



INTERNATIONAL TELECOMMUNICATION UNION

ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

G.993.1

(11/2001)

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

Digital sections and digital line system – Access networks

**Very high speed digital subscriber line
foundation**

ITU-T Recommendation G.993.1

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ITU-T Recommendation G.993.1

Very high speed digital subscriber line foundation

Summary

G.993.1 VDSL (Very high speed Digital Subscriber Line Foundation) permits the transmission of asymmetric and symmetric aggregate data rates up to tens of Mbit/s on twisted pairs. G.993.1 includes world-wide frequency plans that allow asymmetric and symmetric services in the same group of twisted pairs (known as a binder). G.993.1 transceivers must overcome many types of ingress interference from radio and other transmission techniques that occur in the same frequencies of typical deployment scenarios. Similarly, G.993.1 transmission power transmission levels have been designed to minimize potential egress interference into other transmission systems. As with other Recommendations in the G.99x series, G.993.1 uses G.994.1 to handshake and initiate the transceiver training sequence.

Source

ITU-T Recommendation G.993.1 was prepared by ITU-T Study Group 15 (2001-2004) and approved under the WTSA Resolution 1 procedure on 29 November 2001.

FOREWORD

The International Telecommunication Union (ITU) is the United Nations specialized agency in the field of telecommunications. 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.

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ITU-T Recommendation G.993.1

Very high speed digital subscriber line foundation

1 Scope and applications

G.993.1 VDSL (Very high speed Digital Subscriber Lines) permits the transmission of asymmetric and symmetric aggregate data rates up to tens of Mbit/s on twisted pairs. G.993.1 is an access technology that exploits the existing infrastructure of copper wires that were originally deployed for POTS services. While POTS uses approximately the lower 4 kHz and ADSL/HDSL use approximately 1 MHz of the copper wire spectrum, G.993.1 uses up to 12 MHz of the spectrum. G.993.1 can be deployed from central offices or from Fibre-fed cabinets located near the customer premises.

G.993.1 includes world-wide frequency plans that allow asymmetric and symmetric services in the same group of wire pairs (known as a binder). This is accomplished by designating bands for the transmission of upstream and downstream signals.

G.993.1 transceivers must overcome many types of ingress interference from radio and other transmission techniques that occur in the same frequencies of typical deployment scenarios. Similarly, G.993.1 transmission power transmission levels have been designed to minimize potential egress interference into other transmission systems.

As with other Recommendations in the G.99x series, G.993.1 uses G.994.1 to handshake and initiate the transceiver training sequence.

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.

NOTE – The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation

- ITU-T Recommendation G.994.1 (2001), *Handshake procedures for Digital Subscriber Line (DSL) transceivers*.
- ITU-T Recommendation G.996.1 (2001), *Test procedures for digital subscriber line (DSL) transceivers*.
- ITU-T Recommendation G.997.1 (1999), *Physical layer management for digital subscriber line (DSL) transceivers*.
- ITU-T Recommendations I.432.x, *B-ISDN User-Network Interface – Physical layer specification*.
- ISO/IEC 3309:1993, *Information technology – Telecommunications and information exchange between systems – High-level data link control (HDLC) procedures – Frame structure*.

3 Definitions

This Recommendation defines the following terms:

3.1 bit error ratio: The ratio of the number of bits in error to the number of bits sent over a period of time.

3.2 channel: A connection conveying signals between two blocks (the conveyed signals represent information). Channels also convey signals between a block and the environment. Channels may be unidirectional or bidirectional.

3.3 connection: An association of transmission channels or circuits, switching and other functional units set up to provide a means for a transfer of user, control and management information between two or more end points (blocks) in a telecommunications network.

3.4 downstream: Information flow whose direction is from an End-Service Provider System to an End-Service Consumer System.

3.5 interface: A point of demarcation between two blocks through which information flows from one block to the other. See logical- and physical-interface definitions for further details. An interface may be physical-interface or a logical-interface.

3.6 layer/sublayer: A collection of objects of the same hierarchical rank.

3.7 logical information flow path: A sequence of information transfers from an initial information source object to a terminal information destination object, either directly or through intermediate objects. Different physical information flow paths may be associated with a logical information flow path segment or with the entire path, in different implementations.

3.8 logical (functional) interface: An interface where the semantic, syntactic, and symbolic attributes of information flows are defined. Logical interfaces do not define the physical properties of signals used to represent the information. A logical interface can be an internal or external interface. It is defined by a set of information flows and associated protocol stacks.

3.9 Management Plane (MP): A plane that contains management information.

3.10 management information: Information exchanged by Management Plane objects; may be content information or control information.

3.11 network: A collection of interconnected elements that provide connection services to users.

3.12 network control function: The network control function is responsible for the error-free receipt and transmission of content flow information to and from the server.

3.13 Network Termination (NT): The element of the Access Network performing the connection between the infrastructure owned by the Access Network operator and the Service-Consumer System (ownership decoupling). The NT can be passive or active, transparent or not.

3.14 noise margin: The maximum amount by which the reference noise level can be increased during a BER test without causing the modem to fail the BER requirement.

3.15 physical interface: An interface where the physical characteristics of signals used to represent information and the physical characteristics of channels used to carry the signals are defined. A physical interface is an external interface. It is fully defined by its physical and electrical characteristics. Logical information flows map to signal flows that pass through physical interfaces.

3.16 plane: A category that identifies a collection of related objects, e.g. objects that execute similar or complementary functions; or peer objects that interact to use or to provide services in a class that reflects authority, capability, or time period. Management-plane service objects, for example, may authorize ISP-clients' access to certain control-plane service objects that in turn may allow the clients to use services provided by certain user-plane objects.

3.17 primitives: Basic measures of performance, usually obtained from digital signal line codes and frame formats, or as reported in overhead indicators from the far-end. Performance primitives are categorized as events, anomalies, and defects. Primitives may also be basic measures of other quantities (e.g. ac or battery power), usually obtained from equipment indicators.

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

3.19 SNR margin: The modem's estimate of the maximum amount by which the receiver noise (internal and external) could be increased without causing the modem BER to fail the BER requirement.

3.20 symbol: A bit or a defined sequence of bits.

3.21 system: A collection of interacting objects that serves a useful purpose; typically, a primary subdivision of an object of any size or composition (including domains).

3.22 upstream: Information flow whose direction is from an End-Service Customer System to an End-Service Provider System.

3.23 user: A service-consuming object or system (block).

3.24 User Plane (UP): A classification for objects whose principal function is to provide transfer of end-user information: user information may be user-to-user content (e.g. a movie), or private user-to-user data.

4 Abbreviations

This Recommendation uses the following abbreviations:

ATM	Asynchronous Transfer Mode
DS	Downstream
DSL	Digital Subscriber Line
EIO	External Interface Adapter
eoc	Embedded Operations Channel (between the VTU-O and VTU-R)
FDD	Frequency Division Duplexing
FEC	Forward Error Correction
HEC	Header Error Control
ISDN	Integrated Services Digital Network
LCD	Loss of Cell Delineation
LT	Line Termination
MIB	Management Information Base
MSB	Most Significant Bit
NT	Network Termination
NTR	Network Timing Reference
OAM	Operations, Administration and Maintenance
OC	Overhead Channel
ONU	Optical Network Unit

PHY	Physical Layer
PMD	Physical Media Dependent
PMS	Physical Media Specific
PMS-TC	Physical Media Specific-Transmission Convergence
PSD	Power Spectral Density
PTM	Packet Transfer Mode
QoS	Quality of service
RF	Radio Frequency
TBD	To Be Determined
TC	Transmission Convergence
TCM	Time Compression Multiplex
TPS	Transmission Protocol Specific
TPS-TC	Transmission Protocol Specific-Transmission Convergence
Tx	Transmitter
UPBO	Upstream Power Back-off
US	Upstream
VDSL	Very high speed Digital Subscriber Line
VME_O	VTU-O Management Entity
VME_R	VTU-R Management Entity
VTU	VDSL Transceiver Unit
VTU-O	VTU at the ONU
VTU-R	VTU at the Remote site
VTU-x	Any one of VTU-O or VTU-R
xDSL	Generic term covering the family of all DSL technologies, e.g. DSL, HDSL, ADSL, VDSL

5 Reference models

5.1 General reference models

Figure 5-1 shows the reference configuration used for G.993.1. It is essentially a Fibre to the Node architecture with an Optical Network Unit (ONU) sited in the existing metallic access network (or at the serving Local Exchange or Central Office). The first architectural model covers Fibre-to-the-cabinet (FTTCab) type of deployment; the second one is Fibre-to-the-exchange (FTTEx) type of deployment. Existing unscreened twisted metallic access wire-pairs are used to convey the signals to and from the customer's premises.

The reference configuration provides two or four data paths with bit rate under the control of the network operator, consisting of one or two downstream and one or two upstream data paths. A single path in each direction can be of high latency (with lower BER expected) or lower latency (with higher BER expected). Dual paths in each direction provide one path of each type. The dual latency configuration is thought to be the minimum that is capable of supporting a sufficient full service set, although there are organizations supporting both the single latency model with

programmable latency, and others requesting more than two paths/latencies. The model assumes that Forward Error Correction (FEC) will be needed for part of the payload and that deep interleaving will be required to provide adequate protection against impulse noise.

The model introduces service-splitter functional blocks to accommodate shared use of the physical transmission media for VDSL and either POTS or ISDN-BA. The rationale behind this is that network operators are then free to evolve their networks in one of two ways: complete change out or overlay. An active Network Termination (NT) provides termination of the point-to-point VDSL transmission system and presents a standardized set of User Network Interfaces (UNIs) at the customer's premises. The NT provides the network operator with the ability to test the network up to the UNI at the customer's premises in the event of a fault condition or via nighttime routing. The home wiring transmission system is outside the scope of this Recommendation.

It is envisaged that VDSL will find applications in the transport of various protocols. For each application different functional requirements must be developed for the Transport Protocol Specific-Transmission Convergence Layer (TPS-TC). This specification covers the functional requirements for the transport of ATM and PTM. However the G.993.1 core transceiver shall be capable of supporting future additional applications. VDSL service should non-invasively coexist with the narrow-band services on the same pair. Failure of power to the broadband NT or failure of the VDSL service shall not affect any existing narrow-band services. This may imply that the splitter filter is of a passive nature not requiring external power in order to provide frequency separation of the VDSL and existing narrow-band signals.

POTS, if present, shall continue to be powered from the existing exchange node and a DC path is required from the local exchange to the customer telephone. Similarly a DC path is required for ISDN-BA in order to provide remote power feeding to the ISDN-BA NT (and that emergency power can be provided by the local exchange for one ISDN terminal in the event of loss of power at the subscriber premises).

POTS and ISDN-BA cannot exist simultaneously on the same pair at present. Network Operators may provide one or the other but not both over a single wire-pair. Network Operators may choose to provide VDSL on access lines without any narrow-band services.

The broadband NT is not required to be powered remotely.

Repeatered operation is not a requirement for G.993.1.

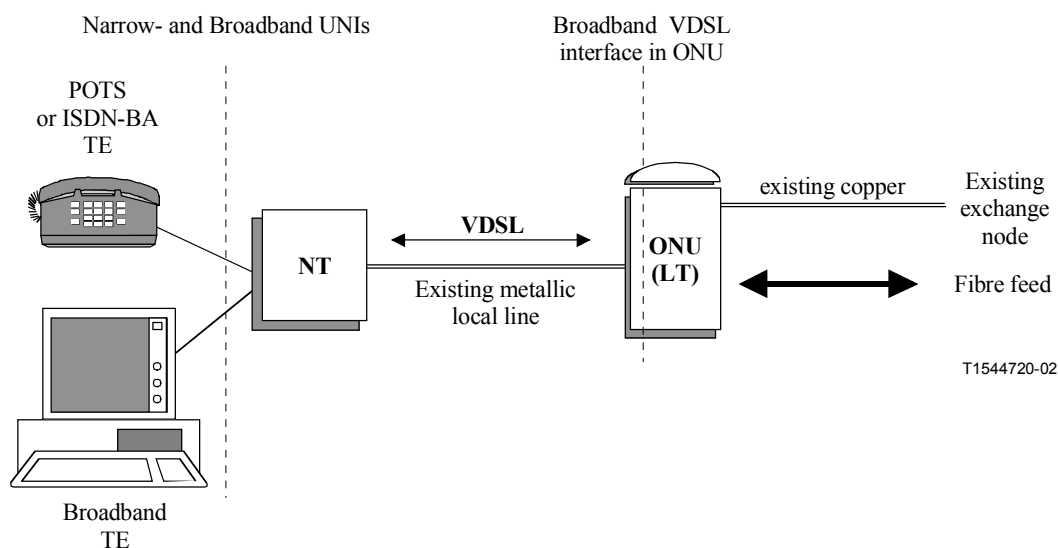


Figure 5-1/G.993.1 – General reference model

5.2 Functional reference model

One of the TPS-TC in Figure 5-2 may be assigned for management purposes and is called Overhead Channel TC (OC-TC).

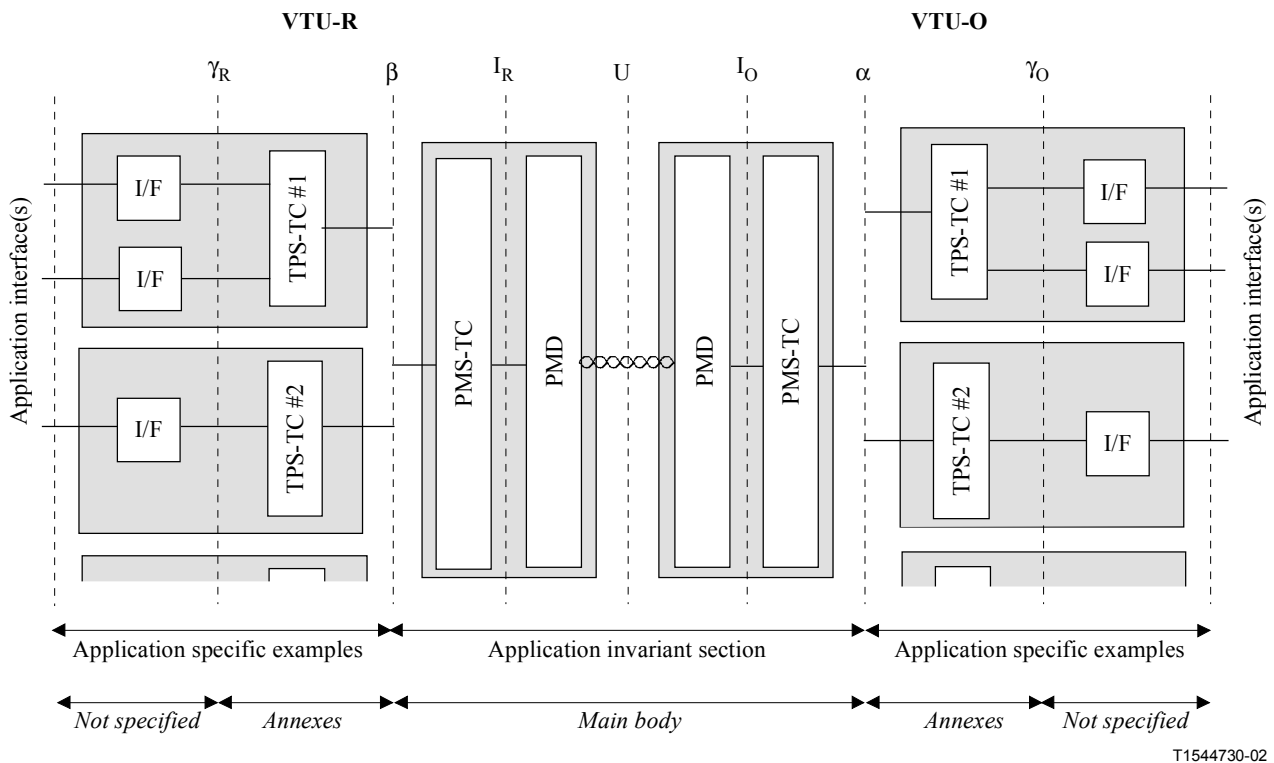


Figure 5-2/G.993.1 – VTU-x functional reference model

5.3 Protocol reference model

Figure 5-3 shows the G.993.1 protocol reference model.

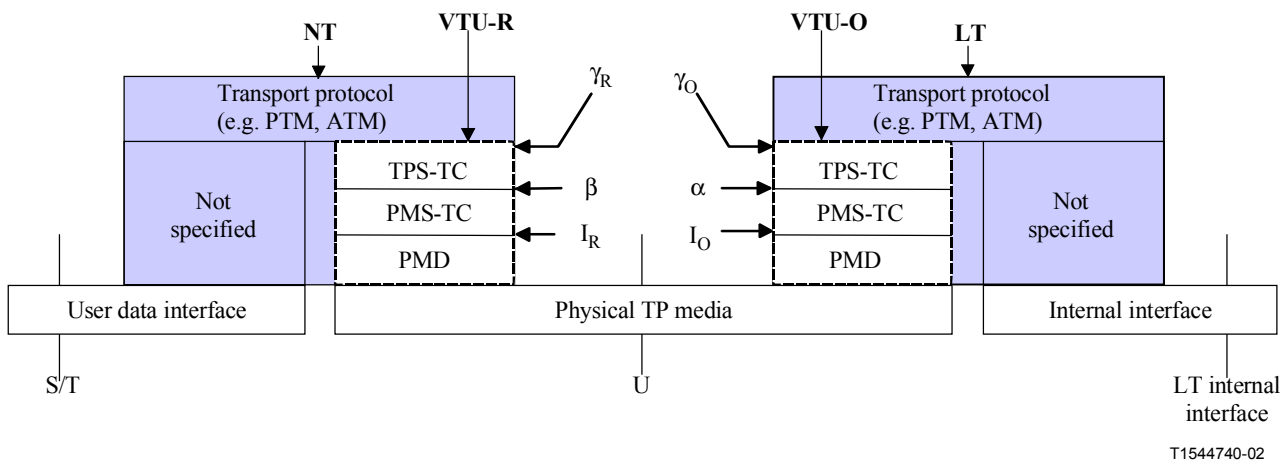


Figure 5-3/G.993.1 – VTU-x protocol reference model

6 Transmission medium interface characteristics

This clause specifies the interface between the transceiver and the transmission medium (U-O2 and U-R2 reference points – see Figure 22/G.995.1 named G.993.1 System Reference Model). For the purposes of this Recommendation, the U-O2/U-R2 and U interfaces are spectrally equivalent.

6.1 Duplexing method

G.993.1 transceivers shall use Frequency Division Duplexing (FDD) in separating upstream and downstream transmission.

G.993.1 systems use a four-band plan that starts at 138 kHz and extends up to 12 MHz. The four frequency bands denoted as DS1, US1, DS2, and US2, for the first downstream band, the first upstream band, the second downstream band, and the second upstream band respectively as shown in Figure 6-1, shall be allocated according to the band separating frequencies f_1, f_2, f_3, f_4 and f_5 .

The use of the band between 25 kHz (f_0) and 138 kHz (f_1) shall be negotiated using G.994.1. The G.994.1 handshake mechanism indicates and selects (see 10.1 and 10.2) if the capability exists in the G.993.1 equipment (bit "Opt Usage") and one of:

- If the band is to be used for upstream (bit "OptUp").
- If the band is to be used for downstream (bit "OptDn").

Other uses of the band between 25 kHz (f_0) and 138 kHz (f_1) are for further study.

See Annexes A, B and C for the specifics of f_0, f_1, f_2, f_3, f_4 and f_5 for the Bandplans.

The use of the bands below 25 kHz (f_0) and above 12 MHz (f_5) is for further study.

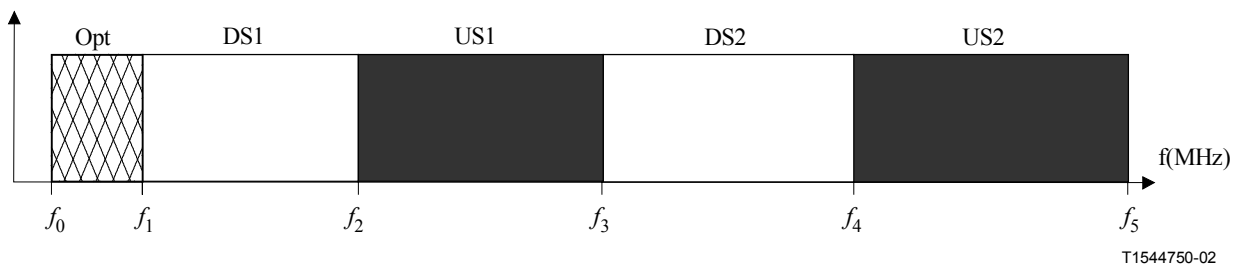


Figure 6-1/G.993.1 – G.993.1 band allocation

6.2 Power Spectral Density (PSD)

6.2.1 Transmit bands

See Annexes D, E and F.

6.2.2 Stop bands

The Power Spectral Density (PSD) mask inside the stop bands shall be as defined in Figure 6-2. The narrow band PSD mask applies between band separating frequencies f_{tr1} and f_{tr2} . The wide band power limit applies in that part of the receive band lying between the transition bands.

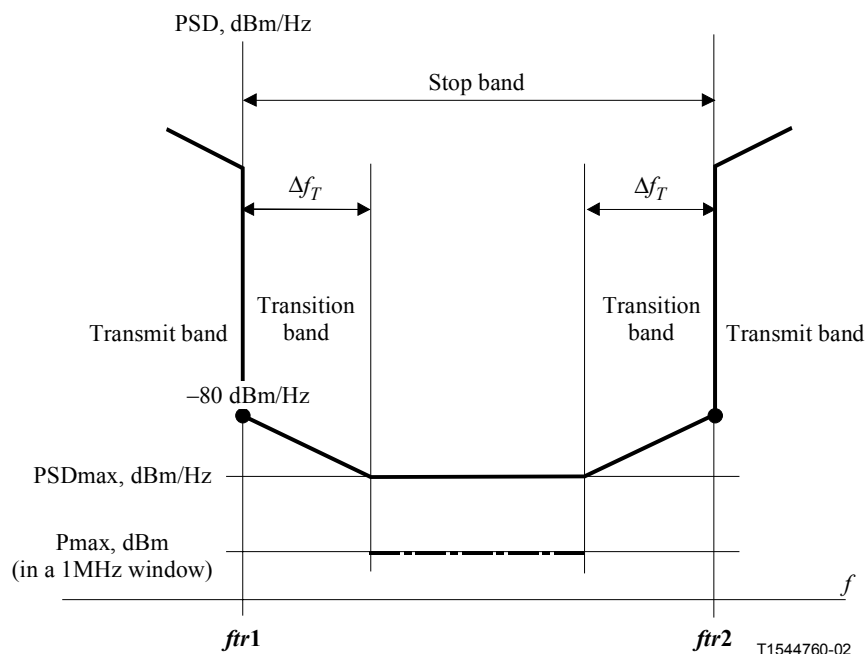


Figure 6-2/G.993.1 – Stop band PSD mask

The width of the transition bands Δf_T shall be independent of frequency and have a value of 175 kHz. Transition bands below 138 kHz are for further study.

The corresponding PSD mask values inside the stop bands shall be as listed in Table 6-1.

Table 6-1/G.993.1 – Stop band PSD mask

Frequency MHz	Maximum PSD PSD_{max} , dBm/Hz	Maximum power in a 1 MHz sliding window P_{max} , dBm
<0.12	-120	–
0.12-0.225	-110	–
0.225-4.0	-100	–
4.0-5.0	-100	-50
5.0-30.0	-100	-52
≥ 30.0	-120	–
Transition frequency	-80	–

The stop band transmit PSD shall comply with *both* the maximum PSD limitations, using a measurement resolution bandwidth of 10 kHz and the maximum power in a 1 MHz sliding window limitations presented in Table 6-1. The power in a 1 MHz sliding window is measured in a 1 MHz bandwidth starting at frequency $f_{tr1} + \Delta f_T$ of the corresponding transmit signal band and finishing at the next transition frequency $f_{tr2} - \Delta f_T$, as defined in Figure 6-2. If the value of the stop band minus $2\Delta f_T$, ($f_{tr2} - f_{tr1} - 2\Delta f_T$), is narrower than 1 MHz, the bandwidth of the measurement device should be set to Δf_M , with Δf_M equal to or less than the value of the stop band minus $2\Delta f_T$ ($\Delta f_M \leq f_{tr2} - f_{tr1} - 2\Delta f_T$), and the measured result should be recalculated to the 1 MHz sliding window as:

$$P_{max} = P - 10 \log(\Delta f_M)$$

where P is the measured result in dBm, Δf_M is the bandwidth used for the measurement in MHz.

6.2.3 PSD reduction function in the frequency region below 1.104 MHz

The implementation of the PSD reduction function in the frequency region below 1.104 MHz is mandatory, and the operator determines whether the function is used or not. The exact PSD reduction function is for further study.

The use of the PSD reduction function shall be selected through G.994.1 (see 10.1 and 10.2).

6.2.4 Egress control

G.993.1 equipment shall be able to reduce the PSD below -80 dBm/Hz in one or more of the standardized Amateur Radio bands simultaneously. The corresponding amateur frequency bands are presented in Table 6-2.

Table 6-2/G.993.1 – International amateur radio bands

Band start (kHz)	Band stop (kHz)
1 810	2 000
3 500	3 800
7 000	7 100
10 100	10 150
14 000	14 350
18 068	18 168
21 000	21 450
24 890	24 990
28 000	29 100

6.3 Upstream Power Back Off (UPBO)

6.3.1 Power Back-off Mechanism

Upstream power back-off (UPBO) shall be applied to provide spectral compatibility between loops of different lengths deployed in the same binder. Only one UPBO mode shall be supported as described below.

- It shall be possible for the network management system to set the limiting transmit PSD mask for the VTU-R to one of the standard transmit PSD masks defined in 6.3.2.
- The VTU-R shall perform UPBO as described in 6.3.2 autonomously, i.e. without sending any significant information to the VTU-O until the UPBO is applied.
- After UPBO has been applied, the VTU-O shall be capable of adjusting the transmit PSD selected by the VTU-R; the adjusted transmit PSD shall be subject to the limitations given in 6.3.2.
- To enable the VTU-R to initiate a connection with the VTU-O, which will occur before UPBO has been applied, the VTU-R shall be allowed to cause more degradation to other loops than expected when using the mode described in 6.3.2. The mechanism by which the VTU-R initiates a connection is for further study.

NOTE – The allowed additional degradation during the initiation is for further study.

6.3.2 Power back-off Mask

The VTU-R shall explicitly estimate the electrical length of its line, kl_0 , and use this value to calculate the transmit PSD mask $TxPSD(kl_0, f)$. The VTU-R shall then adapt its transmit signal to conform strictly to the mask $TxPSD(kl_0, f)$. Given:

$$TxPSD(kl_0, f) = PSDREF(f) + (LOSS(kl_0, f) \text{ in dB})$$
$$LOSS = kl_0 \sqrt{f} \text{ in dB}$$

The *LOSS* function is an approximation of the loop attenuation (loss).

NOTE – The *LOSS* function is for further study.

PSDREF(f) is a function of frequency but is independent of length and type of cable. It is a goal to have a single function, but further study may suggest that the single function is specific to a geographic region; however, within each region there shall only be a single function.

The estimate of the electrical length should be sufficiently accurate to avoid spectrum management problems and additional performance loss. The mechanism to guarantee the necessary accuracy of the estimate is for further study.

7 TPS-TC sublayer general functional characteristics

The physical layer shall be able to transport at least one of ATM or PTM signals. See Annexes G and H for the specifics of these TPS-TC Applications.

7.1 α/β interface specification

The α and β reference points define corresponding interfaces between the TPS-TC and PMS-TC at the VTU-O and VTU-R sides respectively. Both interfaces are hypothetical, application independent, identical. The interfaces comprise the following flows of signals between the TPS-TC and the PMS-TC sublayers:

- data flow;
- synchronization flow.

NOTE – If dual latency is applied, the interface comprises two identical Data and Synchronization flows: one for the Fast and one for the Slow channel respectively. Each flow is between the corresponding TPS-TC and PMS-TC sublayer.

7.1.1 Data flow

Data flow comprise two generic *octet-oriented* streams with the rates defined by the physical net capabilities:

- transmit data stream: **Tx**;
- receive data stream: **Rx**.

The Data flow signals description is presented in Table 7-1.

If data streams are *serial* by implementation, the MSB of each octet is sent first. The **Tx**, **Rx** rate values are set during the system configuration.

Table 7-1/G.993.1 – TPS-TC: α/β interface data and synchronization flows signal summary

Signal(s)	Description	Direction	Notes
<i>Data signals</i>			
Tx	Transmit data	TPS-TC → PMS-TC	
Rx	Receive data	TPS-TC ← PMS-TC	
<i>Synchronization signals</i>			
Clk _t	Transmit bit timing	TPS-TC ← PMS-TC	Optional
Clk _r	Receive bit timing		
Osync _t	Transmit octet timing		
Osync _r	Receive octet timing		

7.1.2 Synchronization flow

This flow provides synchronization between the TPS-TC sublayer and PMS-TC sublayer. The Synchronization flow comprises up to four synchronization signals presented in Table 7-2:

- transmit and receive data flow bit-synchronization (Clk_t, Clk_r);
- transmit and receive data flow octet-synchronization (Osync_t, Osync_r).

All synchronization signals are asserted by PMS-TC and directed towards TPS-TC. The signals Osync_t, Osync_r are mandatory, other signals are *optional*.

The Clk_t and the Clk_r rates are matched with the Tx and the Rx data rates respectively.

7.2 OC TPS-TC application interface (γ_O , γ_R) description

This clause specifies a VDSL Operations Channel Transport Protocol Specific Transmission Convergence sublayer (OC-TC), which describes the transmission of the Embedded Operations Channel (eoc) over a VDSL link between the VDSL Management Entities (VME) at the opposite sides of the link (see Figure 8-2). The OC-TC is specified at both the γ_O and γ_R reference points of the VTU-O and VTU-R sites respectively. Both γ interfaces are functional, identical and contain the following flows of signals:

- data flow;
- synchronization flow.

7.2.1 Data flow

The eoc data flow includes two contra-directional streams of 2-octet blocks each (eoc_{tx}, eoc_{rx}) with independent rates flowing between the eoc application layer (VME) and TPS-TC OC block (OC-TC). The bit rates of both streams are *arbitrary* under a predefined upper limit of the OC channel aggregate transport capability. The data flow signal description is presented in Table 7-1.

If data streams are *serial* by implementation, the MSB of each octet is sent first.

7.2.2 Synchronization flow

This flow provides synchronization between the eoc application layer (VME) and the OC-TC (see 8.4). The flow includes the following synchronization signals, presented in Table 7-2:

- transmit and receive timing signals (eoc_{tx}_clk, eoc_{rx}_clk): both asserted by the eoc processor;

- transmit enable flag (tx_enbl): asserted by OC-TC and allows to transmit the next 2-octet block;
- receive enable flag (rx_enbl): asserted by OC-TC and indicates that the next 2-octet block is allocated in the OC-TC receive buffer.

Table 7-2/G.993.1 – OC-TC: γ interface data and synchronization flow summary

Signal	Description	Direction	Notes
<i>Data flow</i>			
eoc_tx	Transmit eoc data	VME → OC-TC	Two-octet block
eoc_rx	Receive eoc data	VME ← OC-TC	
<i>Synchronization flow</i>			
eoc_tx_clk	Transmit clock	VME → OC-TC	
eoc_rx_clk	Receive clock	VME → OC-TC	
tx_enbl	Transmit enable flag	VME ← OC-TC	
rx_enbl	Receive enable flag	VME ← OC-TC	

NOTE – The main buffering required to implement the eoc communication protocol shall be provided by the VME; only a minimum buffering for eoc is supposed in OC-TC.

8 Management

8.1 OAM function model

The OAM functional model of a VDSL link, as shown in Figure 8-1, contains OAM entities intended to manage the following transmission entities:

- *VDSL Line entity*: The physical transport vehicle provided by PMD and PMS-TC transmission sublayers.
- *VDSL Path entity*: The applicable transport protocol path, provided by TPS-TC sublayer. A path could be either for a single application (single latency, single transport protocol) or multiple, including optionally different transport protocols over single and dual latency.
- *VDSL System entity*: The user-application path, provided by the layers higher than TC. This path also provides the high level OAM functionality between the VTU-O and the VTU-R.

The structure of OAM entities at both the VTU-O and VTU-R is identical. The data exchange between the management processes of the peer OAM entities at the VTU-O and VTU-R is established over three OAM-dedicated communication channels.

Management process also assumes an exchange of management information inside the VTU between the OAM entities and the Network Management Agent (NMA). Such exchange is accomplished:

- via γ interface: between the NMA and the TPS-TC;
- via $\alpha(\beta)$ interface: between the NMA and PMS-TC/PMD.

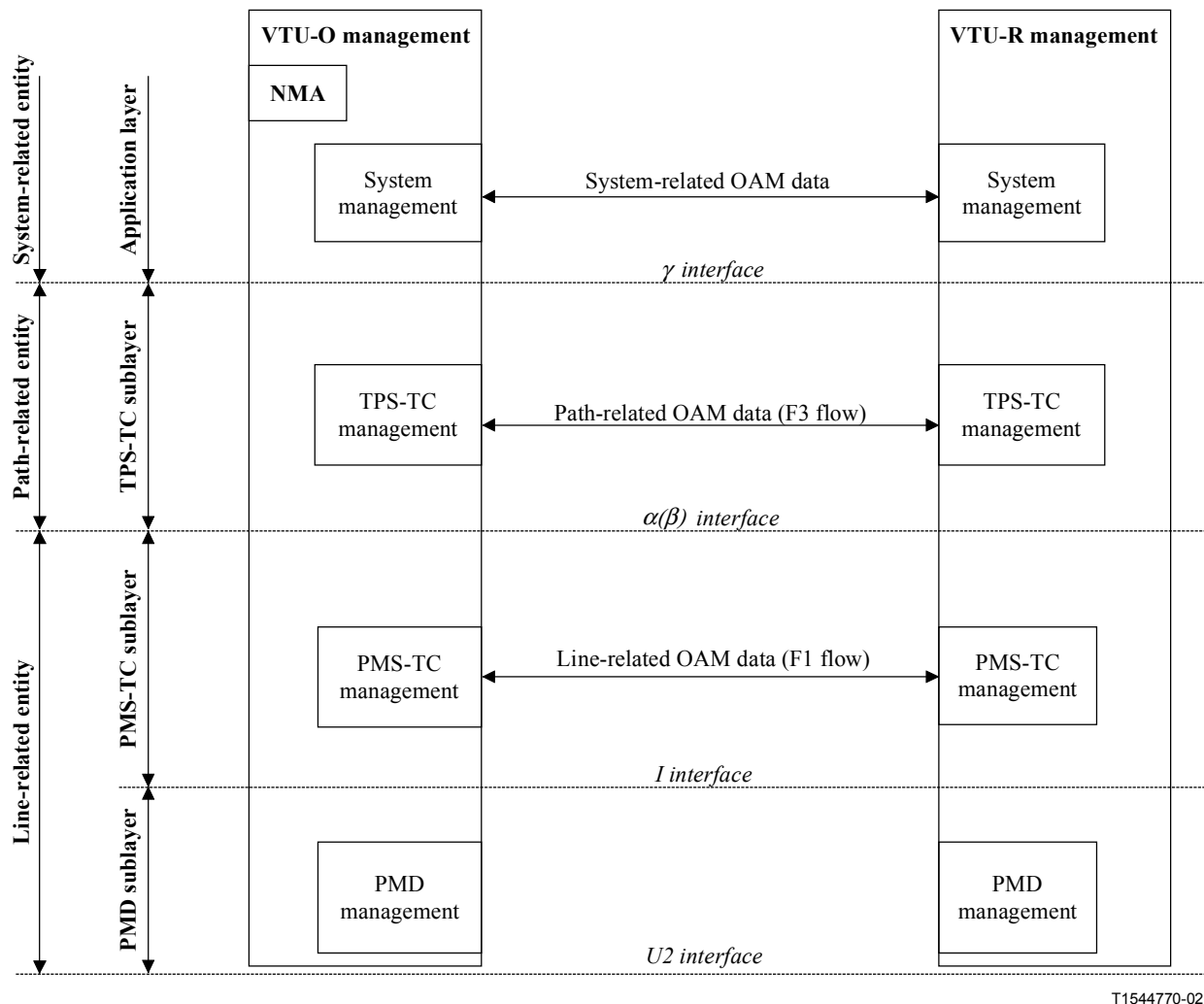


Figure 8-1/G.993.1 – OAM functional model

The OAM flows across both interfaces are bidirectional. They convey, respectively, path-related and line-related primitives and parameters, configuration set-ups, and maintenance commands and acknowledgments of the certain levels.

NOTE – The OAM flow rate should meet requirements for performance calculation and enable the required system management response time.

8.2 OAM communication channels

The following three OAM dedicated communication channels shall be arranged to provide OAM data transfer between the VTU-O and VTU-R:

- Indicator Bits (IB) channel;
- Embedded Operations Channel (eoc);
- VDSL Overhead Control (VOC) Channel.

The three OAM channels shall provide transport of the following OAM data:

- primitives (anomalies, defects, failures) from all the transmission entities;
- parameters (performance and testing);
- configuration set-up;
- maintenance signals.

The interface between a certain OAM channel and the corresponding OAM entity is functional. It is defined by a specific communication protocol and a list of transferred information, including a part for proprietary use. Each OAM channel has specific characteristics and is intended to bear a specific type of OAM data. Partitioning of the OAM data between different OAM channels is described in 8.2.4.

8.2.1 Indicator bits

The IB transport is supported by the PMS-TC sublayer. The IB are used to arrange communication channels between the peer OAM entities intended to transfer the far-end time-sensitive primitives, which require immediate action at the opposite side. The IB channel shall work in unidirectional mode, i.e. independently in both the upstream and downstream directions. The main data to be sent over IB is information on defects/failures, where timing is critical. The IB may also transfer other line-related and path-related primitives.

8.2.2 VDSL embedded operations channel (eoc)

The eoc is supported at the system (application) layer. The eoc is a clear channel to exchange the VDSL system management data and to control traffic between the VTU-O and VTU-R. The exchanged data includes system-related primitives, performance parameters, test parameters, configuration and maintenance.

The eoc, except some special cases, works in bidirectional mode using an echoing protocol. Both transmission directions are required to provide communication for the eoc. The clear eoc channel interface is equal for both the VTU-O and VTU-R.

8.2.3 VDSL overhead control (VOC) channel

The VOC channel is supported by the TPS-TC sublayer and is intended mainly to transfer VDSL link activation and configuration message between the VTU-O and VTU-R. The VOC channel may also transfer line-related and path-related primitives.

The VOC channel works in a bidirectional mode using an echoing protocol and, hence, both transmission directions are required to provide communication for the VOC.

8.2.4 Partitioning of OAM data

The OAM data at both the VTU-O and VTU-R, after being collected from different entities, is stored in the corresponding part of MIB and then could be transferred to the far-end over the corresponding OAM channel. Partitioning of the OAM data between different OAM communication channels is summarized in Table 8-1.

Table 8-1/G.993.1 – OAM data partitioning

OAM Data	Transferred to the far-end by:	Notes
<i>Primitives</i>		
Line-related, time-sensitive	IB	PMD and PMS-TC defects
Path-related, time-sensitive		TPS defects/failures (Note 1), separately for each TPS-TC
Line-related, time-insensitive	IB or VOC	PMD and PMS-TC anomalies
Path-related, time-insensitive	IB or eoc (Note 1)	TPS anomalies, separately for each TPS-TC
System-related primitives	IB or eoc (Note 2)	
<i>Parameters</i>		
Line-related, performance	None	Calculated from retrieved line-related and path-related primitives
Path-related, performance		
Path-related, testing	eoc	For some TPS-TC (Note 3)
Line-related, testing		ATT, SNR margin and other local measurements
Self-test		For some VTU blocks or completely (Note 3)
VTU identification		Vendor ID, revision number, serial number
Service modules parameters		Proprietary (Service modules performance, test or other parameters)
<i>Configuration</i>		
Line-related parameters	VOC or eoc	Frame structure, interleaving depth, etc.
Path-related parameters	eoc	With respect to the applied TPS-TC
System-related parameters	eoc	Proprietary, respective to the applied service modules
<i>Maintenance</i>		
VTU state control	eoc	Hold the state, return to normal state
Self-test activation		A complete VTU self-test and self sub-tests on specific VTU blocks, TBD
Loopback activation		At TPS-TC and application layers
Performance monitoring supervision		Request for FEC corruption test, notify FEC corruption test
<p>NOTE 1 – The IB are necessary to monitor the primitives which destroy the path (for instance ATM cell delineation loss or STM frame delineation loss). The anomalies in a certain active path are monitored by the corresponding TPS-TC management function and delivered to the other side by the standard means of the applicable transport protocol (TP), IB or VOC.</p> <p>NOTE 2 – eoc is preferable for system-related primitives.</p> <p>NOTE 3 – Path-related, testing and self-test parameters are for further study.</p>		

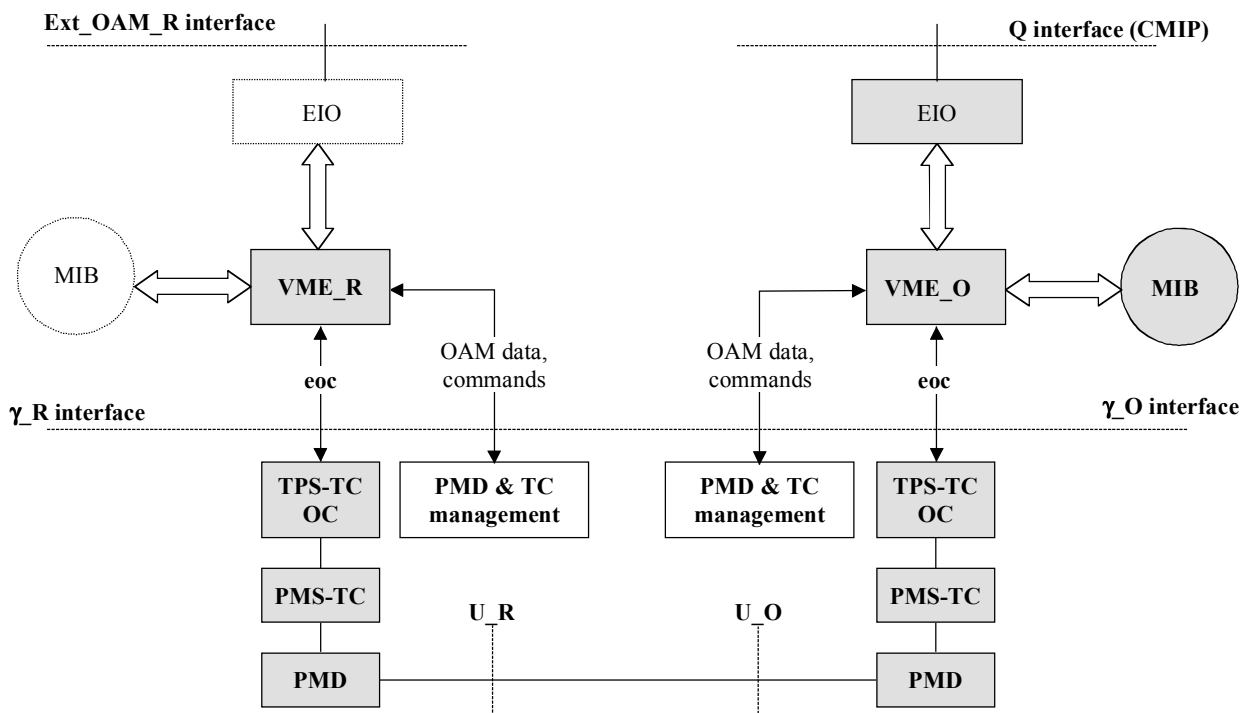
8.3 Embedded operations channel (eoc) functions and description

Embedded Operations Channel (eoc) is intended to exchange the system management data and control traffic between the VTU-O and VTU-R. The exchanged data includes system-related primitives, performance parameters, test parameters, configuration and maintenance commands. The specified eoc can provide both "internal" management functions to support the VDSL transceiver and to be used as a clear management channel between the VTU-O and VTU-R.

8.4 eoc functional model

The eoc functional model is presented in Figure 8-2. The eoc traffic between the VTU-O and VTU-R may include either internal eoc traffic (originated in the VTU-O) or external eoc traffic, delivered through the external Q interface. The VTU-O Management Entity (VME_O) multiplexes the internal and the external traffics into an eoc information stream. The latest is formatted and presented at the γ _O interface to be sent transparently over the VDSL link to the VTU-R Management Entity (VME_R).

The Management Information Base (MIB) contains all the management information related to the VDSL link. It may be implemented either as a part of the VTU-O or as a common part to be shared between several VTU-O. In the first case the Network Management Agent (located outside of the VTU-O) accesses the MIB via the Q-interface and should be supported by the VME_O. If the MIB belongs to the common part of the ONU, VME_O accesses MIB (if necessary) via Q-interface. At the VTU_R the MIB and external interface support are optional.



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EIO External Interface Adapter
MIB Management Information Database
VME VDSL Management Entity

Figure 8-2/G.993.1 – eoc functional model

8.4.1 VME Functionality

VME (both the VME_O and VME_R) shall provide at least the following management functions over the VDSL link:

- performance management;

- configuration management;
- fault management.
- support of the external interface (Q-interface) and MIB interface (only mandatory for the VME_O).

NOTE 1 – This part of VME functionality is beyond the scope of this Recommendation.

The VME provides management functions at the remote end via eoc including:

- Support of VDSL link (maintenance and fault management).
- Performance monitoring (in addition or instead available indicator bits/VOC), including precision measurements for QoS confirmation.
- Configuration management of TPS-TC and, optionally, of PMS-TC.
- User interface related functions.

NOTE 2 – This part of VME functionality is beyond the scope of this Recommendation.

The VME shall also provide the following eoc-related functionality:

- Support of the eoc protocol at the γ interface.
- Multiplexing/de-multiplexing of the internal and external eoc traffic.

9 Performance requirements

9.1 Error performance requirements

The G.993.1 system shall operate with a noise margin of at least +6 dB and a long-term bit error ratio of < 1 in 10^7 . The conditions, test loops and noise models are for further study.

9.2 Latency requirements

Latency requirements are for further study.

9.3 Impulse noise immunity requirements

G.993.1 systems shall provide protection against disturbance from impulse noise.

Furthermore they shall provide at least two levels of protection. The level of protection shall be set and controlled via the Network Management Element Manager.

The lowest level of protection is required to support latency sensitive services such as voice, while the highest level is required to support burst error sensitive services such as entertainment video.

In a high latency VDSL channel, at the maximum delay of 20 ms, the bit error probability of 9.1 should not be exceeded when the path is subject to a noise burst of up to 500 μ s.

Optionally, it is permitted to operate with a maximum delay of up to 10 ms when subject to a noise burst of duration up to 250 μ s.

The impulse noise model and measurement method are for further study.

9.4 Bit rate and reach requirements

Bit Rate and Reach Requirements are for further study.

10 Initialization

10.1 Handshake – VTU-O

The detailed procedures for handshake at the VTU-O are defined in ITU-T Rec. G.994.1. A VTU-O, after power-up, shall enter the initial G.994.1 state C-SILENT1. The VTU-O may transition to C-TONES under instruction of the network operator. From either state, operation shall proceed according to the procedures defined in ITU-T Rec. G.994.1.

If G.994.1 procedures select ITU-T Rec. G.993.1 as the mode of operation, the VTU-O shall transition to G.993.1 at the conclusion of G.994.1 operation.

10.1.1 CL messages

A VTU-O wishing to indicate G.993.1 capabilities in a G.994.1 CL message shall do so by setting to ONE at least one of the Standard Information Field {SPar(1)} G.993.1 bits as defined in Table 11/G.994.1. For each G.993.1 {SPar(1)} bit set to ONE, a corresponding {NPar(2)} field shall also be present (see 9.4/G.994.1). The G.994.1 CL message: {NPar(2)} fields corresponding to the {SPar(1)} bits are defined in Table 10-1.

Table 10-1/G.993.1 – VTU-O CL message bit definitions

G.994.1 bit	Definition
Opt Usage	If set to ONE, signifies that the VTU-O can be configured to use the optional band from 25 to 138 kHz.
OptUp	If set to ONE, signifies that the VTU-O can be configured to use the optional band from 25 to 138 kHz for upstream (VTU-R → VTU-O) transmission.
OptDn	If set to ONE, signifies that the VTU-O can be configured to use the optional band from 25 to 138 kHz for downstream (VTU-O → VTU-R) transmission.
PSDRed	If set to ONE, signifies that the VTU-O can be configured to reduce the PSD in the frequency region below 1.104 MHz.

10.1.2 MS messages

An VTU-O selecting a G.993.1 mode of operation in a G.994.1 MS message shall do so by setting to ONE the appropriate Standard Information Field {SPar(1)} G.993.1 bits as defined in Table 11/G.994.1. For the G.993.1 {SPar(1)} bit set to ONE, a corresponding {NPar(2)} field shall also be present (see 9.4/G.994.1). The G.994.1 MS message {NPar(2)} fields corresponding to the {SPar(1)} bit are defined in Table 10-2.

Table 10-2/G.993.1 – VTU-O MS message bit definitions

G.994.1 bit	Definition
Opt Usage	If set to ONE, signifies to use the optional band from 25 to 138 kHz.
OptUp	If set to ONE, signifies to use the optional band from 25 to 138 kHz for upstream (VTU-R → VTU-O) transmission. In an MS message, only one of OptUp and OptDn may be set to ONE.
OptDn	If set to ONE, signifies to use the optional band from 25 to 138 kHz for downstream (VTU-O → VTU-R) transmission. In an MS message, only one of OptUp and OptDn may be set to ONE.
PSDRed	If set to ONE, signifies to reduce the PSD in the frequency region below 1.104 MHz.

10.2 Handshake – VTU-R

The detailed procedures for handshake at the VTU-R are defined in ITU-T Rec. G.994.1. A VTU-R, after power-up, shall enter the initial G.994.1 state R-SILENT0. Upon command from the host controller, the VTU-R shall initiate handshaking by transitioning from the R-SILENT0 state to the G.994.1 R-TONES-REQ state. Operation shall then proceed according to the procedures defined in ITU-T Rec. G.994.1.

If G.994.1 procedures select ITU-T Rec. G.993.1 as the mode of operation, the VTU-R shall transition to G.993.1 at the conclusion of G.994.1 operation.

10.2.1 CLR messages

An VTU-R wishing to indicate G.993.1 capabilities in a G.994.1 CLR message shall do so by setting to ONE at least one of the Standard Information Field {SPar(1)} G.993.1 bits as defined in Table 11/G.994.1. For each G.993.1 {SPar(1)} bit set to ONE, a corresponding {NPar(2)} field shall also be present (see 9.4/G.994.1). The G.994.1 CLR message {NPar(2)} fields corresponding to the {SPar(1)} bits are defined in Table 10-3.

Table 10-3/G.993.1 – VTU-R CLR message bit definitions

G.994.1 bit	Definition
Opt Usage	If set to ONE, signifies that the VTU-R can be configured to use the optional band from 25 to 138 kHz.
OptUp	If set to ONE, signifies that the VTU-R can be configured to use the optional band from 25 to 138 kHz for upstream (VTU-R → VTU-O) transmission.
OptDn	If set to ONE, signifies that the VTU-R can be configured to use the optional band from 25 to 138 kHz for downstream (VTU-O → VTU-R) transmission.
PSDRed	If set to ONE, signifies that the VTU-R can be configured to reduce the PSD in the frequency region below 1.104 MHz.

10.2.2 MS messages

A VTU-R selecting a Recommendation G.993.1 mode of operation in a G.994.1 MS message shall do so by setting to ONE the appropriate Standard Information Field {SPar(1)} G.993.1 bits as defined in Table 11/G.994.1. For the G.993.1 {SPar(1)} bit set to ONE, a corresponding {NPar(2)} field shall also be present (see 9.4/G.994.1). The G.994.1 MS message {NPar(2)} fields corresponding to the {SPar(1)} bit are defined in Table 10-4.

Table 10-4/G.993.1 – VTU-R MS message bit definitions

G.994.1 bit	Definition
Opt Usage	If set to ONE, signifies to use the optional band from 25 to 138 kHz.
OptUp	If set to ONE, signifies to use the optional band from 25 to 138 kHz for upstream (VTU-R → VTU-O) transmission. In an MS message, only one of OptUp and OptDn may be set to ONE.
OptDn	If set to ONE, signifies to use the optional band from 25 to 138 kHz for downstream (VTU-O → VTU-R) transmission. In an MS message, only one of OptUp and OptDn may be set to ONE.
PSDRed	If set to ONE, signifies to reduce the PSD in the frequency region below 1.104 MHz.

10.2.3 MP messages

A VTU-R proposing a G.993.1 mode of operation in a G.994.1 MP message shall do so by setting to ONE the appropriate Standard Information Field {SPar(1)} G.993.1 bits as defined in Table 11/G.994.1. For the G.993.1 {SPar(1)} bit set to ONE, a corresponding {NPar(2)} field shall also be present (see 9.4/G.994.1). The G.994.1 MP message {NPar(2)} fields corresponding to the {SPar(1)} bit are defined in Table 10-5.

Table 10-5/G.993.1 – VTU-R MS message bit definitions

G.994.1 bit	Definition
Opt Usage	If set to ONE, signifies to propose to use the optional band from 25 to 138 kHz.
OptUp	If set to ONE, signifies to propose to use the optional band from 25 to 138 kHz for upstream (VTU-R → VTU-O) transmission. In an MP message, only one of OptUp and OptDn may be set to ONE.
OptDn	If set to ONE, signifies to propose to use the optional band from 25 to 138 kHz for downstream (VTU-O → VTU-R) transmission. In an MP message, only one of OptUp and OptDn may be set to ONE.
PSDRed	If set to ONE, signifies to propose to reduce the PSD in the frequency region below 1.104 MHz.

11 Electrical requirements

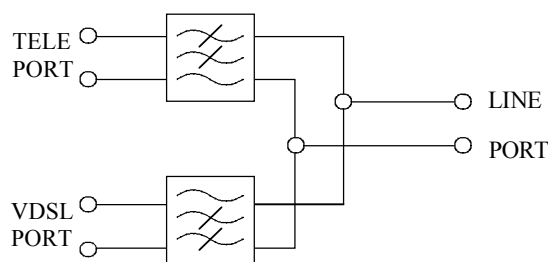
11.1 Service splitters

11.1.1 General

A service splitter (splitter filter) is required at both ends of the line that carries VDSL signals if existing narrow-band services are to remain unaffected by the presence of VDSL signals on the same wire-pair. The structure of the splitter filter is given in Figure 11-1. The VDSL port connects to the VDSL transceiver. The TELE port connects to the existing POTS NT or ISDN-BA NT. The TELE-LINE function is that of a low-pass filter, whereas the VDSL-LINE port function is high-pass. Exceptional isolation is required between TELE and VDSL ports to prevent undesirable interaction between VDSL and the used narrow-band service.

The splitter filter requirements are intended to guarantee the proper operation of POTS and ISDN-BA on lines that carry VDSL signals. The requirements of the high pass filter are more dependent on the VDSL transceiver structure and may be partially combined with an all pass function of the VDSL branch.

NOTE – Splitter implementations may be subject to additional administration-imposed requirements, beyond those contained herein.



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Figure 11-1/G.993.1 – Structure of the VDSL splitter filter

The splitter shall meet the requirements with all VDSL transceiver impedance values that are tolerated by its return loss specification. The reference impedance values associated with the TELE and VDSL ports are as follows:

- TELE port: Z_M
- VDSL port: R_V

The particular values of Z_M and R_V are regionally specific and specified in Annexes D, E and F.

The basic electrical requirements for the splitter are listed in Table 11-1. The values of the parameters, as well as other specific requirements, are regionally specific and described in regional specific Annexes (e.g. Annexes D, E and F).

Table 11-1/G.993.1 – Basic VDSL splitter filter electrical requirements

#	Requirement
1	TELE port to LINE port insertion loss into Z_M , and the insertion loss variation (ripple)
2	TELE port and LINE port return loss against Z_M , and return loss variation (ripple) when the other port is terminated in Z_M
3	LINE port to VDSL port insertion loss into R_V , and the insertion loss variation (ripple)
4	LINE port and VDSL port return loss against R_V , and return loss variation (ripple) when the other port is terminated in R_V
5	TELE port to VDSL port isolation
6	The common-mode isolation between TELE and LINE ports
7	TELE port to LINE port DC resistance

The requirements of Table 11-1 shall be met when the port, which is not in use for the test of a specific requirement, is terminated:

- with the appropriate matching impedance;
- with a mismatched impedance due to reasonable fault conditions at this port (e.g. line break, typical resistive load, ringer load, etc.).

Annex A

Bandplan A

Table A.1 defines the frequencies and usage of Bandplan A as illustrated in Figure A.1.

NOTE – Bandplan A is formerly called Plan 998.

Table A.1/G.993.1 – Bandplan A

	(MHz)	Direction
f_0-f_1	0.025-0.138	Usage and Directional are optional
f_1-f_2	0.138-3.75	Downstream
f_2-f_3	3.75-5.2	Upstream
f_3-f_4	5.2-8.5	Downstream
f_4-f_5	8.5-12	Upstream

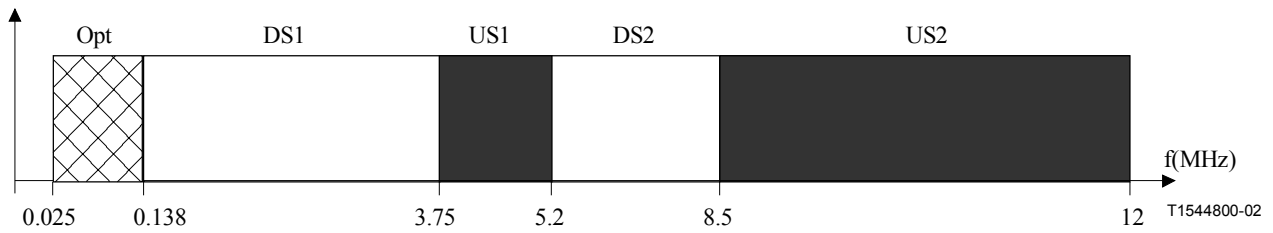


Figure A.1/G.993.1 – Bandplan A

Annex B

Bandplan B

Table B.1 defines the frequencies and usage of Bandplan B as illustrated in Figure B.1.

NOTE – Bandplan B is formerly called Plan 997.

Table B.1/G.993.1 – Bandplan B

	(MHz)	Direction
f_0-f_1	0.025-0.138	Usage and Directional are optional
f_1-f_2	0.138-3.0	Downstream
f_2-f_3	3.0-5.1	Upstream
f_3-f_4	5.1-7.05	Downstream
f_4-f_5	7.05-12	Upstream

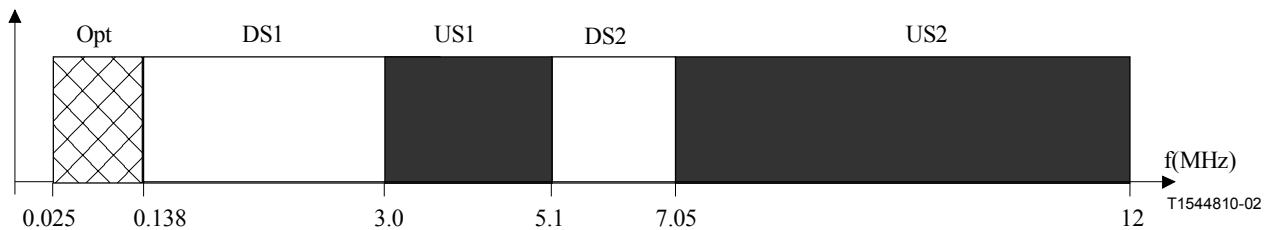


Figure B.1/G.993.1 – Bandplan B

Annex C

Bandplan C

NOTE – This annex is intended for use in Sweden only.

Table C.1 defines the frequencies and usage of Bandplan C as illustrated in Figure C.1.

Fx is a variable frequency.

Table C.1/G.993.1 – Bandplan C

	(MHz)	Direction
f_0-f_1	0.025-0.138	Usage and Directional are optional
f_1-f_2	0.138-2.5	Downstream
f_2-f_3	2.5-3.75	Upstream
f_3-f_4	3.75-Fx	Downstream
f_4-f_5	Fx-12	Upstream

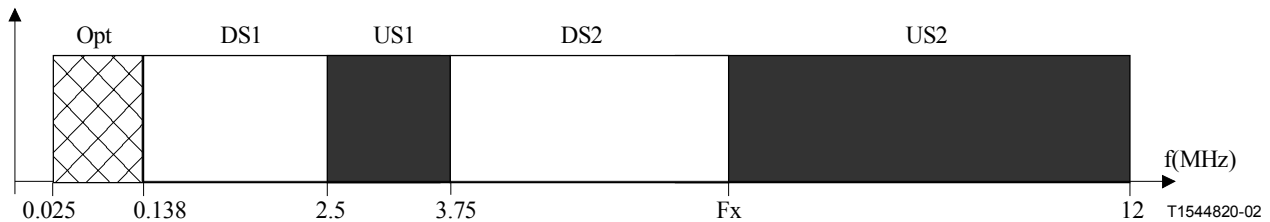


Figure C.1/G.993.1 – Bandplan C

Annex D

Requirements for Region A (North America)

D.1 PSD masks

The PSD masks are for further study.

D.2 Service splitters and electrical characteristics

Service splitter and electrical characteristics are for further study.

D.3 Bandplan

Bandplan A as specified in Annex A shall be used.

Annex E

Requirements for Region B (Europe)

E.1 PSD masks

The PSD masks are for further study.

E.2 Service splitters and electrical characteristics

Service splitter and electrical characteristics are for further study.

Annex F

Regional requirements for environment coexisting with TCM-ISDN DSL as defined in Appendix III/G.961

F.1 PSD masks

The PSD masks are for further study.

F.2 Service splitters and electrical characteristics

Service splitter and electrical characteristics are for further study.

Annex G

ATM-TC

G.1 Scope

This annex specifies a VDSL ATM Transport Protocol Specific Transmission Convergence sublayer (ATM-TC), which describes the ATM based service transmission over a VDSL link. This annex defines a minimum set of requirements to deliver an ATM service from the ONU to the remote customer premises. It is based on the ITU-T Recs. I.432.x. The ATM-TC specification is applicable at both the VTU-O side and the VTU-R side.

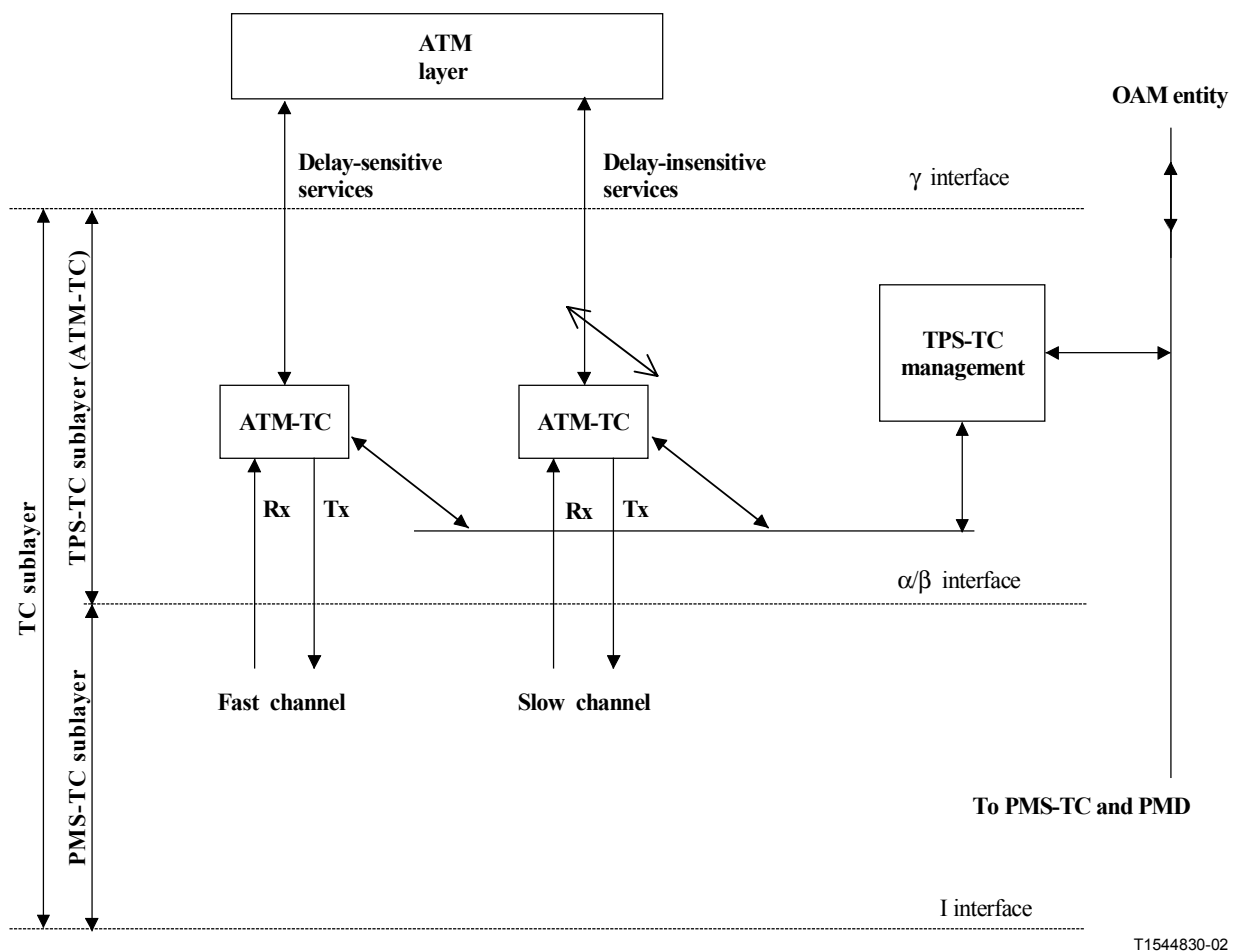
G.2 Reference model for ATM transport

The TPS-TC sublayer for ATM transport reference model is presented in Figure G.1. The model defines the TPS-TC sublayer located between the α/β and γ_O/γ_R reference points.

The TPS-TC sublayer for ATM transport consists of two identical ATM TPS-TC blocks, intended to support ATM transmission over the Fast (*Delay-sensitive* applications) and the Slow (*Delay-insensitive* applications) channels. Among the two ATM channels (Fast, Slow) only the Slow channel is mandatory. The system provides Dual latency if both the Fast and the Slow channels are implemented; the system provides Single latency if only the Slow channel is implemented.

The TPS-TC OAM block provides all necessary OAM functions to support both ATM TPS-TC blocks.

The interface of both ATM TPS-TC at the γ reference point meets the requirements for ATM Layer interfacing (see G.4.1). Both the Fast and the Slow ATM TPS-TC have an application independent format at the α/β interface (see G.4.3).



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NOTE – At VTU-O: Tx = Downstream, Rx = Upstream. At VTU-R: Tx = Upstream, Rx = Downstream

Figure G.1/G.993.1 – ATM-TC reference model

Network Timing Reference (NTR) is an 8 kHz network timing marker, which should be transported to the customer unit via the access network for some specific services. NTR is sent to the VTU-O TC across the γ_0 interface and then transported to VTU-R. NTR is recovered in the PMS_TC of the VTU-R and delivered to the customer unit across the γ_R interface. The method of transporting the NTR has not yet been determined.

G.3 Transport of ATM data

To transport the ATM data both the upstream and the downstream channels shall be set independently from each other to any of the eligible bit rates up to the maximum aggregate channel capacity, determined by the physical net data rate (PMS-TC sublayer). The last is set during the system configuration.

The channelization of different user payloads into either the Fast or the Slow channel is embedded within the ATM data stream by using different Virtual Paths and/or Virtual Channels. To meet the basic requirements for ATM data transport, a G.993.1 system shall support ATM data transport at least in a single latency mode (one downstream channel and one upstream channel).

The need for a single or a dual latency channel for ATM transport depends on the type of service (application). One of the three possible "latency classes" may be used:

- Latency Class 1: single latency both upstream and downstream (not necessarily the same for each direction of transmission) – *mandatory*.
- Latency Class 2: dual latency downstream, single latency upstream – *optional*.

- Latency Class 3: dual latency both upstream and downstream – *optional*.

NOTE – For single latency applications, the Slow channel may be used to implement the Fast channel as well by changing its interleaving depth. Particularly, the interleaver may be disabled in the Slow channel by setting the interleaver depth to 0.

G.4 ATM Transport Protocol Specific TC (ATM_TC)

G.4.1 Application interface description (γ reference point)

The γ reference point defines both the γ_O and γ_R interfaces at the VTU-O and VTU-R sites respectively, as shown in Figure G.1. Both γ interfaces are hypothetical and identical. The interfaces are defined by the following flows of signals between the ATM layer and the ATM-TC sublayer:

- data flow;
- synchronization flow;
- control flow;
- OAM flow.

NOTE 1 – If the dual latency is applied, the γ interface comprises two identical Data flows, Synchronization flows and Control flows – each between the corresponding ATM TPS-TC and ATM layer.

NOTE 2 – For a dual latency implementation ATM cell de-multiplexing to (multiplexing from) the appropriate ATM-TPS TC (i.e. Fast and Slow channel) could be performed at the ATM layer based on the Virtual Path Identifier (VPI) and Virtual Connection Identifier (VCI), both contained in the ATM cell header.

G.4.1.1 Data flow

The Data flow consists of two streams of 53 octet ATM cells each (Tx_ATM, Rx_ATM) with independent rates flowing in opposite directions. Rate values are arbitrary under a predefined upper limit of aggregate channel capacity determined by the data rate at the corresponding α (or β) interface. The Data flow signal description is presented in Table G.1.

The ATM cell format is identical in both transmit and receive directions: 52 out of the 53 octets carry ATM layer data (user data). Octet number 5 is undefined (intended for HEC insertion in the TC sublayer).

NOTE 1 – If data streams are *serial* by implementation, the MSB of each octet is sent first.

NOTE 2 – The Data flow signals are amenable to UTOPIA interface implementation [ATMF UTOPIA].

G.4.1.2 Synchronization flow

This flow provides synchronization between the ATM layer and the ATM-TC sublayer and includes both ATM data synchronization signals and the Network Timing reference signal.

The Synchronization flow comprises the following signals, presented in Table G.1:

- Transmit and receive timing signals (Tx_Clk, Rx_Clk); both asserted by ATM layer;
- Start-of-Cell marker (TxSOC, RxSOC): bidirectional signal, intended to identify the beginning of the transported cell in the corresponding direction;
- Transmit Cell Available flag (TxClAv), asserted by ATM TPS-TC: indicates that ATM TPS-TC is ready to get a transmitted cell from the ATM layer;
- Receive Cell Available flag (RxClAv), asserted by ATM TPS-TC: indicates that TPS-TC contains a valid cell and is ready to transmit it towards ATM layer;
- Transmit Timing Reference (TxRef), applied at the VTU-O only: an incoming from the network 8 kHz NTR;

- Receive Timing Reference (RxRef): a 8 kHz NTR, recovered from the received VDSL signal at the VTU-R.

NOTE 1 – The Tx_Clk and the Rx_Clk rates are matched with the Tx_ATM and the Rx_ATM data rates respectively.

NOTE 2 – Network Timing Reference signals have opposite directions at the VTU-O and the VTU-R.

NOTE 3 – The Synchronization flow signals are amenable to UTOPIA interface implementation [ATMF UTOPIA].

G.4.1.3 Control flow

Two control signals are used to provide multiple ATM TPS-TC connection. Both are asserted by the ATM layer:

- Transmit Enable signal (Enbl_Tx): indicates to the ATM TPS-TC that the next transmitted Tx_ATM cell is valid;
- Receive Enable signal (Enbl_Rx): allows the ATM TPS-TC to transmit a Rx_ATM cell towards the ATM layer.

NOTE – The Control flow signals are amenable to UTOPIA interface implementation [ATMF UTOPIA].

G.4.1.4 OAM flow

The OAM flow across the γ interface exchanges OAM information between the OAM entity and its ATM related TPS-TC management functions. OAM flow is bidirectional.

The OAM flow primitives are for *further study*.

Table G.1/G.993.1 – ATM-TC: γ interface data, synchronization and control flows signal summary

Flow	Signal	Description	Direction	Notes
<i>Transmit signals</i>				
Data	<i>Tx_ATM</i>	Transmit cell	ATM → ATM-TC	
Sync	<i>Tx_Clk</i>	Transmit timing	ATM → ATM-TC	
Sync	<i>TxSOC</i>	Start of the transmit cell	ATM → ATM-TC	
Sync	<i>TxCLAv</i>	TPS-TC is ready to get a cell	ATM ← ATM-TC	
Control	<i>Enbl_Tx</i>	TPS-TC polling for an incoming cell	ATM → ATM-TC	
NTR	<i>TxRef</i>	8 kHz NTR	VTU-O → ATM-TC	VI_O only
<i>Receive signals</i>				
Data	<i>Rx_ATM</i>	Receive cell	ATM ← ATM-TC	
Sync	<i>Rx_Clk</i>	Receive timing	ATM → ATM-TC	
Sync	<i>RxSOC</i>	Start of the receive cell	ATM ← ATM-TC	
Sync	<i>RxCLAv</i>	TPS-TC is ready to transmit a cell	ATM ← ATM-TC	
Control	<i>Enb_Rx</i>	TPS-TC polling for the outgoing cell	ATM → ATM-TC	
NTR	<i>RxRef</i>	8 kHz NTR	VTU-R ← ATM-TC	VI-R only

G.4.2 ATM TPS-TC functionality

The following ATM TPS-TC functionality should be applied both to the downstream and upstream transmission directions.

NOTE – Possible modifications of the ATM TPS-TC to support DPS require further study.

G.4.2.1 Cell rate decoupling

Cell rate decoupling should be implemented by Idle cells insertion in the transmit direction and Idle cells deletion in the receive direction (at the remote ATM TPS-TC), as specified in ITU-T Rec. I.432.1. A standard cell header, also specified in ITU-T Rec. I.432.1 identifies idle cells.

G.4.2.2 HEC generation/verification

The HEC byte shall be generated as described in ITU-T Recs. I.432.x, including the recommended modulo-2 addition (XOR) of the pattern 01010101_2 to the HEC bits. The generator polynomial coefficient set used and the HEC sequence generation procedure shall be in accordance with ITU-T Recs. I.432.x.

The HEC sequence shall be capable of multiple-bit error detection, as defined in ITU-T Recs. I.432.x. The single bit error correction of the cell header shall not be performed.

G.4.2.3 Cell payload randomization and de-randomization

Randomization of the transmit ATM cell payload avoids continuous non-variable bit patterns in the ATM cell stream and so improves the efficiency of the cell delineation algorithm.

The ATM cell randomizer uses a self-synchronizing scrambler polynomial $x^{43} + 1$ and randomization procedures as defined in ITU-T Recs. I.432.x for STM-based transmission shall be implemented. The corresponding de-randomization process should be implemented at the remote ATM TPS-TC.

G.4.2.4 Cell delineation

The cell delineation function permits the identification of the cell boundaries in the payload. It is based on a coding law using the Header Error Control (HEC) field in the cell header.

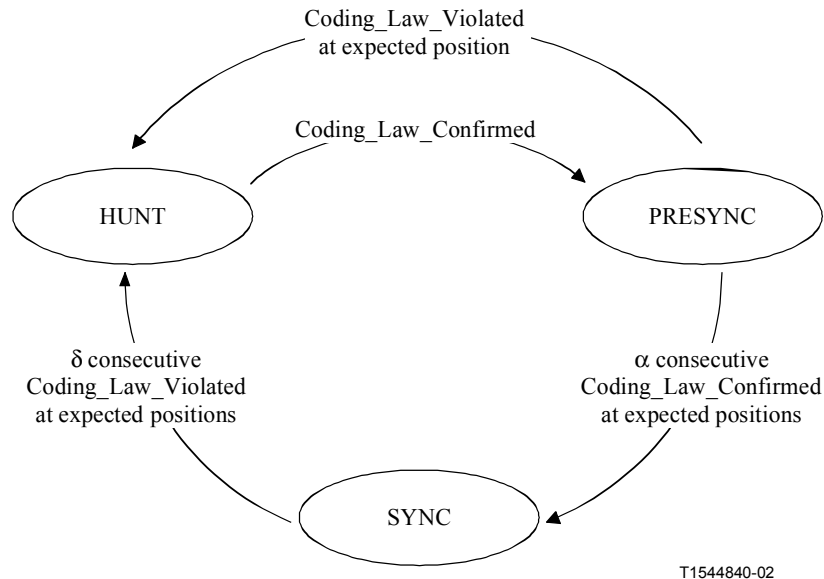


Figure G.2/G.993.1 – ATM cell delineation state machine

The cell delineation algorithm should be as described in ITU-T Recs. I.432.x. It includes the following states and state transitions, presented in Figure G.2:

- "Sync" to "Hunt" state transition when HEC coding law is violated $\alpha =$ TBD times consecutively.
- "Presync" to "Sync" state transition when HEC coding law is confirmed $\delta =$ TBD times consecutively.

G.4.3 $\alpha(\beta)$ interface

The α and β reference points define interfaces between the ATM-TC and PMS-TC at the VTU-O and VTU-R respectively. Both interfaces are functional, application independent, and should comply with the generic definition for all TPS-TC as specified in clause 7.

Annex H

PTM-TC

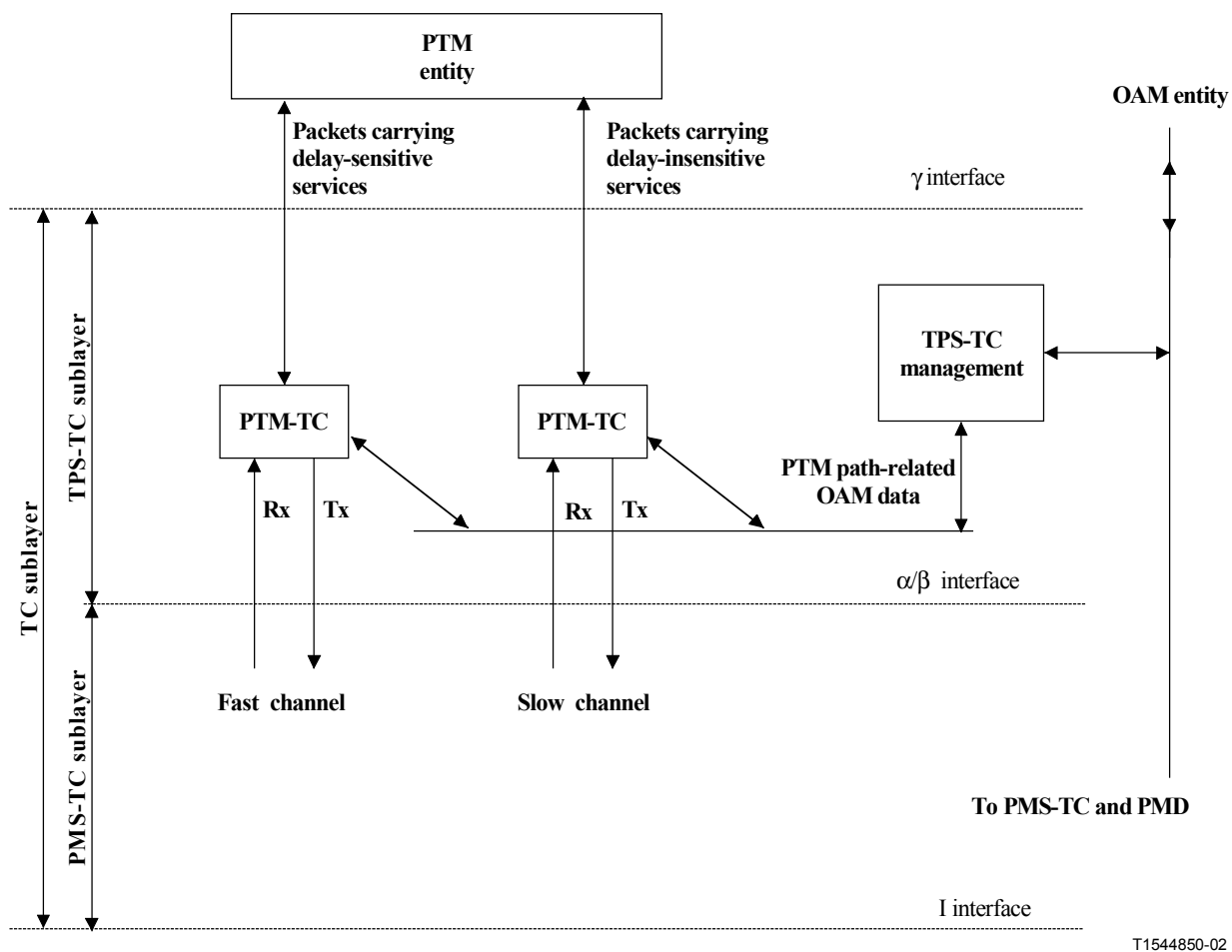
H.1 Packetized data transport

H.1.1 Functional model

The functional model of packetized data transport is presented in Figure H.1. In the transmit direction, the *PTM entity* obtains data packets to be transported over VDSL from the application interface. The PTM entity processes each packet and applies it (depending on the latency requirements) to the γ interface of the either Fast or Slow VDSL path intended for packetized data transport. The corresponding TPS-TC (PTM-TC) receives the packet from γ interface, encapsulates it into a special frame (PTM-TC frame) and maps into the PMS-TC frame (transmission frame) for transmission over the VDSL link.

In the receive direction, the PTM-TC frame extracted from the received PMS-TC frame is directed into the PTM-TC. The PTM-TC recovers the transported packet and delivers it to the PTM entity via the γ interface.

The PTM path-related OAM data, including information on errored packets, shall be presented to the TPS-TC management entity providing all necessary OAM functions to support both PTM-TC.



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Figure H.1/G.993.1 – Functional model of PTM transport

The γ interfaces of both PTM-TC are identical and described in H.3.1. The α/β interfaces are application independent and thus has the same format as for other TPS-TC (see H.3.1.4).

H.2 Transport of PTM data

The bit rate of PTM data transport in the upstream and downstream directions may be set independently of each other to any eligible value which is less than the assigned maximum bit rate in the corresponding direction. Both the upstream and downstream maximum bit rates for PTM transport are set during the system configuration.

The PTM transport could be arranged using either Slow channel or Fast channel or both. The PTM-TC supporting either channel has the same characteristics. The mandatory configuration for packet transport shall include one PTM-TC (either Fast or Slow). The second PTM-TC is optional.

If PTM is the only transport established over the VDSL link, usage of Slow channel is the mandatory configuration for single latency in accordance with the generic TPS-TC sublayer architecture. The required latency should be obtained by adjustment of the interleaving depth.

The PTM-TC shall provide full transparent data transfer between γ_O and γ_R interfaces (except non-correctable errors in the PMD sublayer due to the noise in the loop). The PTM-TC shall provide packet integrity over either Fast or Slow channel.

H.3 Interface description

H.3.1 γ interface

The γ_O and γ_R reference points define interfaces between the PTM entity and PTM-TC at the VTU-O and VTU-R respectively as shown in Figure H.1. Both interfaces are identical, functional, and independent of the contents of the transported packets. The interfaces are defined by the following flows of signals between the PTM entity and the PTM-TC sublayer:

- data flow;
- synchronization flow;
- control flow;
- OAM flow.

H.3.1.1 Data flow

The data flow shall consist of two contra-directional octet-based streams of packets: transmit packets (*Tx_PT*M) and receive packets (*Rx_PT*M). The packet transported in either direction over the γ interface may be of variable length. Bits within an octet are labeled a_1 through a_8 , with a_1 being the LSB and a_8 being the MSB. If either of data streams is transmitted serially, the first octet of the packet shall be transmitted first and bit a_1 of each octet shall be transmitted first as shown in Figure H.3. The Data Flow signal description is presented in Table H.1.

Table H.1/G.993.1 – PTM-TC: γ interface data, synchronization and control flows signal summary

Flow	Signal	Description	Direction
<i>Transmit signals</i>			
Data	<i>Tx_PT</i> M	Transmit data	PTM → PTM-TC
Control	<i>Tx_Enbl</i>	Asserted by the PTM-TC; indicates PTM may push data to the PTM-TC	PTM ← PTM-TC
Control	<i>TX_Err</i>	Errored transmit packet (request to abort)	PTM → PTM-TC
Sync	<i>Tx_Avbl</i>	Asserted by the PTM entity if data is available for transmission	PTM → PTM-TC
Sync	<i>Tx_Clk</i>	Clock signal asserted by the PTM entity	PTM → PTM-TC
Sync	<i>Tx_SoP</i>	Start of the transmit Packet	PTM → PTM-TC
Sync	<i>Tx_EoP</i>	End of the transmit Packet	PTM → PTM-TC
<i>Receive signals</i>			
Data	<i>Rx_PT</i> M	Receive data	PTM ← PTM-TC
Control	<i>Rx_Enbl</i>	Asserted by the PTM-TC; indicates PTM may pull data from the PTM-TC	PTM ← PTM-TC
Control	<i>RX_Err</i>	Received error signals including FCS error, Invalid Frame, and OK	PTM ← PTM-TC
Sync	<i>Rx_Clk</i>	Clock signal asserted by the PTM entity	PTM → PTM-TC
Sync	<i>Rx_SoP</i>	Start of the receive Packet	PTM ← PTM-TC
Sync	<i>Rx_EoP</i>	End of the receive Packet	PTM ← PTM-TC

H.3.1.2 Synchronization flow

This flow provides synchronization between the PTM entity and the PTM-TC sublayer and contains the necessary timing to provide packet integrity during the transport. The synchronization flow shall consist of the following signals presented in Table H.1:

- Transmit and receive timing signals (Tx_Clk, Rx_Clk); both asserted by PTM entity.
- Start of Packet signals (Tx_SoP, Rx_SoP): asserted by PTM entity and by PTM-TC respectively and intended to identify the beginning of the transported packet in the corresponding direction of transmission.
- End of Packet signals (Tx_EoP, Rx_EoP): asserted by PTM entity and by PTM-TC respectively and intended to identify the end of the transported packet in the corresponding direction of transmission.
- Transmit Packet Available signals (Tx_Avbl): asserted by PTM entity to indicate that data for transmission in the corresponding direction is ready.

H.3.1.3 Control flow

Control signals are used to improve robustness of data transport between the PTM-entity and PTM-TC and are presented in Table H.1.

- Enable signals (Tx_Enbl, Rx_Enbl): asserted by PTM-TC and indicates that data may be respectively sent from PTM entity to PTM-TC or pulled from PTM-TC to PTM entity.
- Transmit error message (Tx_Err): asserted by the PTM entity and indicates that the packet or a part of the packet already transported from PTM entity to PTM-TC is errored or undesirable for transmission (abort of transmitted packet).
- Receive error message (Rx_Err): shall be asserted by the PTM-TC to indicate that an errored packet is transported from PTM-TC to PTM entity.

Handling of packet errors is described in H.4.2.

H.3.1.4 OAM flow

The OAM Flow across the γ interface exchanges OAM information between the OAM entity and its PTM related TPS-TC management functions. OAM flow is bidirectional.

The OAM flow primitives are for *further study*.

H.3.2 $\alpha(\beta)$ interface

The α and β reference points define interfaces between the PTM-TC and PMS-TC at the VTU-O and VTU-R respectively. Both interfaces are functional, application independent, and should comply with the generic definition for all TPS-TC as specified in clause 7.

H.4 PTM TPS-TC functionality

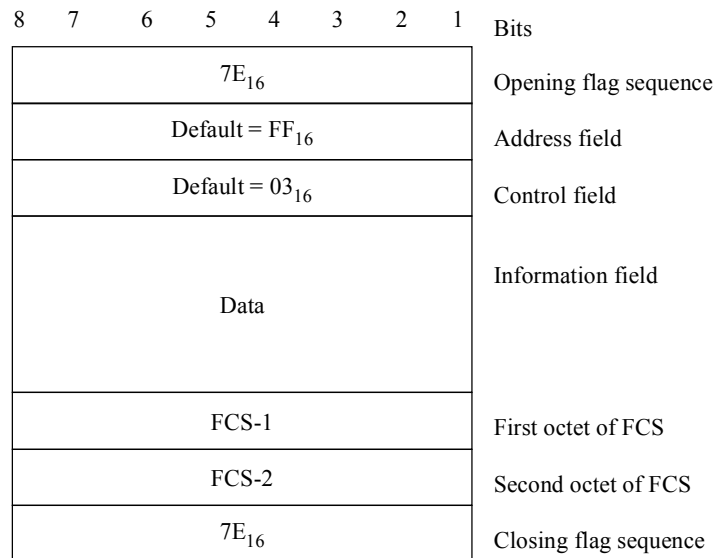
The following PTM TPS-TC functionality should be applied both to the downstream and upstream transmission directions.

H.4.1 Packet encapsulation

For packet encapsulation an HDLC-type mechanism shall be used with detailed characteristics as specified in the following subclauses.

H.4.1.1 Frame structure

The PTM-TC frame format shall be as shown in Figure H.2. The opening and closing Flag Sequences shall be set to 7E₁₆. They identify the start and the end of the frame. Only one Flag Sequence is required between two consecutive frames.



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Figure H.2/G.993.1 – PTM-TC frame format

The Address and Control octets are intended for auxiliary information. They shall be set to their default values of hexadecimal FF₁₆ and 03₁₆ respectively if not used.

NOTE 1 – The address and Control fields may be used for different auxiliary OAM functions. The usage of these fields is for further study.

The Information field shall be filled with the transported data packet. Prior to encapsulation the octets of the data packet shall be numbered sequentially. Octets shall be transmitted in ascending numerical order.

The Frame Check Sequence (FCS) octets are used for packet level error monitoring, and shall be set as described in H.4.3.

After encapsulation, bits within an octet are labeled b_1 through b_8 , as defined in Figure H.3. If the $\alpha(\beta)$ interface is serial by implementation, bit b_8 of each octet shall be transmitted first.

NOTE 2 – In keeping with existing labelling convention for the $\alpha(\beta)$ interface, bit b_8 (MSB) is transmitted first. The PTM-TC functionality defines a correspondence between a_1 and b_8 , a_2 and b_7 , etc., in order to conform to the HDLC convention of transmitting bit a_1 first.

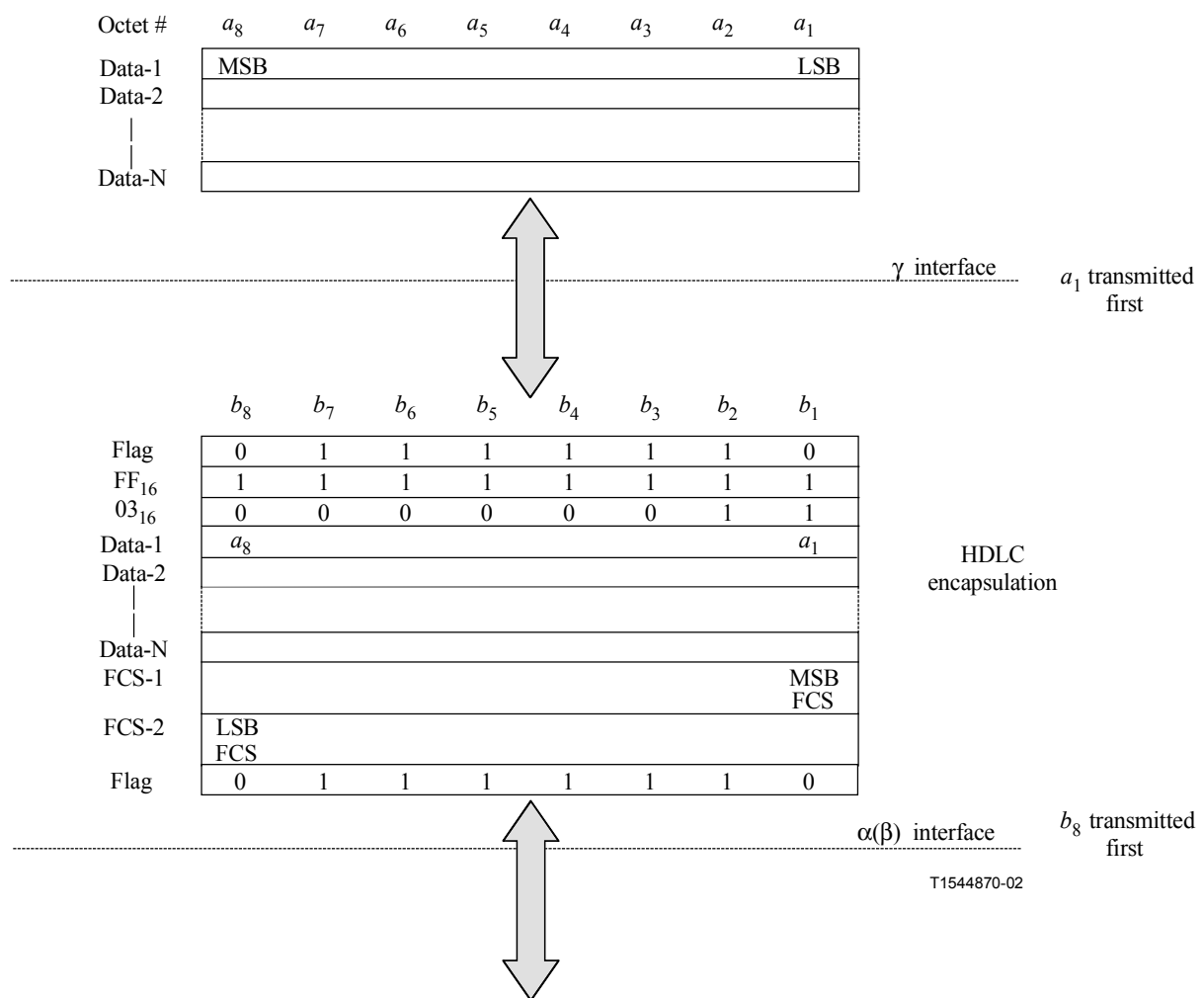


Figure H.3/G.993.1 – PTM-TC data flow

H.4.1.2 Octet transparency

To prevent failures due to false frame synchronization, any octet inside the PTM-TC frame that is equal to hexadecimal 7E₁₆ (the Flag Sequence) or hexadecimal 7D₁₆ (the Control Escape) shall be escaped as described below.

After FCS computation, the transmitter examines the entire frame between the opening and the closing Flag Sequences. Any data octets which are equal to the Flag Sequence or the Control Escape shall be replaced by a two-octet sequence consisting of the Control Escape octet followed by the original octet exclusive-OR'ed with hexadecimal 20₁₆. In summary, the following substitutions shall be made:

- any data octet of 7E₁₆ – encoded as two octets 7D₁₆, 5E₁₆.
- any data octet of 7D₁₆ – encoded as two octets 7D₁₆, 5D₁₆.

On reception, prior to FCS computation, each Control Escape octet shall be removed, and the following octet shall be exclusive-OR'ed with hexadecimal 20₁₆ (unless the following octet is 7E₁₆, which is the flag, and indicates the end of frame, and therefore an abort has occurred). In summary, the following substitutions are made:

- any sequence of 7D₁₆, 5E₁₆ – replaced by the data octet 7E₁₆.
- any sequence of 7D₁₆, 5D₁₆ – replaced by the data octet 7D₁₆.
- a sequence of 7D₁₆, 7E₁₆ aborts the frame.

NOTE – Since octet stuffing is used, the PTM-TC frame is guaranteed to have an integer number of octets.

H.4.1.3 Frame check sequence

The FCS shall be calculated over all bits of the address, control, and information fields of the PTM-TC frame as defined in ISO/IEC 3309, i.e. it shall be the one's complement of the sum (modulo 2) of:

- the remainder of $x^k(x^{15}+x^{14}+x^{13}+x^{12}+x^{11}+x^{10}+x^9+x^8+x^7+x^6+x^5+x^4+x^3+x^2+x+1)$ divided (modulo 2) by the generator polynomial $x^{16}+x^{12}+x^5+1$, where k is the number of bits in the frame existing between, but not including, the last bit of the opening flag and the first bit of the FCS, excluding octets inserted for transparency (H.4.1.2); and
- the remainder of the division (modulo 2) by the generator polynomial $x^{16}+x^{12}+x^5+1$, of the product of x^{16} by the content of the frame existing between, but not including, the last bit of the opening flag and the first bit of the FCS, excluding octets inserted for transparency.

The FCS is 16 bits (2 octets) in length and occupies fields FCS-1, FCS-2 of the PTM-TC frame. The FCS shall be mapped into the frame so that bit a_1 (b_8) of FCS-1 shall be the MSB of the calculated FCS, and bit a_8 (b_1) of the FCS-2 shall be the LSB of the calculated FCS (Figure H.3).

The register used to calculate the FCS at the transmitter shall be initialized to the value $FFFF_{16}$.

NOTE – As a typical implementation at the transmitter, the initial content of the register of the device computing the remainder of the division is preset to all binary ONES and is then modified by division by the generator polynomial, as described above, on the information field. The one's complement of the resulting remainder is transmitted as the 16-bit FCS. As a typical implementation at the receiver, the initial content of the register of the device computing the remainder of the division is preset to all binary ONES. The final remainder, after multiplication by x^{16} and then division (modulo 2) by the generator polynomial $x^{16}+x^{12}+x^5+1$ of the serial incoming protected bits after removal of the transparency octets and the FCS, will be 0001110100001111_2 (x^{15} through x^0 , respectively) in the absence of transmission errors.

H.4.2 Packet error monitoring

Packet error monitoring includes detection of invalid and errored frames at receive side.

H.4.2.1 Invalid frames

The following conditions result in an invalid frame:

- Frames which are less than 4 octets in between flags not including transparency octets (Flag Sequence and Control Escape). These frames shall be discarded.
- Frames which contain a Control Escape octet followed immediately by a Flag (i.e. $7D_{16}$ followed by $7E_{16}$). These frames shall be passed across the γ interface to the PTM entity.
- Frames which contain control escape sequences other than $7D_{16}$, $5E_{16}$ and $7D_{16}$, $5D_{16}$. These frames shall be passed across the γ interface to the PTM entity.

All invalid frames shall not be counted as FCS errors. The receiver shall immediately start looking for the opening flag of a subsequent frame upon detection of an invalid frame. A corresponding receive error message (Rx_Err – see H.3.1.2) shall be sent across the γ interface to the PTM entity.

H.4.2.2 Errored frames

A received frame shall be qualified as an errored frame (FCS-errored) if the CRC calculation result for this frame is different from the one described in H.4.1.3. Errored frames shall be passed across the γ interface. A corresponding receive error message (Rx_Err – see H.3.1.2) shall be sent across the γ interface to the PTM entity.

H.4.3 Data rate decoupling

Data rate decoupling is accomplished by filling the time gaps between transmitted PTM-TC frames with additional Flag Sequences (7E₁₆). Additional Flag Sequences shall be inserted at the transmit side between the closing Flag Sequence of the last transmitted PTM-TC frame and the subsequent opening Flag Sequence of the next PTM-TC frame, and discarded at the receive side respectively.

H.4.4 Frame delineation

The PTM-TC frames should be delineated by detecting of Flag Sequences. The incoming stream is examined on an octet-by-octet basis for the value of hexadecimal 7E₁₆. Two (or more) consecutive Flag Sequences constitute an empty frame (frames), which shall be discarded, and not counted as a FCS error.

Appendix I

UTOPIA implementation of the ATM-TC interface

This appendix describes the implementation of the interface between the ATM-specific TPS-TC Sublayer and ATM Layer at the VTU-O, called γ_0 , interface in the G.993.1 reference model. The implementation is also applicable to the VTU-R.

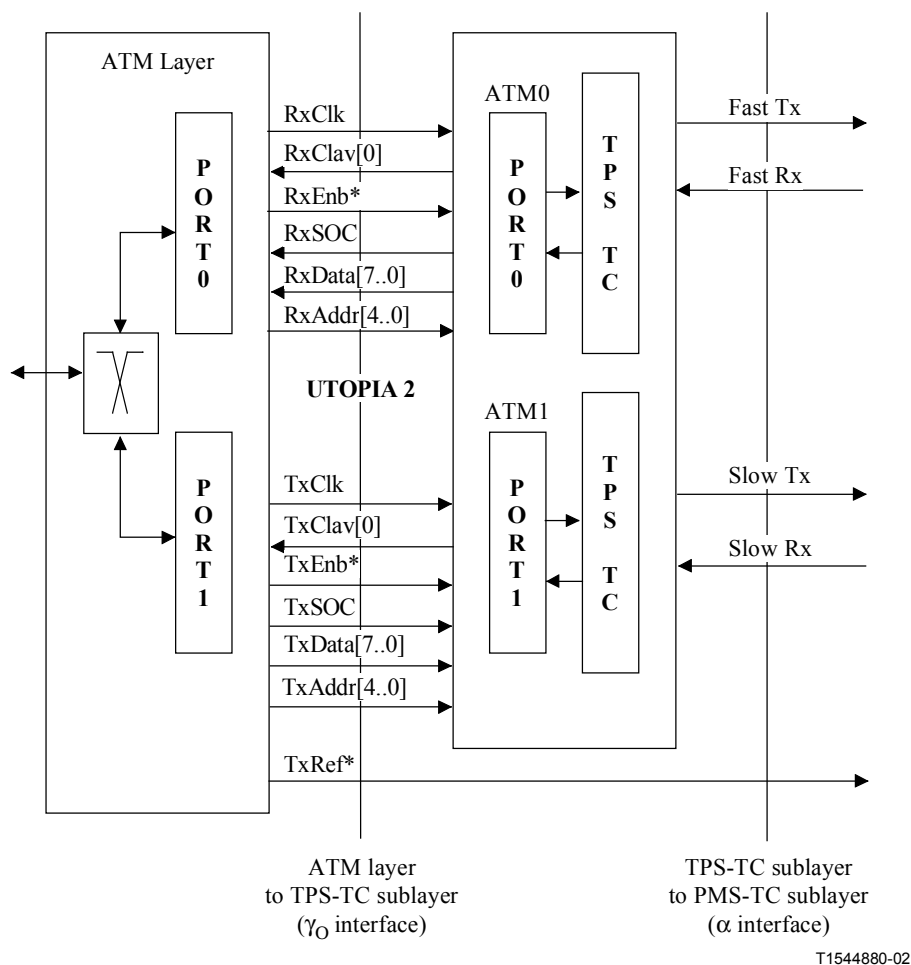


Figure I.1/G.993.1 – UTOPIA-2 implementation of the ATM-TC application interface (VTU-O)

The ATM Layer performs cell multiplexing from and de-multiplexing to the appropriate physical port (i.e. latency path – Fast or Slow) based on the Virtual Path Identifier (VPI) and Virtual Connection Identifier (VCI), both contained in the ATM cell header. Configuration of the cell de-multiplexing process is done by ATM Layer management.

An ATM TPS-TC Sublayer is provided for each latency path separately. ATM-TC functionality is described in Annex G.

The logical input and output interfaces at the reference point γ_O for ATM transport is based on the UTOPIA Level 2 interface with cell level handshake. The logical interface is given in Tables I.1 and I.2 and shown in Figure I.1. When a flow control flag is activated by the VTU-O (i.e. the VTU-O wants to transmit or receive a cell), the ATM layer initiates a cell Tx or cell Rx cycle (53 byte transfer). The VTU supports transfer of a complete cell within 53 consecutive clock cycles. The UTOPIA Tx and Rx clocks are mastered from the ATM layer. The same logical input and output interfaces based on the UTOPIA Level 2 interface can be used at the γ_R reference point in the VTU-R.

Table I.1/G.993.1 – UTOPIA Level 2 ATM interface signals for Tx

Signal name	Direction	Description
<i>Transmit interface</i>		
TxCk	ATM to PHY	Timing signal for transfer
TxCkav[0]	PHY to ATM	Asserted to indicate that the PHY layer has buffer space available to receive a cell from the ATM layer (deasserted 4 cycles before the end of the cell transfer)
TxEnb*	ATM to PHY	Asserted to indicate that the PHY layer must sample and accept data during the current clock cycle
TxSOC	ATM to PHY	Identifies the cell boundary on TxData
TxData[7..0]	ATM to PHY	ATM Cell Data transfer (8-bit mode)
TxAddr[4..0]	ATM to PHY	PHY device address to select the device that will be active or polled for TxClav status
TxRef*	ATM to PHY	Network Timing Reference (8 kHz timing signal) (only at γ_O interface)

Table I.2/G.993.1 – UTOPIA Level 2 ATM interface signals for Rx

Signal Name	Direction	Description
<i>Receive interface</i>		
RxCk	ATM to PHY	Timing signal for transfer
RxCkav[0]	PHY to ATM	Asserted to indicate to the ATM layer that the PHY layer has a cell ready for transfer to the ATM layer (deasserted at the end of the cell transfer)
RxEnb*	ATM to PHY	Asserted to indicate that the ATM layer will sample and accept data during the next clock cycle
RxSOC	PHY to ATM	Identifies the cell boundary on RxData
RxData[7..0]	PHY to ATM	ATM Cell Data transfer (8-bit mode)
RxAddr[4..0]	ATM to PHY	PHY device address to select the device that will be active or polled for RxCkav status
RxRef*	PHY to ATM	Network Timing Reference (8 kHz timing signal) (only at γ_R interface)

More details on the UTOPIA Level 2 interface can be found in [ATMF UTOPIA].

Appendix II

Bibliography

- [ITU-T G.995.1] ITU-T Recommendation G.995.1 (2001), *Overview of Digital Subscriber Line (DSL) Recommendations*.
- [ATMF UTOPIA] ATM Forum Specification af-phy-0039.000, *UTOPIA Level 2*, Version 1.0, June 1995.

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