0.001. The valid values are defined in Table 7-2.

Field #8 "Upstream minimum delay" contains the minimum delay requirement for the upstream bearer channel. The field shall be coded as a single byte. The valid values are defined in Table 7-2. This information can be used by the VTU-R in the transmitter reference state machine.

Field #9 "Upstream *INP_min_REIN* and *iat_REIN_flag*" contains the minimum INP and the inter-arrival time that shall be assumed for REIN protection in the upstream direction. The field shall be coded as a single byte [f00m mmmm], where:

– mmmmm is a five-bit number containing the minimum required INP protection against REIN pulses in the upstream direction (*INP_min_REIN*). The valid values are defined in Table 7-2.

– f is a flag that indicates the frequency of the REIN pulses, where:
  - f = 0 indicates a repetition frequency of REIN of 100 Hz (*iat_REIN_flag*=0).
  - f = 1 indicates a repetition frequency of REIN of 120 Hz (*iat_REIN_flag*=1).

Field #10 "Downstream *leftr_thresh*" contains the threshold for declaring *leftr* detects for downstream transmission. The value of LEFTR_THRESH is obtained by multiplying the 7-bit value with 0.01. The valid values are defined in Table 7-2. A special value of 0 indicates that ETR shall be used as the threshold for *leftr* detects.

Field #11 "CI policy" indicates the channel initialization policy that shall be used in the downstream direction. It shall be coded as [0000 000p], where:

– p = 0 to indicate that CIpolicy 0 shall be used.

– p = 1 reserved by ITU-T.

Field #12 is a variable length field consisting of an integer number of octets. It is formatted as shown in Table E.3. If the VTU-O indicates in O-MSG 1 the LPMode link sub-state L2.1 is enabled and the VTU-R indicates in R-MSG 2 it supports the LPMode link sub-state L2.1, then this field shall have a length of 9 bytes. Otherwise, this field may have a length of 1 byte with value 00_{16}.

When retransmission is enabled in the downstream direction, the remaining parameter values exchanged in O-TPS shall keep their original meaning (as defined in [ITU-T G.993.2]), with the following exceptions:

– The field net_min_n in the downstream bearer channel descriptor (see Table 12-42 of [ITU-T G.993.2]) shall be set to 0.

– The field net_max_n in the downstream bearer descriptor shall contain the downstream *net_max* as defined in clause 7.

– The field INP_min_n in the Impulse noise protection field of the downstream bearer channel (see Table 12-42 of [ITU-T G.993.2]) shall contain the downstream Minimum impulse noise protection as defined in Table 7-2.

– The *CIpolicy* bit of the TPS-TC options field of the downstream bearer channel descriptor (see Table 12-42 of [ITU-T G.993.2]) shall be ignored and superseded by the information contained in the ITU-T G.998.4 parameter field of O-TPS.

– The maximum interleaving delay field of the downstream bearer channel descriptor shall contain the downstream *delay_max* as defined in Table 7-2.

When retransmission is enabled in the upstream direction, the remaining parameter values exchanged in O-TPS shall keep their original meaning (as defined in [ITU-T G.993.2]), with the following exceptions:

The field net_min_n in the upstream bearer channel descriptor (see Table 12-42 of [ITU-T G.993.2]) shall be set to 0.

The field net_max_n in the upstream bearer descriptor shall contain the upstream *net_max* as defined in clause 7.

The field INP_min_n in the Impulse noise protection field of the upstream bearer channel (see Table 12-42 of [ITU-T G.993.2]) shall contain the upstream Minimum impulse noise protection as defined in Table 7-2.

The *CIpolicy* bit of the TPS-TC options field of the upstream bearer channel descriptor (see Table 12-42 of [ITU-T G.993.2]) shall be ignored and superseded by the information contained in the ITU-T G.998.4 parameter field of O-TPS

The maximum interleaving delay field of the upstream bearer channel descriptor shall contain the upstream *delay_max* as defined in Table 7-2.

C.2.1.3 O-PMS

The O-PMS message conveys the initial PMS-TC parameters that shall be used in the upstream direction during Showtime. The ITU-T G.998.4 parameter field for O-PMS shall be structured as shown in Table C.4.

If retransmission is not enabled in the upstream direction (as indicated in the ITU-T G.998.4 parameter field of O-TPS) and OLR is not supported in any direction by the VTU-O, the

ITU-T G.998.4 parameter field of O-PMS may be left empty by the VTU-O (i.e., consist of a single byte with value 0).

Table C.4 – ITU-T G.998.4 parameter field for O-PMS

	Field contents	Format	Description
1	Parameter field length	1 byte	Total number of data bytes in ITU-T G.998.4 parameter field.
2	DTU options	[0000 00aa]	Selected DTU framing type in the upstream direction.
3	Q	1 byte	The number of Reed-Solomon codewords per DTU in the upstream direction.
4	V	1 byte	The number of padding octets per DTU in the upstream direction.
5	Q_{tx}	1 byte	Delay in DTU between two consecutive transmissions of a DTU.
6	lb	1 byte	Look-back value used to calculate the values communicated in the RRC carrying the requests for upstream retransmission, i.e., in the RRC transmitted in the downstream direction.
7	Downstream OLR capabilities with ITU-T G.998.4	1 byte	Indicates support in the downstream direction for the various OLR mechanisms when retransmission is enabled in downstream.
8	Upstream OLR capabilities with ITU-T G.998.4	1 byte	Indicates support in the upstream direction for the various OLR mechanisms when retransmission is enabled in upstream.
9	D_1	1 byte	Block interleaving depth in the upstream direction.

Field #1 "Parameter field length" indicates the number of data bytes in the ITU-T G.998.4 parameter field. The data bytes are the bytes following this length indicator byte (i.e., all bytes in the ITU-T G.998.4 parameter field counting from the penultimate byte). This byte is included to allow CPEs that do not support ITU-T G.998.4 to still correctly parse O-PMS.

Field #2 "DTU options" indicates which of the optional DTU framing types shall be used in the upstream direction. The field is coded as [0000 00aa], where:

– aa=00 indicates that DTU framing type 1 (see clause 8.1.1) shall be used.

– aa=01 indicates that DTU framing type 2 (see clause 8.1.2) shall be used.

– aa=10 indicates that DTU framing type 3 (see clause 8.1.3) shall be used.

– aa=11 indicates that DTU framing type 4 (see clause 8.1.4) shall be used.

The selected value shall be consistent with the support of the optional framing types at the VTU-R as indicated in R-MSG2.

Field #3 "Q" indicates the number of Reed-Solomon codewords per DTU in the upstream direction. Q shall take a value in the range from 1 to 64 (inclusive).

Field #4 "V" indicates the number of padding octets per DTU in the upstream direction. V shall take a value between 0 and 15 (inclusive).

Field #5 "Q_{tx}" indicates the delay (in number of DTUs) between two consecutive upstream transmissions of the same DTU in the transmitter reference state machine assumed by the VTU-O. Q_{tx} shall take a value in the range from 1 to 64 (inclusive).

Field #6 "*lb*" contains the look-back value used to calculate the values communicated in the RRC carrying the requests for upstream retransmission, i.e., in the RRC transmitted in the downstream direction. "*lb*" shall take values in the range from 1 to 31.

Field #7 "Downstream OLR capabilities with ITU-T G.998.4" indicates which of the various optional OLR mechanisms are supported by the VTU-O in the downstream direction when retransmission is enabled in downstream. The field is coded as [0000 00us], where:

– s=1 if OLR type 5 (SRA modified for ITU-T G.998.4) is supported and s=0 otherwise
– u=1 if OLR type 6 (SOS modified for ITU-T G.998.4) is supported and u=0 otherwise

Field #8 "Upstream OLR capabilities with ITU-T G.998.4" indicates which of the various optional OLR mechanisms are supported by the VTU-O in the upstream direction when retransmission is enabled in upstream. The field is coded as [0000 00us], where:

– s=1 if OLR type 5 (SRA modified for ITU-T G.998.4) is supported and s=0 otherwise
– u=1 if OLR type 6 (SOS modified for ITU-T G.998.4) is supported and u=0 otherwise

Field #9 "D_1" indicates the block interleaving depth in the upstream direction on the latency path #1. D_1 shall take a value in the range from 1 to 64 (inclusive). D_1 shall be either equal to 1 or equal to Q.

When retransmission is enabled in the upstream direction, the remaining parameter values exchanged in O-PMS shall keep their original meaning (as defined in [ITU-T G.993.2]), with the following exceptions:

– The fields *F*, *I* and *D* of the of the latency path #1 shall be set to 0 and ignored by the receiver.
– The field max_delay_octet$_{US,0}$ shall specify the maximum value of delay_octet$_{US,0}$ (defined in clause C.1.1).
– The field max_delay_octet$_{US,1}$ shall specify the maximum value of delay_octet$_{US,1}$ (defined in clause C.1.1), specified in bytes as an unsigned integer.

When retransmission is enabled in the downstream direction, the remaining parameter values exchanged in O-PMS shall keep their original meaning (as defined in [ITU-T G.993.2]), with the following exceptions:

– The field max_delay_octet$_{DS,0}$ shall specify the maximum value of delay_octet$_{DS,0}$ (defined in clause C.1.1).
– The field max_delay_octet$_{DS,1}$ shall specify the maximum value of delay_octet$_{DS,1}$ (defined in clause C.1.1), specified in bytes as an unsigned integer. If the value of this field is set to the special value $FFFFFF_{16}$, the field "max_delay_octet$_{DS,0}$" shall indicate the maximum value of (delay_octet$_{DS,0}$ + delay_octet$_{DS,1}$) and the VTU-R shall autonomously partition the number of octets between both downstream latency paths.

C.2.1.4 O-PMD

The O-PMD message conveys the initial PMD parameter settings that shall be used in the upstream direction during Showtime. The ITU-T G.998.4 parameter field of this message is empty (i.e., consist of a single byte with value 00_{16}).

The initialization status reported in field #5 shall be based on the channel initialization policies defined in this Recommendation instead of the policies of [ITU-T G.993.2].

Additionally, if *delay_max* is lower than the actual roundtrip (see clause 8.6), an initialization failure shall be indicated by setting the initialization status to 82_{16} (Configuration not feasible on the line). The actual roundtrip depends on line independent XTU-C and XTU-R characteristics and on line dependent DTU sizes and data rates.

Furthermore, when the VTU-O supports ITU-T G.998.4, the field "initialization status" in O-PMD can take the value 86_{16}, in addition to the valid values listed in [ITU-T G.993.2].

Initialization status shall be set to 86_{16} if ITU-T G.998.4 retransmission mode was not selected while RTX_ENABLE = FORCED.

In case of initialization failure:

– the initialization failure count shall be incremented
– all values in Fields #2 to #4 of O-PMD shall be set to 0, and
– the VTU-O shall return to L3 link state instead of L0 link state at the completion of the initialization procedures.

This failure code shall be generated by the VTU-O.

C.2.2 VTU-R messages

C.2.2.1 R-MSG2

The R-MSG2 message conveys VTU-R capabilities to the VTU-O. The ITU-T G.998.4 parameter field for R-MSG2 shall be structured as shown in Table C.5.

Table C.5 – ITU-T G.998.4 parameter field for R-MSG2

	Field contents	Format	Description
1	Parameter field length	1 byte	Total number of data bytes in ITU-T G.998.4 parameter field (Note 1).
2	Upstream Retransmission support	1 byte [0000 000u]	Indicates support of upstream retransmission at the VTU-R.
3	DTU options	1 byte [0000 0cba]	Indicates the optional framing types supported by the VTU-R transmitter.
4	VTU-R Half-roundtrip Tx	1 byte [00ddssss]	VTU-R transmitter half-roundtrip delay.
5	VTU-R half-roundtrip Rx	1 byte [00ddsssss]	VTU-R receiver half roundtrip delay.
6	US $(1/S)_{max}$	1 byte [0eeeeeee]	Maximum 1/S value supported by the VTU-R in the upstream direction when retransmission is enabled in upstream.
7	DS $(1/S)_{max}$	1 byte [0eeeeeee]	Maximum 1/S value supported by the VTU-R in the downstream direction when retransmission is enabled in downstream.
8	Maximum upstream net data rate	2 bytes	Maximum net data rate supported by the VTU-R in the upstream direction when retransmission is enabled.
9	Upstream D_1 values supported	1 byte [eddddddd]	Indicates the optional block interleaving depth values supported by the VTU-R transmitter
10	Reserved for [ITU-T G.993.5]	3 bytes	Reserved for [ITU-T G.993.5] (see clause D.2.2.1)
11	Support of LPMode Annex E	1 byte [0000 00ab]	Indicates the support of LPMode link sub-states L2.1 and L2.2 in the downstream direction: ab=00 if both L2.1 and L2.2 are not supported ab=01 is reserved for use by the ITU-T ab=10 is reserved for use by the ITU-T ab=11 if both L2.1 and L2.2 are supported

Table C.5 – ITU-T G.998.4 parameter field for R-MSG2

	Field contents	Format	Description
NOTE 1 – If the VTU-R does not support retransmission in either transmission direction, the number of data bytes may be zero.			

Field #1 "Parameter field length" indicates the number of data bytes in the ITU-T G.998.4 parameter field. The data bytes are the bytes following this length indicator byte (i.e., all bytes in the ITU-T G.998.4 parameter field counting from the penultimate byte). This byte is included to allow VTU-Os that do not support ITU-T G.998.4 to still correctly parse R-MSG2.

Field #2 "Retransmission support" indicates the retransmission capabilities of the VTU-R. It shall be coded as a single byte [0000 000u], where:

– u = 0 indicates that retransmission is not supported in the upstream direction.

– u = 1 indicates that retransmission is supported in the upstream direction.

Note that support for downstream retransmission is implied if the VTU-R includes an ITU-T G.998.4 parameter field that has a non-zero number of data bytes in it.

Field #3 "DTU options" indicates which of the optional DTU framing types are supported by the VTU-R transmitter. The field shall be coded as a single byte [0000 0abc], where:

– a = 1 indicates support of DTU Framing type 2 (see clause 8.1.2).

– b = 1 indicates support of DTU Framing type 3 (see clause 8.1.3).

– c = 1 indicates support of DTU Framing type 4 (see clause 8.1.4).

At least one of the bits a, b or c shall be set to 1 when retransmission is supported in the upstream direction.

Field #4 "VTU-R Half-roundtrip Tx" contains the half-roundtrip delay of the VTU-R transmitter. The field shall be coded as a single byte [00ddssss], where:

– ssss is a four-bit number indicating the part of the delay in DMT symbols for the profiles with 4.3125 kHz sub-carrier spacing or in multiple of 2 DMT symbols for the profiles with 8.625 kHz sub-carrier spacing.

– dd is a two-bit number indicating the part of the delay in DTU.

Field #5 "VTU-R Half-roundtrip Rx" contains the half-roundtrip delay of the VTU-R receiver. The field shall be coded as a single byte [00ddssss], where:

– ssss is a four-bit number indicating the part of the delay in DMT symbols for the profiles with 4.3125 kHz sub-carrier spacing or in multiple of 2 DMT symbols for the profiles with 8.625 kHz sub-carrier spacing.

– dd is a two-bit number indicating the part of the delay in DTU.

Field #6 "US $(1/S)_{max}$" contains the maximal $1/S$ value supported by the VTU-R in the upstream direction when retransmission is enabled in upstream. The field shall be coded as an unsigned 8-bit value with a range from 1 to 64 in steps of 1. When retransmission is enabled in upstream, this value supersedes the value of "US $(1/S)_{max}$" exchanged in the PMS-TC capabilities field of R-MSG2.

Field #7 "DS $(1/S)_{max}$" contains the maximal $1/S$ value supported by the VTU-R in the downstream direction when retransmission is enabled in downstream. The field shall be coded as an unsigned 8-bit value with a range from 1 to 64 in steps of 1. When retransmission is enabled in downstream, this value supersedes the value of "DS $(1/S)_{max}$" exchanged in the PMS-TC capabilities field of R-MSG2.

Field #8 "Maximum upstream net data rate" contains the maximal upstream net data rate supported by the VTU-R in upstream when retransmission is enabled in this direction. This field shall be coded as an unsigned 16-bit value with the rate in multiple of 8 kbit/s.

Field #9 "Upstream D_1 values supported" contains the description of the set of upstream block interleaving depth values supported by the VTU-R transmitter. The field shall be coded as a single byte [eddddddd], where:

– ddddddd is a seven-bit unsigned integer indicating the maximum interleaving depth D_1 value supported;

– e is set to 1 to indicate that the VTU-R only supports D_1 values that are an integer power of 2, and set to 0 otherwise.

Field #10 is reserved for [ITU-T G.993.5]. It is a 24-bit field that shall be coded as 000000_{16}.

Field #11 "Support of LPMode Annex E" indicates whether or not the VTU-R supports the LPMode link sub-states L2.1 and L2.2 (as defined in Annex E) in the downstream direction.

When retransmission is enabled, all other parameter values exchanged in R-MSG 2 shall keep their original meaning (as defined in [ITU-T G.993.2]), unless indicated otherwise above.

C.2.2.2 R-PMS

The R-PMS message conveys the initial PMS-TC parameter settings that shall be used in the downstream direction during Showtime. The ITU-T G.998.4 parameter field for R-PMS shall be structured as shown in Table C.6.

If retransmission is not enabled in the downstream direction (as indicated in O-TPS) and OLR is not supported in any direction by the VTU-R, the ITU-T G.998.4 parameter field of R-PMS may be left empty by the VTU-R transmitter (i.e., consist of a single byte with value 0).

Table C.6 – ITU-T G.998.4 parameter field for R-PMS

	Field contents	Format	Description
1	Parameter field length	1 byte	Total number of data bytes in ITU-T G.998.4 parameter field.
2	DTU options	[0000 00aa]	Selected DTU framing type in the downstream direction.
3	Q	1 byte	The number of Reed-Solomon codewords per DTU in the downstream direction.
4	V	1 byte	The number of padding octets per DTU in the downstream direction.
5	Q_{tx}	1 byte	Delay in DTU between two consecutive transmissions of a DTU.
6	*lb*	1 byte	Look-back value used to calculate the values communicated in the RRC carrying the requests for downstream retransmission, i.e., in the RRC transmitted in the upstream direction.
7	Downstream OLR capabilities with ITU-T G.998.4	1 byte	Indicates support in the downstream direction for the various OLR mechanisms when retransmission is enabled in downstream.
8	Upstream OLR capabilities	1 byte	Indicates support in the upstream direction for the various OLR mechanisms when retransmission is enabled in upstream.

Table C.6 – ITU-T G.998.4 parameter field for R-PMS

	Field contents	Format	Description
	with ITU-T G.998.4		
9	D_1	1 byte	Block interleaving depth in the downstream direction.

Field #1 "Parameter field length" indicates the number of data bytes in the field (i.e., counting from the penultimate byte). This field is included to allow a VTU-O that does not support ITU-T G.998.4 to still correctly parse R-PMS.

Field #2 "DTU options" indicates which of the optional DTU framing types shall be used in the downstream direction. The field is coded as [0000 00aa], where:

– aa=00 indicates that DTU framing type 1 (see clause 8.1.1) shall be used.

– aa=01 indicates that DTU framing type 2 (see clause 8.1.2) shall be used.

– aa=10 indicates that DTU framing type 3 (see clause 8.1.3) shall be used.

– aa=11 indicates that DTU framing type 4 (see clause 8.1.4) shall be used.

Field #3 "Q" indicates the number of Reed-Solomon codewords per DTU in the downstream direction. Q shall take a value in the range from 1 to 64 (inclusive).

Field #4 "V" indicates the number of padding octets per DTU in the downstream direction. V shall take a value between 0 and 15 (inclusive).

Field #5 "Q_{tx}" indicates the delay (in number of DTUs) between two consecutive downstream transmissions of the same DTU in the transmitter reference state machine assumed by the VTU-R. Q_{tx} shall take a value in the range from 1 to 64 (inclusive).

Field #6 "*lb*" contains the look-back value used to calculate the values communicated in the RRC carrying the requests for upstream retransmission, i.e., in the RRC transmitted in the downstream direction. "*lb*" shall take values in the range from 1 to 31.

Field #7 "Downstream OLR capabilities with ITU-T G.998.4" indicates which of the various optional OLR mechanisms are supported by the VTU-R in the downstream direction when retransmission is enabled in downstream. The field is coded as [0000 00us], where:

– s=1 if OLR type 5 (SRA modified for ITU-T G.998.4) is supported and s=0 otherwise

– u=1 if OLR type 6 (SOS modified for ITU-T G.998.4) is supported and u=0 otherwise

Field #8 "Upstream OLR capabilities with ITU-T G.998.4" indicates which of the various optional OLR mechanisms are supported by the VTU-R in the upstream direction when retransmission is enabled in upstream. The field is coded as [0000 00us], where:

– s=1 if OLR type 5 (SRA modified for ITU-T G.998.4) is supported and s=0 otherwise

– u=1 if OLR type 6 (SOS modified for ITU-T G.998.4) is supported and u=0 otherwise

Field #9 "D_1" indicates the block interleaving depth in the downstream direction on the latency path #1. D_1 shall take a value in the range from 1 to 64 (inclusive). D_1 shall be either equal to 1 or equal to Q.

When retransmission is enabled in the downstream direction, the remaining parameter values exchanged in R-PMS shall keep their original meaning (as defined in [ITU-T G.993.2]), with the following exceptions:

The fields F, I and D of the of the latency path #1 shall be set to 0 and ignored by the receiver.

C.3 Management plane procedures

C.3.1 Test parameter read commands

Four test parameters have been added to Table 11-27 of [ITU-T G.993.2] as described in Table C.7.

The parameter with ID=41_{16} contains the actual INP against SHINE as derived by the far-end transmitter. It is represented as an unsigned 16-bit integer in multiple of 0.1. This parameter shall be included in the response of a VTU to a single read command if retransmission is enabled in its transmit direction.

The parameter with ID=42_{16} contains the actual INP against REIN as derived by the far-end transmitter. It is represented as an unsigned 8-bit integer in multiple of 0.1. This parameter shall be included in the response of a VTU to a single read command if retransmission is enabled in its transmit direction.

The parameter with ID=43_{16} contains the actual ETR as derived by the far-end receiver. It is represented as an unsigned 32-bit integer in multiple of 1 kbit/s. This parameter shall be included in the response of a VTU to a single read command if retransmission is enabled in its receive direction.

The parameter with ID=44_{16} contains the actual delay as derived by the far-end receiver. It is represented as an unsigned 8-bit integer in multiple of 1 ms. This parameter shall be in the response of a VTU to a single read command if retransmission is enabled in its receive direction.

Table C.7 – Additional PMD test parameter ID values and length of responses

Test parameter ID	Test parameter name	Length for Single Read (octets)	Length for Multiple Read (octets)	Length for Block Read (octets)
41_{16}	Far-end RTX Transmitter Actual Impulse Noise protection against SHINE (INP_act_SHINE)	2 octets	n/a	n/a
42_{16}	Far-end RTX Transmitter Actual Impulse Noise protection against REIN (INP_act_REIN)	1 octet	n/a	n/a
43_{16}	RTX Receiver Expected Throughput (ETR)	4 octets	n/a	n/a
44_{16}	RTX Receiver Actual Delay (*delay_act_RTX*)	1 octet	n/a	n/a

C.3.1.2 Management counter read commands and responses

Replace Table 11-16 of [ITU-T G.993.2] and Table 11-17 of [ITU-T G.993.2] with Table C.8 and Table C.9, respectively.

The field "*EFTR_min*" contains the *EFTR_min* as derived by the far-end receiver. It is represented as an unsigned 32-bit integer in multiple of 1 kbit/s. This field shall be present in the response from the VTU if retransmission is enabled in its receive direction. Although this parameter is reported via the management counter eoc commands, this performance monitoring parameter is not a counter. Therefore, the requirements of [ITU-T G.993.2] and [ITU-T G.997.1] applicable to counters in general do not apply to this parameter.

Table C.8 – Management counter read responses sent by the responding VTU

Name	Length (Octets)	Octet number	Content
ACK	variable	2	81_{16} (Note 1)
		3 to 2 + 4 × *Nc*	octets for all of the PMS-TC counter values (Note 2)
		3 + 4 × 13 and above	octets for all of the TPS-TC counter values (Note 2)
NOTE 1 – All other values for octet number 2 are reserved by the ITU-T. NOTE 2 – N_C is the number of counters for the PMS-TC. N_C = 14 if retransmission is enabled only in the receive direction. N_C = 8 if retransmission is enabled only in the transmit direction. *Nc* = 15 if retransmission is enabled in both directions, *Nc*=7 if retransmission is disabled in both directions.			

Table C.9 – VTU management counters

PMS-TC counters
Counter of the FEC-0 anomalies (Note 1)
Counter of the FEC-1 anomalies (Note 1)
Counter of the CRC-0 anomalies (Note 1)
Counter of the CRC-1 anomalies (Note 1)
Counter of rtx-tx (Note 3)
Counter of rtx-c (Note 2)
Counter of rtx-uc (Note 2)
FEC errored seconds counter
Errored seconds counter
Severely errored seconds counter
los errored seconds counter
Unavailable errored seconds counter
Counter of "leftr" defect seconds (Note 2)
Counter of error free bits (Note 2)
EFTR_min (Note 2)
TPS-TC counters
Counters for TPS-TC #0
NOTE 1 – If reported for a direction where retransmission is enabled, the VTU shall include the fields of the FEC and CRC anomalies for the latency path #0 and #1; the FEC and CRC for the latency path #0 shall be vendor discretionary. If reported for a direction where retransmission is disabled, the VTU shall include only the fields of the FEC and CRC anomalies for the latency path #0. NOTE 2 – These counters shall be included if the report is from a VTU with retransmission enabled in the receiver. NOTE 3 – This counter shall be included if the report is from a VTU with retransmission enabled in the transmitter.

C.3.1.3 Diagnostic commands and responses

Replace Table 11-8 of [ITU-T G.993.2] with Table C.10.

Table C.10 – Diagnostic commands sent by the VTU-O

Name	Length (Octets)	Octet number	Content
Perform Self-test	2	2	01_{16} (Note)
Update Test Parameters	2	2	02_{16} (Note)
Start TX Corrupt CRC	2	2	03_{16} (Note)
End TX Corrupt CRC	2	2	04_{16} (Note)
Start RX Corrupt CRC	2	2	05_{16} (Note)
End RX Corrupt CRC	2	2	06_{16} (Note)
Enter RTX_TESTMODE	2	2	07_{16} (Note)
Leave RTX_TESTMODE	2	2	08_{16} (Note)
NOTE – All other values for octet number 2 are reserved by the ITU-T.			

C.3.1.3.1 Retransmission test mode

A special test mode is defined for accelerated testing of the MTBE (see clause 10.4). A diagnostic command is defined to enter or leave the mode during Showtime.

Upon reception of the Enter RTX_TESTMODE command, the VTU-R shall acknowledge it with an ACK response. Afterwards, the VTU-R shall acknowledge all received DTUs if retransmission is enabled in the downstream direction and shall stop retransmitting any DTU if retransmission is enabled in upstream.

Upon reception of the Leave RTX_TESTMODE command, the VTU-R shall resume the normal behaviour of retransmission in the direction where it is enabled.

C.3.2 On-line reconfiguration (OLR) commands and responses

ITU-T G.998.4 defines two new OLR commands for ITU-T G.993.2. These OLR commands shall replace the OLR Request type 3 (SRA) and OLR Request type 4 (SOS) when retransmission is enabled. They are designated in [ITU-T G.993.2] as OLR Request types 5 and 6 respectively and are fully defined below in Table C.11. In addition, two new OLR responses are defined, corresponding to OLR Request types 5 and 6. These messages are defined in Table C.12.

When SRA and retransmission are simultaneously enabled, the modems shall use OLR Request type 5 to initiate an SRA request and OLR response type 5 to reject an SRA request. When SOS and retransmission are simultaneously enabled, the modems shall use OLR Request type 6 to initiate an SOS request and OLR response type 6 to reject an SOS request.

The first byte of the eoc messages defined in Table C.11 and Table C.12 is the value of the OLR command type, as defined in clause 11.2.3.2 of [ITU-T G.993.2]. The eoc protocol is identical to the one specified in clause 11.2.3 of [ITU-T G.993.2].

In every OLR request of type 5, the new framer settings shall be selected such that all configuration constraints are met as well as the maximum number of bytes reserved for the upstream and downstream transmitter retransmission queue as selected during initialization.

In every OLR request of type 6, the new framer settings shall be selected such that all configuration constraints, except those defined for SOS in [ITU-T G.993.2], are met as well as the maximum number of bytes reserved for the upstream and downstream transmitter retransmission queues as selected during initialization.

If the block interleaver (see clause 9.2) is supported in the direction of the OLR of type 5 or 6, the most significant bit of the octet containing the new *Q* value indicates if the new interleaver depth is equal to 1 or *Q*. If the msb is set to 0, the new block interleaver depth *D* shall be equal 1. If the msb is set to 1, the new block interleaver depth *D* shall be equal to *Q*.

Table C.11 – OLR commands sent by the initiating VTUName

<table>
<tr><th></th><th>Length (octets)</th><th>Octet number</th><th colspan="2">Content</th><th>Support</th></tr>
<tr><td rowspan="13">Request type 5 (SRA/ ITU-T G.998.4)</td><td rowspan="13">14+4 N_f ($N_f \leq 128$)</td><td>2</td><td colspan="2">08_{16}</td><td rowspan="13">Optional</td></tr>
<tr><td>3-4</td><td colspan="2">two octets containing the new value for L_1</td></tr>
<tr><td>5</td><td colspan="2">one octet containing the new value for B_{10}</td></tr>
<tr><td>6</td><td colspan="2">one octet containing the new value for M_1</td></tr>
<tr><td>7</td><td colspan="2">one octet containing the new value for R_1</td></tr>
<tr><td>8</td><td colspan="2">one octet containing the new value for Q</td></tr>
<tr><td>9</td><td colspan="2">one octet containing the new value for V</td></tr>
<tr><td>10</td><td colspan="2">one octet containing the new value for Q_{tx}</td></tr>
<tr><td>11</td><td colspan="2">one octet containing the new value for *lb*</td></tr>
<tr><td>12 – 13</td><td colspan="2">2 octets for the number of sub-carriers N_f to be modified</td></tr>
<tr><td>14 – 13+4 N_f</td><td colspan="2">4 N_f octets describing the sub-carrier parameter field for each sub-carrier</td></tr>
<tr><td>14+4 N_f</td><td colspan="2">1 octet for Segment Code (SC)</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td rowspan="9">Request type 6 (SOS/ ITU-T G.998.4)</td><td rowspan="9">$N_{TG}/2+12$</td><td>2</td><td colspan="2">09_{16}</td><td rowspan="9">Optional</td></tr>
<tr><td>3</td><td colspan="2">Message ID</td></tr>
<tr><td rowspan="4">4 to $N_{TG}/2+3$</td><td>$\Delta b(2)$</td><td>$\Delta b(1)$</td></tr>
<tr><td>$\Delta b(4)$</td><td>$\Delta b(3)$</td></tr>
<tr><td>…</td><td></td></tr>
<tr><td>$\Delta b(N_{TG})$</td><td>$\Delta b(N_{TG} - 1)$</td></tr>
<tr><td>$N_{TG}/2+4$ to $N_{TG}/2+5$</td><td colspan="2">two octets containing the new value for L_1</td></tr>
<tr><td>$N_{TG}/2+6$</td><td colspan="2">one octet containing the new value for B_{10}</td></tr>
<tr><td>$N_{TG}/2+7$</td><td colspan="2">one octet containing the new value for M_1</td></tr>
</table>

Table C.11 – OLR commands sent by the initiating VTUName

	Length (octets)	Octet number	Content	Support
		$N_{TG}/2+8$	one octet containing the new value for R_1	
		$N_{TG}/2+9$	one octet containing the new value for Q	
		$N_{TG}/2+10$	one octet containing the new value for V	
		$N_{TG}/2+11$	one octet containing the new value for Q_{tx}	
		$N_{TG}/2+12$	one octet containing the new value for *lb*	

Table C.12 – OLR responses sent by the responding VTU

Name	Length (octets)	Octet number	Content	Support
Reject type 5 Request	3	2	85_{16} (Note)	Optional
		3	1 octet for reason code (Table 11-7)	
Reject type 6 Request	3	2	86_{16} (Note)	Optional
		3	1 octet for reason code (Table 11-7)	
NOTE – All other values for octet number 2 are reserved by ITU-T.				

C.3.3 OLR receiver initiated procedure

If a VTU receiver initiates a reconfiguration, it computes the necessary change in the related parameters (e.g., bits and gains table) and requests this change in the transmit PMD function of the VTU at the other end of the line. After it receives a positive acknowledgment, as specified in clause 11.2.3.3 of [ITU-T G.993.2], the VTU shall change the relevant control parameters of its own receive PMD function and the PMS-TC function at the time specified in clause C.4.

A VTU receiver may initiate an OLR type 1 (Bit Swapping). A bit swap request shall change only the bits and gains table. It shall not modify the *L* value. Bit swapping reconfigurations involve changes of only the PMD sub-layer configuration parameters. They do not change the TPS-TC and PMS-TC sub-layer configuration parameters.

The transmit PMD function shall support bit swaps requested by the receive PMD function.

If OLR type 5 (SRA) is supported (in downstream or upstream direction, respectively), and enabled (through RA-MODE=3), a VTU receiver shall initiate an SRA when the conditions in clause C.3.3.1 or clause C.3.3.2 are satisfied.

If OLR type 5 (SRA) is supported (in downstream or upstream direction, respectively), and enabled (through RA-MODE=4), a VTU receiver shall initiate an SRA when the conditions in clause C.3.3.1, clause C.3.3.2, or clause C.3.3.3 are satisfied. A VTU receiver may initiate a SRA when the conditions in clause C.3.3.4 are satisfied.

If OLR type 6 (SOS) is supported (in downstream or upstream direction, respectively), and enabled (through RA-MODE=4), a VTU receiver shall initiate an SOS when the conditions in clause C.3.3.3 are satisfied.

A VTU receiver shall only send OLR request commands that meet all of following constraints:

– Impulse noise protection at least against a combined threat of worst-case REIN impulses as described by the CO MIB parameters INPmin_REIN and IAT_REIN_flag and of worst-case SHINE impulses as described by the CO MIB parameter INPmin.
– Minimum delay ≤ Delay ≤ Maximum delay.

A VTU receiver shall only send SOS requests that meet the following constraint:

– Expected throughput (*ETR*) ≥ Minimum SOS net data rate (MIN-SOS-BR) for the bearer channel.

NOTE 1 – Due to framing parameter range constraints it may not be possible to decrease ETR down to MIN-SOS-BR.

NOTE 2 – An SOS request could result in a message overhead data rate that is temporarily below the configured minimum message overhead data rate. This will be corrected by a subsequent SRA procedure. See clause 13.4.3.3 of [ITU-T G.993.2].

A VTU receiver shall only send SRA requests that meet the following constraints:

– $ETR\_max \geq ETR \geq ETR\_min$ for the bearer channel, unless the actual net data rate is below the minimum net data rate as a result of an SOS procedure. In that case, SRA is only allowed to ask for rate increases, but the requested *ETR* is allowed to be below *ETR_min* .
– Message overhead data rate ≥ Minimum message overhead data rate.

C.3.3.1 Receiver initiated SRA downshift procedure

See clause 13.4.1 of [ITU-T G.993.2].

C.3.3.2 Receiver initiated SRA upshift procedure

See clause 13.4.2 of [ITU-T G.993.2].

C.3.3.3 Receiver initiated SOS

See clause 13.4.3 of [ITU-T G.993.2].

C.3.3.4 Receiver initiated SRA following an SOS procedure

A VTU shall send one or more SRA requests following an SOS procedure to remediate the situation in which the current *ETR* is less than *ETR_min*. As long as the current *ETR* is less than *ETR_min*, these SRA requests are not required to respect either RA-UTIME or RA-USNRM.

NOTE – Although these SRA requests can be issued at the discretion of the VTU, the NOTE in clause 13.1 of [ITU-T G.993.2] defines a goal for the overall duration of the SOS procedure.

C.4 Timing of changes in control parameters

This clause specifies the timing of changes for the parameters included in OLR types 5 and 6. The timing of the changes in the values of the various control parameters shall be done per the procedure defined in clause 13.2.

NOTE – After the change in RS and DTU parameters, DTUs that were encoded with the old parameter values can no longer be retransmitted. The modems should try to ensure that all DTUs that were encoded with the old framing parameters have been correctly received before the changes in framing parameters are executed. This may be done by temporarily interrupting the transmission of new DTUs over the α_1 interface and autonomously retransmitting only DTUs from the retransmission queue for a suitable period of time. This period of time shall not exceed $T_{DTU\text{-}Stoppage}$.

For all the used tones in an SOS tone group *k*, the same b_i reduction $\Delta b(k)$ is applied, except for tones that belong to the ROC. Specifically, the new $b_i'=b_i-\Delta b(k)$. If the new b_i' value is <2, it shall be set to 0. Thus, no new 1-bit loading will be created in SOS. If the resulting b_i' contains an odd number of 1-bit constellation points and trellis is enabled, the last (according to reordered tone ordering table) 1-bit constellation should be set to $b_i'=0$.

If SOS is supported, single step SOS is a mandatory capability. The VTU-O shall set O-MSG 1 field #14 and field #15 to 00_{16}. The VTU-R shall set R-MSG 2 field #5 and field #6 to 00_{16}. Execution of the SOS request in multiple steps is for further study.

After it has received an SOS request, the VTU shall respond within 200 ms with either a Syncflag or a reject type 6 invalid parameters response (see Table 11-7 of [ITU-T G.993.2]).

During the transition of OLR type 6 in a single step, bit errors may occur. Once the transition is completed, the VTU shall operate at a BER not exceeding the nominal BER, unless the line conditions do not allow it.

Annex D

Support of ITU-T G.998.4 with ITU-T G.993.5

(This annex forms an integral part of this Recommendation.)

Operation according to this Annex D can be activated in 2 ways:

– If ITU-T G.993.5 vectoring is selected (as indicated in the ITU-T G.994.1 MS message), then operation of ITU-T G.998.4 shall comply with this Annex D.

– If the ITU-T G.998.4 extension "G.998.4 Annex D support" NPar(3) is set to ONE (see Table 11.68.11 of ITU-T G.994.1), then operation of ITU-T G.998.4 shall comply with this Annex D.

Annex D is defined relative to Annex C. All requirements of Annex C apply, with the replacements and supplements as identified in this Annex D.

D.1.1 Memory (replaces clause C.1.1)

The following definitions shall apply:

$$\text{delay\_octet}_{\text{DS},0} = (D_{DS,0} - 1) \times (I_{DS,0} - 1)$$

$$\text{delay\_octet}_{\text{US},0} = (D_{US,0} - 1) \times (I_{US,0} - 1).$$

If retransmission is enabled in the downstream direction,

then $\text{delay\_octet}_{\text{DS},1} = 2 \times Q_{tx,DS} \times Q_{DS} \times H_{DS}$

otherwise $\text{delay\_octet}_{\text{DS},1} = (D_{DS,1} - 1) \times (I_{DS,1} - 1)$

If retransmission is enabled in the upstream direction,

then $\text{delay\_octet}_{\text{US},1} = 2 \times Q_{tx,US} \times Q_{US} \times H_{US}$

otherwise $\text{delay\_octet}_{\text{DS},1} = (D_{US,1} - 1) \times (I_{US,1} - 1)$

The AGGDELAYOCTET is defined as:

$$\text{AGGDELAYOCTET} = \text{delay\_octet}_{\text{DS},0} + \text{delay\_octet}_{\text{DS},1} + \text{delay\_octet}_{\text{US},0} + \text{delay\_octet}_{\text{US},1}$$

The following constraint shall apply:

$$\text{AGGDELAYOCTET} \leq \text{MAXDELAYOCTET\_ext}.$$

If the MAXDELAYOCTET_ext_R (as indicated by the VTU-R in R-MSG 2, see clause C.2.2.1) is greater than MAXDELAYOCTET (the parameter "aggregate interleaver and de-interleaver delay", in octets, specified in Table 6-1 of [ITU-T G.993.2] for the profile) then extended memory operation shall be enabled with MAXDELAYOCTET_ext equal to the minimum of MAXDELAYOCTET_ext_R (defined in clause C.1.1.1) and MAXDELAYOCTET_ext_O (defined in clause C.1.1.1). Otherwise extended memory operation shall be disabled, with MAXDELAYOCTET_ext equal to MAXDELAYOCTET.

NOTE – Since the VTU-O controls the splitting of the MAXDELAYOCTET_ext octets over upstream and downstream (see clause C.2.1.3), the MAXDELAYOCTET_ext_O value does not need to be communicated from the VTU-O to the VTU-R.

Moreover, the following constraint shall apply on the memory allocated for the interleavers:

– If retransmission is enabled in both directions:

$$\text{delay\_octet}_{\text{DS},0} + \text{delay\_octet}_{\text{US},0} \leq \text{MAXDELAYOCTET}.$$

– If retransmission is enabled only in downstream direction:

$$\text{delay\_octet}_{\text{DS},0} + \text{delay\_octet}_{\text{US},0} + \text{delay\_octet}_{\text{US},1} \leq \text{MAXDELAYOCTET}.$$

– If retransmission is enabled only in the upstream direction:

$$delay\_octet_{DS,0} + delay\_octet_{DS,1} + delay\_octet_{US,0} \leq MAXDELAYOCTET.$$

The VTU-O and VTU-R shall support all values of $delay\_octet_{DS,0}$, $delay\_octet_{DS,1}$, $delay\_octet_{US,0}$, and $delay\_octet_{US,1}$ such that both of the above constraints are met. The minimum amount of memory required in a transceiver (VTU-O or VTU-R) to meet this requirement is $\frac{MAXDELAYOCTET\_ext}{2}$ octets. The actual amount of memory used is implementation specific.

The minimum memory for the receiver retransmission queue shall be identical to the amount of the memory for the related transmit queue of the same direction.

The maximal DTU size in octets ($Q \times H$) shall be equal to the value given in Table D.1 depending on the profile and direction.

Table D.1 – Maximal DTU size

Profile	Maximal DTU size (*Q*×*H*)	
	Downstream	Upstream
8a,8b,8c,8d	2048 bytes	512 bytes
12a	2048 bytes	1536 bytes
17a	3072 bytes	1536 bytes
30a	3072 bytes	3072 bytes

The MAXDELAYOCTET-split (MDOSPLIT) configuration parameter shall be applied in ITU-T G.998.4 to the MAXDELAYOCTET_ext. With $delay\_octet_{x,p}$ (with x = DS or US and p = 0 or 1) as defined in this clause, the sum of the max_delay_octet values specified in O-PMS (see clause C.2.1.3) shall be limited to (see clause 11.4.2.7 of [ITU-T G.993.2]):

$$max\_delay\_octet_{DS,0} + max\_delay\_octet_{DS,1} \leq MAXDELAYOCTET\_DS,$$

$$max\_delay\_octet_{US,0} + max\_delay\_octet_{US,1} \leq MAXDELAYOCTET\_US.$$

with $MAXDELAYOCTET\_DS = \lceil MDOSPLIT \times MAXDELAYOCTET\_ext \rceil$,

$MAXDELAYOCTET\_US = MAXDELAYOCTET\_ext - MAXDELAYOCTET\_DS$,

and $\lceil x \rceil$ denoting rounding to the higher integer.

D.1.1.1 Extended memory operation for enhanced net data rates with ITU-T G.993.5 (vectoring) (new clause)

The reference half roundtrip (HRT_{ref}) values for determining AggAchievableNDR_O and AggAchievableNDR_R are the following:

– Profile 17a: HRT_{ref} = 8 DMT symbols (2 ms)

– Profile 30a: HRT_{ref} = 12 DMT symbols (1.5 ms)

The maximum aggregate achievable net data rate (MaxAggAchievableNDR) for each profile, are the following:

– Profile 17a = 150 Mbit/s

– Profile 30a = 250 Mbit/s

The above values may be used for provisioning the amount of memory in the VTU based on knowledge of the VTU's actual half roundtrip value (HRT_{VTU}) and the reference half roundtrip (HRT_{ref}) assumed for the far-end VTU.

If the VTU-O

– has actual half roundtrips expressed in symbols ≤ HRT_{ref} , i.e., $HRT_{rx}^{S} \leq HRT_{ref}$, and HRT_{tx}^{S} ≤ HRT_{ref} and,

– has actual half roundtrips computed in DTU equal to 0, i.e., HRT_{rx}^{D} =0, and HRT_{tx}^{D} =0 and,

– aligns the sync symbols in the direction of DTU transmission with the sync symbols in the RRC direction in a range from $-HRT_{rx}^{S} + \lfloor Q \times S_1 \rfloor$ to $HRT_{tx}^{S} - 1$ DMT symbols, where a positive value indicates that the sync symbol in the direction of DTU transmission is sent after the sync symbol in the RRC direction,

then for a given value of AGGDELAYOCTET supported in the VTU-O (denoted as MAXDELAYOCTET_ext_O), the AggAchievableNDR_O shall be computed as follows:

$$AggAchievableNDR\_O(\text{kbit/s}) = \min\left(\frac{8\,(\text{bits/byte}) \times \text{MAXDELAYOCTET\_ext\_O (bytes)}/2}{(HRT_{VTU-O}^{S} + HRT_{ref} + 1)/\text{f}_{\text{DMT}}\text{ (kHz)}}, MaxAggAchievableNDR\right),$$

with HRT_{VTU-O}^{S} being the highest of the VTU-O's actual half roundtrips HRT_{tx}^{S} and HRT_{rx}^{S}. Otherwise, the AggAchievableNDR_O shall be undefined.

If the VTU-R

– has actual half roundtrips expressed in symbols ≤ HRT_{ref} , i.e., $HRT_{rx}^{S} \leq HRT_{ref}$, and HRT_{tx}^{S} ≤ HRT_{ref} and,

– has actual half roundtrips computed in DTU equal to 0, i.e., HRT_{rx}^{D} =0, and HRT_{tx}^{D} =0,

then for a given value of AGGDELAYOCTET supported in the VTU-R (denoted as MAXDELAYOCTET_ext_R), the AggAchievableNDR_R shall be computed as follows:

$$AggAchievableNDR\_R(\text{kbit/s}) = \min\left(\frac{8\,(\text{bits/byte}) \times \text{MAXDELAYOCTET\_ext\_R (bytes)}/2}{(HRT_{VTU-R}^{S} + HRT_{ref} + 1)/\text{f}_{\text{DMT}}\text{ (kHz)}}, MaxAggAchievableNDR\right),$$

with HRT_{VTU-R}^{S} being the highest of the VTU-R's actual half roundtrips HRT_{tx}^{S} and HRT_{rx}^{S}. Otherwise, the AggAchievableNDR_R shall be undefined.

The AggAchievableNDR_O shall be reported in the CO-MIB asAGGACHNDR_NE. The AggAchievableNDR_R shall be reported in the CO-MIB asAGGACHNDR_FE. A special value shall be reported to indicate that the AggAchievableNDR is undefined.

NOTE 1 – Some transceiver designs may choose to implement additional memory or lower HRT to potentially support net data rates that are greater than the above MaxAggAchievableNDR values. If the actual memory used in Showtime is sufficiently large or the actual roundtrip in Showtime is sufficiently small, then net data rates greater than MaxAggAchievableNDR may be achieved.

NOTE 2 – The above calculation assumes that the DTU is configured within one DMT symbol. If this or other conditions are not satisfied, then the actual aggregate NDR may be less than the minimum of AggAchievableNDR_O and AggAchievableNDR_R.

NOTE 3 – The following is an example:

- To support MaxAggNDR for profile 17a, transceiver A has an actual half roundtrip value of $HRT^S = 8$ DMT symbols. To support the profile 17a MaxAggNDR value of 150 Mbit/s, the transceiver needs 79,688 bytes of memory under the assumption that far-end transceiver has an *HRT* no higher than the HRT_{ref} of 2 ms.
- Transceiver B has an actual half roundtrip value of $HRT^S = 7$ DMT symbols. To support the MaxAggNDR of 150 Mbit/s, this transceiver needs 75,000 bytes of memory.
- If transceivers A and B were to interoperate with each other, then operation at 150 Mbit/s NDR would be achieved, assuming that the line conditions permit.

D.1.3.3 ATTNDR_MAXDELAYOCTET-split (ATTNDR_MDOSPLIT) (supplements clause C.1.3.3)

See clause 11.4.2.8 of [ITU-T G.993.2], with:

ATTNDR_MAXDELAYOCTET_DS = ⌈ATTNDR_MDOSPLIT × MAXDELAYOCTET_ext⌉,

ATTNDR_MAXDELAYOCTET_US = MAXDELAYOCTET_ext – ATTNDR_MAXDELAYOCTET_DS

and ⌈x⌉ denoting rounding to the higher integer.

D.2.2.1 R-MSG 2 (supplements clause C.2.2.1)

Replace field #10 of Table C.5 with field definition as follows:

Table C.5 – ITU-T G.998.4 parameter field for R-MSG2

	Field content	Format	Description
10	MAXDELAYOCTET_ext_R	3 bytes	Value of AGGDELAYOCTET supported in the VTU-R for extended memory operation

Field #10 "MAXDELAYOCTET_ext_R" is a 3 octet field that indicates the value of AGGDELAYOCTET supported in the VTU-R (see clause C.1.1.1) for extended memory operation (see clause C.1.1). This field shall be coded as an unsigned 24-bit integer representing the value in multiples of 1 octet.

Annex E

VDSL2 low power mode operation

(This annex forms an integral part of this Recommendation.)

E.1 Scope

This annex defines the optional low power mode (LPMode) operation with [ITU-T G.993.2] and [ITU-T G.993.5]. When both VTUs are operating according to this annex, the link is in the L2 link state. Two link sub-states related to LPMode operation are defined, referred to as L2.1 and L2.2, each with different Quality-of-Service (QoS) levels. The LPMode operation does not prohibit the use of [ITU-T G.993.5] and does not require the use of [ITU-T G.993.5].

E.2 Functionality

To facilitate LPMode, this annex defines a set of power management states for the VDSL2 link and the use of eoc messages to coordinate power management between the VTUs. Power reduction can be achieved by minimizing the energy transmitted by the VTU onto the U reference point as well as by reducing the power consumed by the VTUs (e.g., reducing clock speed, number of used subcarriers, turning off line drivers). [ITU-T G.993.2] defines a set of VDSL2 link states (i.e., the L0 and L3 link states) between the VTU-R and VTU-O by specifying the signals that are active on the link in each state, the link transition events and associated procedures. LPMode in a particular link is achieved by transitioning the link from the L0 link state into the LPMode link state (referred to as the L2 link state), with two link sub-states L2.1 (defined in clause E.2.1) and L2.2 (defined in clause E.2.2), each with different levels of power saving, different QoS levels and procedures to enter and exit these link sub-states.

The details of the VTU coordination with system power management functions are outside the scope of this Recommendation.

For a particular direction of transmission, the transmitting VTU determines the need for transitions into the L2.1 and L2.2 link sub-states through primitives sent by the near-end VME. The higher layer function at the transmitting VTU determines the need for transition out of the L2.1 and L2.2 link sub-states. The VTU is instructed to transition out of the L2.1 and L2.2 link sub-states through primitives sent by the higher layer function to the near-end VME. The receiving VTU receives the primitives through eoc messages from the far-end VME. Transitions into and out of the L2.1 and L2.2 link sub-states are controlled by the near-end VME setting control variables for the near-end TPS-TC, PMS-TC and PMD functions as well as sending eoc messages to the far-end VME.

The LPMode functionality defined in this annex is an optional capability for both the VTU-O and the VTU-R. If a VTU supports LPMode operation according to this annex, the VTU shall support downstream LPMode operation as defined for the L2.1 link sub-state in clause E.3.1 and the L2.2 link sub-state in clause E.3.2. Upstream LPMode operation is for further study.

During the initialization phase (see messages O-MSG 1 in Table C.2, R-MSG 2 in Table C.5 and O-TPS in Table C.3), it is determined based on the VTU-O capabilities, the VTU-R capabilities and the CO-MIB configuration parameters (see Table E.1), whether the particular LPMode operation is enabled or disabled. LPMode operation can be enabled or disabled, separately for upstream and downstream and separately for the L2.1 and L2.2 link sub-states. If the L2.1 link sub-state is disabled in a particular direction, then the L2.2 link sub-state shall also be disabled.

If a VTU supports LPMode operation according to this annex, the VTU shall support SNRM_MODE = 5 (see clause 11.4.1.1.6.1.5 of [ITU-T G.993.2]). The VTU-O may send the SAVN-Update command during L0 link state, between the L2.1 entry steps and during L2.1 steady-state operation (i.e., after the last step of the L2.1 entry procedure is completed). The VTU-O shall not send the SAVN-Update command during the L2.1 entry step, during the exit from L2.1 link sub-state into L0 link state and during OLR procedures associated with change of the bit loading or framing parameters in the downstream direction in either L0 or L2.1 steady-state operation.

E.3 Link states and link state diagram

This clause amends clause 12.1.1 of [ITU-T G.993.2] with the L2 link state and L2.1 and L2.2 link sub-states.

The VDSL2 link states and activation/deactivation procedures diagram is illustrated in Figure E.1.

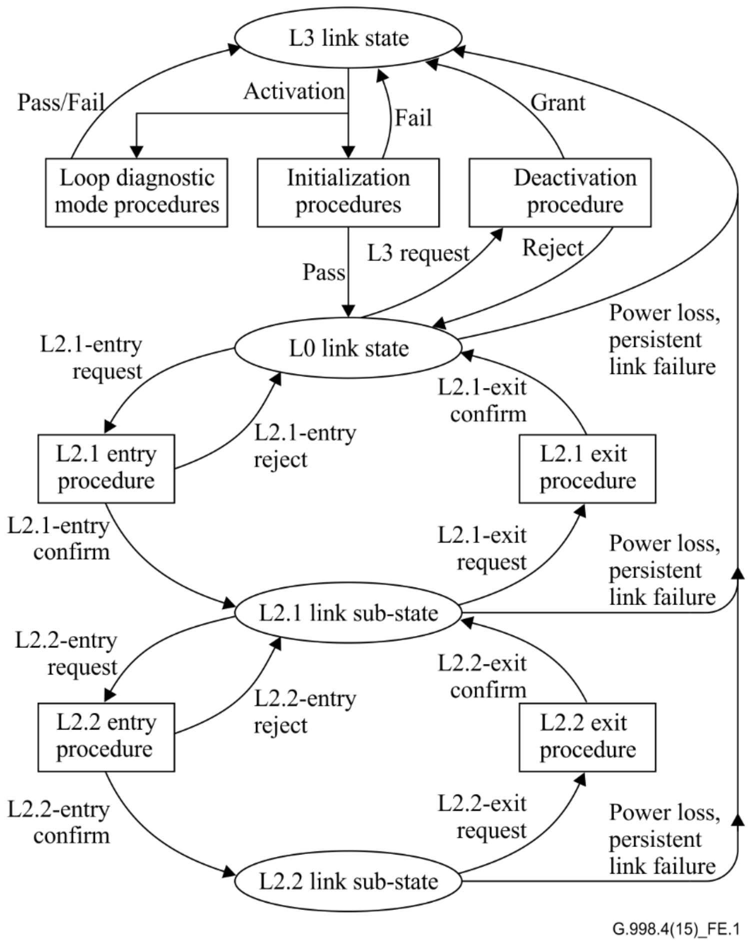


Figure E.1 – VDSL2 link states and link state diagram

Figure E.1 shows three link states (L0, L2 and L3), with the L2 link state consisting of the two link sub-states L2.1 and L2.2 and also shows the procedures that facilitate transitions from one link state to another. The link states are shown in rounded boxes, whilst the procedures are shown as rectangular boxes.

The L3 link state is the link state where the VTU is provisioned through a management interface for the service defined by the operator. In this link state, both the VTU-O and VTU-R do not transmit any signal.

The L0 link state is the link state achieved after the initialization procedure has been completed successfully by both VTUs. In the L0 link state, the link transports user information with performance characteristics according to the CO-MIB configuration. When the link is in the L0 link state, both the VTU-O and VTU-R are in the Showtime transceiver state.

The L2 link state is represented by two link sub-states, L2.1 and L2.2. Link sub-state L2.1 is defined in clause E.3.1 and link sub-state L2.2 is defined in clause E.3.2. When the link is in either of the L2 link sub-states, both the VTU-O and VTU-R are in the Showtime transceiver state.

A procedure for a direct exit from L2.2 to L0 is not defined. An exit from L2.2 to L0 shall consist of an L2.2 exit to L2.1 (i.e., L2.2 exit procedure) followed by an L2.1 exit to L0 (i.e., L2.1 exit procedure). Similarly, a procedure for a direct entry from L0 to L2.2 is not defined. An entry from L0 to L2.2 shall consist of an entry from L0 to L2.1 (i.e., L2.1 entry procedure) followed by an entry from L2.1 to L2.2 (i.e., L2.2 entry procedure).

The VTU may apply a vendor discretionary flow control during the L2.1 and L2.2 link sub-states and during transition periods into and out of the L2.1 and L2.2 link sub-states. The applied flow control towards the upper layers shall ensure that the data rate at the gamma reference point is not higher than the data rate that can be carried over the U reference point.

Figure E.2 shows an example of PSD level trims in L2 link state transitions. The L2.1 entry procedure (see clause E.3.1.1) may consist of one or more steps, with each step executing one PSD level trim down. The L2.1 exit procedure (see clause E.3.1.2) may consist of one or more steps, with each step executing one PSD level trim up. The transition from L2.1 into L2.2 and back is a one-step transition (for each case).

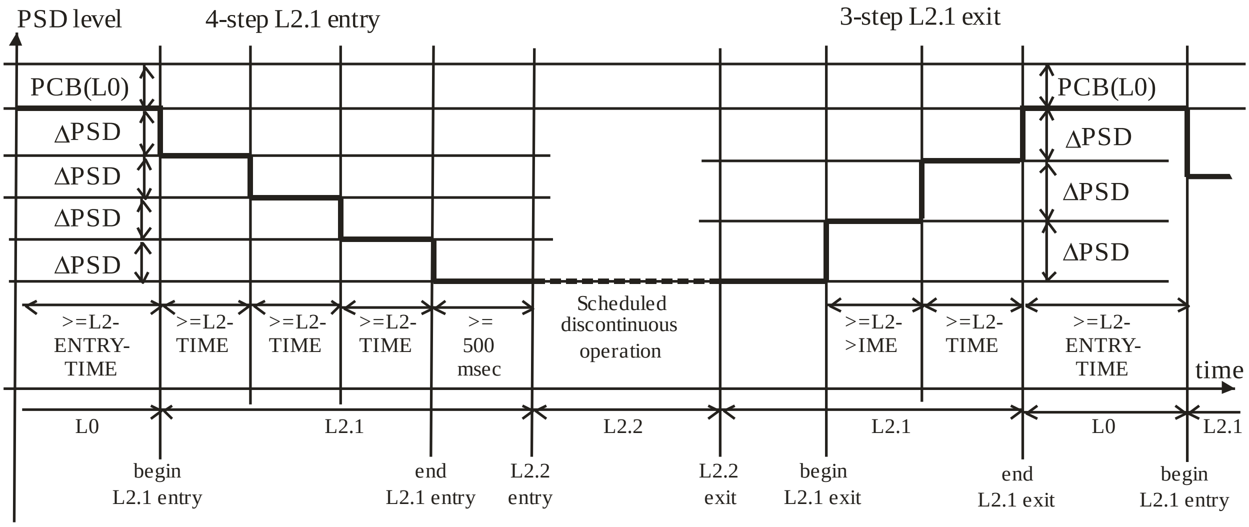


Figure E.2 – Example of PSD level trims in L2 link state transitions

E.3.1 Link sub-state L2.1

The main applications for the LPMode operation in the L2.1 link sub-state are the transport of VoIP (POTS level) and keep-alive data. For LPMode operation in the L2.1 link sub-state, the power scaling technique is based on reduction of the transmit power on all or on a subset of the sub-carriers, keeping continuous transmission of symbols. The transmit power may be reduced by reducing the number of active sub-carriers, or by reducing the transmit power per sub-carrier (PSD reduction), or both.

With the link in the L2.1 link sub-state, the VTUs shall track channel changes (e.g., noise variations) through on-line reconfiguration (OLR, see clause E.3.1.3).

With the link in the L2.1 link sub-state, the TPS-TC (see clause 7), the retransmission functions (see clause 8), the PMS-TC (see clause 9) and the PMD (see clause 10) characteristics and the management functions (see clause 13) shall apply with the following differences:

– the *ETR_min* and *ETR_max* (see clause 7.1.1) do not apply. The L2.1 specific ETR bounds are configured through the CO-MIB (see clause E.4);

– the *INP_act_SHINE* (see clause 11.2.3) may be less than *INP_min* (see clause 7.1.1) and may be as low as 0, while *INP_act_REIN* (see clause 11.2.4) shall be no less than *INP_min_rein* (see clause 7.1.1);

– the *delay_act_RTX* (see clause 11.2.5):

  - shall be less than max(6 ms, *delay_max*);

– the *msg* (see clause 9.5.4 of [ITU-T G.993.2]) shall be set to at least 64 kbit/s in both directions. The msg shall be configured through the CO-MIB parameter *MSGmin*;

– the *TARSNRM*, *MAXSNRM, and SNRMOFFSET-ROC* (Note) do not apply. L2 specific SNRM bounds are configured through the CO-MIB (see clause E.4).

NOTE – Implementers should set sufficient SNR margins for ROC sub-carriers so that during L2.1 the robustness of the ROC is not compromised.

E.3.1.1 L2.1 entry from L0

With the link in the L0 link state, the transmitting VTU shall measure the incoming throughput (*THRP)* in bits/s as received from higher layers over the γ reference point. The *THRP* shall be measured by counting the number of bytes received over the γ-interface during each complete second.

The L2.1 entry criterion shall be defined as the *THRP* being less than the throughput threshold for entry into L2 (L2.1-ENTRY-THRP = 0.75 × L2.1-MIN-ETR, for L2.1-MIN-ETR see clause E.4) for a continuous time period that is longer than the time threshold for entry into L2 (L2.1-ENTRY-TIME, see clause E.4). The transmitting VTU shall start counting this continuous time period after the first second the *THRP* is below L2.1-ENTRY-THRP, and shall end counting it and reset the count at any second the *THRP* is equal to or above L2.1-ENTRY-THRP.

The transition from L0 into L2.1 (L2.1 entry procedure) is shown in Figure E.3. When the L2.1 entry criterion is met, then the transmitting VTU shall initiate a transition of the link from the L0 link state to the L2.1 link sub-state (see L2.1-entry-request primitive in Figure E.1 and Figure E.3). The transition may occur in a single step (using a single-step entry procedure defined in clause E.3.1.1.1) or in multiple steps (using a multi-step entry procedure defined in clause E.3.1.1.2). A multi-step entry procedure consists of executing a single-step entry procedure multiple times, once for each step in a multi-step entry procedure.

When a single-step entry procedure (for transition in a single step) or at least one step of a multi-step entry procedure (for transition in multiple steps) is completed, the link shall be considered to be in L2.1 link sub-state until the L2.1 exit to L0 procedure is executed, or the link transitions to the L3 link state.

If the L2.1 exit criterion is met prior to completion of the L2.1 entry procedure, the transmitting VTU shall abort the L2.1 entry procedure (as defined in clauses E.3.1.1.1 and E.3.1.1.2) and initiate a transition of the link back to the L0 link state, using the L2.1 exit procedure defined in clause E.3.1.2.

The L2.1 entry procedure shall use the following L2 configuration parameters provided by the CO-MIB (see clause E.4):

- Maximum ATP (dB) reduction per step (L2.1-ATPD);
- Maximum total ATP (dB) reduction (L2.1-ATPRT);
- Minimum time between steps (L2-TIME);
- Minimum ETR in L2.1 (L2.1-ETR-MIN);
- Maximum ETR in L2.1 (L2.1-ETR-MAX);
- Target SNR margin in L2.1 (L2-TARSNRM);
- Maximum SNR margin in L2.1 (L2-MAXSNRM);
- Frequency bands in which disabling of subcarriers in L2.1 link sub-state is not allowed (L2-BANDS).

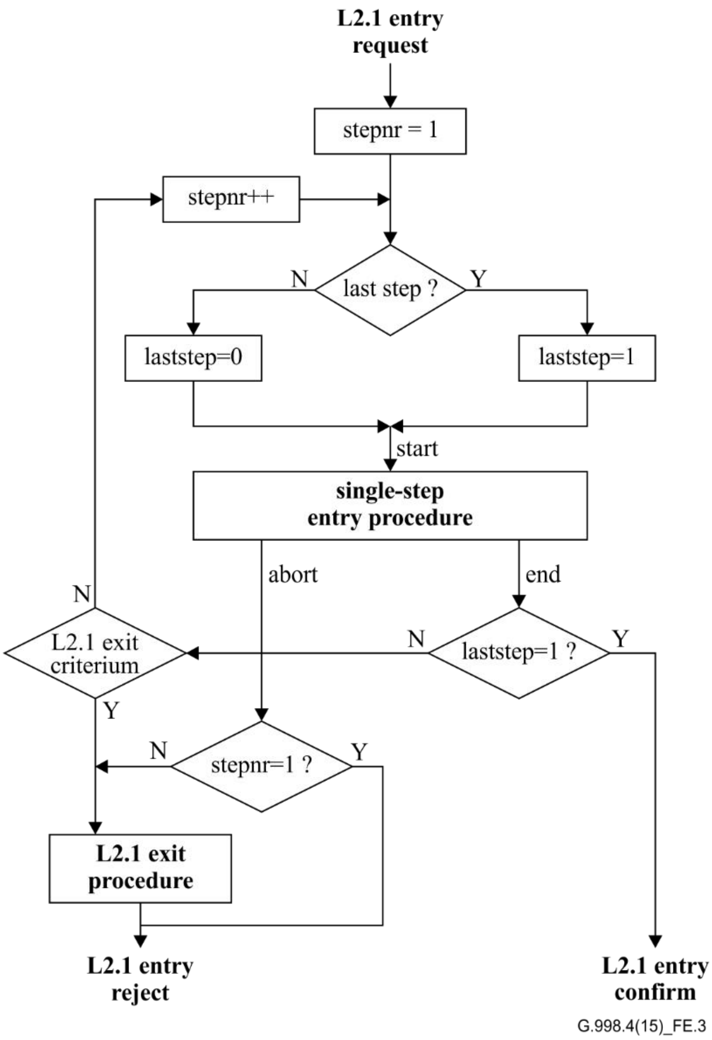


Figure E.3 – L2.1 entry procedure

E.3.1.1.1 Single-step entry procedure

The single-step entry procedure implements first a change of bit loading and framer parameters, followed by a change of transmit PSD and set of active sub-carriers.

– The modification of the bit-loading table (BLT) and framing parameters, and the modification (reduction) of the transmit PSD level and the set of active sub-carriers shall be performed separately, in different super-frames. Fine gains (i.e., the g_i values) shall not be modified.

– If operation according to [ITU-T G.993.5] is disabled then an L2-SYNCHRO pattern is defined as consisting of one inverted sync symbol (transmitted at the end of the superframe, at the sync frame position, see Figure 10-2 of [ITU-T G.993.2]) followed by a pattern of 9 sync symbols. If operation according to [ITU-T G.993.5] is enabled then an L2-SYNCHRO pattern is defined as consisting of one sync symbol with inverted flag tones (transmitted at the end of the superframe, at the sync symbol position, see Figure 10-2 of [ITU-T G.993.2]) followed by a pattern of 9 sync symbols.

– To trigger the modification of bit-loading table and framing parameters, and the modification (reduction) of the transmit PSD level and the set of active sub-carriers, the transmitting VTU shall transmit an L2-SYNCHRO pattern. The modification shall apply starting from the first symbol after the last symbol of the L2-SYNCHRO pattern, i.e., from the 9-th symbol count (starting count from 0) of the corresponding super-frame.

– The single-step entry procedure shall implement a change of bit loading and framing parameters after the first L2-SYNCHRO pattern followed by a change of transmit PSD level and set of active sub-carriers after the second L2-SYNCHRO pattern. The change in the PSD level and the time between the first and the second L2-SYNCHRO pattern are determined by the transmitting VTU. The bit loading, the set of active sub-carriers and the framing parameters are determined by the receiving VTU. Changes of parameters shall be within boundary conditions and a policy defined in this clause.

E.3.1.1.1.1 Exchange between VTUs

The exchange between VTUs in the single-step entry procedure (see L2.1 entry procedure in Figure E.1 and VTU exchange in Figure E.4) is defined as follows:

1. The transmitting VTU shall initiate a single-step entry procedure by sending an L2.1-Entry-Step-Request command (see clause E.5.1) and wait for acknowledgement. This L2.1-Entry-Step-Request command may be repeated until acknowledgement is received. The L2.1-Entry-Step-Request command contains the sequence number of the step and whether or not this step is the last step in the L2.1 entry procedure. The L2.1-Entry-Step-Request command indicates the target PSD trim (ΔPSD_{TAR}) to be applied in the step and whether a flat or ceiled PSD trim shall be applied. After sending the L2.1-Entry-Step-Request command, the transmitting VTU shall ignore any incoming OLR commands from the receiving VTU (see clause E.3.1.3).
2. Upon reception of an L2.1-Entry-Step-Request command, within 128 ms the receiving VTU shall either acknowledge the L2.1-Entry-Step-Request command by sending an L2-SRA-Request command or reject it by sending an L2.1-Entry-Step-Reject response (see clause E.5.3). After receiving the L2.1-Entry-Step-Request command, the receiving VTU shall discard any pending OLR commands (see clause E.3.1.3). The L2-SRA-Request command indicates the actual PSD trim (ΔPSD_{ACT}, determined by the receiver) to be applied in the step, the bit loading, the set of active sub-carriers and the framing parameters that fit the ΔPSDACT. The receiving VTU shall compute the transmission parameters indicated in L2-SRA-Request command (including ΔPSD_{ACT}) to meet all the boundary conditions and policy defined in this clause.
3. After sending the L2-SRA-Request command, during the following 128 ms the receiving VTU shall expect receiving the first L2-SYNCHRO pattern or an L2-SRA-Reject response or an L2.1-Exit-Step-Request command. After sending an L2.1-Entry-Step-Reject response, the receiving VTU shall expect a new L2.1-Entry-Step-Request command (with the same or a different value of ΔPSD_{TAR}), or an L2.1-Exit-Step-Request command.
4. Upon reception of the L2-SRA-Request command, within 128 ms the transmitting VTU shall either acknowledge the L2-SRA-Request command by sending the first L2-SYNCHRO pattern, or reject it by sending an L2-SRA-Reject response with a corresponding reason code, or send an L2.1-Exit-Step-Request command (if the transmitting VTU received an L2.1-exit-request primitive over the near-end γ_MGMT reference point and thus proceeding with the L2.1 entry procedure is not possible, or the transmitting VTU chooses to abort the L2.1 entry procedure). Upon reception of an L2.1-Entry-Step-Reject response, within 128 ms the transmitting VTU shall acknowledge the L2.1-Entry-Step-Reject response with either a new L2.1-Entry-Step-Request command (with the same or a different value of ΔPSD_{TAR}), or send an L2.1-Exit-Step-Request command.
5. Starting from the first symbol following the first L2-SYNCHRO pattern, both the transmitting VTU and the receiving VTU shall apply the bit loading and the framing parameters indicated in the L2-SRA-Request command. The transmitting VTU shall not change the set of active sub-carriers and the transmit PSD.
6. Upon reception of the first L2-SYNCHRO pattern, within 64 ms the receiving VTU shall acknowledge the first L2-SYNCHRO pattern by sending the L2-ΔPSD-Request command

(see clause E.5.3). The L2-ΔPSD-Request command indicates that the receiving VTU is ready to apply the actual PSD trim (ΔPSDACT) indicated in the L2-SRA-Request command. After sending the L2-ΔPSD-Request command, during the following 128 ms the receiving VTU shall expect receiving the second L2-SYNCHRO pattern or an L2.1-Exit-Step-Request command or an L2-ΔPSD-Reject response. If the receiving VTU does not receive the second L2-SYNCHRO pattern or an L2.1-Exit-Step-Request command or an L2-ΔPSD-Reject response within this time, it shall retransmit the L2-ΔPSD-Request command. Upon reception of an L2-ΔPSD-Reject response, the receiving VTU shall not acknowledge the L2-ΔPSD-Reject response and within 128 ms expect to receive a new L2.1-Entry-Step-Request command (with the same step number as the previous L2.1-Entry-Step-Request command and the same or a different value of ΔPSD_{TAR}) or an L2.1-Exit-Step-Request command.

7. Upon receiving the L2-ΔPSD-Request command, within 128 ms the transmitting VTU shall either acknowledge the L2-ΔPSD-Request command by sending the second L2-SYNCHRO pattern or reject it by sending an L2.1-Exit-Step-Request command or an L2-ΔPSD-Reject response.

8. Starting from the first symbol following the second L2-SYNCHRO pattern, both the transmitting VTU and the receiving VTU shall apply the actual PSD trim (ΔPSD_{ACT}) indicated in the L2-SRA-Request command, according to the procedure defined in clause E.3.1.1.1.3.

If during a single-step entry procedure the receiving VTU receives an L2.1-Exit-Step-Request command, it shall abandon the L2.1 single-step entry procedure and acknowledge the L2.1-Exit-Step-Request command as defined for the L2.1 single-step exit procedure in clause E.3.1.2.

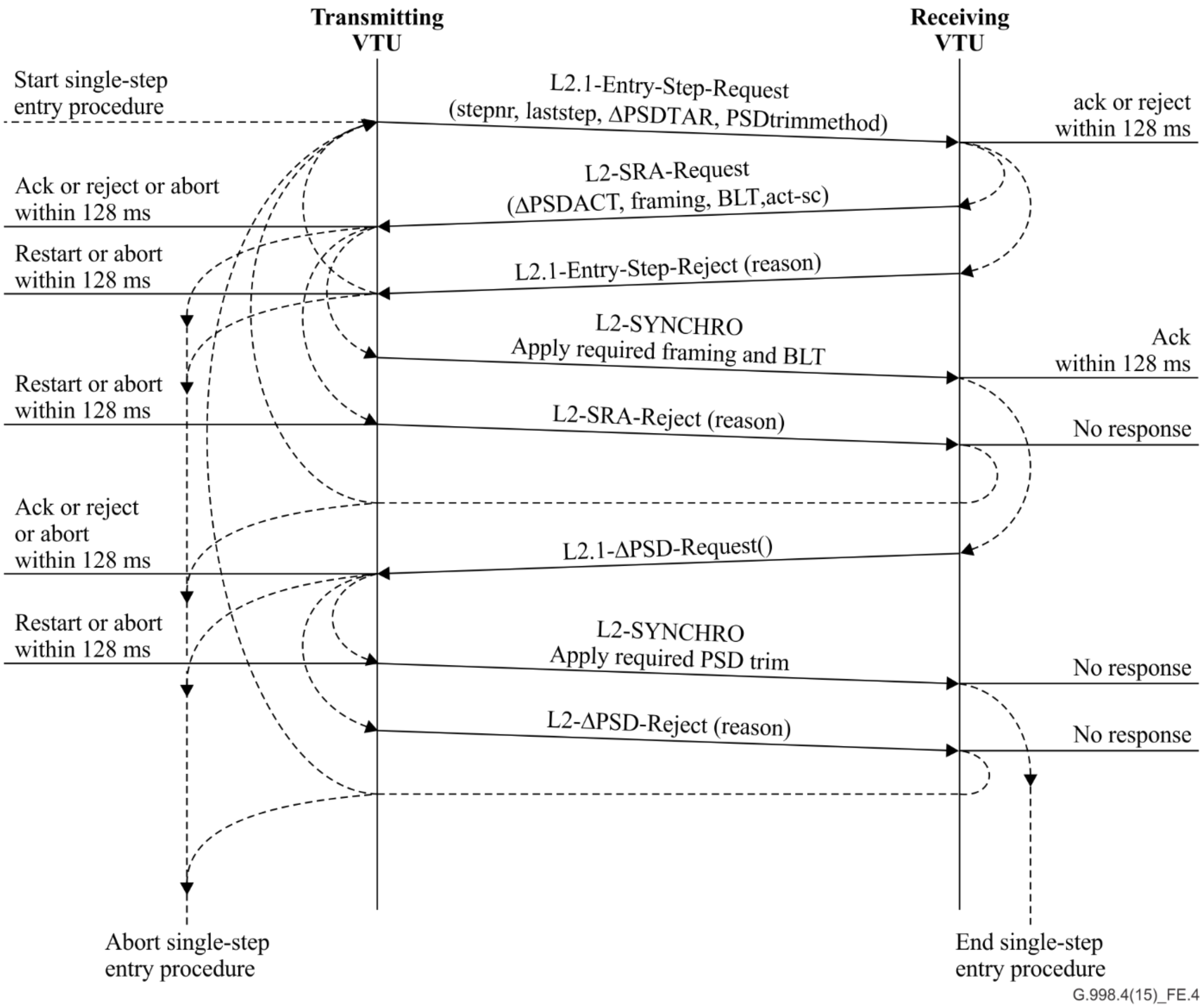


Figure E.4 – VTU exchange in the single-step L2.1 entry procedure

E.3.1.1.1.2 Boundary conditions and policy

The transmitting VTU shall select the parameters indicated in the L2.1-Entry-Step-Request command to meet the following boundary condition:

– The target PSD trim (ΔPSD_{TAR}) value shall not exceed L2.1-ATPD;

– The set of subcarriers for which disabling in L2.1 is not allowed shall be equal to or a superset of the set of subcarriers indicated in L2-BANDS.

The receiving VTU shall select the parameters indicated in L2-SRA-Request command to meet the following boundary conditions:

– $\Delta PSD_{ACT} \leq \Delta PSD_{TAR}$;

– All subcarriers that are inactive at the instant the L2.1-Entry-Step-Request command is sent, shall remain inactive. All active subcarriers that are in the frequency bands indicated in the L2-BANDS, shall remain active (turning into a monitored subcarrier when b_i is lowered to b_i=0 in the L2.1 link sub-state). Other active subcarriers may become inactive. The fine gains (i.e., the gi values) and tssi values of the inactive subcarriers shall be stored during the L2 link state in order to be used during the first single-step exit procedure. In the L0 link state, the set of active sub-carriers is defined as the set of sub-carriers in the MEDLEY set with g_i>0 on linear scale;

– The NOMATP reduction after each entry step (relative to the instant the L2.1-Entry-Step-Request command was sent) resulting from the transmitting VTU applying the actual PSD trim (ΔPSD_{ACT}) according to the procedure defined in clause E.3.1.2.1.3, shall not exceed L2.1-ATPD;

– The total NOMATP reduction (relative to the instant the entry into L2.1 was triggered) resulting from the transmitting VTU applying the actual PSD trim (ΔPSD_{ACT}) according to the procedure defined in clause E.3.1.2.1.3, shall not exceed L2.1-ATPRT;

– The SNRM shall be equal to or higher than L2-TARSNRM and shall be equal to or less than the L2-MAXSNRM;

– If the single-step entry procedure is not the last step of the L2.1 entry procedure, then the primary framing parameter values shall result in a derived $ETR \geq$ L2.1-ETR-MAX, and not to exceed ETR_{max};

– If the single-step entry procedure is the last step of the L2.1 entry procedure, then the primary framing parameter values shall result in a derived $ETR \geq$ L2.1-ETR-MIN, and not to exceed L2-ETR-MAX;

NOTE – A first L2.1 exit step is required to have primary framing parameters that result in a derived ETR that is equal to or higher than L2.1-ETR-MAX (see clause E.3.1.2). The above ETR boundary conditions imply this requirement will be satisfied (assuming channel conditions at the time of the first step in the L2.1 exit procedure are the same as at the time of the last step in the L2.1 entry procedure). This requirement is also monitored during the L2.1 steady-state (see clause E.3.1.3).

Within these boundary conditions, the transmitting VTU and the receiving VTU shall determine the modification of the bit loading and framing parameters and the modification (reduction) of the transmit PSD and the set of active sub-carriers according to the following L2.1 entry policy:

– Maximize the target PSD trim (ΔPSD_{TAR}) up to a value that will result in NOMATP reduction that does not exceed L2.1–ATPD.

– Maximize the actual PSD trim (ΔPSD_{ACT}) up to the target PSD trim (ΔPSD_{TAR}) determined by the transmitting VTU for the step;

– If the single-step entry procedure is not the last step of the L2.1 entry procedure:

  • Maximize the ETR;

  NOTE – This policy guarantees a smooth exit back to L0 during or after each intermediate step since the ETR is maximized and also exceeds L2.1-ETR-MAX.

– If the single-step entry procedure is the last step of the L2.1 entry procedure:

  • Maximize the SNRM;

  • Minimize the nominal aggregate transmit power in L2.1 (L2.1-NOMATP).

NOTE – This policy implies that after the L2.1 entry from L0 (see L2.1 entry procedure in Figure E.1) is completed, the line reaches the target ATPT reduction (or as close as possible to it) and provides the required minimum bit rate while the SNRM is maximized. The latter requires the receiver to minimize the number of turned off subcarriers and increases its capability to reach L2.1-ETR-MAX after the first exit step.

E.3.1.1.1.3 Applying the actual PSD trim

The transmitting VTU shall apply the actual PSD trim (ΔPSD_{ACT}) as follows:

– If the single-step entry procedure is the first step of the L2.1 entry procedure, then set the total PSD reduction variable, $\Delta PSD_{TOT} = \Delta PSD_{ACT}$; otherwise increment the current value of ΔPSD_{TOT} by ΔPSD_{ACT};

– If a flat PSD trim is applied, then the transmit PSD (in dBm/Hz) shall be reduced on all active sub-carriers such that:

$$L2.1\text{-}MREFPSD(f) = MREFPSD(f) - \Delta PSD_{TOT}$$

– If a ceiled PSD trim is applied, then the transmit PSD (in dBm/Hz) shall be reduced on all active sub-carriers such that:

$L2.1\text{-}MREFPSD(f) = \text{MIN}\ (\ MREFPSD(f)\ ;\ MAXMREFPSD - \Delta PSD_{TOT}\ ),$

where *L2.1-MREFPSD* applies in the L2.1 link sub-state in the same way as *MREFPSD* applies in the L0 link state, and,

where *MAXMREFPSD* is the highest PSD level in the PSD descriptor used to convey *MREFPSD* in the O-PRM message or R-PRM message during initialization (see clause 12.3.3.2.1.3 of [ITU-T G.993.2] or 12.3.3.2.2.3 of [ITU-T G.993.2] respectively).

– Calculate the *L2.1-NOMATP* as follows:

$$L2.1\text{-}NOMATP = 10\log_{10}\Delta f + 10\log_{10}\left(\sum_{i \in ACTIVE\ \text{set}}\left(10^{\frac{\text{L2.1-MREFPSD}[i]}{10}} g_i^2\right)\right),$$

with *ACTIVEset* representing the set of active subcarriers indicated in the L2-SRA-Request;

– Sub-carriers in the MEDLEY set that became inactive during the L2.1 link sub-state shall have Zi=0;

NOTE 1 – In case of non-vectored ITU-T G.993.2, this results in no power at the U reference point.

NOTE 2 – In case of vectored ITU-T G.993.2, there may be power at the U reference point due to pre-compensation signals (i.e., Zi' different from 0).

– If downstream vectoring is applied, the downstream PSD reduction shall not cause any change to the values of pre-compensation signals at the U-O reference point;

– Sub-carriers in the *MEDLEY set* shall be transmitted at the same PSD level during sync symbols and data symbols.

– ROC and RRC sub-carriers shall not be set to inactive.

NOTE 3 – For transceivers operating per [ITU-T G.993.5] or per [ITU-T G.993.2] Annex X or Y, implementers should avoid changes of the transceiver impedance on any of the subcarriers in the MEDLEY set.

E.3.1.1.2 Multi-step entry procedure

For a multi-step entry procedure, the single-step entry procedure shall be executed multiple times, once for each step in the multi-step entry procedure. Each execution of the single-step entry procedure shall be according to the requirements defined in clause E.3.1.1.1. All steps in a multi-step L2.1 entry procedure shall use the same PSD trim method (i.e., either all flat PSD trims or all ceiled PSD trims).

In a multi-step entry procedure, the subsequent single-step procedure of L2.1 entry shall be initiated only if:

– the L2.1 entry criterion is still met during the entire time after the previous single-step entry procedure is completed;

– this time exceeds L2-TIME; and

– the L2.1 exit criterion (see clause E.3.1.2) is not met during this time.

If the L2.1 exit criterion is met during a multi-step L2.1 entry procedure after one or more steps and prior to completion of the last step, the transmitting VTU shall abort the multi-step entry procedure by initiating a transition of the link back to the L0 link state using the L2.1 exit procedure defined in clause E.3.1.2.

E.3.1.2 L2.1 exit to L0

The L2.1 exit criterion shall be defined as the transmitting VTU receiving a primitive from the higher layer function indicating the need for the link to transition out of the L2.1 link sub-state.

The transition from L2.1 into L0 (L2.1 exit procedure) is shown in Figure E.5. When the link is in the L2.1 link sub-state and the L2.1 exit criterion is met, then the transmitting VTU shall initiate a transition of the link from link sub-state L2.1 to link state L0 (see L2.1-exit-request primitive in Figure E.1 and Figure E.5). The transition may occur in a single step (using a single-step exit procedure defined in clause E.3.1.2.1) or in multiple steps (using a multi-step exit procedure defined in clause E.3.1.2.2). A multi-step exit procedure consists of executing single-step exit procedure multiple times, once for each step in the multi-step exit procedure.

Once the L2.1 exit procedure has been initiated, the transmitting VTU shall complete the L2.1 exit procedure to bring the link back to L0 link state, regardless whether or not the L2.1 exit criterion (see clause E.3.1.2) is still met during the execution of the L2.1 exit procedure.

When the single-step exit procedure (for transition in a single step) or all steps of the multi-step exit procedure (for transition in multiple steps) are completed, the link shall be considered to be back in L0 link state. Until then the link shall be considered to be in the L2.1 link sub-state.

The L2.1 exit procedure shall use the following L2 configuration parameters determined from the CO-MIB (see clause E.4):

- Maximum ATP (dB) increase per step (L2.1-ATPD);
- Minimum time between steps (L2-TIME);
- Maximum ETR in L2.1 (L2-ETR-MAX);
- Minimum SNR margin in L2 (L2-MINSNRM, only for a multi-step exit procedure);
- Target SNR margin in L2.1 (L2-TARSNRM);
- Maximum SNR margin in L2.1 (L2-MAXSNRM).

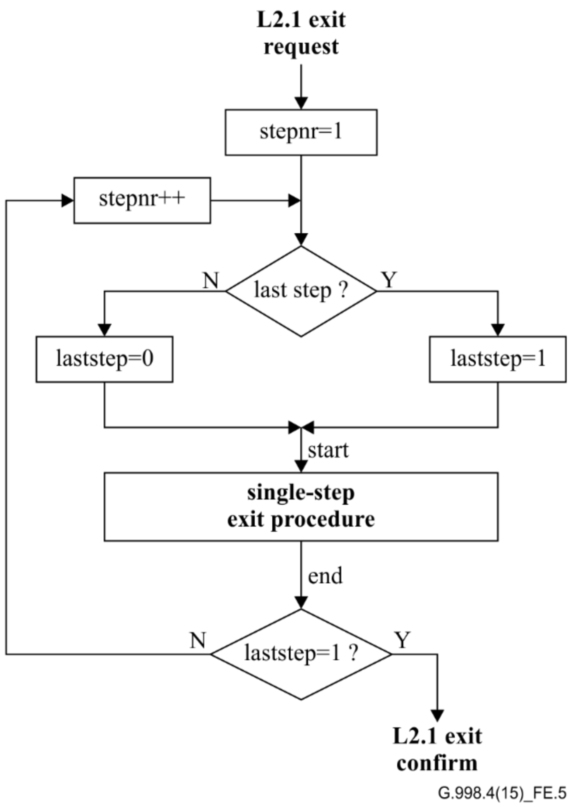


Figure E.5 –L2.1 exit procedure

E.3.1.2.1 Single-step exit procedure

The single-step exit procedure implements first a change of transmit PSD and set of active sub-carriers, followed by a change of bit loading and framer parameters.

– The modification of the bit loading table (BLT) and framing parameters, and the modification (increase) of the transmit PSD and the set of active sub-carriers shall be performed separately, in different super-frames. Fine gains (i.e., the g_i values) shall not be modified.

– To trigger the modification of bit loading and framing parameters and the modification (increase) of the transmit PSD and the set of active sub-carriers, the transmitting VTU shall transmit an L2-SYNCHRO pattern. The L2-SYNCHRO pattern for the single-step exit procedure is defined as identical to the L2-SYNCHRO pattern for the single-step entry procedure defined in clause E.3.1.1.1. The modification shall apply starting from the first symbol after the last symbol of the L2-SYNCHRO pattern, i.e., from the 9-th symbol count (starting count from 0) of the corresponding super-frame.

– The single-step exit procedure shall implement a change of transmit PSD level and set of active sub-carriers after the first L2-SYNCHRO pattern followed by a change of bit loading and framing parameters after the second L2-SYNCHRO pattern. The change in the PSD level and the time between the first and the second L2-SYNCHRO pattern is controlled by the transmitting VTU. The bit loading, the set of active sub-carriers and the framing parameters are determined by the receiving VTU.

E.3.1.2.1.1 Exchange between VTUs

The exchange between VTUs in the single-step exit procedure (see L2.1 exit procedure in Figure E.1 and VTU exchange in Figure E.6) is defined as follows:

1. The transmitting VTU shall initiate a single-step procedure by sending an L2.1-Exit-Step-Request command (see clause E.5.2) and wait for acknowledgement. This L2.1-Exit-Step-Request command may be repeated until acknowledgement is received. The L2.1-Exit-Step-Request command contains the sequence number of the step and whether or not this step is the last step in the L2.1 exit procedure. The L2.1-Exit-Step-Request command indicates the actual PSD trim (ΔPSD_{ACT}) to be applied in the step. After sending the first L2.1-Exit-Step-Request command, the transmitting VTU shall ignore any incoming OLR commands from the receiving VTU (see clause E.3.1.3).

2. Upon reception of an L2.1-Exit-Step-Request command, the receiving VTU shall acknowledge the L2.1-Exit-Step-Request command by sending an L2-ΔPSD-Request command (see clause E.5.4) within 128 ms. After receiving the L2.1-Exit-Step-Request command, the receiving VTU shall discard any pending OLR commands (see clause E.3.1.3). The L2-ΔPSD-Request command indicates that the receiving VTU is ready to apply the actual PSD trim (ΔPSD_{ACT}) indicated in the L2.1-Exit-Step-Request command

3. After sending the exit L2-ΔPSD-Request command, the receiving VTU shall expect receiving the first L2-SYNCHRO pattern during the following 128ms. If the L2.1-Exit-Step-Request command is received more than once prior the reception of the first L2-SYNCHRO pattern, the receiving VTU shall acknowledge each L2.1-Exit-Step-Request command with an identical L2-ΔPSD-Request command.

4. Upon reception of the L2-ΔPSD-Request command, the transmitting VTU shall acknowledge the L2-ΔPSD-Request command by sending the first L2-SYNCHRO pattern within 128 ms.

5. Starting from the first symbol following the first L2-SYNCHRO pattern, both the transmitting VTU and the receiving VTU shall apply the actual PSD trim (ΔPSD_{ACT}) indicated in the L2.1-Exit-Step-Request command, according to the procedure defined in clause E.3.1.2.1.3. The transmitting VTU shall not change the bit loading and the framing parameters.

6. Upon reception of the first L2-SYNCHRO pattern, the receiving VTU shall estimate the SNR and acknowledge the first L2-SYNCHRO pattern by sending the L2-SRA-Request command (see clause E.5.3) within 128 ms. The L2-SRA-Request command indicates the actual PSD rim (ΔPSD_{ACT}) already applied in the step, the bit loading and the framing parameters that fit the actual PSD trim (ΔPSD_{ACT}) indicated in the L2.1-Exit-Step-Request command. After sending the L2-SRA-Request command, the receiving VTU shall expect receiving the second L2-SYNCHRO pattern during the following 128ms. If the receiving VTU does not receive the second L2-SYNCHRO pattern within this time, it shall retransmit the L2-SRA-Request command.
7. Upon receiving the L2-SRA-Request command, the transmitting VTU shall acknowledge the L2-SRA-Request command by sending the second L2-SYNCHRO pattern within 128ms.
8. Starting from the first symbol following the second L2-SYNCHRO pattern, both the transmitting VTU and the receiving VTU shall apply the bit loading and the framing parameters indicated in the L2-SRA-Request command.

The execution time from sending the L2.1-Exit-Step-Request command to sending the second L2-SYNCHRO pattern should not exceed 1 second.

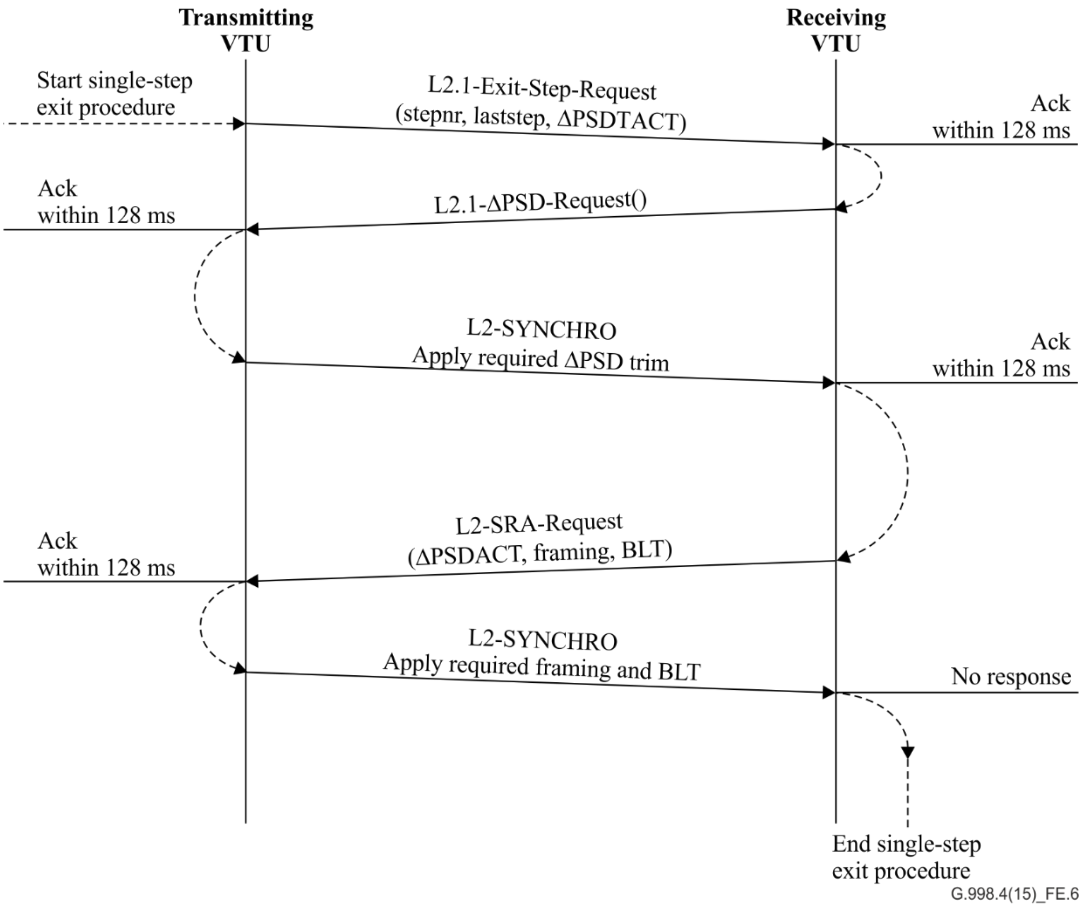


Figure E.6 – VTU Exchange in the single-step L2.1 exit procedure

E.3.1.2.1.2 Boundary conditions and policy

The transmitting VTU shall select the parameters indicated in the L2.1-Exit-Step-Request command to meet the following boundary conditions:

– The actual PSD trim (ΔPSD_{ACT}) value shall not exceed L2.1-ATPD;

– The actual PSD trim (ΔPSD_{ACT}) for the first exit step shall be equal to a value that will result in NOMATP increase that is equal to L2.1-ATPD, relative to the value of NOMATP after all sub-carriers that were turned inactive during L2.1 are re-activated.

– If the single-step exit procedure is the last step of the L2.1 exit procedure:

  • $\Delta PSD_{ACT} = \Delta PSD_{TOT}$;

  NOTE 1 – This ΔPSD_{ACT} value brings the transmit PSD back to the transmit PSD that was in use at the instant the last previous L2.1 entry from the L0 link state was initiated.

The receiving VTU shall select the transmission parameters indicated in L2-SRA-Request command to meet the following boundary conditions:

– The set of active sub-carriers after the first single-step exit procedure shall be equal to the set of active sub-carriers in the L0 link state. The fine gains and tssi values of the inactive sub-carriers shall be restored to the values that were in use at the instant the last previous L2.1 entry from the L0 link state was initiated. In the L0 link state, the set of active sub-carriers is defined as the set of sub-carriers in the MEDLEY set with g_i>0 on linear scale;

  NOTE 2 – Because all sub-carriers that became inactive in the L2 link state are re-activated during the first single-step exit procedure, the increase in L2.1-NOMATP (defined in clause E.3.1.1.1) resulting from the first single-step exit procedure may be higher than L2.1-ATPD.

– If the single-step exit procedure is the first step and not the last step of the L2.1 exit procedure:

  • The primary framing parameters shall result in a derived ETR that is equal to or higher than L2.1-ETR-MAX, and not to exceed ETR_{max};

  • The SNRM shall be equal to or higher than L2-MINSNRM;

– If the single-step exit procedure is not the first step of the L2.1 exit procedure:

  • The SNRM shall be equal to or higher than L2-TARSNRM and shall be equal to or less than the L2-MAXSNRM;

– If the single-step exit procedure is the last step of the L2.1 exit procedure:

  • The SNRM shall be in the range between MINSNRM and MAXSNRM;

  • The primary framing parameter values shall, if possible according to channel conditions, have a derived framing parameter *NDR* that is equal to or higher than the *NDR* that was in use at the instant the last previous L2.1 entry from the L0 link state was initiated;

  • If channel conditions do not allow for the *NDR* that was in use at the instant the last previous L2.1 entry from the L0 link state was initiated, , then the L2-SRA-Request command may require different primary framing parameter values (resulting in a lower derived framing parameter *NDR* than upon L2.1 entry), while still complying with the CO-MIB configuration.

Within these boundary conditions, the transmitting VTU and receiving VTU shall determine the modification (increase) of the transmit PSD and the modification of the bit loading and framing parameters, according to the following L2 exit policy:

– Maximize the actual PSD trim (ΔPSD_{ACT}) up to a value that will result in NOMATP increase that does not exceed L2.1-ATPD.

– Select the primary framing parameters that maximize the derived ETR.

NOTE 3 – This policy implies that after the first L2.1 exit step (after which the line reaches the bit rate of L2.1-ETR-MAX or more under the given circumstances), each of the following steps will provide the maximum possible increase of the ETR. The policy provides the fastest return to L0 (minimum number of exit steps under given PSD increase constraint).

E.3.1.2.1.3 Applying the actual PSD trim

The transmitting VTU shall apply the actual PSD trim (ΔPSD_{ACT}) as follows:

– Decrement ΔPSD_{TOT} by ΔPSD_{ACT} ;

– If a flat PSD trim was applied during the L2.1 entry, then the transmit PSD (in dBm/Hz) shall be increased on all active sub-carriers and set on all re-activated subcarriers such that:

$L2.1\text{-}MREFPSD(f) = MREFPSD(f) - \Delta PSD_{TOT}$

– If a ceiled PSD trim was applied during the L2.1 entry, then the transmit PSD (in dB) shall be applied on all active sub-carriers and set on all re-activated subcarriers such that:

$L2.1\text{-}MREFPSD(f) = \text{MIN} (MREFPSD(f) ; MAXMREFPSD - \Delta PSD_{TOT})$,

where *L2.1-MREFPSD* applies in the L2.1 link sub-state in the same way as *MREFPSD* applies in the L0 link state, and,

where *MAXMREFPSD* is the highest PSD level in the PSD descriptor used to convey *MREFPSD* during initialization (see clause 12.3.3.2.1.3 of [ITU-T G.993.2] or 12.3.3.2.2.3 of [ITU-T G.993.2] respectively).

If downstream vectoring is applied, the downstream PSD increase shall not cause any change to the values of pre-compensation signals at the U-O reference point.

NOTE – For transceivers operating per [ITU-T G.993.5] or per [ITU-T G.993.2] Annex X or Y, implementers should avoid changes of the transceiver impedance on any of the subcarriers in the MEDLEY set.

E.3.1.2.2 Multi-step exit procedure

For a multi-step exit procedure, the single-step exit procedure shall be executed multiple times, once for each step in the multi-step exit procedure. Each execution of the single-step exit procedure shall be according to the requirements defined in clause E.3.1.2.1. All sub-carriers that became inactive in the L2.1 link sub-state shall be re-activated during the first single-step exit procedure.

E.3.1.3 On-line reconfiguration in L2.1

While in L2.1 link sub-state (except when executing the L2.1 entry procedure or the L2.1 exit procedure), the following boundary conditions shall be met:

– The SNRM shall be equal to or higher than MINSNRM;

– A first L2.1 exit step (assuming current channel conditions) shall allow framing parameters with a derived ETR that is equal to or higher than L2.1-ETR-MAX.

NOTE 1 – A first L2.1 exit step is required to have framing parameters with a derived ETR that is equal to or higher than L2.1-ETR-MAX (see clause E.3.1.2). In the L2.1 link sub-state, the above ETR boundary condition assures that this requirement can be met in a first L2.1 exit step.

While in L2.1 link sub-state (except when executing the L2.1 entry procedure or the L2.1 exit procedure), VTUs shall be capable to use the bit swapping procedure as defined in clause 11.2.2.3 of [ITU-T G.993.2] (OLR Request Type 1) in the aim to maintain the SNRM equal to or higher than L2-TARSNRM.

SRA (OLR Request type 5) shall be a mandatory capability during L2.1 entry and L2.1 steady-state. SOS (OLR Request Type 6) shall not be used while executing the L2.1 entry procedure or the L2.1 exit procedure or while the link is in L2.1 link sub-state. The enable/disable of SRA functionality through the downstream rate adaptation mode (RA-MODE) parameter in the CO-MIB only applies to the L0 link state.

NOTE 2 - After the L2.1 exit procedure is completed, the receiving VTU may initiate the OLR requests enabled in the L0 link state (Request type 1, Request type 5, Request type 6) to optimize the performance of the line.

NOTE 3 – Modification of the fine gains of active subcarriers during OLR procedures may impact the ATP of the L0 link state after exiting L2.1 due to the fact that when re-entering L0 the fine gains of the inactive subcarriers will be restored to the values of the previous L0 link state.

E.3.2 Link sub-state L2.2

The main application for the LPMode operation in the L2.2 link sub-state is the transport of "keep alive" data at times when there is no user activity. Besides power reduction techniques applied in L2.1, for LPMode operation in the L2.2 link sub-state, the additional power scaling technique referred to as scheduled discontinuous operation (SDO) shall be used.

With SDO, symbols are transmitted only in a predefined subset of the available 256 data symbol positions per super-frame. The 256 symbol positions within each super-frame shall be divided into four groups of 64 contiguous symbol positions. Each group shall start with contiguous symbol periods where data symbols shall be transmitted, followed by contiguous symbol positions where quiet symbols (i.e., Z_i=0 for all sub-carriers) shall be transmitted. The symbol positions where data symbols and the symbol positions where quiet symbols are transmitted shall be the same in all super-frames during the time the link is in link sub-state L2.2.

The SDO during L2.2 is shown in Figure E.7. There are four groups, each of 64 symbol positions. Data symbols are transmitted in the first 9 symbol positions and quiet symbols are transmitted in the last 55 symbol positions of each group.

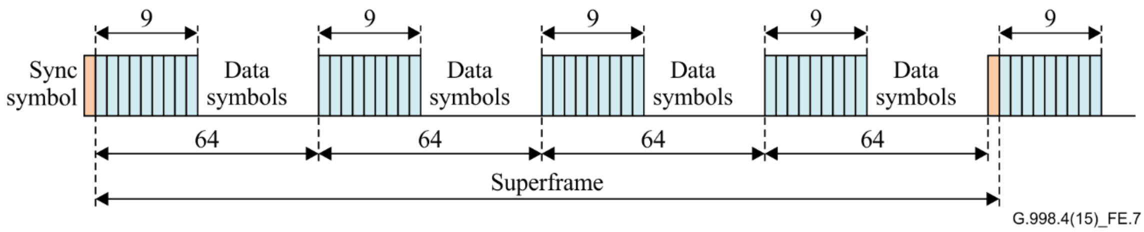


Figure E.7 – Example of link sub-state L2.2

The L2-SYNCHRO pattern defined for synchronization of L2.2 entry and exit (see clauses E.3.2.1 and E.3.2.2) shall be transmitted at the sync symbol position followed by the first nine symbol positions of the first group of 64 symbol positions, instead of transmitting 9 data symbols.

NOTE 1 – During transmission of quiet data symbols, a backpressure should be applied towards the PMS-TC that prevents eoc being sent.

NOTE 2 – For transceivers operating per [ITU-T G.993.5] or per [ITU-T G.993.2] Annex X or Y, implementers should avoid changes of the transceiver impedance on any of the subcarriers in the MEDLEY set, including during transmission of QUIET symbols.

While the link is in the L2.2 link sub-state, the TPS-TC functions (see clause 7), the retransmission functions (see clause 8), the PMS-TC function (see clause 9), the PMD functions (see clause 10) and the retransmission management functions (see clause 11) shall apply with the following differences:

– The retransmission functions shall be disabled in both downstream and upstream directions. The transmitting VTU shall not retransmit DTUs, regardless what was received over RRC (the content of the RRC shall be ignored by the transmitting VTU). However, data is mapped into DTUs with the same valid range of framing parameters and DTU sizes as in link sub-state L2.1.

– The *ETR_min* and *ETR_max* (see clause 7.1.1) do not apply in both upstream and downstream directions. Since retransmission is disabled, no specific *ETR* bounds are defined for link sub-state L2.2 through the CO-MIB.

– The *TARSNRM*, *MAXSNRM*, and *SNRMOFFSET-ROC* (Note 3) do not apply. The L2 specific SNRM bounds are configured through the CO-MIB (see clause E.4).

– The test parameters shall not be updated in the CO-MIB, and *ETR*, *EFTR*, and *delay_act_RTX* shall not be defined (see clause 11.2), the *fec* and *crc* anomalies and *leftr* and *seftr* defects shall not occur (see clause 11.3) and the number of error-free bits passed over the β1-reference point shall be counted as zero (see clause 11.4);

– The *INP_act_SHINE* (see clause 11.2.3) may be less than *INP_min* (see clause 7.1.1) and may be as low as 0;

– The *INP_act_REIN* (see clause 11.2.4) may be less than *INP_min_rein* (see clause 7.1.1) and may be as low as 0.

NOTE 3 – If vectoring is enabled during the L2.1 link sub-state, it may be necessary to continue supporting of FEXT cancellation also during the L2.2 link sub-state with the aim of using the same bit loading as per the L2.1 link sub-state.

The transmitting VTU shall assess the stability of the received channel, knowing that retransmission will be disabled in both directions, before triggering an entry into the L2.2 link sub-state.

E.3.2.1 L2.2 entry from L2.1

The L2.2 entry criterion shall be defined as no data having been received from higher layers over the γ reference point for a time period longer than 500 ms, while sufficient stability of the received channel has been assessed.

When the link is in the L2.1 link sub-state and the L2.2 entry criterion is met, then the transmitting VTU shall initiate a transition of the link from the L2.1 link sub-state to the L2.2 link sub-state (see L2.2-entry-request primitive in Figure E.1).

The bit-loading table (b_i), the set of active sub-carriers and the fine gains (g_i) in L2.2 shall be the same as they were in L2.1 steady-state.

The entry procedure (see L2.2 entry procedure in Figure E.1) is defined as follows:

1. The transmitting VTU shall initiate an L2.2 entry procedure by sending an L2.2-Entry-Request command (see clause E.5.5) and wait for acknowledgement. This L2.2-Entry-Request command may be repeated until acknowledgement is received. After sending the L2.2-Entry-Request command, the transmitting VTU shall ignore any incoming OLR requests from the receiving VTU.
2. Upon reception of an L2.2-Entry-Request command, within 128 ms, the receiving VTU shall discard any pending OLR request and acknowledge the L2.2-Entry-Request command with an L2.2-Entry-ACK response (see clause E.5.5) or reject the L2.2-Entry-Request command with an L2.2-Entry-Reject response. After sending the L2.2-Entry-ACK response, the receiving VTU shall expect to receive an L2-SYNCHRO pattern during the following 128 ms. If the L2.2-Entry-Request command is received more than once prior to the reception of the L2-SYNCHRO pattern, the receiving VTU shall acknowledge or reject each L2.2-Entry-Request command with an L2.2-Entry-ACK response or an L2.2-Entry-Reject response, respectively.
3. Upon reception of the L2.2-Entry-ACK response, the transmitting VTU shall acknowledge the L2.2-Entry-ACK response by sending an L2-SYNCHRO pattern within 128 ms. Upon reception of the L2.2-Entry-Reject response, the transmitting VTU may repeat the L2.2-Entry-Request command.
4. Starting from the first symbol following the L2-SYNCHRO pattern, the transmitting VTU shall transmit and the receiving VTU shall receive data symbols at the data symbol positions defined by the SDO (see clause E.3.2).

When the L2.2 entry procedure is completed, the link shall be considered to be in the L2.2 link sub-state until the L2.2 exit procedure is executed, or the link transitions to the L3 link state.

While the link is in the L2.2 link sub-state, the receiving VTU shall track channel changes (e.g., noise variations) through OLR. If the receiving VTU detects that the *SNRM* during the L2.2 link sub-state is less than L2-MINSNRM, it shall send an L2.2-RX-Exit-Request command with reason code

"OLR2 (see clause E.5.6) to the transmitting VTU. While the link is in the L2.1 link sub-state, the *SNRM* shall be adjusted using the standard OLR procedure, as defined in clause E.3.1.3. After this OLR procedure is complete, the transmitting VTU shall initiate a transition of the link from the L2.1 link sub-state to the L2.2 link sub-state if the L2.2 entry criterion is still met (see L2.2-entry-request primitive in Figure E.1).

If the transmitting VTU detects errors due to the presence of REIN while the link in the L2.1 link sub-state, the transmitting VTU should not initiate a transition of the link from the L2.1 link sub-state to the L2.2 link sub-state. If the receiving VTU detects the presence of REIN while the link is in the L2.2 link sub-state, it shall send an L2.2-RX-Exit-Request command with reason code "REIN" (see clause E.5.6) to the transmitting VTU.

E.3.2.2 L2.2 exit to L2.1

The L2.2 exit criterion shall be defined as the transmitting VTU receiving a primitive from the higher layer management function indicating the need for the link to transition out of the L2.2 link sub-state, or the transmitting VTU detecting a condition that upon persistency may trigger a retrain, or the transmitting VTU receiving an L2.2-RX-Exit-Request command from the receiving VTU.

When the link is in the L2.2 link sub-state and the L2.2 exit criterion is met, then the transmitting VTU shall initiate a transition of the link from the L2.2 link sub-state to the L2.1 link sub-state (see L2.2-exit-request primitive in Figure E.1).

The exit procedure (see L2.2 exit procedure in Figure E.1) is defined as follows:

1. The transmitting VTU shall initiate an L2.2 exit procedure by sending an L2.2-Exit-Request command (see clause E.5.6) and wait for acknowledgement. This L2.2-Exit-Request command may be repeated until acknowledgement is received.
2. Upon reception of an L2.2-Exit-Request command, the receiving VTU shall acknowledge the L2.2-Exit-Request command with an L2.2-Exit-ACK response (see clause E.5.6) within 128 ms. After sending the L2.2-Exit-ACK response, the receiving VTU shall expect receiving an L2-SYNCHRO pattern during the following 128 ms. If the L2.2-Exit-Request command is received more than once prior to the reception of the L2-SYNCHRO pattern, the receiving VTU shall acknowledge each L2.2-Exit-Request command with an L2.2-Entry-ACK response.
3. Upon reception of the L2.2-Exit-ACK response, the transmitting VTU shall acknowledge the L2.2-Exit-ACK response by sending an L2-SYNCHRO pattern within 128 ms.
4. Starting from the first symbol following the L2-SYNCHRO pattern, the transmitting VTU shall transmit and the receiving VTU shall receive data symbols at all the data symbol positions with parameters defined for L2.1 operation.

When the L2.2 exit procedure is completed, the link shall be considered to be back in the L2.1 link sub-state. Until then the link shall be considered to be in the L2.2 link sub-state.

E.4 CO-MIB configuration and status reporting

The CO-MIB configuration parameters related to LPMode are defined in Table E.1. The CO-MIB reporting parameters related to LPMode are defined in Table E.2.

NOTE – A data rate of 5 Mbit/s is recommended by the Broadband Forum as the data rate to be present after the first exit step in an L2.1 exit procedure (see clause E.3.1.2). Such a data rate allows an L2.1 exit to L0 without additional exit steps causing excessive delay or interruption of service. This data rate can be an appropriate setting for L2.1-ETR-MAX.

Table E.1 – CO-MIB configuration parameters related to LPMode

Configuration parameter	ITU-T G.997.1 reference	Definition
Power management state forced (PMSF)	7.3.1.1.3	The power management state force indicates the PM state that the VTU is forced to enter via the CO-MIB.
Power management state enabling (PMMode)	7.3.1.1.4	The power management mode indicates the allowed link states. This parameter communicated to the VTU-R during initialization. Bit 0: indicates whether the L3 link state is allowed (1) or not allowed (0). Bit 1: indicates whether the L2.1 link sub-state is allowed (1) or not allowed (0) in the downstream direction. Bit 2: indicates whether the L2.2 link sub-state is allowed (1) or not allowed (0) in the downstream direction.
Minimum time interval between consecutive L2 ΔPSD trims during an L2.1 entry or L2.1 exit procedure (L2-TIME)	7.3.1.1.6	The minimum time (in seconds) the same transmit PSD is applied between consecutive L2 ΔPSD trims during an L2.1 entry or L2.1 exit procedure. It ranges from 0 to 255 seconds in steps of 1 second.
Maximum delta in aggregate transmit power (reduction or increase) per L2 ΔPSD trim during L2.1 entry or exit procedure respectively (L2.1-ATPD)	7.3.1.1.7	Maximum delta in aggregate transmit power (in dB) per L2 ΔPSD trim during an L2.1 entry or L2.1 exit procedure. It ranges from 0 dB to 31 dB in steps of 1 dB.
Total maximum aggregate transmit power reduction in L2.1 (L2.1-ATPRT)	7.3.1.1.9	Total maximum aggregate transmit power reduction (in dB) that can be performed in the L2.1 link sub-state. This is the sum of the ATP reductions provided by all L2 ΔPSD trims during an L2.1 entry or exit procedure. It ranges from 0 dB to 31 dB in steps of 1 dB.
Time threshold for entry into L2 (L2.1-ENTRY-TIME)		Time period (in seconds) for triggering a transition from L0 link state to L2.1 link sub-state. It ranges from 1 to 255 seconds in steps of 1 second.
L2.1-ETR-MIN		The minimum ETR (in kbit/s) that shall be maintained in L2.1 link sub-state. The valid range is from 256 kbits/s to 8192 kbits/s in 8 kbit/s steps.
L2.1-ETR-MAX		The maximum ETR (in kbit/s) that shall be allowed in L2.1 link sub-state (Note). The valid range is from 4096 kbits/s to 32768 bits/s in 8 kbit/s steps.
L2-MINSNRM		Minimum SNR margin (in dB) allowed after the first L2.1 exit step of a multi-step L2.1 exit procedure. It ranges from 0 to 31 dB, with 0.1 dB steps.
L2-TARSNRM		The target SNR margin (in dB) to be maintained in L2.1 link sub-state. It ranges from 0 to 31 dB, with 0.1 dB steps.

Table E.1 – CO-MIB configuration parameters related to LPMode

Configuration parameter	ITU-T G.997.1 reference	Definition
L2-MAXSNRM		Maximum SNR margin (in dB) in L2.1 link sub-state, including entry to L2.1 link sub-state and exit from L2.1 link sub-state. It ranges from 0 to 31 dB, with 0.1 dB steps.
L2-BANDS		Frequency bands where disabling of subcarriers in L2.1 link sub-state is not allowed.

Table E.2 – CO-MIB reporting parameters related to LPMode

Reporting parameter	ITU-T G.997.1 reference	Definition
Power management state (PM-STATE)	7.5.1.5	The power management state the link is in (i.e., L0, L2.1, L2.2 or L3). Its value is configured by the near-end VTU control function, possibly based on configuration forced through the CO-MIB and/or by the far-end control function. It is defined separately for downstream and upstream.
PSD trim method		The type of PSD trim applied at the last entry into L2.1 link sub-state. Valid values for the PSD trim method are "flat PSD trim" and "ceiled PSD trim".

The CO-MIB configuration parameters communicated to the VTU-R are included in the G.998.4 LPMode parameter field shown in Table E.3. A G.998.4 LPMode parameter field shall be included in the G.998.4 parameter field in initialization message O-TPS (see Table C.3).

Table E.3 – ITU-T G.998.4 LPMode parameter field for O-TPS

Field nr	Field name	Format	Description
1	Parameter field length	1 byte	Total number of data bytes in ITU-T G.998.4 LPMode parameter field (Note).
2	L2.1-ATPDds	1 byte	See Table E.1.
3	L2.1-ATPRTds	1 byte	See Table E.1
4	L2-MINSNRMds	2 bytes	See Table E.1
5	L2-TARSNRMds	2 bytes	See Table E.1
6	L2-MAXSNRMds	2 bytes	See Table E.1
7	L2.1-ETR-MINds	2 bytes	See Table E.1
8	L2.1-ETR-MAXds	2 bytes	See Table E.1
9	L2-BANDSds	variable	See Table E.1
NOTE – If operation according to this annex is disabled, the number of data bytes may be zero.			

Field #1 "Parameter field length" indicates the number of data bytes in the ITU-T G.998.4 LPMode parameter field. The data bytes are the bytes following this length indicator byte (i.e., all bytes in the ITU-T G.998.4 LPMode parameter field counting from the penultimate byte). This byte is included to allow VTU-Rs that do not support ITU-T G.998.4 LPMode to still correctly parse O-TPS.

Field #2 "L2.1-ATPDds" is a 1-byte field representing an unsigned integer in the 0..31 range (0 dB to 31 dB in steps of 1 dB).

Field #3 "L2.1-ATPRTds" is a 1-byte field representing an unsigned integer in the 0..31 range (0 dB to 31 dB in steps of 1 dB).

Field #4 "L2-MINSNRMds" is a 2-byte field representing an unsigned integer in the 0..310 range (0 dB to 31 dB in steps of 0.1 dB).

Field #5 "L2-TARSNRMds" is a 2-byte field representing an unsigned integer in the 0..310 range (0 dB to 31 dB in steps of 0.1 dB).

Field #6 "L2-MAXSNRMds" is a 2-byte field representing an unsigned integer in the 0..310 range (0 dB to 31 dB in steps of 0.1 dB).

Field #7 "L2.1-ETR-MINds" is a 2-byte field representing an ETR as a multiple of 8 kbit/s.

Field #8 "L2.1-ETR-MAXds" is a 2-byte field representing an ETR as a multiple of 8 kbit/s.

Field #9 "L2-BANDSds" is a bands descriptor as defined in Table 12-22 of [ITU-T G.993.2].

E.5 Coordination of link state transitions between VTU-O and VTU-R

This clause amends clause 11.2.3.9 of [ITU-T G.993.2] with power management eoc messages for the L2 link state and its link sub-states L2.1 and L2.2.

This clause defines the following eoc messages:

– L2.1-Entry-Step-Request command and responses (see clause E.5.1);
– L2.1-Exit-Step-Request command and responses (see clause E.5.2);
– L2-SRA-Request command and responses (see clause E.5.3);
– L2-ΔPSD-Request command and responses (see clause E.5.4);
– L2.2-Entry-Request command and responses (see clause E.5.5);
– L2.2-Exit-Request command and responses (see clause E.5.6).

E.5.1 L2.1-Entry-Step-Request command and responses

The L2.1-Entry-Step-Request command is defined in Table E.4. The L2.1-Entry-Step-Request responses are defined in Table E.5. The L2.1-Entry-Step-Request command shall be initiated by the transmitting VTU for execution of the single-step L2.1 entry procedure. The L2-Entry-Step command contains the sequence number of the step and whether or not this step is the last step in the L2.1 entry procedure. The L2.1-Entry-Step-Request command indicates the target PSD trim (ΔPSD_{TAR}) and whether a flat or ceiled PSD trim shall be applied. The receiver shall either acknowledge the command by sending an L2-SRA-Request command or reject the command by sending L2.1-Entry-Step-Reject response with a corresponding reason code defined in Table E.5.

The first octet of the command and response is defined in Table 11-4 of [ITU-T G.993.2] (normal priority). The other octets are defined in Table E.4 and Table E.5, respectively.

Table E.4 – L2.1-Entry-Step-Request command sent by the transmitting VTU

Name	Length (Octets)	Octet number	Content
L2.1-Entry-Step-Request	5	2	01_{16} (Note 1)
		3	One octet containing: Bit 7 (MSB): set to 1 indicates that this step is the last step of the L2.1 entry procedure; Bits 6-0 (LSBs): the count of the step number represented as unsigned integer (Note 2).
		4	One octet containing the ΔPSD_{TAR} value in the range from 0 to 25.5 dB in units of 0.1 dB, represented as an unsigned integer.
		5	PSD trim method: 00_{16}: flat PSD trim 01_{16}: ceiled PSD trim (Note 1)

NOTE 1 – All other values are reserved by ITU-T.

NOTE 2 – The count of the step number shall be set to "1" for the first step of an L2.1 entry procedure, and shall increment by 1 at each subsequent step in a multi-step entry procedure.

Table E.5 – L2.1-Entry-Step-Request responses sent by the receiving VTU

Name	Length (Octets)	Octet number	Content
L2-SRA-Request	See clause E.5.3.		See clause E.5.3.
L2.1-Entry-Step-Reject	3	2	81_{16} (Note)
		3	1 octet for reason code with the following valid values: 01_{16} – busy 02_{16} – invalid parameters 03_{16} – excessive PSD reduction (Note)

NOTE – All other values are reserved by ITU-T.

E.5.2 L2.1-Exit-Step command and responses

The L2.1-Exit-Step-Request command is defined in Table E.6. The L2.1-Exit-Step-Request responses are defined in Table E.7. The L2.1-Exit-Step-Request command initiates the execution of the single-step exit procedure with the indicated actual PSD trim that will be applied starting from the first data symbol position following the first L2-SYNCHRO pattern (see clause E.3.1.2).

The first octet of the command and response is defined in Table 11-2 of [ITU-T G.993.2] (high priority). The other octets are defined in Table E.6 and Table E.7, respectively.

Table E.6 – L2.1-Exit-Step-Request command sent by the transmitting VTU

Name	Length (Octets)	Octet number	Content
L2.1-Exit-Step-Request	4	2	02_{16} (Note 1)
		3	One octet containing: Bit 7 (MSB): set to 1 indicates that this step is the last step of the L2.1 exit procedure; Bits 6-0 (LSBs): the count of the step number represented as unsigned integer (Note 2).
		4	One octet containing the ΔPSD_{ACT} value in the range from 0 to 25.5 dB in units of 0.1 dB, represented as an unsigned integer (Note 3).
NOTE 1 – All other values are reserved by ITU-T. NOTE 2 – The count of the step number shall be "1" at the first exit step, and shall increment by 1 at each subsequent step in a multi-step exit procedure. NOTE 3 – The same type of PSD trim (either flat or ceiled) as requested in associated L2.1-Entry-Step-Request command shall be used.			

Table E.7 – L2.1-Exit-Step-Request responses sent by the receiving VTU

Name	Length (Octets)	Octet number	Content
L2-ΔPSD-Request	See clause E.5.4.		See clause E.5.4.

E.5.3 L2-SRA-Request command and responses

The L2-SRA-Request command is defined in Table E.8. The L2-SRA-Request command is initiated by the receiving VTU and shall either be acknowledged by an L2-SYNCHRO pattern or rejected by a response defined in Table E.9. The L2-SRA-Request message indicates the actual PSD trim, the bit loading (bits only, with no gains and no tone indices, overall 4 bits per subcarrier), the set of active sub-carriers, and the framing parameters that will be applied starting from the first data symbol position following the subsequent L2-SYNCHRO pattern (see clauses E.3.1.1 and E.3.1.2). The sub-carrier grouping (with a sub-carrier grouping value (G) of 1, 2 or 4) shall reduce the length of the command down to a length not requiring segmentation.

The timing of changes for the parameters indicated in the L2-SRA-Request command shall be as specified in clause Q.3.1.1.1 (single-step procedure).

The first octet of the command and response is defined in Table 11-2 of [ITU-T G.993.2] (high priority). The other octets are defined in Table E.8 and Table E.9, respectively.

Table E.8 – L2-SRA-Request command sent by the receiving VTU

Name	Length (Octets)	Octet number	Content
L2-SRA-Request	Variable	2	03_{16} (Note 1)
		3	One octet containing the ΔPSD_{ACT} value in the range from 0 to 25.5 dB in units of 0.1 dB, represented as an unsigned integer.
		4-5	two octets containing the new value for L_1
		6	one octet containing the new value for B_{10}
		7	one octet containing the new value for M_1
		8	one octet containing the new value for R_1
		9	one octet containing the new value for Q
		10	one octet containing the new value for V
		11	one octet containing the new value for Q_{tx}
		12	one octet containing the new value for lb
		13	Sub-carrier grouping value (G) for the bit-loading (G=1, 2, or 4).
		Variable	Bit-loading of 1st band of MEDLEY set using the sub-carrier grouping (Note 2, Note 3).
		Variable	Bit-loading of 2nd band of MEDLEY set using the sub-carrier grouping (Note 2, Note 3).
		...	...
		Variable	Bit-loading of last band of MEDLEY set using the sub-carrier grouping (Note 2, Note 3).
NOTE 1 – All other values for octet numbers 2 are reserved by ITU-T. NOTE 2 – The bands of the MEDLEY set are defined in O-PRM (Table 12-30 of [ITU-T G.993.2]) for downstream and in R-PRM (Table 12-36 of [ITU-T G.993.2]) for upstream, with the bands descriptor format defined in Table 12-22 of [ITU-T G.993.2]. The bit-loading for a band is $\lceil$(index of last sub-carrier – index of first sub-carrier + 1)/(2×G)$\rceil$ octets in length (4 bits per sub-carrier group with LSBs of the last octet set to 0 if the number of sub-carrier groups in the band is odd). NOTE 3 – If the command is sent in response to the L2.1-Entry-Step-Request command, then the 4-bits per subcarrier coding F_{16} is a special value and indicates that the sub-carrier shall be inactive and remain inactive until the L2.1-Exit-Step-Request command is received.			

Table E.9 – L2-SRA-Request responses sent by the transmitting VTU

Name	Length (Octets)	Octet number	Content
L2-SRA-Reject	3	2	83_{16} (Note 1)
		3	1 octet for reason code with the following valid values (Note 1): 01_{16} – busy 02_{16} – invalid parameters
L2.1-Exit-Step-Request (Note 2)	See clause E.5.2		See clause E.5.2.
NOTE 1 – All other values are reserved by ITU-T. NOTE 2 – The transmitting VTU shall use this command only if it received an L2.1-exit-request primitive over the near-end γ_MGMT reference point and thus proceeding with the L2.1 entry procedure is not possible, or if it chooses to abort the L2.1 entry procedure.			

E.5.4 L2-ΔPSD-Request command and responses

The L2-ΔPSD-Request command is defined in Table E.10. The L2-ΔPSD-Request command is initiated by the receiving VTU and shall either be acknowledged by an L2-SYNCHRO pattern or rejected by a response defined in Table E.11. The L2-ΔPSD-Request command indicates that the receiving VTU is ready for the ΔPSD trim (indicated in the L2.1-Exit-Step-Request command) to be applied by the transmitting VTU starting from the first data symbol position after the subsequent L2-SYNCHRO pattern (see clauses E.3.1.1 and E.3.1.2).

The first octet of the command and response is defined in Table 11-2 of [ITU-T G.993.2] (high priority). The other octets are defined in Table E.10 and Table E.11, respectively.

Table E.10 – L2-ΔPSD-Request command sent by the receiving VTU

Name	Length (Octets)	Octet number	Content
L2-ΔPSD-Request	2	2	04_{16} (Note)
NOTE – All other values are reserved by ITU-T.			

Table E.11 – L2-ΔPSD-Request responses sent by the transmitting VTU

Name	Length (Octets)	Octet number	Content
L2-ΔPSD-Reject (Note 2, Note 3)	3	2	84_{16} (Note 1)
		3	1 octet for reason code with the following valid values (Note 1): 01_{16} – busy
NOTE 1 – All other values are reserved by ITU-T. NOTE 2 – The transmitting VTU may use this command during L2.1 entry procedure only. During L2.1 exit procedure, the transmitting VTU shall be prepared to implement the L2-ΔPSD-Request. NOTE 3 –The transmitting VTU shall use this command only if it received an L2.1-exit-request primitive over the near-end γ_MGMT reference point and thus proceeding with the L2.1 entry procedure is not possible, or if it chooses to abort the L2.1 entry procedure.			

E.5.5 L2.2-Entry-Request command and responses

The L2.2-Entry-Request command is defined in Table E.12. The L2.2-Entry-Request responses are defined in Table E.13. The L2.2-Entry-Request command initiates the entry procedure with transmission as defined for the L2.2 link sub-state to start from the first data symbol position after the subsequent L2-SYNCHRO pattern (see clause E.3.2.1).

The first octet of the command and response is defined in Table 11-4 of [ITU-T G.993.2] (normal priority). The other octets are defined in Table E.12 and Table E.13, respectively.

Table E.12 – L2.2-Entry-Request command sent by the transmitting VTU

Name	Length (Octets)	Octet number	Content
L2.2-Entry-Request	2	2	05_{16} (Note)
NOTE – All other values are reserved by ITU-T.			

Table E.13 – L2.2-Entry-Request responses sent by the receiving VTU

Name	Length (Octets)	Octet number	Content
L2.2-Entry-ACK	2	2	80_{16} (Note)
L2.2-Entry-Reject	3	2	85_{16} (Note)
		3	1 octet for reason code with the following valid values (Note): 01_{16} – busy
NOTE – All other values are reserved by ITU-T.			

E.5.6 L2.2-Exit-Request command and responses

The L2.2-Exit-Request command is defined in Table E.14. The L2.2-Exit-Request responses are defined in Table E.15. The L2.2-Exit-Request command initiates the exit procedure with transmission as defined for the L2.1 link sub-state to start from the first data symbol position after the subsequent L2-SYNCHRO pattern (see clause E.3.2.1).

The first octet of the command and response is defined in Table 11-4 of [ITU-T G.993.2] (normal priority). The other octets are defined in Table E.14 and Table E.15, respectively.

Table E.14 – L2.2-Exit-Request command sent by the transmitting VTU

Name	Length (Octets)	Octet number	Content
L2.2-Exit-Request	2	2	06_{16} (Note)
NOTE – All other values are reserved by ITU-T.			

Table E.15 – L2.2-Exit-Request responses sent by the receiving VTU

Name	Length (Octets)	Octet number	Content
L2.2-Exit-ACK	2	2	80_{16} (Note)
NOTE – All other values are reserved by ITU-T.			

E.5.7 L2.2-RX-Exit-Request command and responses

The L2.2-RX-Exit-Request command is defined in Table E.16. The L2.2-RX-Exit-Request responses are defined in Table E.17. The L2.2-RX-Exit-Requst command is a request from the receiving VTU to exit from the L2.2 link sub-state in the aim to perform OLR while in the L2.1 link sub-state (reason code "OLR") or in the aim to avoid the link being in the L2.2 link sub-state in the presence of REIN (reason code "REIN").

The first octet of the command and response is defined in Table 11-4 of [ITU-T G.993.2] (normal priority). The other octets are defined in Table E.16 and Table E.17, respectively.

Table E.16 – L2.2-RX-Exit-Request command sent by the receiving VTU

Name	Length (Octets)	Octet number	Content
L2.2-RX-Exit-Request	3	2	07_{16} (Note 1)
		3	1 octet for reason code with the following valid values (Note 1): 01_{16} – OLR 02_{16} – REIN
NOTE – All other values are reserved by ITU-T.			

Table E.17 – L2.2-RX-Exit-Request response sent by the transmitting VTU

Name	Length (Octets)	Octet number	Content
L2.2-Exit-Request	See clause E.5.6		See clause E.5.6.

Appendix I

Transmit state machine

(This appendix does not form an integral part of this Recommendation.)

I.1 Reference transmit state machine

NOTE – The equations derived below for the reference transmit state machine assume a transmission of data symbols at a frequency f_s without insertion of sync symbols.

The reference transmit state machine retransmits unacknowledged DTUs exactly Q_{tx} DTUs after the last transmission of the same DTUs. An unacknowledged DTU is not retransmitted more than *delay_max* after the first transmission of the same DTU. Therefore, the maximum size of the receive buffer expressed in number of DTUs ($Q_{rx,max}$) can be derived from *delay_max* as:

$$Q_{rx,\max} = \left\lfloor \frac{Delay\_\max . f_S}{S.Q} \right\rfloor$$

Likewise, to meet the minimum delay requirement *delay_min*, the minimum size of the receive buffer expressed in number of DTUs ($Q_{rx,min}$) can be derived from *delay_min* as:

$$Q_{rx,\max} = \left\lceil \frac{Delay\_\min . f_S}{S.Q} \right\rceil$$

The informative transmit state machine has no limitation on the number of retransmissions per unit of time.

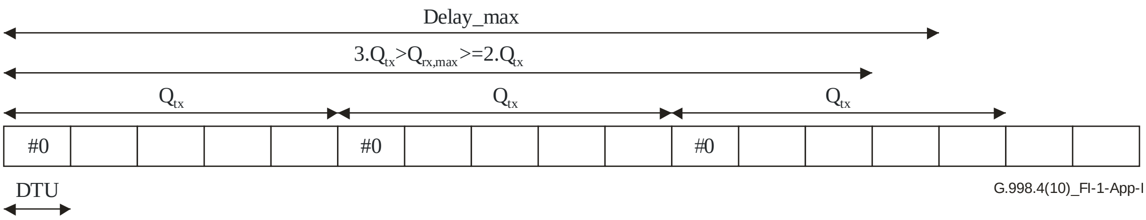


Figure I.1 – Example of multiple retransmissions of DTU with SID=0 and 2.Q_{tx}≤$Q_{rx,max}$<3.Q_{tx}

With the reference transmit state machine, the longest impulse (expressed in DMT symbols) that can be corrected in the absence of REIN (i.e., *INP_REIN_min*=0) is:

$$INP = \begin{cases} \lfloor (Nret \times Q_{tx} - 1) \times S \times Q \rfloor & \text{if } Q_{tx} \geq roundtrip_{DTU} \\ 0 & \text{otherwise} \end{cases}$$

where $roundtrip_{DTU} = \left\lceil \frac{HRT_{tx}^{S} + HRT_{Rx}^{S}}{S.Q} \right\rceil + HRT_{Tx}^{DTU} + HRT_{Rx}^{DTU} + 1$ is the total roundtrip in DTU.

Nret is the maximum number of retransmissions within the maximum delay constraint, as defined in clause 8.6.4.

If REIN protection is required (i.e., *INP_REIN_min* > 0), the INP is given by:

$$INP = \lfloor ((Nret - 1) \times Q_{tx} - 1) \times S \times Q \rfloor$$

provided that the following conditions are met:

(i) $Nret \geq 2$

(ii) $Q_{tx} \geq roundtrip_{DTU}$

(iii) $$\left(Nret \times Q_{tx} + \left\lceil \frac{INP\_\min\_rein}{S_1 \times Q} \right\rceil + 1\right) \times S_1 \times Q \le \left\lfloor \frac{k \times f_{DMT}}{f_{REIN}} \right\rfloor$$

(iv) $$Nret \times Q_{tx} \ge \left\lceil \left(\left\lceil \frac{(k-1) \times f_{DMT}}{f_{REIN}} + INP\_\min\_rein \right\rceil \right) \times \frac{1}{S_1 \times Q} \right\rceil + 1$$

(v) $$\left(Q_{tx} + \left\lceil \frac{INP\_\min\_rein}{S_1 \times Q} \right\rceil + 1\right) \times S_1 \times Q \le \left\lfloor \frac{f_{DMT}}{f_{REIN}} \right\rfloor$$

If any of the above conditions are not met, the INP is 0.

I.2 Last chance retransmission state machine

If a DTU, situated anywhere in the TX retransmission buffer, would exceed the *delay_max* constraint, because it is to be retransmitted later than the next outgoing DTU-container, then, the DTU is retransmitted in the next outgoing container and is marked as acknowledged. No other changes are necessary in the buffer. The transmitted DTU is not fed into the beginning of the queue. This last chance retransmission is made, even though, a previous retransmission could not have been acknowledged at that time. Scheduled (re)transmissions of other DTUs are delayed by one DTU-Container. Figure I.2 depicts such a scheme.

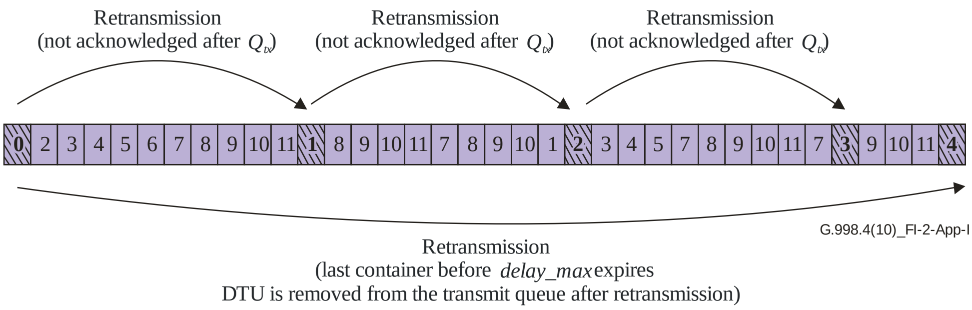


Figure I.2 – A pictorial representation of a last chance retransmission state machine

A last chance retransmission state machine provides the highest achievable impulse noise protection of INP_min ~ *delay_max*.

Appendix II

Motivation of MTBE accelerated test

(This appendix does not form an integral part of this Recommendation.)

This appendix provides motivation for the P_{DTU} requirement in the accelerated test for MTBE.

Stationary noise can trigger retransmissions depending on the noise level. It can be assumed that the probability that a DTU is corrupted due to stationary noise is identical for all retransmissions of the same DTU. That is because the time between the retransmissions is large compared to effects from the Viterbi decoder.

When considering an environment with only stationary noise, the MTBE after retransmission can be calculated as:

$$MTBE_{RET} = \frac{T_{DTU}}{(P_{DTU})^{M_{RET}+1}}$$

Where:

$MTBE_{RET}$	is the MTBE after retransmissions, expressed in seconds
P_{DTU}	is the Probability that a DTU is corrupted, i.e., a DTU is not received correctly in a single transmission
T_{DTU}	is the time duration of a DTU expressed in seconds
M_{RET}	is the number of retransmissions allowed for additional robustness against stationary noise errors. This is the number of retransmissions that the system can support in addition to the number of retransmissions that are needed to meet the various impulse noise protection requirements.

Inversely, for a given required $MTBE_{RET}$, the required P_{DTU} can be calculated as:

$$P_{DTU} = \left(\frac{T_{DTU}}{MTBE_{RET}}\right)^{\frac{1}{M_{RET}+1}}$$

In this version of Recommendation ITU-T G.998.4, it is assumed that $M_{RET} = 1$. Operation conditions which allow further optimization of the performance are for further study. In this case, we have:

$$P_{DTU} = \left(\frac{T_{DTU}}{MTBE_{RET}}\right)^{1/2}$$

We further assume that $MTBE_{RET} = 14400$ seconds (see clause 10.3). With this, we get:

$$P_{DTU} = \left(\frac{T_{DTU\_in\_DMT}}{14400 \times f_s}\right)^{1/2} = \frac{8.3333 \times 10^{-3}}{\sqrt{f_s}} \times \left(T_{DTU\_in\_DMT}\right)^{1/2}$$

Where:

f_s	is the symbol rate in Hz
$T_{DTU\_in\_DMT}$	is the duration of the DTU expressed in DMT symbols. This is identical to $Q \times S_1$.

As specified in clause 8.1, $T_{DTU\_in\_DMT}$ can vary between ½ and 4 DMT symbols.

Table II.1 shows some example numerical values of P_{DTU} for a selection of different DTU sizes.

Table II.1 – Value of P_{DTU} as function of DTU duration

$T_{DTU\_in\_DMT}$	P_{DTU} for f_s=4000	P_{DTU} for f_s=8000
0.5	0.9317×10^{-4}	0.6588×10^{-4}
1	1.3176×10^{-4}	0.9317×10^{-4}
2	1.8634×10^{-4}	1.3176×10^{-4}
4	2.6352×10^{-4}	1.8634×10^{-4}

The retransmission overhead due to a correction of stationary noise (*STAT_OH*, see Table 9-2) is approximately equal to P_{DTU}. In Table 9-2, this value is approximated as a single value 10^{-4}, independent of DTU size and symbol rate. This value is consistent with the range of values shown in Table II.1.

Bibliography

[b-TR-126] Broadband Forum TR-126 (2006), *Triple-Play Services Quality of Experience (QoE) Requirements*.

SERIES OF ITU-T RECOMMENDATIONS

Series A	Organization of the work of ITU-T
Series D	General tariff principles
Series E	Overall network operation, telephone service, service operation and human factors
Series F	Non-telephone telecommunication services
Series G	**Transmission systems and media, digital systems and networks**
Series H	Audiovisual and multimedia systems
Series I	Integrated services digital network
Series J	Cable networks and transmission of television, sound programme and other multimedia signals
Series K	Protection against interference
Series L	Environment and ICTs, climate change, e-waste, energy efficiency; construction, installation and protection of cables and other elements of outside plant
Series M	Telecommunication management, including TMN and network maintenance
Series N	Maintenance: international sound programme and television transmission circuits
Series O	Specifications of measuring equipment
Series P	Terminals and subjective and objective assessment methods
Series Q	Switching and signalling
Series R	Telegraph transmission
Series S	Telegraph services terminal equipment
Series T	Terminals for telematic services
Series U	Telegraph switching
Series V	Data communication over the telephone network
Series X	Data networks, open system communications and security
Series Y	Global information infrastructure, Internet protocol aspects and next-generation networks
Series Z	Languages and general software aspects for telecommunication systems

Printed in Switzerland
Geneva, 2015