ETSI TS 101 270-2 V1.2.1 (2003-07)

Technical Specification

Transmission and Multiplexing (TM);
Access transmission systems on metallic access cables;
Very High Speed Digital Subscriber Line (VDSL);
Part 2: Transceiver specification

Reference
RTS/TM-06023

Keywords
access, ATM, B-ISDN, IP, network, transmission,
VDSL, XDSL

ETSI

650 Route des Lucioles
F-06921 Sophia Antipolis Cedex - FRANCE

Tel.: +33 4 92 94 42 00 Fax: +33 4 93 65 47 16

Siret N° 348 623 562 00017 - NAF 742 C
Association à but non lucratif enregistrée à la
Sous-Préfecture de Grasse (06) N° 7803/88

Important notice

Individual copies of the present document can be downloaded from:
http://www.etsi.org

The present document may be made available in more than one electronic version or in print. In any case of existing or perceived difference in contents between such versions, the reference version is the Portable Document Format (PDF). In case of dispute, the reference shall be the printing on ETSI printers of the PDF version kept on a specific network drive within ETSI Secretariat.

Users of the present document should be aware that the document may be subject to revision or change of status. Information on the current status of this and other ETSI documents is available at
http://portal.etsi.org/tb/status/status.asp

If you find errors in the present document, send your comment to:
editor@etsi.org

Copyright Notification

No part may be reproduced except as authorized by written permission.
The copyright and the foregoing restriction extend to reproduction in all media.

© European Telecommunications Standards Institute 2003.
All rights reserved.

DECTTM, **PLUGTESTS**TM and **UMTS**TM are Trade Marks of ETSI registered for the benefit of its Members.
TIPHONTM and the **TIPHON logo** are Trade Marks currently being registered by ETSI for the benefit of its Members.
3GPPTM is a Trade Mark of ETSI registered for the benefit of its Members and of the 3GPP Organizational Partners.

Contents

Intellectual Property Rights

IPRs essential or potentially essential to the present document may have been declared to ETSI. The information pertaining to these essential IPRs, if any, is publicly available for **ETSI members and non-members**, and can be found in ETSI SR 000 314: *"Intellectual Property Rights (IPRs); Essential, or potentially Essential, IPRs notified to ETSI in respect of ETSI standards"*, which is available from the ETSI Secretariat. Latest updates are available on the ETSI Web server (http://webapp.etsi.org/IPR/home.asp).

Pursuant to the ETSI IPR Policy, no investigation, including IPR searches, has been carried out by ETSI. No guarantee can be given as to the existence of other IPRs not referenced in ETSI SR 000 314 (or the updates on the ETSI Web server) which are, or may be, or may become, essential to the present document.

Foreword

This Technical Specification (TS) has been produced by ETSI Technical Committee Transmission and Multiplexing (TM).

The present document is part 2 of a multi-part deliverable covering the Transmission and Multiplexing (TM); Access transmission systems on metallic access cables; Very High Speed Digital Subscriber Line (VDSL), as identified below:

Part 1: "Functional requirements";

Part 2: "Transceiver specification issue 2".

1 Scope

The present document specifies requirements for transceivers that provide very high bit-rate digital transmission on metallic, unshielded, access network wire pairs. The technology is referred to as Very high speed Digital Subscriber Line (VDSL).

This present document is part 2 of the specification for VDSL and is applicable to metallic access transmission systems designed to provide multi-megabit/s digital access over part of the existing, unshielded, metallic access network. It is concerned with the specification of the line-code and duplex method which enable the requirements stated in TS 101 270-1 to be met.

The present document allows the VDSL transceiver to be implemented using either Single Carrier or Multi-Carrier modulation schemes.

2 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

- References are either specific (identified by date of publication and/or edition number or version number) or non-specific.
- For a specific reference, subsequent revisions do not apply.
- For a non-specific reference, the latest version applies.

Referenced documents which are not found to be publicly available in the expected location might be found at http://docbox.etsi.org/Reference.

[1]	ETSI ETS 101 270-1: "Transmission & Multiplexing (TM); Access transmission systems on metallic access cables; Very high speed Digital Subscriber Line (VDSL); Part 1: Functional requirements".
[2]	ITU-T Recommendation I.432.1: "B-ISDN user-network Interface - Physical layer specification; General characteristics".
[3]	ITU-T Recommendation I.432: "B-ISDN User-Network Interface - Physical layer specification".
[4]	ITU-T Recommendation G.992.1: "Asymmetrical digital subscriber line (ADSL) transceivers".
[5]	ITU-T Recommendation G.992.2: "Splitterless asymmetric digital subscriber line (ADSL) transceivers".
[6]	ITU-T Recommendation G.994.1: "Handshake procedures for digital subscriber line (DSL) transceivers".
[7]	ITU-T Recommendation X.700: "Management framework for Open Systems Interconnection (OSI) for CCITT applications".
[8]	ITU-T Recommendation G.997.1: "Physical layer management for digital subscriber line (DSL) transceivers".
[9]	ETSI TS 101 272: "Transmission and Multiplexing (TM); Optical Access Networks (OANs) for evolving services; ATM Passive Optical Networks (PONs) and the transport of ATM over digital subscriber lines".
[10]	ISO/IEC 13239: "Information technology - Telecommunications and information exchange between systems - High-level data link control (HDLC) procedures".

3 Definitions and abbreviations

3.1 Definitions

For the purposes of the present document, the following terms and definitions apply:

aggregate bit rate: data rate transmitted by a VDSL system in one direction

NOTE 1: The aggregate data rate includes both net data rate and overhead used by the system for cyclic redundancy checks, the embedded operations channel, VDSL overhead channel, synchronisation of the various data streams, and fixed indicator bits for operations, administration, and maintenance.

NOTE 2: The aggregate data rate does not include forward error correction code redundancy.

asymmetric: condition occurring when the bit rate supported in one transmission direction exceeds the bit rate supported in the opposite direction

NOTE: Typically, asymmetric implies that the downstream bit rate exceeds the upstream bit rate.

ATM cell: digital information block of fixed length (53 octets) identified by a label at the asynchronous transfer mode level

available bit rate: ATM service whose bit rate varies between upper and lower limits and is characterised by an average bit rate

NOTE: The minimum, maximum, and average bit rates may vary while a connection is established.

bridged taps: sections of unterminated twisted-pair cable connected in parallel across the cable under consideration

broadband: service or system that supports data using one or more frequency bands above the POTS band

NOTE: Broadband typically implies transmission of bit rates greater than 100 kbps.

constant bit rate: ATM service characterised by a deterministic bit rate that remains constant with time

downstream: direction from the ONU to the subscriber premises

DR: Data carrying capacity for a single carrier in an SCM system

dynamic range: ratio between the largest and smallest usable signals that meet the requirements defined in the present document

errored second: one-second interval of received signal containing one or more bit errors

fast channel: channel with low latency but less immunity to impulse noise in comparison to the slow channel. In contrast to the slow channel the fast channel is not interleaved.

impulse noise: short-duration noise source characterised by sharp rise and fall times and a large amplitude

line rate: total bit rate supported by a connection in one direction. Line rate is the sum of the payload bit rate and all bit rate overhead required for forward error correction, synchronisation, cyclic redundancy checks, the embedded operations channel, the VDSL overhead channel, and fixed indicator bits for operations, administration, and maintenance.

network termination: termination at the subscriber premises of a point-to-point VDSL transmission system

payload bit rate: total data rate that is available to user data in any one direction

quality of service: set of parameters characterising the success or failure of an end-to-end connection to meet the service contract negotiated for the transfer of ATM cells

slow channel: channel with high latency and more immunity to impulse noise in comparison to the fast channel. Unlike the fast channel, the slow channel is interleaved

splitter: low-pass/high-pass pair of filters that separate high-frequency (VDSL) and low-frequency (POTS/ISDN) signals

sub-channel: frequency band used by a DMT transceiver. Using an inverse discrete Fourier transform (IDFT), the total system bandwidth is partitioned into a set of orthogonal, independent sub-channels

subscriber premise: location at which the remote transceiver resides

NOTE: It is presumed that the remote transceiver may be located either inside or outside the subscriber premises.

superframe: set of successive DMT symbols in multi-carrier modulation

symmetric: condition occurring when the same bit rate is supported in both transmission directions

TR: Total data carrying capacity using both carriers in an SCM system

unspecified bit rate: "best effort" ATM service for which no traffic parameters are specified and no level of performance is guaranteed

upstream: direction from the subscriber premises to the ONU

variable bit rate: ATM service whose bit rate is characterised by the average and peak bit rates. These parameters remain constant for the duration of a connection

xDSL: Generic term for the family of DSL technologies, including HDSL, ISDN, ADSL, VDSL, etc.

3.2 Abbreviations

For the purposes of the present document, the following abbreviations apply:

ADSL	Asymmetric Digital Subscriber Line
ATM	Asynchronous Transfer Mode
ATM-TC	ATM Transmission Convergence sub-layer
ATN	Attenuation
ATP	Access Termination Point
BER	Bit Error Rate
BSR	Basic Symbol Rate
BSS	Baseband Spectral Shaping
CO	Central Office (or local exchange)
CP	Customer Premise
CPE	Customer Premises Equipment
DFT	Discrete Fourier Transform
DMT	Discrete Multi-Tone
DS	DownStream
DSL	Digital Subscriber Line (or loop)
EIA	External Interface Adapter
EOC	Embedded Operations Channel
FEC	Forward Error Correction
FEXT	Far-End crosstalk
FTTCab	Fibre To The CABinet
FTTEx	Fibre To The Exchange
HDLC	High-level Data Link Control protocol
HDSL	High-rate Digital Subscriber Line
HEC	Header Error Control
IB	Indicator bits
IDFT	Inverse Discrete Fourier Transform
ISDN	Integrated Services Digital Network
LT	Line Termination
MIB	Management Information Base
MIB	Management Information data Base
MSB	Most Significant Bit
NEXT	Near-End crosstalk
NMS	Network Management System
NT	Network Termination
NTR	Network Timing Reference
OAM	Operation, Administration and Maintenance
ONU	Optical Network Unit
PDH	Plesiochronous Digital Hierarchy
PMD	Physical Medium-Dependent
PMS	Physical Medium-Specific
PMS-TC	Physical Medium-Specific Transmission Convergence layer
PON	Passive Optical Network
POTS	Plain Old Telephone Service
PSD	Power Spectral Density
PSS	Passband Spectral Shaping
PTM	Packet Transfer Mode
PTM-TC	Packet Transfer Mode Transmission Convergence layer
QAM	Quadrature Amplitude Modulation

RF	Radio-Frequency
RFI	Radio-Frequency Interference
SDH	Synchronous Digital Hierarchy
SM	Service Module
SNR	Signal-to-Noise Ratio
SOC	Special Operations Channel
SONET	Synchronous Optical NETwork
SR	Symbol Rate
STM	Synchronous Transfer Mode
STP	Set of Transmission Parameters
TA	Timing Advance
TBD	To Be Determined
TC	Transmission Convergence
TP	Transmission Parameters
TPS-TC	Transport Protocol Specific Transmission Convergence layer
UNI	User-Network Interface
UPBO	Upstream Power Back-Off
US	UpStream
UTOPIA	Universal Test & Operations Physical-layer Interface for ATM
VDSL	Very high-speed Digital Subscriber Line
VME	VDSL Management Entity
VOC	VDSL Overhead Channel
VTU	VDSL Transceiver Unit
VTU-O	VTU at the ONU
VTU-R	VTU at the Remote site

4 Reference models

4.1 Interface model

Figure 1 illustrates the generic interface reference model for the copper access section of the VDSL network. The vertical lines indicate the eight specification interfaces. The splitters separate VDSL signals from signals of lower frequency services, such as POTS or ISDN signals.

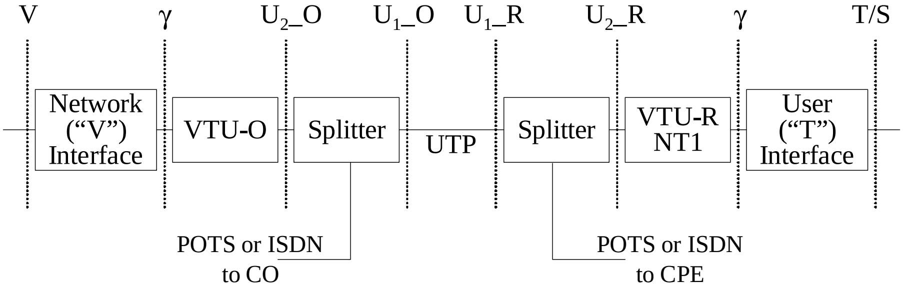


Figure 1: Interface reference model

4.2 Protocol model

4.2.1 Protocol layer model

The Transmission Convergence (TC) layer is split into a transport protocol specific part (TPS-TC part) and an application independent part (the Physical Medium Specific - Transmission Convergence (PMS-TC) part). The application independent part also contains the transceiver (PMD) functions. The positions of the different interfaces with respect to the VDSL sub-layers are shown in figure 2. The functional blocks described by the present document are shown in grey.

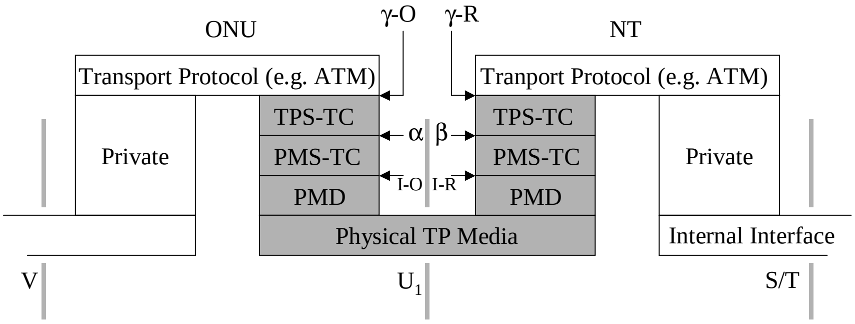


Figure 2: VDSL protocol layer model

4.2.2 Functional decomposition

VDSL will find application in the transport of various protocols; the present document covers the transport of ATM and STM (SDH) and data packets, but the VDSL core transceiver is capable of supporting future additional applications. The internal structures of the different Transport Protocol Specific - Transmission Convergence (TPS-TC) layers are application specific. Figure 3 shows the functional decomposition of the VDSL with the associated reference points. The grey areas show the functional boundary of the TC layer.

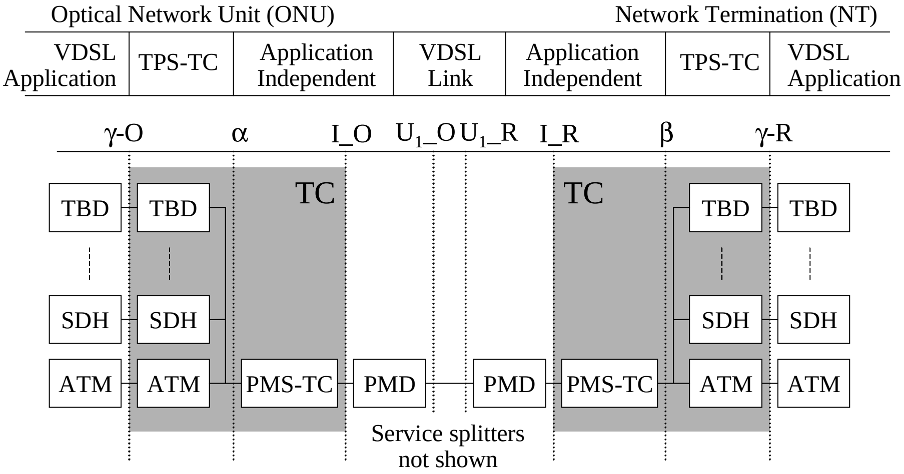


Figure 3: Functional decomposition

4.3 Reference points

Of the reference points defined below only the U reference point is within the scope of the present document. The V, S and T reference points are equipment interfaces described in other standards (e.g. TS 101 272 [9]).

4.3.1 V reference point

The V reference point is at the physical network interface between the VTU-O and the ONU.

4.3.2 U reference points

ISDN/POTS signals can occupy the same physical media as the VDSL signal by using splitters. Thus, the U_1 reference point refers to the copper-pair media carrying composite signals, whereas the U_2 reference point specifies the VDSL modem ports only.

4.3.3 S and T reference points

The Access Termination Point (ATP) specifies the protection and distribution cable termination.

4.4 Deployment configurations

VDSL serves the general fibre-to-the-node architecture illustrated in figure 4. An Optical Network Unit (ONU) situated in the existing access network (or, in some cases, at the local exchange) serves hundreds of customers. Existing twisted-pair lines transfer narrowband (for example, POTS or ISDN) and broadband (such as ADSL, HDSL, and VDSL) signals between the ONU and Customer Premise (CP). For VDSL applications, a Network Termination (NT) at the customer premise is defined as the termination of point-to-point VDSL. The NT provides a standardised set of user network interfaces (UNI) for the various applications served by VDSL. In addition, the NT allows the network operator to test the network up to the NT to determine if the cause of service problems is inside the CP or between the CP and the ONU.

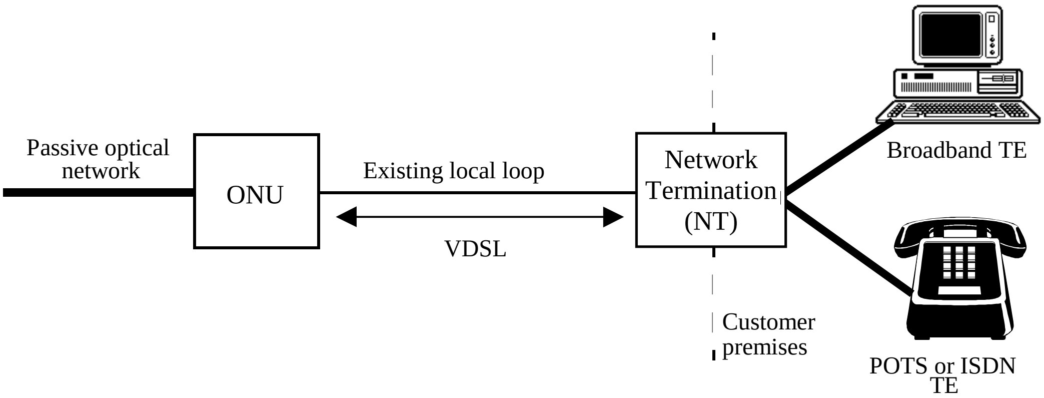


Figure 4: General fibre-to-the-node architecture for VDSL

All twisted-pair lines between the ONU and the NT are considered to be part of the VDSL loop. Thus, any vertical drop or rise segments of twisted-pair lines at either the CP or ONU end of the network shall be considered specifically part of the loop.

The NT in figure 4 performs termination of the VDSL modulation scheme, link control and maintenance functions and provides one or more application-specific interfaces (S- or T-proprietary) to customer equipment. The reference model does not imply specific ownership of the NT equipment by customer or network operator.

5 Physical Medium Dependent (PMD) layer

5.1 Multi-carrier PMD sub-layer specification

5.1.1 PMD functional model

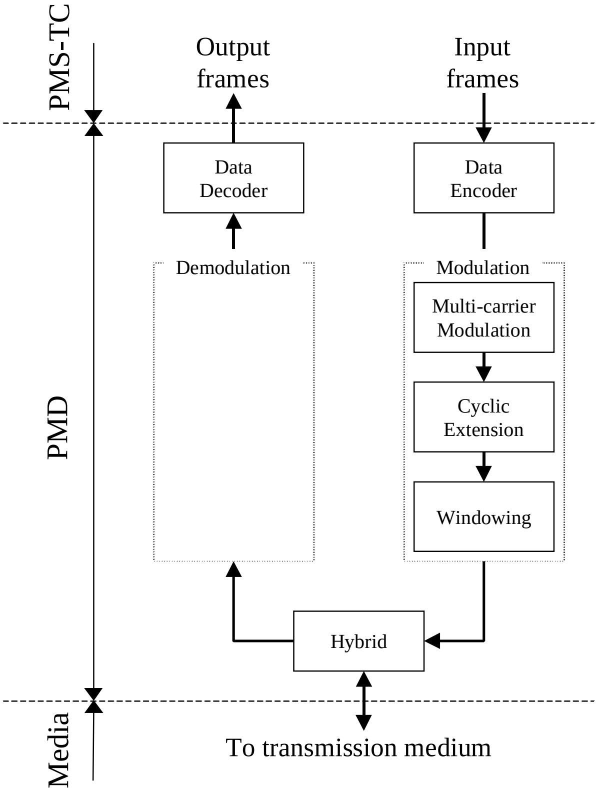


Figure 5: Functional model of PMD Sub-layer

The functional model of the PMD sub-layer is presented in figure 5.

In the transmit direction, the PMD layer shall receive input frames from the PMS-TC sub-layer. A frame shall contain exactly the number of octets that shall be modulated onto one DMT symbol. This shall be an integer number. Each sub-carrier has a number of bits assigned to it during initialisation. The bits that are to be transmitted on a sub-carrier are encoded into constellation points according to the rules given in clause 5.1.2.5. After encoding, the sub-carriers are modulated and summed using an IDFT. The resulting digital signal is cyclically extended and windowed before being sent toward the transmission medium over the U-interface.

In the receive direction, the modem shall receive the signal over the U interface and perform the required actions to recover the transmitted signal. The data obtained from the demodulator shall be sent to the data decoder that shall extract the output data frames. These data frames shall be sent to the PMS-TC layer over the I-interface.

The management block is responsible for all OAM functions relating to the PMD layer.

5.1.2 VTU-O and VTU-R functional characteristics

5.1.2.1 Modulation

The modulation shall use a maximum number of sub-carriers equal to $N_{sc} = 256 \times 2^n$, where *n* shall take at least one of the values 2, 3, 4. Optionally, when use of the band below 138 kHz is allowed for upstream transmission, *n* can also take the values 0 or 1. Disjoint subsets of the N_{sc} sub-carriers are defined for use in the downstream and upstream directions. These subsets are determined by the frequency plan (defined in TS 101 270-1 [1]). The exact subsets of sub-carriers used to modulate data in each direction are determined during initialisation based on management system settings and the signal-to-noise ratios (SNRs) of the sub-channels. In many cases the number of sub-carriers used in a direction will be less than the maximum number allowed by the partitioning.

5.1.2.1.1 Sub-carriers

The frequency spacing, Δf, between the sub-carriers is 4,3125 kHz, with a tolerance of 50 ppm. The sub-carriers are centred at frequencies $f = k \times \Delta f$, where k, the tone index, takes the values 0, 1, 2,.., N_{sc} -1. Tone spacing other than specified above is for further study and can be considered to meet future requirements.

5.1.2.1.2 Data sub-carriers

Transmission may take place on up to N_{sc} -1 sub-carriers. The sub-channel centred at DC is not used. The number of sub-carriers may be reduced, depending on the need to notch transmission in the amateur radio frequency bands, the presence of a POTS or ISDN splitter, PSD masks, implementation specific filters and services to be provided.

5.1.2.1.3 Modulation by the Inverse Discrete Fourier Transform (IDFT)

The encoder generates N_{SC} complex values Z_i($i = 0,\ldots,N_{SC} - 1$), including the zero at DC because the sub-carrier centred at DC is not used. To generate real, time-domain values x_k using a complex-to-real IDFT, the set of frequency-domain values Z_i is augmented to generate a new vector Z_i'. The vector Z_i' is Hermitian. That is,

$$Z'_i = Z_i,\ i = 0, \ldots, N_{SC} - 1$$

and

$$Z'_i = conj\ (Z_{2N_{sc}-i})\ ,\ i = N_{SC}, \ldots, 2N_{SC} - 1$$

The Nyquist frequency is not modulated, therefore $Z'_i = 0$ for $i = N_{SC}$. The vector Z_i' is transformed to the time domain by an inverse discrete Fourier transform (IDFT). The modulating transform defines the relationship between the $2N_{SC}$ real, time-domain values x_k and the $2N_{SC}$ complex numbers Z_i':

$$x_k = \sum_{i=0}^{2N_{SC}-1} Z'_i e^{j\frac{2\pi ki}{2N_{SC}}}, \quad k = 0,\ldots,2N_{SC} - 1$$

5.1.2.2 Cyclic extension

The last L_{CP} samples of the IDFT output x_k shall be prepended to the $2N_{SC}$ time-domain samples x_k as the cyclic prefix. The first L_{CS} samples of x_k shall be appended to the block of time-domain samples as the cyclic suffix.

The first β samples of the prefix and last β samples of the suffix are used for shaping the envelope of the transmitted signal. The maximum value of β is 16×2^n, with values of *n* as defined in clause 5.1.2.1. The windowed parts of consecutive symbols overlap (β samples).

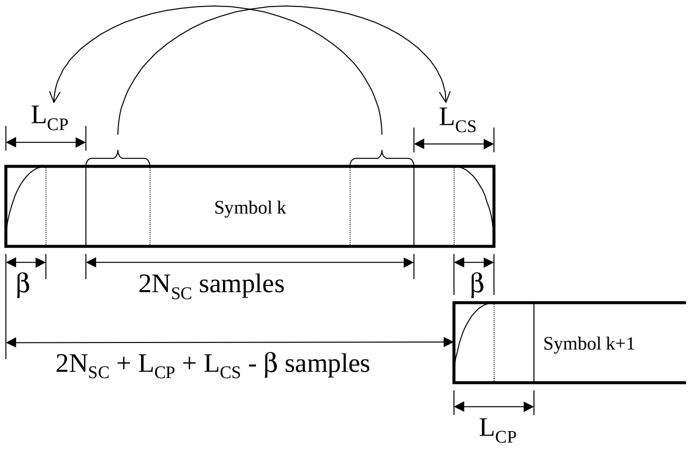


Figure 6: Cyclic extensions, windowing and overlap of DMT symbols

Figure 6 illustrates the relationships between the cyclic extension, prefix, suffix and β. The cyclic extension length, L_{CE}, is $L_{CE} = L_{CP} + L_{CS} - \beta$ samples.

The values L_{CP}, L_{CS} and β must be chosen in order to satisfy the equation $(Lcp + Lcs - \beta) = m \times 2^{n+1}$, where m is an integer value. The modem shall support a cyclic extension length (L_{CE}) equal to 40×2^n. Other values are also allowed.

In all cases, $\beta < L_{CP}$ and $\beta < L_{CS}$. In the (optional) synchronous mode of operation, the size of the non-windowed part of the suffix shall be the same for all modem pairs in a binder group and its duration shall be equal to the propagation delay (one way) of the longest line in the binder. This means that VTU-Os and VTU-Rs operating in the same binder have a common frame clock and all transceivers start transmission of DMT frames at the same time.

Table 1 lists example values for the number of samples in the cyclic extension as a function of the total number of sub-carriers. With these values each VDSL frame (i.e. DMT symbol + cyclic extension) has a duration of 250 µs, irrespective of the sampling rate.

Table 1: Selection of cyclic extension as a function of the number of sub-carriers to achieve a 4 kHz symbol rate

Number of sub-carriers N_{sc}	Cyclic extension length (in samples)
256	40
512	80
1 024	160
2048	320
4096	640

The symbols shall be transmitted at a rate equal to:

$$f_s = \frac{2 \times N_{SC} \times \Delta f}{2 \times N_{SC} + L_{CP} + L_{CS} - \beta}.$$

5.1.2.3 Synchronisation

5.1.2.3.1 Pilot tone

Use of a dedicated pilot tone is optional. During initialisation, the VTU-R shall select a sub-channel to use for timing recovery. The VTU-R may require a dedicated pilot tone on which data shall not be transmitted, or it may be capable of performing timing recovery using sub-channels that support data. If the VTU-R requires a dedicated pilot tone, it indicates its choice of pilot tone to the VTU-O during initialisation (clause 8.2.6.3.1.4). The VTU-O then transmits the 4QAM value of 00 on that tone during every symbol.

5.1.2.3.2 Loop timing

The VTU-R shall loop time its local sampling clock to the pilot selected during initialisation.

5.1.2.3.3 Timing advance

VTU-R transmitters shall be capable of implementing an offset called Timing Advance (TA). The TA forces the VTU-O/VTU-R pair to start transmissions of frames in opposite directions simultaneously. The timing advance shall be equal to the propagation delay from the VTU-O to the VTU-R. It shall be calculated by the VTU-R during initialisation (clause 8.2.4.1). The TA is subtracted from the received symbol start time, and the result is used as the VTU-R's individual symbol start time so that both the VTU-O and VTU-R transmitters start transmitting each DMT frame at the same time.

Note that timing advance shall be applied at the U2 interface to obtain the desired orthogonality between transmit and receive signals.

5.1.2.3.4 Synchronous mode (optional)

In synchronous mode, all VTU-O transceivers on the same cable binder shall transmit with respect to a common symbol clock, and thus start the transmission of DMT symbols at the same time. The symbol clock, which may be derived from a reference clock, shall be phase synchronous at all VTU-Os in a shared cable with a 1 µs maximum phase error tolerance. The VTU-R shall extract the symbol clock from the received data. Timing advance (clause 5.1.2.3.3) shall be used to correct the VTU-R symbol timing to synchronise VTU-O and VTU-R transmissions.

In synchronous mode, near-end crosstalk (NEXT) due to other (synchronised) VDSL systems is orthogonal to the desired signal on every line.

5.1.2.4 Power back-off in the upstream direction

To mitigate the effects of FEXT from short lines into long lines in distributed cable topologies, upstream power back-off shall be applied. Transceivers shall be capable of performing frequency-dependent power back-off.

The upstream power back-off method is defined by a reference PSD (PSD_{REF}) at the VTU-O. The reference PSD shall be set using the management interface and shall be transmitted from the VTU-O to the VTU-R (clause 8.2.4.2.1.1).

The mechanism for power back-off shall comply with the procedure in TS 101 270-1 [1]. This shall be implemented as described below.

The VTU-R shall estimate the insertion loss of the upstream bands based on the received downstream signals. The shape of the LOSS function (or the equivalent electrical length) shall be derived from the estimated insertion loss. The VTU-R shall compute the transmit PSD by dividing the reference PSD in the upstream bands by the estimated LOSS function. The VTU-R shall find the lower of the two values of the computed PSD and the transmit PSD limit for each tone in the upstream direction. The resulting PSD for each tone shall be used for the initial upstream transmit PSD. The PSD received by the VTU-O should equal the reference PSD. Upon receiving signals from the VTU-R the VTU-O shall compare the actual received PSD to the reference PSD. If necessary, it shall instruct the VTU-R to fine-tune its PSD.

The VTU-O shall also have the capability to impose a maximum allowed transmit PSD at the VTU-R. This maximum transmit PSD shall be set by the management interface and transmitted from the VTU-O to the VTU-R during initialisation. The management interface at the VTU-O shall select one of these two methods. If the upstream power back-off is defined as a maximum transmit PSD at the VTU-R, the VTU-R shall also comply with the transmit PSD limits given in TS 101 270-1 [1].

5.1.2.5 Constellation encoder

An algorithmic QAM constellation encoder shall be used to construct sub-channel constellations with a minimum number of bits equal to 1. The maximum number of bits that shall be supported is negotiated during initialisation. The maximum number in the downstream direction is B_{max_d}; the maximum number in the upstream direction is denoted as B_{max_u}. The values of B_{max_d} and B_{max_u} shall be constrained by $8 \le B_{max\_d} \le 15$ and $8 \le B_{max\_u} \le 15$.

For a given sub-channel, the encoder shall select an odd-integer point (X,Y) from the square-grid constellation based on the b bits $\{v_{b-1}, v_{b-2},...,v_1,v_0\}$. For ease of description, these b bits are identified with an integer label whose binary representation is ($v_{b-1}, v_{b-2},...,v_1,v_0$). For example, for b=2, the four constellation points are labelled 0, 1, 2, and 3 corresponding to (v_1,v_0) = (0,0), (0,1), (1,0), and (1,1), respectively.

5.1.2.5.1 Even values of *b*

For even values of b, the integer values X and Y of the constellation point (X,Y) shall be determined from the b bits $\{v_{b-1}, v_{b-2},...,v_1,v_0\}$ as follows. X and Y are the odd integers with twos-compliment binary representations ($v_{b-1}, v_{b-3}, ..., v_1, 1$) and ($v_{b-2}, v_{b-4}, ..., v_0, 1$), respectively. The most significant bits (MSBs), v_{b-1} and v_{b-2}, are the sign bits for X and Y, respectively. Figure 7 shows example constellations for b = 2 and b = 4.

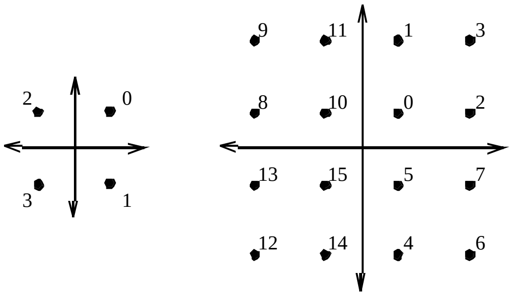


Figure 7: Constellation labels for *b* = 2 and *b* = 4

The 4-bit constellation can be obtained from the 2-bit constellation by replacing each label n by the 2x2 block of labels:

$4n + 1$	$4n + 3$
$4n$	$4n + 2$

The same procedure can be used to construct the larger even-bit constellations recursively.

The constellations obtained for even values of b are square in shape.

5.1.2.5.2 Odd values of b, b = 1 or b = 3

Figure 8 shows the constellations for the cases b = 1 and b = 3.

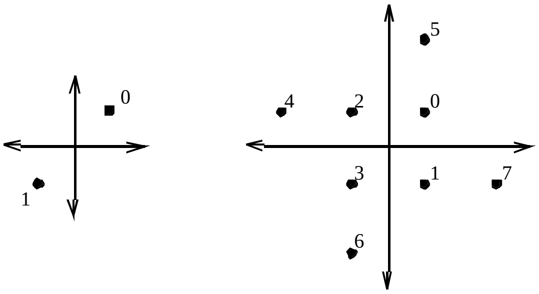


Figure 8: Constellation labels for *b* = 1 and *b* = 3

5.1.2.5.3 Odd values of b, b > 3

If b is odd and greater than 3, the 2 MSBs of X and the 2 MSBs of Y are determined by the 5 MSBs of the b bits. Let $c = (b+1)/2$, then X and Y have the twos-compliment binary representations (X_c, X_{c-1}, v_{b-4}, v_{b-6},...,v_3, v_1, 1) and (Y_c, Y_{c-1}, v_{b-5}, v_{b-7}, v_{b-9},...,v_2, v_0, 1), where X_c and Y_c are the sign bits of X and Y respectively. The relationship between X_c, X_{c-1}, Y_c, Y_{c-1}, and v_{b-1}, v_{b-2},...,v_{b-5} is shown in table 2.

Table 2: Determining the top two bits of *X* and *Y*

$v_{b-1}, v_{b-2},\ldots,v_{b-5}$	X_c, X_{c-1}	Y_c, Y_{c-1}
0 0 0 0 0	0 0	0 0
0 0 0 0 1	0 0	0 0
0 0 0 1 0	0 0	0 0
0 0 0 1 1	0 0	0 0
0 0 1 0 0	0 0	1 1
0 0 1 0 1	0 0	1 1
0 0 1 1 0	0 0	1 1
0 0 1 1 1	0 0	1 1
0 1 0 0 0	1 1	0 0
0 1 0 0 1	1 1	0 0
0 1 0 1 0	1 1	0 0
0 1 0 1 1	1 1	0 0
0 1 1 0 0	1 1	1 1
0 1 1 0 1	1 1	1 1
0 1 1 1 0	1 1	1 1
0 1 1 1 1	1 1	1 1
1 0 0 0 0	0 1	0 0
1 0 0 0 1	0 1	0 0
1 0 0 1 0	1 0	0 0
1 0 0 1 1	1 0	0 0
1 0 1 0 0	0 0	0 1
1 0 1 0 1	0 0	1 0
1 0 1 1 0	0 0	0 1
1 0 1 1 1	0 0	1 0
1 1 0 0 0	1 1	0 1
1 1 0 0 1	1 1	1 0
1 1 0 1 0	1 1	0 1
1 1 0 1 1	1 1	1 0
1 1 1 0 0	0 1	1 1
1 1 1 0 1	0 1	1 1
1 1 1 1 0	1 0	1 1
1 1 1 1 1	1 0	1 1

Figure 9 shows the constellation for the case b = 5.

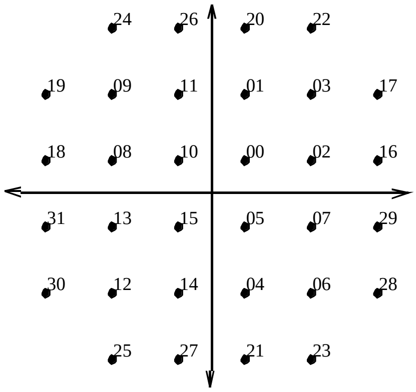


Figure 9: Constellation labels for *b* = 5

The 7-bit constellation shall be obtained from the 5-bit constellation by replacing each label n by the 2 x 2 block of labels:

$$\begin{array}{cc} 4n+1 & 4n+3 \\ 4n & 4n+2 \end{array}$$

The same procedure shall then be used to construct the larger odd-bit constellations recursively.

5.1.2.6 Gain scaling

A gain adjuster g_i shall be used to effect a frequency-dependent transmit power spectral density (PSD). It consists of a fine gain adjustment with a range from approximately 0,75 to 1,33 (i.e. ±2,5 dB), which may be used to equalise the expected error rates for all the sub-channels. Each point (X_i, Y_i), or complex number $Z_i = X_i + jY_i$, output from the encoder is multiplied by g_i: $Z_i' = g_i Z_i$.

Other uses of gain scaling are for further study.

5.1.2.7 Tone ordering

Because the DMT symbol has a high peak to average power ratio (PAR), peak values in the signal may be clipped by the D/A-converter. To a first approximation, this leads to an additive noise that is comparable with impulse noise (with an amplitude equal to the clipped portion, but with opposite sign). This noise will be almost white over all the tones. It is likely that the tones with the densest constellations (i.e. the tones with the largest SNR) will be more affected when this noise is present. Thus, the occurrence of an error is more likely on these tones due to the smaller distance between the constellation points.

If the dual latency option is supported, bits in the slow buffer shall be assigned to tones with the highest SNRs. With this scheme, occasional errors on these tones due to clipping can be corrected by the combination of interleaving and RS coding. The bits on tones with smaller constellations are less likely to be in error due to clipping noise and therefore support bits from the fast buffer.

The "tone-ordered" encoding shall first assign all the bits from the fast buffer to the tones with the smallest number of bits assigned to them, and then assign all the bits from the interleaved buffer to the remaining tones. All tones shall be encoded with the number of bits assigned to them. Therefore, a single tone may support a mixture of bits from the fast and slow buffers.

The ordered bit table b'_i shall be based on the original bit table b_i as follows:

For $k = 0$ to $B_{\text{max\_d or u}}$

- From the bit table, find the set of all i with the number of bits per tone $b_i = k$;
- Assign b_i to the ordered bit allocation table in ascending order of i.

A complementary de-ordering procedure shall be performed by the receiver at the other end of the line. It is not necessary to transmit the results of the ordering procedure to the receiver because all the information required to perform the de-ordering already exists at the receiver.

If only one single-latency channel is supported, bits are assigned to tones starting from the lowest available frequency based on the original bit table b_i.

Figure 10 illustrates how the bits are extracted from the fast and interleaved data buffers when tone-ordering is applied. In this example, both fast and interleaved buffers are one octet long. Following the above rule, the first bits are taken from the fast buffer, starting from the LSB and are placed on the tones with the lowest number of bits assigned to it. The fourth tone to be loaded (carrying b_3' bits) takes bits from both the fast and interleaved buffers.

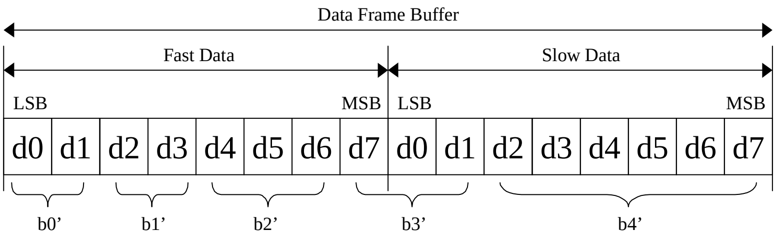


Figure 10: Bit extraction after tone ordering

5.1.2.8 U_1-interface characteristics

5.1.2.8.1 Egress

In the default mode, emissions from both the VTU-O and VTU-R shall be controlled by constraining the transmitted PSD in frequency bands allocated in the over-the-air spectrum for amateur radio transmissions. An optional mode enables sub-channels within one or more of the amateur radio bands for data transmission. This optional mode, which can be invoked only by the network operator via the network management interface, improves VDSL performance when emissions into the amateur radio bands are not of concern.

5.1.2.8.2 Power Spectral Density of all signals

The VDSL transmit PSD in the passband shall not exceed the PSD as defined in TS 101 270-1 [1].

Avoidance of the amateur radio bands (as described in clause 5.1.2.8.1) is mandatory; support of an option to enable transmission in one or more amateur radio bands is discretionary.

The VDSL PSD in the POTS and ISDN bands shall comply with the requirements given in TS 101 270-1 [1].

5.1.2.8.3 Wideband launch power

The wideband launch power shall comply with TS 101 270-1 [1].

5.2 Single carrier PMD sub-layer specification

The Physical Medium-Dependent (PMD) sub-layer specifies the modulation schemes, the duplexing method and the electrical characteristics of the signal to be transmitted over the physical medium.

5.2.1 Basic principles

5.2.1.1 Functional model

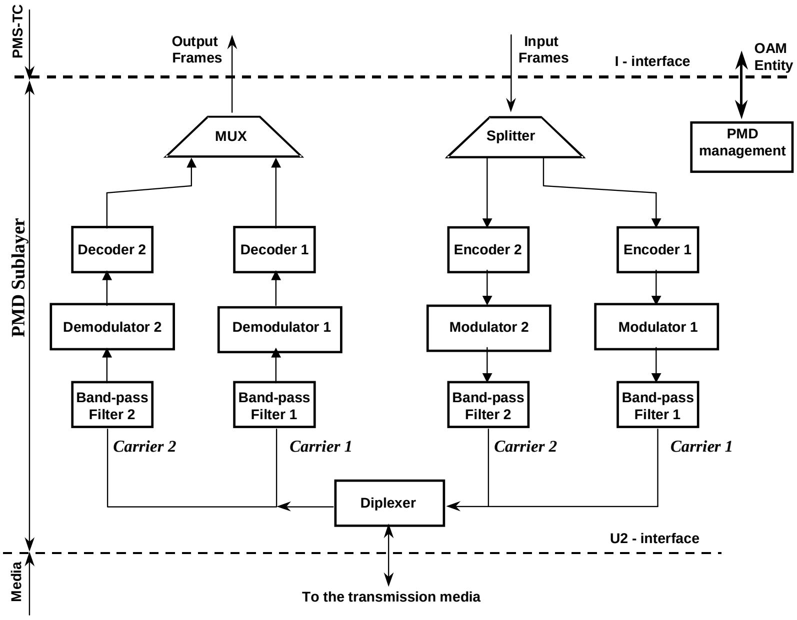
The VDSL transceiver functional model is presented in figure 11. This model defines the PMD sub-layer between the I_O (I_R) and U_2_O (U_2_R) reference points respectively.

In the transmit direction the input frame (clause 6.5.1) coming from the PMS-TC via the I-interface, is split into two streams with data rate ratio N_1/N_2, where N_1, N_2 are integers. Each stream is encoded, modulated and sent onto the transmission line via the U_1-interface. Each stream is transmitted in a separate frequency band, defined by the corresponding band-pass filter. The signal transmitted in a certain band is called a "Carrier". Up to two carriers can be transmitted in both upstream and downstream directions. If the first carrier can transmit all the input data the second carrier is not used. In this case ($N_1 = 1$, $N_2 = 0$) both the splitter and the multiplexer are bypassed.

In the receive direction the carriers received in both bands are demodulated, decoded and multiplexed into the output transmission frame, which has the same structure as the input frame. The output frame is sent towards the PMS-TC via the I-interface.

The band-pass filters in the transmit and receive directions restrict the transmit out-of-band power to prevent crosstalk between the US and DS carriers.

The PMD management block provides all the OAM functions required by the PMD. The exchange of management information between the VTU OAM entity and PMD management block is accomplished via the I-interface.



NOTE: The name of the carrier (carrier 1 and carrier 2) is not associated with any particular frequency band. If additional spectrum either below f_0 or above f_5 (see TS 101 270-1 [1]) is used the existing carriers will be extended.

Figure 11: VTU PMD Sub-layer Functional Model

5.2.1.2 Timing

The transmitters of both carriers in the VTU-O shall use a transmit clock which is derived from the network clock (e.g. SONET clock, SDH clock, PON clock) to allow end-to-end network synchronisation. If the network clock is not available, the VTU-O shall use a locally generated master clock with a maximum tolerance of ±50 ppm.

The transmitters of both carriers in the VTU-R shall use a transmit clock which is derived from the received data clock of either the first or the second downstream carrier (loop timing). If the received data clock is lost during the steady-state transmission, the VTU-R shall use a locally generated clock with a maximum tolerance of ±50 ppm to perform the link activation.

5.2.2 Transmit functionality

5.2.2.1 Frame splitting

The splitter shall originate a special frame (PMD-frame) for both transmitted carriers prior to encoding to compensate for the propagation delay difference between the two carriers at the receive side. The PMD-frame is independent of the carrier data rate. It consists of a total of 405 octets: a 2-octet Syncword, and a 403-octet data field combined from different fields of the input frame (figure 11). The same splitting procedure is applied for both the upstream and downstream carriers. The PMD-frame Syncword contains Sync1 and Sync2 octets (clause 6.5.1.3).

The PMD-frame structure and mapping of the input frame (figure 15) into the PMD-frame for both carriers are presented in figure 12. The splitter maps the input frame into two PMD-frames to be transmitted by two carriers with data rate ratio of N_1/N_2. The procedure starts from the frame alignment octet Sync1 of an auxiliary input frame (input frame #1 in figure 12). The Sync1 octet and the following Sync2 octet from the input frame are sent into both carrier-1 and carrier-2 streams to form their own Syncwords. All Sync1, Sync2 octets of the input frames following frame #1 shall be removed.

The N_1 octets of the input frame #1 following the Sync2 octet shall be mapped into carrier-1 and the N_2 following octets of the input frame shall be mapped into carrier-2. A repetition of this process forms the information field of the PMD-frame. An inverted Syncword shall be inserted into each PMD-frame (both carrier-1 and carrier-2) after every 403 data octets inserted into its information field. If fewer than N_1 or N_2 octet positions remain at the end of a given PMD-frame, the next group of N_1 or N_2 octets is split between the end of that PMD-frame and the beginning of the next PMD-frame, as shown in figure 12.

The splitting process is cyclic. A cycle contains (N_1+N_2) input frames. During the splitting cycle exactly N_1 frames are mapped into the carrier-1 and exactly N_2 frames are mapped into the carrier-2. For simplicity the start of the PMD-frames of both carriers in figure 12 are aligned with the Sync1 octet of the input frame #1.

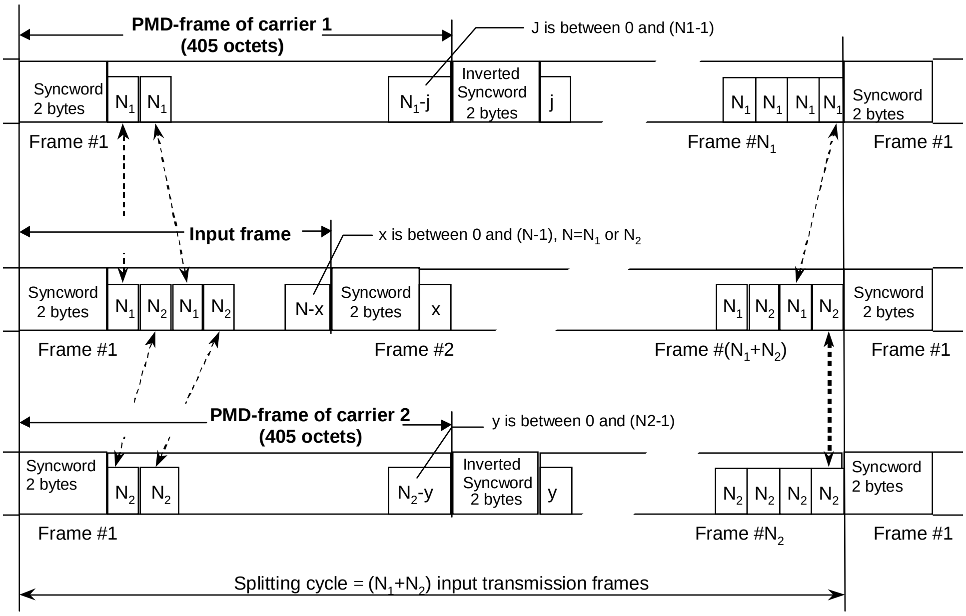


Figure 12: PMD-frame Format

The time difference between the beginning of the splitting cycles of the PMD-frames transmitted by carrier 1 and carrier 2 respectively, measured at the output of the transceiver, shall be less than

$Max\{5+40\times Abs(T_1-T_2),20\}$ µs, where T_1 = 1/SR_1, T_2 = 1/SR_2, SR_1 and SR_2 are the symbol rates of carriers 1 and 2 respectively. The timing difference shall be measured with respect to the start of the first bit of the PMD frame #1 for each carrier.

The modem shall at a minimum support values of N_1 and N_2 that provide the bit rates (DR) listed in tables 6, 8, 10 and 12.

NOTE: Using the greater common divisor G = gcd(DR_1,DR_2) of the bit rates DR_1, DR_2 of carrier 1 and carrier 2, the values of N_1 and N_2 shall be DR_1/G and DR_2/G respectively.

5.2.2.2 Coding and modulation

The transmission capability and timing between the VTU-O and the VTU-R over both carriers in both the downstream and upstream directions is provided by using Single Carrier Modulation (SCM) with either Pass-band Spectral Shaping (PSS) or Base-band Spectral Shaping (BSS). The transmitters in the VTU-O and VTU-R may be implemented using either PSS or BSS. The receivers in the corresponding VTU-R and VTU-O are responsible for detecting the type of spectral shaping and decoding either PSS shaped or BSS shaped incoming signals.

The functional blocks shown in figures 13 and 14 describe the coding and modulation functionality. Any implementation that produces the same functional behaviour at the transmitter output is equally valid. The input data stream shall be encoded into two symbol streams I_n and Q_n, where n designates the nth symbol period. The symbol streams I_n and Q_n shall be modulated using the corresponding spectral shaping and sent into the transmission media via a band-pass filter.

Figure 13 shows the block diagram of an SCM transmitter using PSS while figure 14 shows the block diagram of an SCM transmitter using BSS.

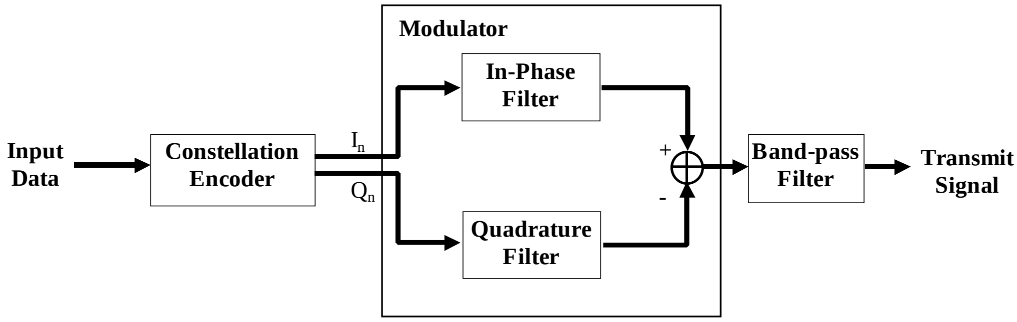


Figure 13: Block Diagram of a SCM Transmitter Using PSS

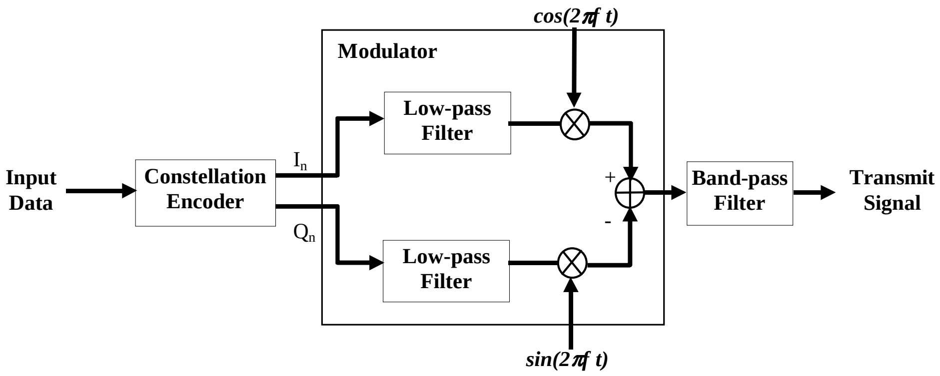


Figure 14: Block Diagram of a SCM Transmitter Using BSS

5.2.2.2.1 Constellation encoder

The encoding procedure shall treat the input data as a serial stream of bits with the most significant bit first. For a given constellation of size 2^M, a group of M consecutive bits $\{b_1,b_2,\ldots b_M\}$ of the input data shall be encoded into one symbol, and consecutive groups of M bits are encoded into consecutive symbols as illustrated in figure 15. Differential quadrant encoding shall be used. For M = 1, every input bit shall be encoded as specified in the upper part of table 3. The two possible values of $\{b_1\}$ represent the transition of the symbol between the first and third quadrants (figure 16). For M > 1, the first two bits $\{b_1,b_2\}$ shall be encoded as described in the lower part of table 3. The four values of $\{b_1,b_2\}$ represent the quadrant transition of the symbols. The remaining (M-2) bits shall be encoded in accordance with the relevant constellation diagrams. The constellation diagrams for 4, 8, 16, 32, 64, 128, 256 and 512 points are given in figures 16 through 23. The constellation diagram for 1 024 points is similar to other constellations with even values of M, the encoding is described in table 4.

NOTE 1: For constellation sizes 32 to 1 024 the second, third and fourth quadrant mappings shall be derived from the mappings in the first quadrant shown in figures 19 to 23 and table 4 by rotating the quadrant counter-clockwise by 90°, 180°, and 270°, respectively.

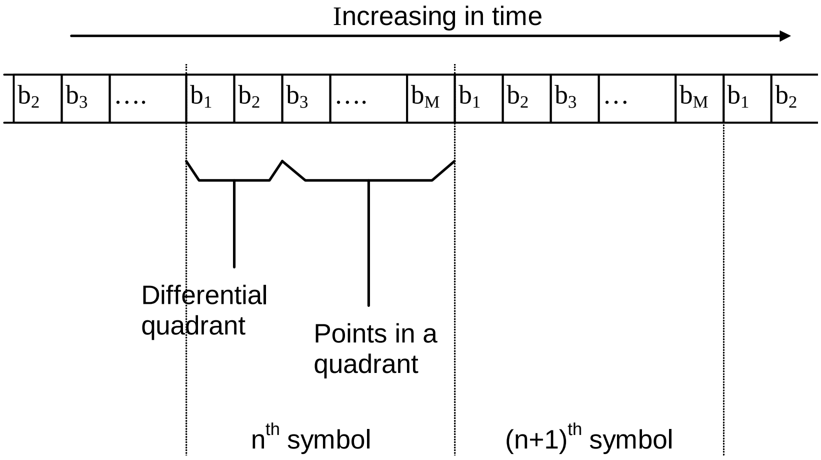


Figure 15: Bit to symbol mapping

Table 3: Differential Encoding of b1, b2

b_1 or b_1, b_2	**Previous quadrant**	**Sign of previous symbol**	**Current quadrant**	**Sign of current symbol**
	number	I_{n-1} Q_{n-1}	number	I_n Q_n
0	1st	+ +	1st	+ +
0	3rd	- -	3rd	- -
1	1st	+ +	1st	- -
1	3rd	- -	3rd	+ +
00	1st	+ +	1st	+ +
00	2nd	- +	2nd	- +
00	3rd	- -	3rd	- -
00	4th	+ -	4th	+ -
01	1st	+ +	4th	+ -
01	2nd	- +	1st	+ +
01	3rd	- -	2nd	- +
01	4th	+ -	3rd	- -
10	1st	+ +	2nd	- +
10	2nd	- +	3rd	- -
10	3rd	- -	4th	+ -
10	4th	+ -	1st	+ +
11	1st	+ +	3rd	- -
11	2nd	- +	4th	+ -
11	3rd	- -	1st	+ +
11	4th	+ -	2nd	- +

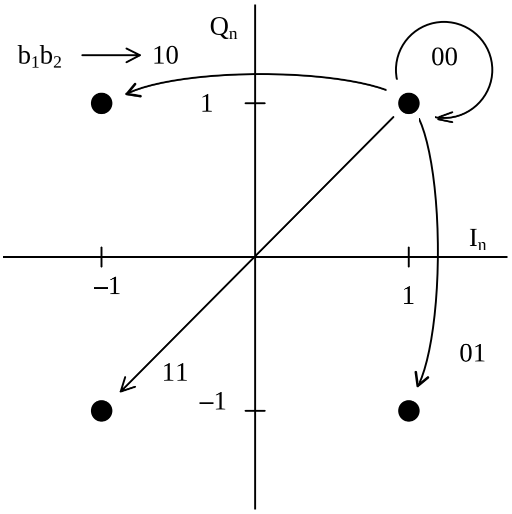


Figure 16: 4-point Constellation with Differential Bit Encoding

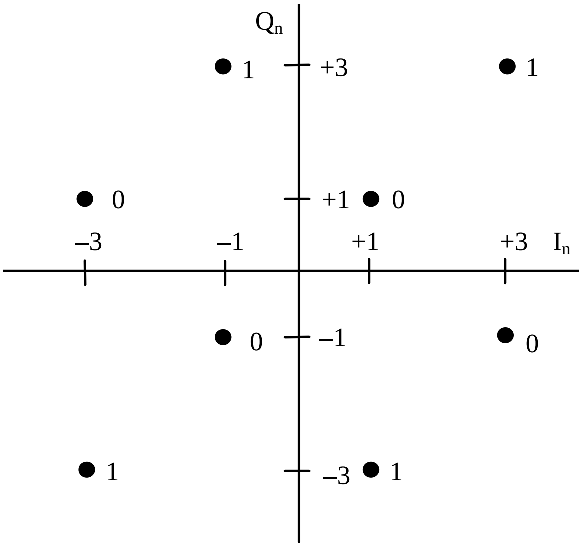


Figure 17: 8-point Constellation and Bit Mapping

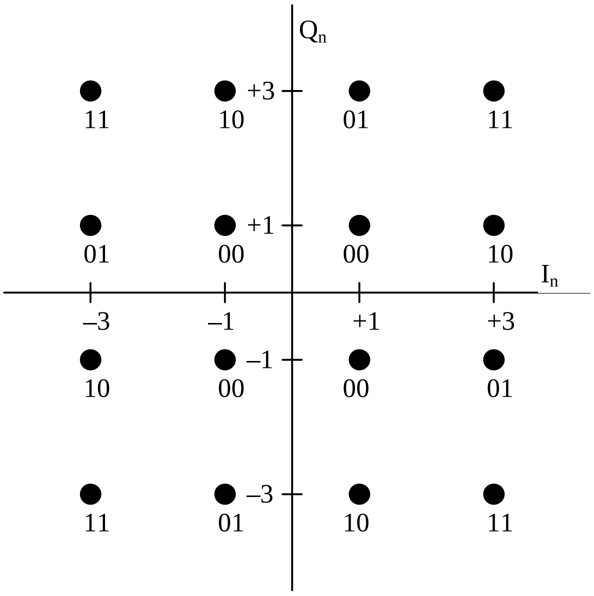


Figure 18: 16-point Constellation and Bit Mapping

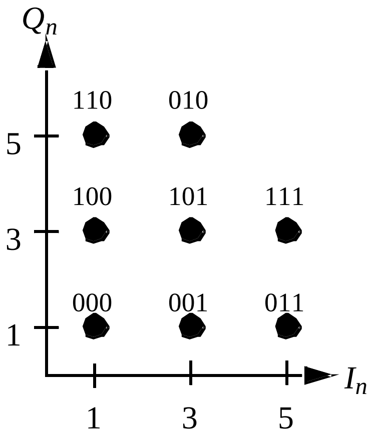


Figure 19: First Quadrant of 32-point Constellation and Bit Mapping

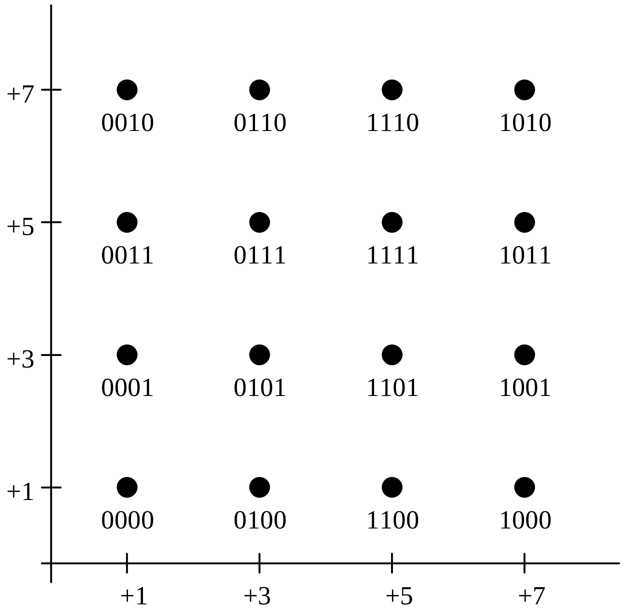


Figure 20: First Quadrant Of 64-Point Constellation and Bit Mapping

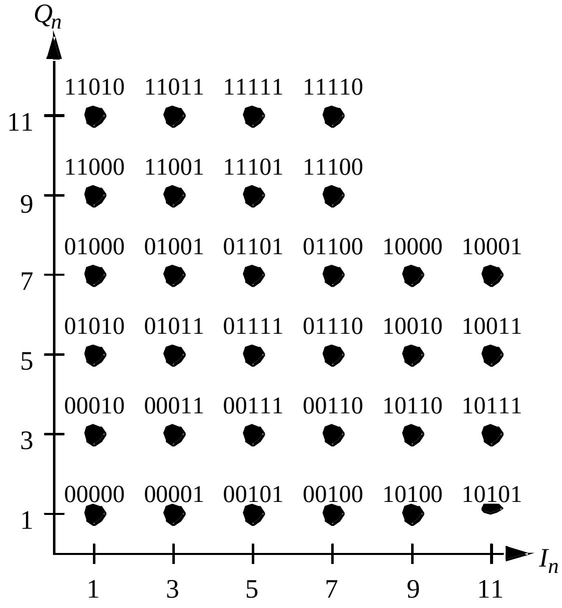


Figure 21: First Quadrant of 128-point Constellation and Bit Mapping

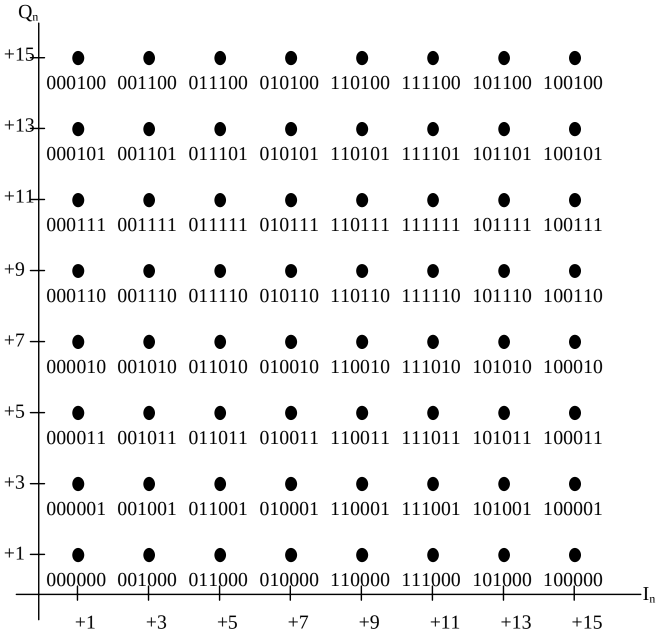


Figure 22: First Quadrant of 256-Point Constellation and Bit Mapping

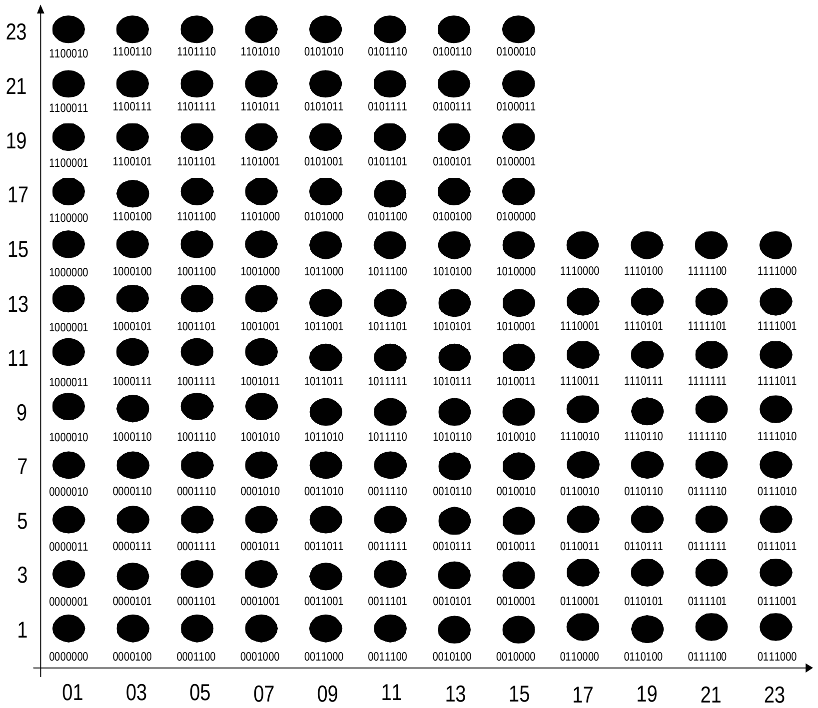


Figure 23: First Quadrant of 512-Point Constellation and Bit Mapping

Table 4: First quadrant of 1 024-point constellation bit mapping

I_n (binary representation)	Q_n (binary representation)
$I_n = x_1\ x_2\ x_3\ x_4\ 1$	$Q_n = y_1\ y_2\ y_3\ y_4\ 1$
$x_1 = b_3$	$y_1 = b_7$
$x_2 = x_1 + b_4$	$y_2 = y_1 + b_8$
$x_3 = x_2 + b_5$	$y_3 = y_2 + b_9$
$x_4 = x_3 + b_6$	$y_4 = y_3 + b_{10}$

NOTE 2: The following example clarifies the usage of table 4: for $b_3b_4b_5b_6b_7b_8b_9b_{10}$ = 00000001, we get $x_1 = x_2 = x_3 = x_4 = 0$, $y_1 = y_2 = y_3 = 0$, $y_4 = 1$ and I_n = 00001 (bin) = 1 (dec) and Q_n = 00011 (bin) = 3 (dec). Similarly, a constellation point with $I_n = 1$ and $Q_n = 3$ will be coded 00000001 (bin).

5.2.2.2.2 Modulator

If the transmitter uses PSS then the two encoded streams I_n and Q_n are sent to pass-band in-phase and quadrature shaping filters, respectively. The output of the in-phase filter and the inverted output of the quadrature filter are summed to form a signal with two orthogonal components. The result is passed through a band-pass filter, and then transmitted onto the media.

If the transmitter uses BSS then the two encoded streams, I_n and Q_n, are sent to low-pass shaping filters. The output of the filter for the in-phase path is heterodyned with a cosine carrier signal. The output of the filter for the quadrature path is heterodyned with a sine carrier signal of the same frequency. The outputs of the two paths are subtracted to form a signal with two orthogonal components. The result is passed through a band-pass filter, and then transmitted onto the media.

The amplitudes of I_n and Q_n components in the transmitted constellations shall maintain the relative values of 1, 3, 5, 7, 9, … 31 with a tolerance of ±0,06 relative to these values, as it depicted in the constellation diagrams in figures 16 to 23 and table 4.

5.2.2.2.2.1 Symbol rates and carrier frequencies

Both the downstream and upstream Symbol Rates (SR) are scaleable. All available symbol rates are multiples of the Basic Symbol Rate (BSR):

$$SR = s \times BSR,$$

where s is an integer, BSR = 33,75 kBaud.

The carrier signal frequencies f_C for transmitters using BSS shall be an integer multiple of $½BSR$:

$$f_C = ½BSR \times k\ , \text{[MHz]},$$

where k is an integer. The resulting f_C shifting granularity is equal to 16,875 kHz.

NOTE: The value of SR/f_C shall be an exact ratio of two integers under all possible frequency tolerances. The particular values of f_C and SR for standard transmission profiles can be found in clause 5.2.5.2.

5.2.2.2.2.2 Spectral Shaping Filters

For both BSS and PSS filters, the low-pass, the in-phase and the quadrature filters shall have an excess bandwidth of α = 0,20 (square-root raised-cosine approximation of the frequency response, see table 5).

The BSS low-pass filter (see figure 14) impulse response is an approximation of:

$$g(t) = \frac{\sin(\pi\frac{4t}{5T}) + (\frac{4t}{5T})\cos(\pi\frac{6t}{5T})}{(\pi\frac{t}{T})[1-(\frac{4t}{5T})^2]},$$

where $T = 1/SR$ is the symbol period.

The impulse response of the PSS in-phase filter (see figure 13) is an approximation of:

$$f(t) = g(t) \times \cos(2\pi f_c t)\,.$$

The impulse response of the PSS quadrature filter (see figure 13) is an approximation of:

$$f'(t) = g(t) \times \sin(2\pi f_c t)\,,$$

where f_C is the centre frequency of the transmit signal, and is also equal to the carrier frequency f_C used in the corresponding BSS transmitter.

5.2.2.3 Carrier spectral shaping

The transmit signal of any carrier inside the transmit band shall meet the power spectrum template, G, and the group delay distortion template, D, defined in table 5. The nominal, lower and upper limits of the attenuation and group delay distortion are defined as a function of the normalised frequency x, where:

$$x = \frac{f - f_c}{SR/2}$$

Table 5: Power Spectrum Template

Normalised frequency (*x*)	***G* (min) dB**	***G* (nom) dB**	***G* (max) dB**	***D*(x)-*D*min s**
-1,5		-∞	< -40	
-1,4		-∞	< -40	
-1,3		-∞	< -30	
-1,2		-∞	< -20	
-1,15	-19	-14,2	-10	< 8T
-1,1	-12	-8,4	-6	< -5T
-1,05	-8,5	-5,1	-3	< -4,5T
-1	-4	-3	-2	< -4T
-0,95	-2,6	-1,6	-0,6	< -3T
-0,9	-1,7	-0,7	0,3	
-0,8	-1	0	1	
0	-1	0	1	
0,8	-1	0	1	
0,9	-1,7	-0,7	0,3	
0,95	-2,6	-1,6	-0,6	
1	-4	-3	-2	< -4T
1,05	-8,5	-5,1	-3	< -4,5T
1,1	-12	-8,4	-6	< -5T
1,15	-19	-14,2	-10	< -8T
1,2		∞	< -20	
1,3		∞	< -30	
1,4		∞	< -40	
1,5		∞	< -40	

NOTE 1: The absolute value of the nominal transmit PSD corresponds to the template level of 0 dB.

NOTE 2: The part of the templates for G and D defined by |x| < 1,2 account for the effects of all the filters shown in figure 13 and 14.

NOTE 3: The values for the PSD given in table 5 for |x| > 1,2 may not be sufficient to meet the generic requirements for the out-of-band PSD. The band-pass filter shall provide the additional out-of-band filtering if necessary.

NOTE 4: The templates only relate to flat-shaped and unnotched transmit PSDs. Templates for non-flat transmit PSDs are for further study.

NOTE 5: Dmin is the minimum group delay within the in-band spectrum:

$$D\min = Min\{D(x), |x| \leq 1.2\}.$$

5.2.3 Receive functionality

The receiver demodulates and decodes the incoming signal of both carriers received from the transmission line, and multiplexes them into an output frame (figure 11). The VTU-R modem receiver functionality shall include recovery of the symbol timing.

Both the demodulation and decoding process shall be matched with the modulation and encoding process respectively. The demodulator shall automatically recognise whether PSS or BSS shaping is applied at the transmitter side.

The PMD-frame delineation algorithm of the receiver is proprietary.

The multiplexing procedure combines PMD-frames of the carrier-1 and the carrier-2, as presented in figure 12, into the original transmission frame as described in clause 6.5.1, and reconstructs the original frame alignment octets Sync1, Sync2. The multiplexing procedure shall be matched with the splitting procedure as specified in clause 5.2.2.1.

The receiver must tolerate a delay difference caused by the transmitter and the transmission path (twisted pair line, splitters etc). The latter is usually less than 1 µs.

5.2.4 Interface specification

5.2.4.1 I-interface

The I_O and I_R reference points define interface between the PMD and PMS-TC sub-layers. Both interfaces are identical and described in clause 6.3.2.

5.2.4.2 U1-interface (Transmission Media Interface)

5.2.4.2.1 Transmit signal power

The nominal power of the transmit signal for either all upstream or all downstream carriers shall not exceed the limit specified in TS 101 270-1 [1].

5.2.4.2.2 Transmit signal Power Spectral Density

The transmit Power Spectral Density (PSD) shall comply with the masks M1 and M2 defined in TS 101 270-1 [1].

5.2.4.2.3 Transmit PSD control

All PSD control options shall be available independently in both the upstream and downstream directions by the Network Operator via the management system. Some of these options may be established automatically, upon the corresponding link activation procedure.

5.2.4.2.3.1 PSD

Control of the transmit PSD is available for all upstream and downstream carriers in both transmission directions, as specified in clause 7.5.3.3.1

The particular value of the PSD for any application and deployment scenario is limited by the transmit signal power value, as defined in clause 5.2.4.2.1, and by the applied PSD mask, as defined in TS 101 270-1 [1] (PSD masks M1, M2).

5.2.4.2.3.2 Transmit PSD notches

To reduce the effect of the radiated emission from a VDSL modem on amateur radio services the PSD of the transmit signal within amateur radio bands shall be able to be decreased to below -80 dBm/Hz. The minimum number of notches that can be applied simultaneously in both directions shall be four. The corresponding amateur frequency bands are presented in TS 101 270-1 [1].

The order of the transfer function that implements a notch filter (a stop-band filter) shall not be higher than 6th order per notch (6 or less poles per notch). Any notch may be applied independently by the corresponding command during the system configuration (clause 7.5.3.3).

5.2.4.2.3.3 Upstream Power Back-Off

5.2.4.2.3.3.1 Introduction

Upstream power back-off will be provided by the VTU-R in accordance with the up-stream power back-off requirements specified in TS 101 270-1 [1] By implementation, two types of power back-off will be available for both upstream carriers independently:

- Start-up PSD back-off;
- Steady-state PSD shaping.

5.2.4.2.3.3.2 Start-up Power Back-off

The start-up power back-off shall only be performed during the Cold-start (clause 8.3.1.2) by applying a flat transmit PSD reduction on the upstream carrier(s) at the beginning of Cold-start activation. The VTU-R receiver shall compute the transmit PSD for each upstream carrier (TxPSD_U) autonomously (with no assistance from the VTU-O) based on the received downstream signal from the VTU-O using the following rule:

$$TxPSD = PSD_{REF}(f_C) + LOSS(f_C) - LOSS\_CORR$$

where PSD_{REF} and *LOSS* are defined in TS 101 270-1 [1], f_C is the centre frequency of the upstream carrier and *LOSS_CORR* is an additional (6 dB) reduction of the upstream transmit PSD to compensate for possible inaccuracy in the estimated electrical length of the loop.

The VTU-R shall also comply with the upstream transmit PSD limit defined in TS 101 270-1 [1].

NOTE: The value of *LOSS_CORR* depends on the VDSL link transmission parameters used during Cold-start. The value of 6 dB is only applicable when using the specified values for DF_STP (table 90).

5.2.4.2.3.3.3 Steady-state PSD Shaping

The *Steady-state PSD shaping* is intended for fine tuning the upstream transmit PSD during the steady-state transmission by an algorithm including an exchange of the related parameters between the VTU-O and VTU-R. The PSD shaping algorithm is proprietary and shall comply with TS 101 270-1 [1]. The exchange parameters are the following:

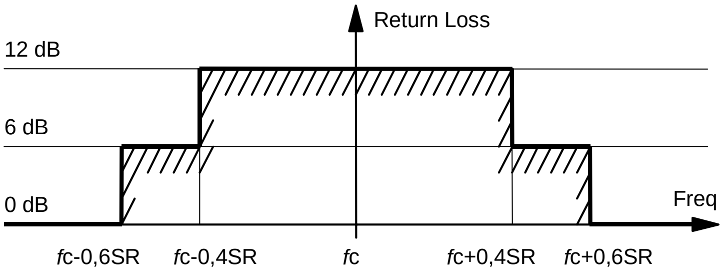
- insertion loss for each carrier;
- SNR for each carrier.

The detailed *Steady-state PSD shaping* method and the other exchange parameters are for further study.

5.2.4.2.4 Return Loss

The return loss shall comply with the requirements specified in clause 8.3.2 of TS 101 270-1 [1]. The return loss mask for any carrier, in both the transmit and receive directions, is shown in figure 24.

The return loss shall be measured on a resistive test load of *Rv* (135 Ω ± 0,2 %) while the tested implementation of the VTU is powered.



NOTE: See clause 5.2.5.2 for the particular f_C and *SR* values for standard transmission profiles.

Figure 24: Return Loss Mask

5.2.4.2.5 Output Signal Balance (OSB)

Output Signal Balance (OSB) shall comply with the requirements in clause 8.3.3 of TS 101 270-1 [1] in the VDSL band of each transmitted carrier, as defined in clause 5.2.5.1.3 (from f_C - 1/2SR to f_C + 1/2SR).

5.2.5 Transmission profiles

Transmission profile is a set of parameters, which define the following transmission characteristics of the VDSL link:

- transport capacity;
- spectral allocation;
- PSD mask;
- deployment characteristics.

5.2.5.1 Transmission profile specification

5.2.5.1.1 Profile code

Each profile is specified by a special code consisting of 8 characters [XY-$X_1X_2X_3X_4X_5$-X_6].

The first two characters XY define the profile type and coincide with the names of standard classes of operation A1-A4 (Class I, asymmetric) and S1-S5 (Class II, symmetric) as specified in TS 101 270-1. The six other characters have the following description.

1) X_1 is a profile sub-number with an integer value between 0 and 3. Sub-number 0 shall be used for *standard* profiles (clause 5.2.5.2), providing the original bit rate for the given profile type XY. Sub-number 1 shall be used for profiles with reduced bit rate in the US. Sub-number 2 shall be used for profiles with a reduced bit rate in the DS. Sub-number 3 shall be used for profiles with reduced bit rate in both US and DS.

2) X_2 specifies the spectral allocation scheme and has a value between 0 and 3. The following types of spectral allocation are defined:

    - "0" for DS-US-DS-US type using carriers 1D, 1U, 2D, 2U;
    - "1" for DS-US-DS type using carriers 1D, 1U, 2D;
    - "2" for DS-US type using carriers 1D, 1U;
    - "3" for DS-US-US type using carriers 1D, 1U, 2U.

3) X_3 specifies whether notching of amateur radio bands is applied or not and has a value of N (notched) or O (unnotched). X_3 has value "X" to indicate that either value may be applied.

4) X_4 specifies whether the transmit signal occupies the ADSL frequency band. It shall have a value of "N" if it occupies the spectrum, the value "A" if FTTCab variant A is used and the value "B" if FTTCab variant B is used.

5) X_5 - *optional* - specifies whether the profile is intended for FTTEx, FTTCab or for both applications and can have values E, C or G respectively.

6) X_6 is the profile spectral compatibility marker, which can have values:

    - "M" for profiles utilising the VDSL band allocation (see TS 101 270-1 [1]);
    - "R1" for profiles utilising the optional regional specific band allocation;
    - "R2","R3"… for profiles utilising other regional band allocations.

5.2.5.1.2 Bit Rates

The transmission profile total bit rate (TR) in the corresponding directions is defined by the bit rates (DR) of its carriers in either upstream or downstream direction.

The DR of the particular carrier is defined by the applied symbol rate *SR* and constellation size *C*:

$$DR = SR \times \log_2 C \, .$$

The TR in a certain direction is defined by symbol rates *SR1*, *SR2* and constellation sizes *C1*, *C2* over both carriers in this direction:

$$TR = SR_1 \times \log_2 C_1 + SR_2 \times \log_2 C_2 ,$$

where index 1 or 2 corresponds with carrier 1, 2 respectively.

The minimum available transmission rate is achieved when both the minimum symbol rate $SR = BSR$ = 33,75 kBaud and the minimum constellation size $C = 2$ are applied. The Basic Bit Rate BBR = 33,75 x C kb/s defines the transmission bit rate granularity.

5.2.5.1.3 Spectral allocation of the Transmit Signal

Spectrum allocation of the transmit signal of a carrier with a specific DR is defined by the carrier centre frequency f_C (clause 5.2.2.2.2.1) and its symbol rate *SR.*

In accordance with the transmit filter characteristics described in clause 5.2.2.2.2.2, both carriers of the downstream and of the upstream transmit signals shall have a square-root raised-cosine power spectral shaping with 20 % excess bandwidth. Thus the lowest frequency (f_{LOW}) and the highest frequency (f_{HIGH}) for each carrier could be calculated as:

$$f_{LOW} = f_C - 0{,}6 \times SR , \; f_{HIGH} = f_C + 0{,}6 \times SR .$$

The 3dB-bandwidth of a carrier occupies the frequency range between:

$$f_C - 0{,}5 \times SR \text{ and } f_C + 0{,}5 \times SR .$$

5.2.5.2 Standard Transmission Profiles

Standard transmission profiles are intended to provide both symmetric and asymmetric operation (services) with the payload rates defined in TS 101 270-1 [1]. A specific standard profile is defined for each payload rate utilising either the VDSL band allocation or the optional regional specific band allocation. The Symbol Rates (SR), bit rates (DR) and band allocation of both carriers for standard asymmetric operation are presented in tables 6 and 7 (VDSL band allocation) and tables 10 and 11 (optional regional specific band allocation). The same parameters for standard symmetric operation are presented in tables 8 and 9 (VDSL band allocation) and tables 12 and 13 (optional regional specific band allocation).

NOTE 1: The symbol rates, constellation sizes and band allocation recommended in tables 6 to 13 are intended for use in either FTTEx or FTTCab (variants A or B) deployments. These parameters can be modified using the procedure described in clause 8.3.2 to improve performance in particular loop/noise environments.

NOTE 2: Standard transmission profiles do not support service at bit rate S5.

5.2.5.2.1 Standard Transmission Profiles - VDSL Band Allocation

Table 6: Asymmetric Profiles: Bit Rates

Profile Code	Carrier	Symbol Rate *SR* (MBaud)	Constell. C	Data Rate *DR* (Mb/s)	Total Rate *TR* (Mb/s)		Maximum Payload Rate (Mb/s)
A1-02OAG-M A1-02OBG-M	1D	1,485 (22 x 67,5)	32	7,425	DS	7,425	6,637
	1U	1,215 (18 x 67,5)	4	2,43	US	2,43	2,172
A2-02OAG-M	1D	1,485 (22 x 67,5)	64	8,91	DS	10,26	9,171
	2D	1,35 (20 x 67,5)	2	1,35			
	1U	1,215 (18 x 67,5)	4	2,43	US	2,43	2,172
A2-02OBG-M	1D	1,62 (24 x 67,5)	64	9,72	DS	9,72	8,688
	1U	1,215 (18 x 67,5)	4	2,43	US	2.43	2,172
A3-01OAG-M A3-01OBG-M	1D	1,51875 (22,5 x 67,5)	256	12,15	DS	16,2	14,48
	2D	1,35 (20 x 67,5)	8	4,05			
	1U	1,215 (18 x 67,5)	8	3,645	US	3,645	3,258
A4-01ONE-M	1D	2,16 (32 x 67,5)	256	17,28	DS	25,92	23,168
	2D	1,08 (16 x 67,5)	256	8,64			
	1U	1,215 (18 x 67,5)	16	4,86	US	4,86	4,096
NOTE: Payload rate is calculated assuming single latency.							

Table 7: Asymmetric Profiles - Spectrum Allocation

Profile code	Carrier	Carrier frequency f_C (MHz)	Lowest frequency f_{LOW} (MHz)	Highest frequency f_{HIGH} (MHz)	PSD (dBm/Hz)
A1-02OAG-M A1-02OBG-M	1D	2,05875 (61 x 33,75)	1,17	2,95	-61
	1U	3,8475 (114 x 33,75)	3,12	4,58	
A2-02OAG-M	1D	2,05875 (61 x 33,75)	1,17	2,95	
	2D	6,17625(183 x 33,75)	5,37	6,99	
	1U	3,8475 (114 x 33,75)	3,12	4,58	
A2-02OBG-M	1D	1,92375 (57 x 33,75)	0,95	2,9	
	1U	3,8475 (114 x 33,75)	3,12	4,58	
A3-01OAG-M A3-01OBG-M	1D	2,025 (60 x 33,75)	1,14	2,94	
	2D	6,17625 (183 x 33,75)	5,37	6,99	
	1U	3,8475 (114 x 33,75)	3,12	4,58	
A4-01ONE-A	1D	1,485 (44 x 33,75)	0,189	2,781	
	2D	6,075 (180 x 33,75)	5,427	6,723	
	1U	3,8475 (114 x 33,75)	3,12	4,58	

Table 8: Symmetric Profiles - Bit Rates

Profile code	Carrier	Symbol Rate *SR* (MBaud)	Constell. C	Data Rate *DR* (Mb/s)	Total Rate TR (Mb/s)		Maximum Payload Rate (Mb/s)
S1-03OAG-M S1-03OBG-M	1D	1,485 (22 x 67,5)	32	7,425	DS	7,425	6,637
	1U	1,62 (24 x 67,5)	16	6,48	US	7,29	6,516
	2U	0,81 (12 x 67,5)	2	0,81			
S2-03OAG-M S2-03OBG-M	1D	1,485 (22 x 67,5)	64	8,91	DS	10,26	9,171
	2D	1,35 (20 x 67,5)	2	1,35			
	1U	1,62 (24 x 67,5)	16	6,48	US	9,72	8,688
	2U	1,62 (24 x 67,5)	4	3,24			
S3-00OAG-M S3-00OBG-M	1D	1,51875 (22,5 x 67,5)	256	12,15	DS	16,2	14,48
	2D	1,35 (20 x 67,5)	8	4,05			
	1U	1,62 (24 x 67,5)	32	8,1	US	16,2	14,48
	2U	2,7 (40 x 67,5)	8	8,1			
S4-00OAG-M S4-00OBG-M	1D	1,51875 (22,5 x 67,5)	1 024	15,188	DS	25,988	23,228
	2D	1,35 (20 x 67,5)	256	10,8			
	1U	1,62 (24 x 67,5)	256	12,96	US	26,46	23,651
	2U	2,7 (40 x 67,5)	32	13,5			
NOTE: Payload rate is calculated assuming single latency.							

Table 9: Symmetric Profiles - Spectrum Allocation

Profile Code	Carrier	Carrier frequency f_C (MHz)	Lowest frequency f_{LOW} (MHz)	Highest frequency f_{HIGH} (MHz)	PSD (dBm/Hz)
S1-03OAG-M S1-03OBG-M	1D	2,05875 (61 x 33,75)	1,17	2,95	-61
	1U	4,1175 (122 x 33,75)	3,15	5,09	
	2U	8,370 (248 x 33,75)	7,88	8,57	
S2-03OAG-M S2-03OBG-M	1D	2,05875 (61 x 33,75)	1,17	2,95	
	2D	6,17625 (183 x 33,75)	5,37	6,99	
	1U	4,1175 (122 x 33,75)	3,15	5,09	
	2U	8,8425 (262 x 33,75)	7,87	9,81	
S3-00OAG-M S3-00OBG-M S4-00OAG-M S4-00OBG-M	1D	2,025 (60 x 33,75)	1,14	2,94	
	2D	6,17625 (183 x 33,75)	5,37	6,99	
	1U	4,1175 (122 x 33,75)	3,15	5,09	
	2U	9,5175 (282 x 33,75)	7,9	11,14	

5.2.5.2.2 Standard Transmission Profiles - Optional Regional Specific Band Allocation

Table 10: Asymmetric Profiles : Bit Rates

Profile Code	Carrier	Symbol Rate *SR* (MBaud)	Constell. C	Data Rate *DR* (Mb/s)	Total Rate *TR* (Mb/s)		Maximum Payload Rate (Mb/s)
A1-02OAG-R1	1D	1,89 (28 x 67,5)	16	7,56	DS	7,56	6,757
A1-02OBG-R1	1U	0,81 (12 x 67,5)	8	2,43	US	2,43	2,172
A2-02OAG-R1	1D	2,025 (30 x 67,5)	32	10,125	DS	10,125	9,05
A2-02OBG-R1	1U	0,81 (12 x 67,5)	8	2,43	US	2,43	2,172
A3-01OAG-R1 A3-01OBG-R1	1D	2,025 (30 x 67,5)	64	12,15	DS	16,47	14,721
	2D	2,16 (32 x 67,5)	4	4,32			
	1U	0,945 (14 x 67,5)	16	3,78	US	3,78	3,378
A4-01OAG-R1 A4-01OBG-R1	1D	2,025 (30 x 67,5)	256	16,2	DS	26,8	24,133
	2D	2,16 (32 x 67,5)	32	10,8			
	1U	0,945 (14 x 67,5)	16	3,78	US	3,78	3,378
NOTE: Payload rate is calculated assuming single latency.							

Table 11: Asymmetric Profiles - Optional Regional Specific Spectrum Allocation

Profile code	Carrier	Carrier frequency f_C (MHz)	Lowest frequency f_{LOW} (MHz)	Highest frequency f_{HIGH} (MHz)	PSD (dBm/Hz)
A1-02OAG-R1	1D	2,26125 (67 x 33,75)	1,13	3,4	-61
A1-02OBG-R1	1U	4,455 (132 x 33,75)	3,97	4,94	
A2-02OAG-R1	1D	2,32875 (69 x 33,75)	1,12	3,54	
A2-02OBG-R1	1U	4,455 (132 x 33,75)	3,97	4,94	
A3-01OAG-R1 A3-01OBG-R1	1D	2,32875 (69 x 33,75)	1,12	3,54	
	2D	6,885 (204 x 33,75)	5,59	8,18	
	1U	4,5225 (134 x 33,75)	3,96	5,09	
A4-01OAG-R1 A4-01OBG-R1	1D	2,32875 (69 x 33,75)	1,12	3,54	
	2D	6,885 (204 x 33,75)	5,59	8,18	
	1U	4,5225 (134 x 33,75)	3,96	5,09	

Table 12: Symmetric Profiles - Bit Rates

Profile code	Carrier	Symbol Rate *SR* (MBaud)	Constell. C	Data Rate *DR* (Mb/s)	Total Rate TR (Mb/s)		Maximum Payload Rate (Mb/s)
S1-03OAG-R1 S1-03OBG-R1	1D	1,89 (28 x 67,5)	16	7,56	DS	7,56	6,757
	1U	0,945 (14 x 67,5)	32	4,725	US	7,56	6,757
	2U	1,4175 (21 x 67,5)	4	2,835			
S2-03OAG-R1 S2-03OBG-R1	1D	2,025 (30 x 67,5)	32	10,125	DS	10,125	9,05
	1U	0,945 (14 x 67,5)	32	4,725	US	10,395	9,291
	2U	1,89 (28 x 67,5)	8	5,67			
S3-00OAG-R1 S3-00OBG-R1	1D	1,89 (28 x 67,5)	32	9,45	DS	17,55	15,687
	2D	2,025 (30 x 67,5)	16	8,1			
	1U	1,08 (16 x 67,5)	32	5,4	US	16,2	14,48
	2U	2,7 (40 x 67,5)	16	10,8			
S4-00OAG-R1 S4-00OBG-R1	1D	1,89 (28 x 67,5)	256	15,12	DS	27,27	24,375
	2D	2,025 (30 x 67,5)	64	12,15			
	1U	1,08 (16 x 67,5)	512	9,72	US	25,92	23,168
	2U	2,7 (40 x 67,5)	64	16,2			
NOTE: Payload rate is calculated assuming single latency.							

Table 13: Symmetric Profiles - Optional Regional Specific Spectrum Allocation

Profile Code	Carrier	Carrier frequency f_C (MHz)	Lowest frequency f_{LOW} (MHz)	Highest frequency f_{HIGH} (MHz)	PSD (dBm/Hz)
S1-03OAG-R1 S1-03OBG-R1	1D	2,26125 (67 x 33,75)	1,13	3,4	-61
	1U	4,5225 (134 x 33,75)	3,95	5,09	
	2U	10,125 (300 x 33,75)	9,27	10,98	
S2-03OAG-R1 S2-03OBG-R1	1D	2,32875 (69 x 33,75)	1,12	3,54	
	1U	4,5225 (134 x 33,75)	3,95	5,09	
	2U	10,395 (308 x 33,75)	9,26	11,53	
S3-00OAG-R1 S3-00OBG-R1	1D	2,32875 (69 x 33,75)	1,13	3,4	
	2D	6,885 (204 x 33,75)	5,67	8,1	
	1U	4,5225 (134 x 33,75)	3,87	5,17	
	2U	10,36125 (307 x 33,75)	8,74	11,98	
S4-00OAG-R1 S4-00OBG-R1	1D	2,26125 (67 x 33,75)	1,13	3,4	
	2D	6,885 (204 x 33,75)	5,67	8,1	
	1U	4,5225 (134 x 33,75)	3,87	5,17	
	2U	10,36125 (307 x 33,75)	8,74	11,98	

6 Transmission Convergence (TC) layer

The Transmission Convergence (TC) sub-layer provides adaptation of different applied transport protocols to the PMD by transformation of any applied protocol into a generic octet-oriented stream and mapping it into the transmission frame format generated by the PMS-TC sub-layer.

6.1 TC layer functionality

6.1.1 Generic functional model

The TC layer functional model, as presented in figure 25, defines the TPS-TC and PMS-TC sub-layers. The functional model is identical for the VTU-O and VTU-R except for the method of providing the Network Timing Reference (NTR).

The TPS-TC sub-layer contains a number of TPS-TC blocks intended for different transport protocols. The main transport protocols are ATM, STM and PTM. A special TPS-TC block supports the Operation Channel (OC) including the clear eoc.

The TPS-TC signals are multiplexed into either the *Delay-sensitive* (Fast) or *Delay-insensitive* (Slow) channels corresponding to their latency requirements by two time division multiplexers: MUX_f and MUX_s, as shown in figure 25. Both the Fast and Slow multiplexed signals have an application independent format on the α(β)-interface.

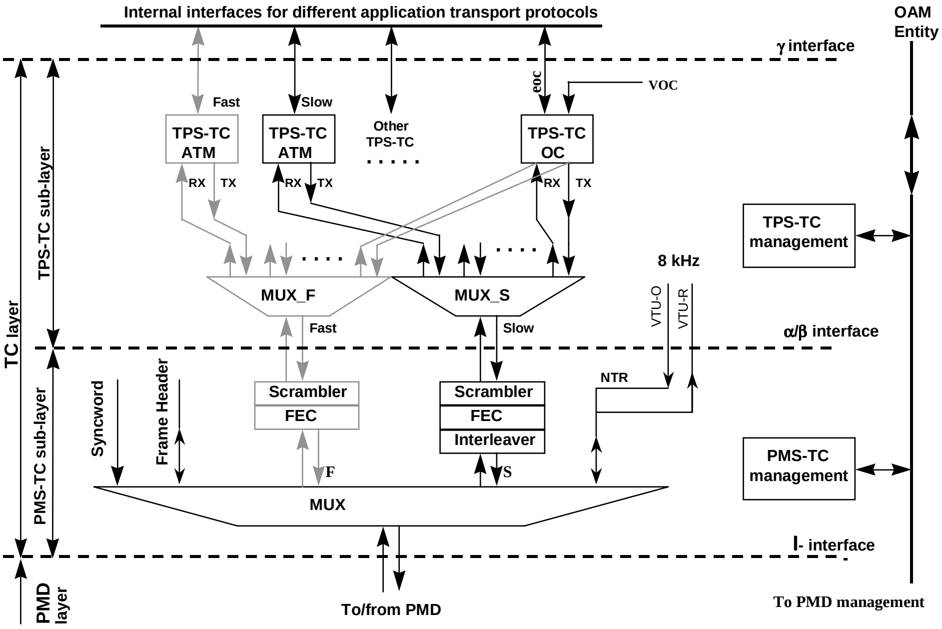
On the PMS-TC sub-layer both the Fast and Slow channels are randomised, protected by FEC and mapped into the transmission frame. The Slow channel protection includes interleaving. The transmission frame contains separate fields for Fast and Slow channels. The frame header carries frame alignment, OAM data and NTR markers.

The Slow channel is *mandatory*, the Fast channel is *optional*. The system provides dual latency if both the Fast and Slow channels are implemented. If only the Slow channel is implemented, the system provides single latency.

The particular data rates and payload allocations for each of the multiplexed TPS-TC at the α(β) reference point are asserted during the system configuration. The mandatory TC configuration shall provide one application transport protocol over the Slow channel. All other configurations are *optional*.

The TC OAM entity is divided between TPS-TC Management (Path related functions) and PMS-TC Management (Line related functions). The exchange of management information with TPS-TC Management is accomplished via the γ-interface; with PMS-TC Management it is accomplished via the α(β)-interface.

The NTR 8 kHz network timing shall be transported to the customer unit via the VDSL link to support some specific services. The NTR timing marker is sent to the VTU-O TC across the α interface and delivered to the customer unit across the β interface at the VTU-R. The method of transporting the NTR is described in clause 6.1.5.



NOTE 1: At the VTU-O the downstream is transmitted and the upstream is received. At the VTU-R the downstream is received and the upstream is transmitted.

NOTE 2: The set of TPS-TC blocks may be different in each transmission direction (dual latency downstream and single latency upstream, for instance).

NOTE 3: If there is more than one application of the same type (two Fast STM, for instance), the corresponding multiplexing shall be done above the TC sub-layer.

NOTE 4: The Fast and Slow channels meet different performance requirements because of the interleaving.

Figure 25: TC Functional Model

6.1.2 ATM transport

6.1.2.1 Functional model of ATM transport

The TPS-TC sub-layer functional model of ATM transport derived from figure 25 is presented in figure 26. It contains two identical ATM TPS-TC blocks (ATM_TC), intended to support ATM transmission over the Fast (*Delay-sensitive* applications) and the Slow (*Delay-insensitive* applications) channels. The mandatory configuration shall include one ATM_TC (Slow, single-latency). For optional dual latency operation the second ATM_TC is required.

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

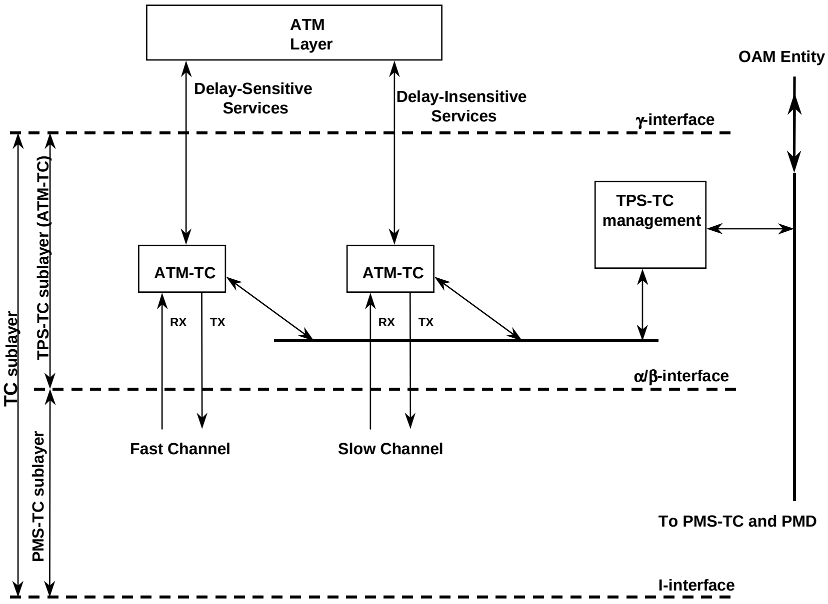


Figure 26: Functional Model of ATM Transport

The γ-interface of both ATM_TC shall interface the ATM Layer as described in clause 6.2.1.1. Both the Fast and Slow ATM_TC have the same application independent format at the α/β-interface.

6.1.2.2 Transport of ATM data

To transport ATM data, the bit rates of both the upstream and downstream channels shall be set independently of each other to any of the eligible bit rates up to the maximum rate determined by the payload rate of the applied transmission profile and the applied transmission frame. Both are set during the system configuration.

The channelisation 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, at least a single latency mode (in both downstream and upstream channel) shall be supported.

The need for either a single or a dual latency for ATM transport depends on the type of service. One of the three "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 upstream and downstream - *optional*.

NOTE: For single latency applications the Slow channel may be used to implement the Fast channel as well by changing of its interleaving depth. In particular, the interleaver may be disabled in the Slow channel by setting the interleaver depth to zero.

6.1.3 STM transport

This clause specifies both PDH and SDH data transport.

6.1.3.1 Functional model of STM transport

The TPS-TC sub-layer functional model of STM transport derived from figure 25 is presented in figure 27. It contains one STM TPS-TC block (STM_TC), intended to support SDH or PDH transmission over the Fast channel or the Slow channel. Any STM application uses only single latency.

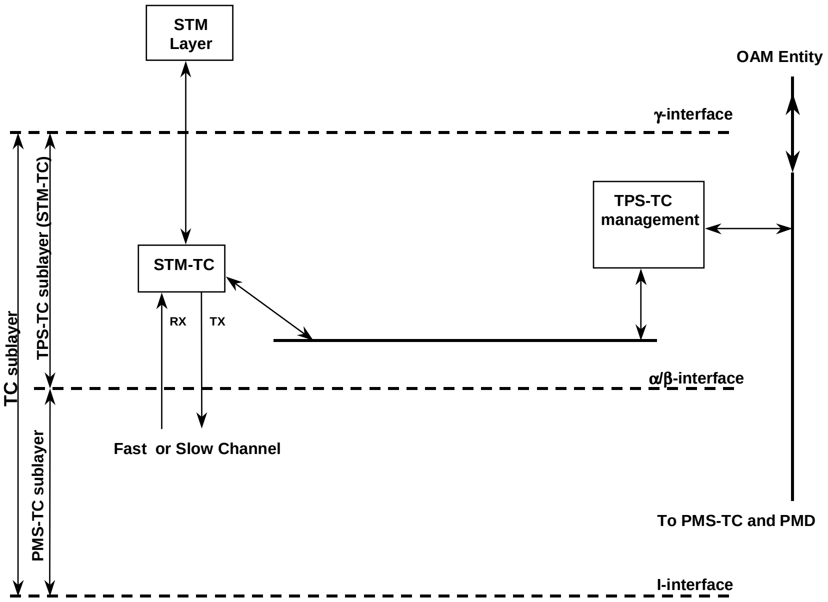


Figure 27: Functional Model of STM Transport

The TPS-TC OAM block provides all necessary OAM functions to support the STM_TC.

NOTE 1: STM services are usually delay-sensitive, hence the set interleaving depth of the Slow channel shall correspond to the applied service latency requirements.

NOTE 2: If there are more than one STM application, some of them can be transmitted over the Fast channel and some over the Slow channel. In this case the system shall provide dual latency.

The γ-interface of STM_TC shall interface with the corresponding STM Layer as described in clause 6.2. The STM_TC has a standard application-independent format at the α/β-interface as described in clauses 6.3 and 6.4.

6.1.3.2 Transport of STM data

To transport STM data the same bit rates shall be applied in both the upstream and downstream channels (symmetric profiles only). The channel aggregate payload rate, which is determined by the applied transmission profile and the applied transmission frame, shall be higher than the rate of the applied STM transport. Both are set during the system configuration.

The details of this section are for further study.

6.1.4 Packets Transport Mode (PTM)

6.1.4.1 Functional Model of PTM transport

The functional model of PTM transport is shown in figure 28. 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 sends it, depending on the latency requirement to the γ-interface of either the Fast or Slow path intended for packetized data transport. The corresponding TPS-TC (PTM-TC) receives the packet from the γ-interface, encapsulates it into the specific frame format (PTM-TC frame) and maps it into the PMS-TC frame (transmission frame) for transmission over the VDSL link.

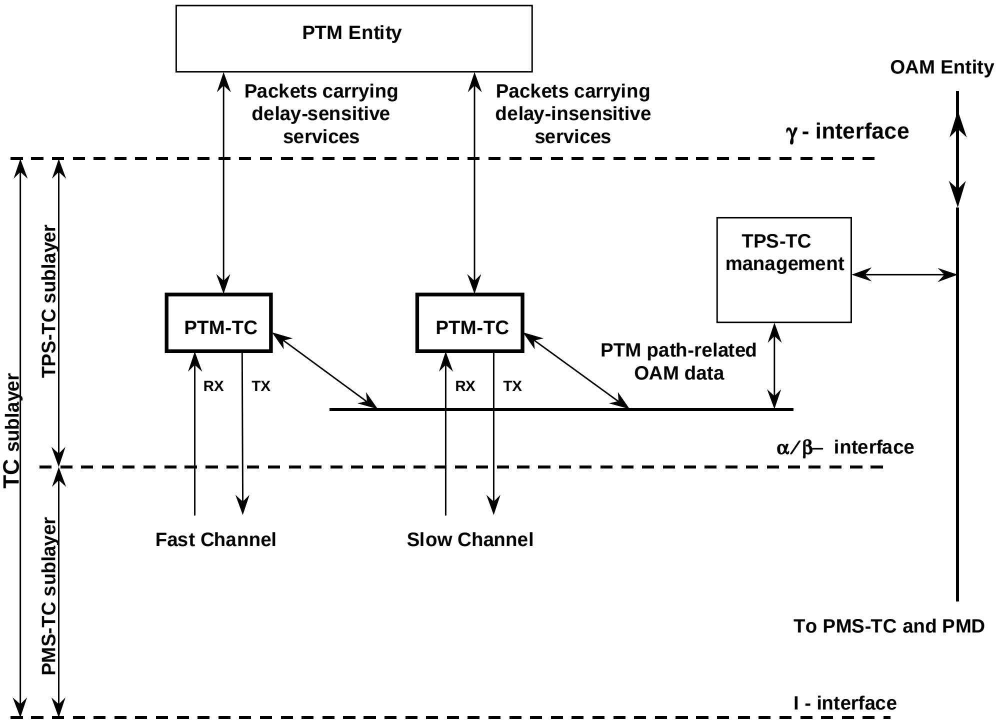


Figure 28: Functional model of PTM transport

In the receive direction, the PTM-TC frame extracted from the received PMS-TC frame is sent to 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.

The γ-interfaces of both PTM-TC are identical and described in clause 6.2.4. The α/β-interfaces are application independent and are described in clause 6.3.2.1.

6.1.4.2 Transport of PTM Data

The bit rate of PTM data transport in the upstream and downstream directions may be set independently 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 can use either the Slow channel or Fast channel or both. The PTM-TC for either channel has the same characteristics. The packet transport shall include at least one PTM-TC (either Fast or Slow). The second PTM-TC is optional.

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

The PTM-TC shall provide transparent data transfer between the 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 and packet error monitoring over either the Fast or Slow channels.

6.1.5 Network timing reference transport

The Network Timing Reference (NTR) timing marker is mapped into the transmission frame at the VTU-O, extracted in the PMS-TC of the VTU-R and delivered to the customer unit across the β interface (clauses 6.4.4.4.4 and 6.5.1.3.6).

6.2 Transport Protocol Specific TC (TPS-TC) sub-layer

6.2.1 ATM Transport Protocol Specific TC (ATM_TC)

6.2.1.1 Application interface description

The ATM_TC application interface (figure 26) is specified at both the γ_O and γ_R reference points of the VTU-O and VTU-R respectively. Both γ-interfaces are functional, identical and shall be defined by the following flows of signals:

- data flow;
- synchronisation flow;
- control flow;
- OAM flow.

NOTE 1: If dual latency is supported, the γ-interface comprises two identical flows of signals - each belongs to the corresponding ATM_TC.

NOTE 2: For a dual latency implementation ATM cell de-multiplexing to (multiplexing from) the appropriate ATM_TC (of the Fast or the Slow channel) shall be performed at the ATM layer based on the Virtual Path Identifier (VPI) and Virtual Channel Identifier (VCI), both contained in the ATM cell header.

6.2.1.1.1 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 pre-defined upper limit of channel aggregate transport capability, determined by the data rate at the α(β) interface. The data flow signal description is presented in table 14.

The ATM cell format is identical in transmit and receive directions. Octet number 5 is undefined and is reserved for HEC insertion in the TC layer.

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 as shown in annex A.

6.2.1.1.2 Synchronisation flow

This flow provides synchronisation between the ATM layer and the ATM_TC. It includes both the ATM data synchronisation signals and the NTR signal.

The synchronisation flow comprises the following signals, presented in table 14:

- transmit and receive timing signals (Tx_Clk, Rx_Clk) are both asserted by the ATM layer;
- Start-of-Cell marker (TxSOC, RxSOC), a bi-directional signal intended to identify the beginning of the transported cell in the corresponding direction;
- Transmit Cell Available flag (TxClAv), asserted by ATM TPS-TC to indicate that ATM TPS-TC is ready to get a received cell from the ATM layer;
- Receive Cell Available flag (RxClAv), asserted by ATM TPS-TC to indicate that TPS-TC contains a valid cell and is ready to transmit it towards ATM layer;
- Transmit Timing Reference (TxRef), applied only at the VTU-O, and coming from the network 8 kHz NTR;
- Receive Timing Reference (RxRef), is an 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 to the Tx_ATM and the Rx_ATM data rates respectively.

NOTE 2: NTR signal has opposite directions at the VTU-O and the VTU-R.

NOTE 3: The synchronisation flow signals can be implemented using a UTOPIA interface as shown in annex A.

6.2.1.1.3 Control flow

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

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

NOTE: The control flow signals are amenable to UTOPIA interface implementation as shown in annex A.

Table 14: ATM-TC: γ-interface Data, Synchronisation and Control Flow Signal Summary

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

6.2.1.1.4 OAM flow

The OAM Flow across the γ-interface exchanges OAM information between the VTU OAM entity and its ATM_TC-related part of TPS-TC management functions. OAM flow is bi-directional and transports ATM path-related primitives, parameters and maintenance signals/commands described in clauses 7.3.2.1 and 7.3.5.3.1.

6.2.1.2 ATM_TC functionality

The following ATM_TC functionality shall be applied in both the downstream and upstream transmission directions.

6.2.1.2.1 Cell rate de-coupling

The cell rate de-coupling shall be implemented by insertion of Idle cells in the transmit direction and deletion of Idle cells in the receive direction (at the remote ATM_TC), as specified in ITU-T Recommendation I.432.1 [2]. A standard cell header shall identify Idle cells as specified in ITU-T Recommendation I.432.1 [2].

6.2.1.2.2 HEC generation and verification

The HEC byte shall be generated as described in ITU-T Recommendation I.432 [3], including the recommended modulo-2 addition (XOR) of the pattern 01010101b to the HEC bits. The generator polynomial coefficient set used and the HEC sequence generation procedure shall be in accordance with ITU-T Recommendation I.432 [3].

The HEC sequence shall be capable of multiple-bit error detection, as defined in ITU-T Recommendation I.432 [2]. The single-bit error correction of the cell header shall not be performed.

6.2.1.2.3 Cell payload randomisation and de-randomisation

Randomisation 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 randomiser shall use a self-synchronising scrambler polynomial $x^{43} + 1$. The randomisation procedure shall be as defined in ITU-T Recommendation I.432 [3] for SDH-based transmission. The corresponding de-randomisation process shall be implemented by the remote ATM_TC.

6.2.1.2.4 Cell delineation

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

The cell delineation algorithm shall be implemented as described in ITU-T Recommendation I.432 [3]. It includes the following states and state transitions, presented in figure 29:

- "HUNT" to "PRESYNC" state transition when HEC coding law is confirmed once.
- "PRESYNC" to "SYNC" state transition when HEC coding law is confirmed α = 5 times consequently;
- "SYNC" to "HUNT" state transition when HEC coding law is violated δ = 7 times consecutively.

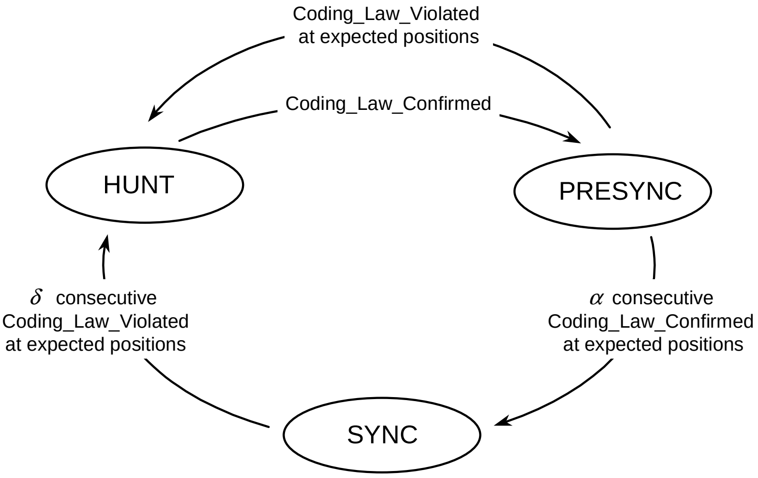


Figure 29: ATM Cell Delineation State Machine

6.2.2 SDH Transport Protocol Specific TC (SDH_TC)

6.2.2.1 Application interface description

The SDH_TC application interface is specified at both the γ_O and γ_R reference points of the VTU-O and VTU-R sites respectively, as shown in figure 27. Both γ-interfaces are functional, identical and shall be defined by the following flows of signals:

- data flow;
- synchronisation flow;
- OAM flow.

6.2.2.1.1 Data flow

For further study.

6.2.2.1.2 Synchronisation flow

For further study.

6.2.2.1.3 OAM flow

For further study.

6.2.2.2 SDH TPS-TC functionality

For further study.

6.2.3 Overhead channel TPS-TC (OC_TC)

6.2.3.1 Application interface description

The OC_TC application interface is specified at both the γ_O and γ_R reference points of the VTU-O and VTU-R sites respectively, as shown in figure 25. Both γ-interfaces are functionally identical and shall be defined by the following flows of signals:

- data flow;
- synchronisation flow.

6.2.3.1.1 Data flow

The data flow includes two streams of 2-octet messages (eoc messages; Tx_eoc, Rx_eoc) with independent rates flowing in opposite directions. Rate values are *arbitrary* under a pre-defined upper limit of the OC aggregate transport capability. The data flow signal description is presented in table 15.

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

6.2.3.1.2 Synchronisation flow

This flow provides synchronisation between the VDSL Management Entity (VME) serving as the eoc application layer (figure 48) and the OC_TC. It includes the following synchronisation signals, presented in table 15:

- 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 transmission of the next 2-octet message;
- receive enable flag (rx_enbl): asserted by OC_TC and indicates that the next 2-octet message is allocated in the OC_TC receive buffer.

Table 15: OC_TC: γ-interface Data and Synchronisation Flow Summary

Signal	Description	Direction	Notes
Data flow			
eoc_tx	Transmit eoc data	VME → OC-TC	Two octet message
eoc_rx	Receive eoc data	VME ← OC-TC	
Synchronisation flow			
eoc_tx_clk	Transmit clock	VME → OC-TC	
eoc_rx_clk	Receive clock	VME → OC-TC	
tx_enbl	Transmit enable flag	VME ← OC-TC	Active if the transmit OPCODE = IDLE
rx_enbl	Receive enable flag	VME ← OC-TC	Active if the received OPCODE = IDLE
NOTE: All the buffering required to implement the eoc communication protocol should be provided by the VME; no buffering for eoc is expected in the OC-TC.			

6.2.3.2 Single Carrier OC_TC functionality

The following OC_TC functionality shall be applied in both the downstream and upstream transmission directions.

6.2.3.2.1 VOC and eoc multiplexing

The VOC and eoc multiplexing/de-multiplexing is based on the applied OC channel OPCODE value (clause 6.5.1) which distinguishes the OC field contents. The VOC shall get priority in the multiplexing process: if both a VOC and eoc messages are ready to be sent, the VOC message shall be sent first.

When no VOC message is to be sent in the given Slow codeword, the OC OPCODE octet of this codeword shall be set to either 0xFF or 0xFC ("IDLE" message OC OPCODE or "EOC" message OC OPCODE, clause 7.5.3.1). In the IDLE message 0x0000 shall be inserted into the OC DATA field. In the EOC message the next two octets of the eoc message shall be inserted into the OC DATA field. When a VOC message other than IDLE has to be sent eoc transparency shall be interrupted and the relevant VOC OPCODE (clause 7.5.3) shall be used. When the VOC message transmission is complete, the OPCODE value shall be set to IDLE. After the specified number of IDLE messages have been sent (clause 7.5.2), eoc transport over the OC may be resumed.

6.2.3.2.2 De-multiplexing

If the received OC OPCODE equals 0xFC, the contents of the OC DATA field shall be output to the VME via the γ-interface. The OC OPCODE 0xFF indicates that no OC data is transferred (IDLE). If the received OC OPCODE is equal to any other value (not 0xFF, nor 0xFC), the received OC DATA field shall be processed as a possible valid VOC OPCODE (clause 7.5.3) by the VOC processor.

NOTE: The OC OPCODE 0xFC indicates that the received OC DATA octets may contain an eoc message. The eoc processor will identify valid messages as described in clause 7.6.3).

6.2.4 PTM transport protocol specific TC (PTM-TC)

6.2.4.1 Application Interface Description

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 28. 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.

6.2.4.1.1 Data Flow

The data flow shall consist of two contra-directional octet-based streams of packets: transmit packets (*Tx_PTM*) and receive packets (*Rx_PTM*). 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 30. The Data Flow signal description is presented in table 16.

Table 16: PTM -TC γ-interface Data, Syncronization and Control Flows Signal Summary

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

6.2.4.1.2 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 is presented in table 16.

- 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.

6.2.4.1.3 Control Flow

Control signals are used to improve robustness of data transport between the PTM-entity and PTM-TC and are presented in table 16.

- Enable signals (Tx_Enbl, Rx_Enbl): asserted by PTM-TC and indicates that data may be respectively send 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 clause 6.2.4.2.5.

6.2.4.1.4 OAM Flow

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

The OAM flow primitives are for *further stud*y.

6.2.4.2 PTM TPS-TC Functionality

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

6.2.4.2.1 Packet encapsulation

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

6.2.4.2.2 Frame structure

The PMS-TC frame format shall be as shown in figure 30. The opening and closing Flag Sequences which identify the start and the end of each frame shall be set to 0x7E. Only one Flag Sequence is required between two consecutive frames.

8 7 6 5 4 3 2 1	Bits
0x7E	Opening Flag Sequence
Default = 0xFF	Address field
Default = 0x03	Control field
Data	Information field
FCS-1	First octet of FCS
FCS-2	Second octet of FCS
0x7E	Closing Flag Sequence

Figure 30: PTM-TC frame format

The Address and Control octets are intended for auxiliary information. They shall be set to their default values of 0xFF and 0x03 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 clause 6.2.4.2.4.

After encapsulation, bits within an octet are labeled b_1 through b_8, as defined in figure 31. If the $\alpha(\beta)$ interface is serial by implementation, bit b_8 of each octet shall be transmitted first.

NOTE 2: In keeping with the labelling convention for the α(β) 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.

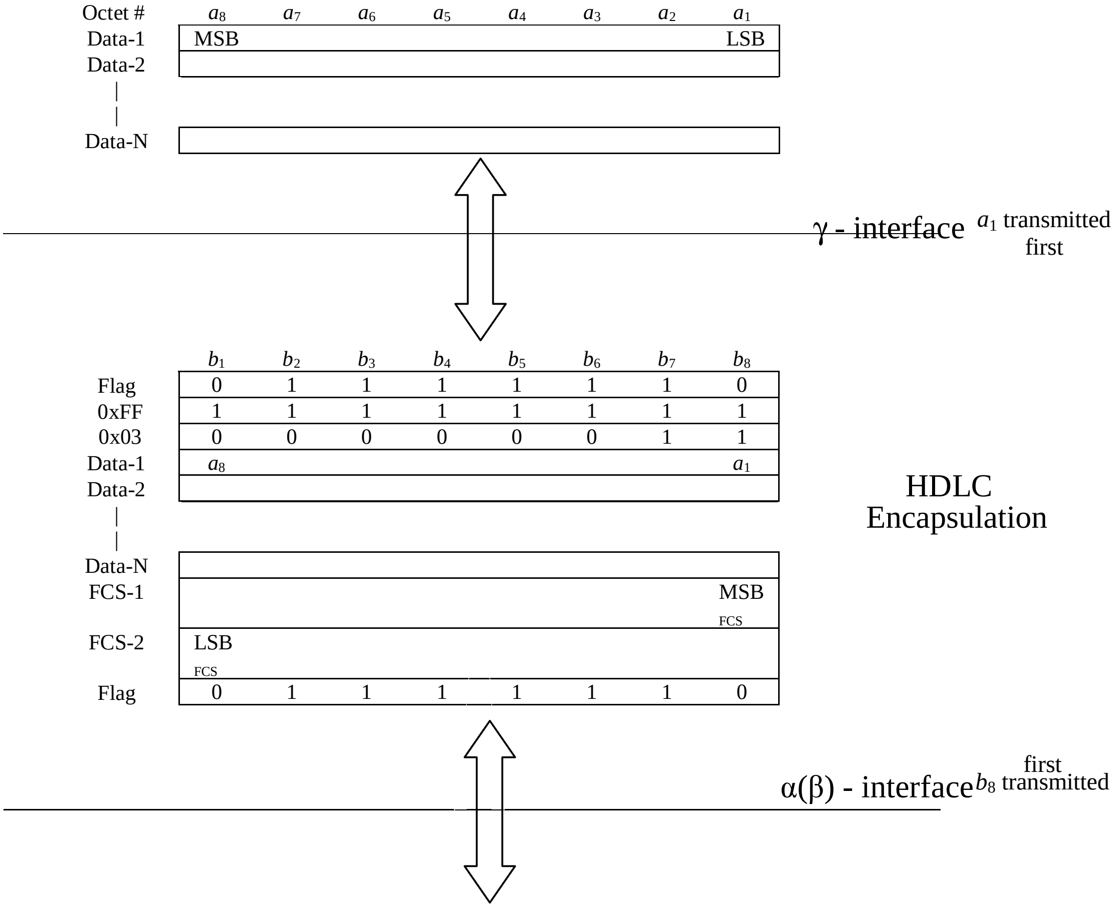


Figure 31: PTM-TC data flow

6.2.4.2.3 Octet transparency

To prevent false frame synchronisation, any octet inside the PTM-TC frame that is equal to 0x7E (the Flag Sequence) or 0x7D (the Control Escape) shall be escaped as described below.

After the Frame Check Sequence has been calculated, the transmitter shall examine the entire frame between the opening and the closing Flag Sequences. Any data octets whose value equals 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 0x20. In summary, the following substitutions shall be made:

- any data octet equal to 0x7E shall be encoded as a two octet sequence 0x7D, 0x5E;
- any data octet equal to 0x7D shall be encoded as a two octet sequence 0x7D, 0x5D.

On reception, prior to Frame Check Sequence calculation, each Control Escape octet shall be removed, and the following octet shall be exclusive-OR'ed with 0x20 (unless the following octet is 0x7E (Flag Sequence) which indicates that the transmission of current frame has been aborted). In summary, the following substitutions are made:

- any sequence of 0x7D, 0x5E shall be replaced by the data octet 0x7E;
- any sequence of 0x7D, 0x5D shall be replaced by the data octet 0x7D;
- a sequence of 0x7D, 0x7E shall indicate the end of an aborted frame.

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

6.2.4.2.4 Frame Check Sequence (FCS)

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 13239, 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 (clause 6.2.4.2.3);

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 and 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 31).

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.

6.2.4.2.5 Packet error monitoring

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

6.2.4.2.5.1 Invalid frames

The following conditions result in an invalid frame:

- Frames which are less than 4 octets long between the 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. 0x7D followed by 0x7E). These frames shall be passed across the γ-interface to the PTM entity;
- Frames which contain control escape sequences other than 0x7D, 0x5E or 0x7D, 0x5D. 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) shall be sent across the γ-interface to the PTM entity.

6.2.4.2.5.2 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 described in clause 6.2.4.2.4. Errored frames shall be passed across the γ-interface. A corresponding receive error message (Rx_Err) shall be sent across the γ-interface to the PTM entity.

6.2.4.3 Data rate decoupling

Data rate decoupling is accomplished by filling the time gaps between transmitted PTM-TC frames with additional Flag Sequences (0x7E). 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.

6.2.4.4 Frame delineation

The PTM-TC frames shall be delineated by detecting Flag Sequences. The incoming stream is examined on an octet-by-octet basis for the value 0x7E. Two (or more) consecutive Flag Sequences constitute an empty frame (frames), which shall be discarded, and not counted as a FCS error.

6.3 Physical Medium-Specific TC (PMS-TC) sub-layer

6.3.1 Functional model

The PMS-TC sub-layer functional model for both VTU-O and VTU-R is presented in figure 32. The PMS-TC sub-layer includes functional blocks for randomisation/de-randomisation (Scrambler), Forward Error Correction (FEC), interleaving, transmission frame encapsulation (MUX) and management.

Both Fast and Slow channels have an application independent format at α(β)-interface. The transmission frame is multiplexed from the Slow and Fast data and a header. The header is combined from NTR markers, Indicator Bits (IB) special flags for VDSL link activation and a SyncWord for transmission frame alignment. The formatted transmission frame is output via the I-interface towards the PMD layer.

The management block provides all OAM functions corresponding with PMS-TC (clause 7.2).

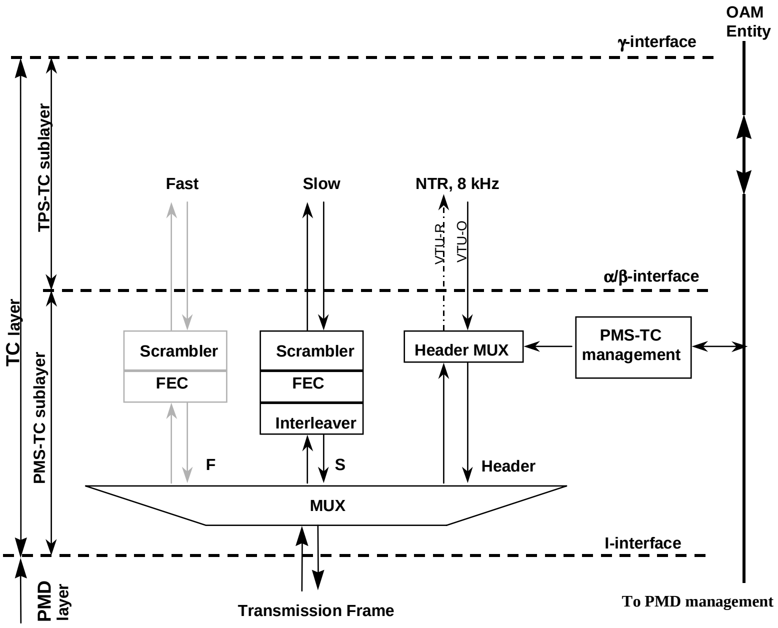


Figure 32: PMS-TC functional model

The data incoming from α(β)-interface of both the Fast and Slow channels is randomised, protected by FEC and multiplexed into the transmission frame. The Slow channel error protection includes interleaving. The Fast channel is *optional*. If both Fast and Slow channels are implemented, the PMS-TC provides dual latency. The latency due to the interleaver can be different in the downstream and upstream transmission directions.

The number of data channels, their transport capability and transmission frame format at the I_O (I_R) reference point are defined by the transmission frame Transport Class and asserted during the system configuration.

6.3.2 Interface specification

6.3.2.1 α(β) - Interface

The α and β reference points define interfaces between the TPS-TC and PMS-TC in the VTU-O and VTU-R respectively (figure 32). The interfaces are functional, application-independent and identical, excepting the direction of the NTR signals. Both interfaces are defined by the following signal flows:

- data flow;
- synchronisation flow;
- OAM flow.

6.3.2.1.1 Data flow

The data flow comprises of up to four generic *octet-oriented asymmetric* streams with bit rates defined by the PMD transmission capabilities:

- two transmit data streams: Slow (Tx_s), Fast (Tx_f);
- two receive data streams: Slow (Rx_s), Fast (Rx_f).

The streams Tx_s and Rx_s are mandatory, Tx_f and Rx_f are optional. The Data flow signal description is summarised in table 17.

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

NOTE 2: The Tx_, Rx_ bit rate values are set during the system configuration.

6.3.2.1.2 Synchronisation flow

The synchronisation flow comprises of up to eight synchronisation signals:

- transmit and receive data flow bit-synchronisation (Clk_t, Clk_r, respectively);
- transmit and receive data flow octet-synchronisation (Osync_t, Osync_r, respectively);
- transmit and receive data flow frame-synchronisation (Fsync_t, Fsync_r, respectively);
- transmit or receive NTR marker (NTR_t, NTR_r, respectively).

All synchronisation signals, except NTR_t, are asserted by PMS-TC and directed towards TPS-TC; NTR-t is directed towards TPS-TC.

Signals Osync_t, Osync_r are *mandatory*, other signals are *optional*. The synchronisation flow signal description is summarised in table 17.

Table 17: α(β)-Interface Signal Summary

Signal(s)	Description	Direction	Notes
Data Signals			
Tx_s	Transmit data, Slow	TPS-TC → PMS-TC	**Mandatory**
Tx_f	Transmit data, Fast		Optional
Rx_s	Receive data, Slow	TPS-TC ← PMS-TC	**Mandatory**
Rx_f	Receive data, Fast		Optional
Synchronisation Signals			
Clk_t	Transmit bit timing	TPS-TC ← PMS-TC	Optional
Osync_t	Transmit octet timing		**Mandatory**
Fsync_t	Transmit frame timing		Optional
Clk_r	Receive bit timing		Optional
Osync_r	Receive octet timing		**Mandatory**
Fsync_r	Receive frame timing		Optional
NTR_t	Transmit NTR	TPS-TC → PMS-TC	Optional, VTU-O only
NTR_r	Receive NTR	TPS-TC ← PMS-TC	Optional, VTU-R only

6.3.2.1.3 OAM flow

The OAM Flow across the α(β) interface exchanges OAM information between the VTU- OAM entity, PMS-TC and PMD. OAM flow is bi-directional and transports line related primitives, parameters, configuration setup and maintenance signals/commands as specified in clauses 7.3.1, 7.3.3, 7.3.5.2 and 7.3.6.

6.3.2.2 I-Interface

The I_O and I_R reference points define interfaces between the PMS-TC and PMD in the VTU-O and VTU-R respectively (figure 32). The interfaces are application independent and identical. Both interfaces are defined by the following signal flows:

- data flow;
- synchronisation flow.

6.3.2.2.1 Data flow

The Data flow consists of two *octet-oriented asymmetric* streams, both formatted by a transmission frame with the bit rates defined by the applied PMD transmission profile:

- transmit data (Tx);
- receive data (Rx).

The Data flow signal description is summarised in table 18.

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

NOTE 2: Each stream bit rate value is set during the PMD configuration.

6.3.2.2.2 Synchronisation flow

The synchronisation flow consists of the transmit and receive data flow bit-synchronisation signals (Clkp_t, Clkp_r) and the frame-synchronisation signals (Fsync_t, Fsync_r). Both signals are asserted by the PMD and directed towards the PMS-TC. The Synchronisation flow signal description is summarised in table 18.

Table 18: I-interface signal summary

Signal(s)	Description	Direction	Notes
	Data Signals		
Tx	Transmit data stream	PMS-TC → PMD	Transmission frame format
Rx	Receive data stream	PMS-TC ← PMD	
	Synchronisation Signals		
Fsync_t	Transmit frame timing	PMS-TC → PMD	
Fsync_r	Receive frame timing	PMS-TC ← PMD	
Clkp_t	Transmit bit timing	PMS-TC ← PMD	
Clkp_r	Receive bit timing	PMS-TC ← PMD	

6.4 PMS-TC functions for multi-carrier modulation

All data octets shall be transmitted MSB first. However, all serial processing (such as scrambling and CRC calculation) shall be performed LSB first, with the payload MSB considered as the LSB within the PMS-TC. As a result the first bit processed by the PMS-TC will be the MSB of the first payload octet.

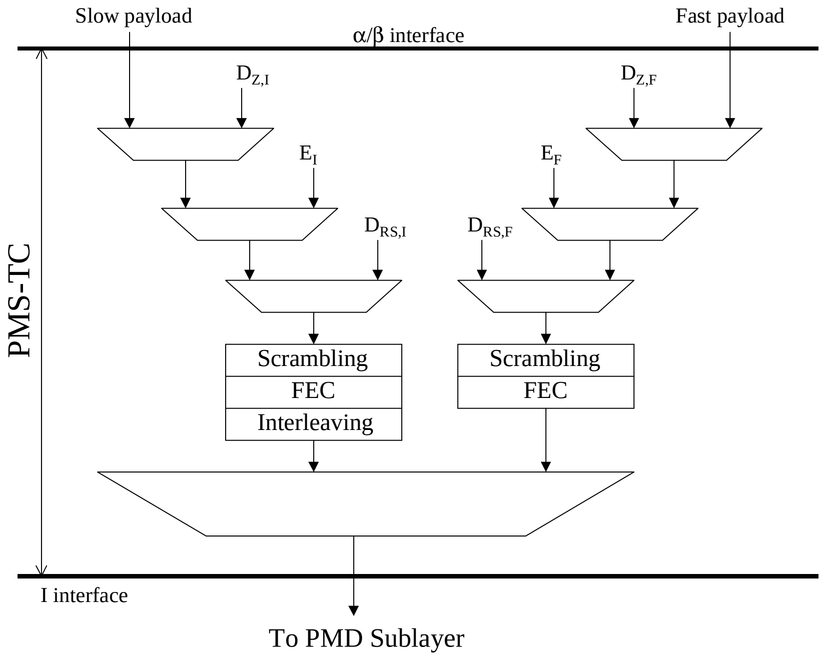


Figure 33: PMS-TC block diagram

6.4.1 Scrambler

A scrambler shall be used to reduce the likelihood that a long sequence of zeros will be transmitted over the channel. The scrambler shall be self-synchronising so that descrambling can occur without requiring a particular alignment with the scrambled sequence. The scrambler is represented by the equation below where *m(n)* is a message bit at time *n* and the output of the scrambler is *x(n)*:

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

all arithmetic is modulo 2. As long as the scrambler is initialised with values other than zero, an "all zeros" sequence for *m(n)* will result in a pseudo random sequence of length 2^{23} - 1. At the input to the scrambler, the LSB of each octet enters the scrambler first. At the output of the scrambler, the LSB of each octet leaves the scrambler first.

6.4.2 Forward error correction

A standard octet-oriented Reed-Solomon code shall be used to provide protection against random and burst errors. Comprised of *R* redundant check octets $c_0, c_1, ..., c_{R-2}, c_{R-1}$ appended to *K* message octets $m_0, m_1, ..., m_{K-2}, m_{K-1}$, a Reed-Solomon code word contains *N*=*K*+*R* octets. The check octets are computed from the message octets using the equation:

$$C(D) = M(D)D^R \bmod G(D),$$

where

$$M(D) = m_0 D^{K-1} \oplus m_1 D^{K-2} \oplus ... \oplus m_{K-2} D \oplus m_{K-1}$$

is the message polynomial,

$$C(D) = c_0 D^{R-1} \oplus c_1 D^{R-2} \oplus ... \oplus c_{R-2} D \oplus c_{R-1}$$

is the check polynomial, and $G(D) = \prod (D \oplus \alpha^i)$ is the generator polynomial of the Reed-Solomon code, where the index of the product runs from i = 0 to *R*-1. That is, *C(D)* is the remainder obtained from dividing $M(D)D^R$ by *G(D).* The arithmetic is performed in the Galois Field GF(256), where α is a primitive element that satisfies the primitive binary polynomial $x^8 \oplus x^4 \oplus x^3 \oplus x^2 \oplus 1$. A data octet ($d_7, d_6, …, d_1, d_0$) is identified with the Galois Field element $d_7\alpha^7 \oplus d_6\alpha^6 \oplus ... \oplus d_1\alpha \oplus d_0$.

Both *K* and *R* are programmable parameters. Redundancy values of *R = 0, 2, 4, 6, 8 … 16* shall be supported. The following code word parameters specified as *(N,K)* shall be supported: (144,128) and (240, 224). Other values for *N* and *K* are optional. However, *N* shall be less than or equal to 255.

6.4.3 Interleaving

6.4.3.1 General

Interleaving shall be used to protect the data against bursts of errors by spreading the errors over a number of Reed-Solomon codewords. The interleaver and de-interleaver shall be adjustable via the management system to meet latency requirements. The latency of the slow path is a function of the data rate and burst error correction capability. For data rates greater than or equal to 13 Mbps, the latency between the α and β interfaces shall not exceed 10 ms when the interleaver delay is set to the maximum. At lower data rates there is a trade-off between higher latency and decreased burst error correction ability. At any data rate, the minimum latency occurs when the interleaver is turned off.

When the interleaver is on, the codewords shall be interleaved before transmission to increase the immunity of RS codewords to bursts of errors. The convolutional interleaver is defined by two parameters: the interleaver block length, *I*, and the interleaving depth, *D*. The block length *I* divides the RS codeword length *N*. The convolutional interleaver uses a memory in which a block of *I* octets is written while an (interleaved) block of *I* octets is read.

The convolutional interleaver introduces a read-to-write delay, Δ_I, that increments linearly with the octet index within a block of I octets:

$$\Delta_I = (D-1) \times j \text{, where } j = 0, 1, 2, \ldots, I-1.$$

6.4.3.2 Triangular implementation

To decrease the implementation complexity, the delay increment (*D-1*) shall be chosen as a multiple of the interleaver block length (*I*). Therefore, *M* x *I* = (*D-1*), where the parameter *M* is an integer. The characteristics of convolutional interleaving are shown in Annex C. Table 19 summarizes interleaving depth, interleaving (and de-interleaving) memory size, and end-to-end delay. The correction capability is calculated using t = number of octets that can be corrected by RS codewords which equals half the number of redundancy octets (R/2) and q = length of RS codeword divided by the length of an interleaved block (N/I).

Table 19: Characteristics of triangular, convolutional interleaver

Parameter	Value
Interleaver block length	I octets (I must divide N)
Interleaving depth *D*	M x I + 1 octets
(De)interleaver memory size	M x I x (I–1)/2 octets
End-to-end delay	M x I x (I–1) octets
Correction capability	⌊t/q⌋ x M x (I+1) octets

6.4.4 Framing

6.4.4.1 Frame description

A *frame* is a set of octets carried by one DMT symbol. The frame frequency depends on the length of the cyclic extension. A frame is composed of two sources: the "fast" buffer and the "interleaved" buffer. The index *i* refers to parameters related to the fast or interleaved buffers ($i \in \{F, I\}$). The inclusion of the fast buffer is optional. When the fast buffer is not included, the interleaved buffer can carry non-interleaved data by setting the interleaver depth to zero.

Both the fast and interleaved buffers contain an integer number of RS-encoded octets. Neither the fast nor the interleaved buffer is required to carry an integer number of RS codewords. To reduce the end-to-end delay, it is recommended that the fast buffer (or the interleaved buffer when the interleaver depth is zero) carries at least one RS codeword. The framing parameters are exchanged between the VTU-O and VTU-R during initialisation.

The framing rules described in this clause are summarised in figure 34:

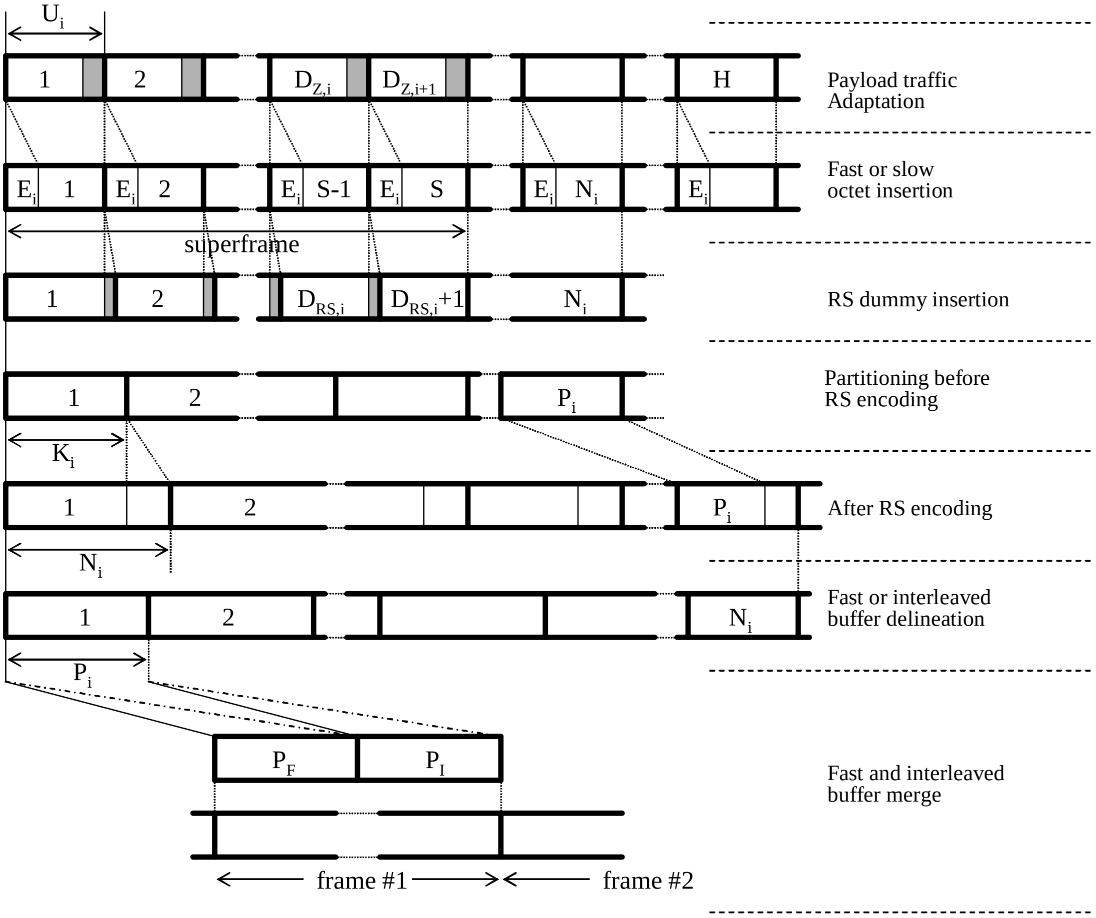


Figure 34: Framing description

6.4.4.2 Payload adaptation

Each frame shall carry an integer number of TPS-TC payload octets provided by the α/β interface. To map TPS-TC payload octets at a rate multiple of 64 kbps into a frame, it is required to stuff the TPS-TC octet flow with dummies. For a payload data rate of n_i x 64 kbps rate, we have on average $n_i \times 8\,000/f_s$ octets per frame, with f_s the frame rate (i.e. DMT-symbol frequency).

We define k as the number of TPS-TC payload octets carried in a sequence of H = 138 frames at a payload data rate of 64 kbps. (Since the cyclic extension $L_{CP} + L_{CS} - \beta$ is a multiple of 2^{n+1}, we always have an integer number of TPS-TC payload octets every H = 138 frames. If the cyclic extension $L_{CP} + L_{CS} - \beta$ is equal to 40 x 2^n, then the frame rate is 4 kHz and any value of H would result in an integer number of TPS-TC payload octets per H frames).

$$k = \frac{H \times 8000}{f_s} \text{ bytes}$$

When the payload data rate is equal to n_i x 64kbps, then n_i x k payload octets are carried in H = 138 frames. In order to transport an integer number of TPS-TC payload octets per frame, an appropriate number of dummy octets may have to be inserted into the stream of TPS-TC payload octets. Every frame will contain a total of U_i octets (TPS-TC octets + dummy octets), with:

$$U_i = \left\lceil \frac{n_i \times k}{H} \right\rceil .$$

The number of dummy octets $D_{Z,i}$ to be inserted every H packets is then:

$$D_{Z,i} = \left\lceil \frac{n_i \times k}{H} \right\rceil \times H - (n_i \times k)$$

These dummy octets are inserted in the last position of the first $D_{Z,i}$ packets of U_i octets in a sequence of H frames (figure 34). The value of the $D_{Z,i}$ dummies is 0x3A.

6.4.4.3 Reed-Solomon encoding

After payload adaptation, E_i overhead octets are added to the head-end of each packet of U_i octets (figure 34). These octets are called fast and slow octets for the fast and slow channel, respectively (clause 6.4.4.4). Next, a sequence of N_i packets of (E_i + U_i) octets is RS-encoded. In order to achieve an integer number of RS-codewords per N_i packets, RS-dummy octets may have to be inserted. The RS-codeword length is equal to the parameter N_i .

The number of RS-encoded octets, B_i, per N_i packets is given by:

$$B_i = \left[N_i \times (E_i + U_i) + D_{RS,i}\right] \times \frac{N_i}{K_i}$$

In the above equation, the parameter N_i denotes both the number of packets of (E_i + U_i) octets and also the length of an RS-codeword (in octets). The parameter K_i is the number of information octets in an RS-codeword.

The number of RS dummy octets, $D_{RS,i}$, inserted to carry an integer number of RS-codewords in every N_i frames is given by

$$D_{RS,i} = \left\lceil \frac{N_i \times (E_i + U_i)}{K_i} \right\rceil \times K_i - N_i \times (E_i + U_i)$$

Each one of the $D_{RS,i}$ dummies is inserted at the tail-end of the first $D_{RS,i}$ packets of (E_i+U_i) octets in a sequence of N_i packets (figure 34). The value of the $D_{RS,i}$ octets is 0xD3.

After RS-dummy insertion, the number of RS-encoded octets per frame carried in either the fast or interleaved buffer is given by:

$$P_i = \frac{B_i}{N_i} = \frac{N_i \times (E_i + U_i) + D_{RS,i}}{K_i} = \left\lceil \frac{N_i \times (E_i + U_i)}{K_i} \right\rceil$$

Note that the paramter $B_i = P_i N_i$ represents both the number of octets in N_i frames (with P_i octets per frame) and also the number of octets in P_i codewords (with N_i octets per codeword).

6.4.4.4 Superframe description and contents of fast and slow octets

A superframe is composed of 10 packets of U_i+E_i octets. Each packet within the superframe transports E_i fast or slow octets (in the fast and slow channel, respectively). The content of these octets is summarised in table 20. If the fast buffer is empty, the F-EOC octets are transported in the S-EOC octets. Otherwise the S-EOC octets are replaced with payload octets. There are V VOC octets per packet; they are always transported in the slow channel. A setting of V=1 shall be supported, other values for V are optional. The fast and slow dummy octets shall have the value 0xFF.

If the fast path is active, the NTR octet and IB octet in the slow channel shall be replaced with dummy octets.

Table 20: Contents of fast and slow octets

Packet	**Fast octets**	**Slow octets**			
	First octet	**Other octets (if any)**	**First octet**	**Octets 2 to (*V*+1)**	**Other octets (if any)**
1	F-CRC	F-EOC	S-CRC	VOC	S-EOC/payload
2	Synch octet	F-EOC	Synch octet	VOC	S-EOC/payload
3 to 5	IB	F-EOC	IB/dummy	VOC	S-EOC/payload
6	NTR	F-EOC	NTR/dummy	VOC	S-EOC/payload
7 to 10	Dummy	F-EOC	Dummy	VOC	S-EOC/payload

6.4.4.4.1 Cyclic redundancy check

Two cyclic redundancy checks (CRCs), one for the fast buffer and one for the interleaved buffer, shall be generated for each superframe and transmitted in the first packet of the following superframe. The CRC in the first superframe shall be set to zero. Eight bits per buffer type (fast or interleaved) per superframe are allocated to the CRC check bits. These bits are computed from the k message bits using the equation:

$$crc(D)= M(D)\ D^8 \text{ modulo } G(D)$$

where

$$M(D) = m_0D^{k-1}+m_1D^{k-2}+ \dots +m_{k-2}D+m_{k-1} \text{ is the message polynomial}$$

$$G(D) = D^8+D^4+D^3+D^2+1 \text{ is the generating polynomial,}$$

$$crc(D) = c_0D^7 + c_1D^6 + \dots + c_6D + c_7 \text{ is the check polynomial,}$$

$$D \text{ is the delay operator.}$$

That is, crc is the remainder when $M(D)D^8$ is divided by G(D).

The bits covered by the CRC include:

- fast buffer: all bits of the fast buffer before RS encoding, except the CRC;
- interleaved buffer: all bits of the interleaved buffer before RS encoding, except the CRC.

Each octet shall be clocked into the CRC with least significant bit first.

6.4.4.4.2 Synchronisation octet

The synchronisation octet has the value 0x3C. This synchronisation octet is used to monitor the frame synchronisation.

6.4.4.4.3 Indicator bits (IB)

The indicator bits are used to transmit far-end defects and anomalies. The description of the contents of the three indicator octets are described in table 21. If the fast channel is active, the indicator octets are transmitted in this channel, and the indicator octets in the slow channel are replaced by dummies.

Table 21: Content of indicator bits

Octet#	Bit#	Definition
1	b0 to b7	Reserved for future use
2	b0	Febe-s
	b1	Ffec-s
	b2	Febe-f
	b3	Ffec-f
	b4	Flos
	b5	Rdi
	b6	Fpo
	b7	Flpr
3	b0	LoM (loss of margin)
	b1	Fhec-s (used for ATM only, shall be set to 0 for STM)
	b2	Fhec-f (used for ATM only, shall be set to 0 for STM)
	b3	Fncd-s/Focd-s (used for ATM only, shall be set to 0 for STM)
	b4	Fncd-f/Focd-f (used for ATM only, shall be set to 0 for STM)
	b5 to b7	Reserved for future use

The active state of a bit is one (high). Bits that are not used are set to zero (low). The LoM bit shall signal the loss of margin at the far end. It shall become high once loss of margin is detected and shall remain high as long as this condition exists.

6.4.4.4.4 Network Timing Reference (NTR)

Isochronous services require the same timing reference at transmit and receive sides in higher layers of the protocol stack. To support the transmission of this timing signal, the VDSL system will transport an 8 kHz timing marker.

For applications that require NTR, it will be transported as follows:

- The VTU-O will derive a local 8 kHz timing reference (LTR) by dividing its sample clock by the appropriate number. For a VDSL system using $N_{SC} = 256 \times 2^n$ tones, the sampling frequency could be $2N_{SC}\Delta f$ and the divisor would then be $69 \times 2^{n+2}$.

- The VTU-O shall estimate the change in phase offset between the NTR and the LTR from the previous superframe to the present. This value shall be expressed in cycles of a clock running at frequency $2N_{SC}\Delta f$ and shall be transported in the NTR overhead octet (see table 20) as a 2's-complement number.

- A positive value of the change in phase offset shall indicate that the LTR has a higher frequency than the NTR. A negative value of the change in phase offset shall indicate that the LTR has a lower frequency than the NTR.

The LTR, being proportional to Δf, has a maximum frequency variation of 50 ppm. The NTR has a maximum frequency variation of 32 ppm. The combined maximum difference is therefore 82 ppm. This would result in a combined maximum phase offset of 205 ns per superframe. This corresponds to approximately $0,45 \times 2^n$ samples. For the largest value of n ($n = 4$), this is slightly more than 7 samples (in the positive or negative direction). One octet of information is therefore sufficient to code the phase offset.

6.4.4.5 Convergence of fast and interleaved buffers

Data from the interleaved and (optional) fast buffer are combined so that in each frame there is first a segment of fast data followed by a segment of interleaved data. Figure 35 illustrates this process.

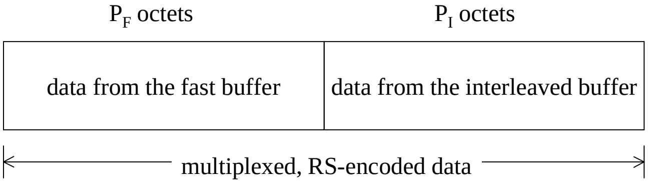


Figure 35: Convergence of the fast and interleaved data into one frame

The total number of RS-encoded octets per frame, P_{total}, is given by

$$P_{total} = P_I + P_F$$

where P_I and P_F are the number of RS-encoded octets from the interleaved and fast paths.

6.5 PMS-TC for single carrier modulation

6.5.1 Transmission frame format

The format of the transmission frame, as shown in figure 36, shall be applied in both the upstream and downstream directions. The frame shall contain 405 octets:

- a 5-octet header;
- and a 400-octet payload.

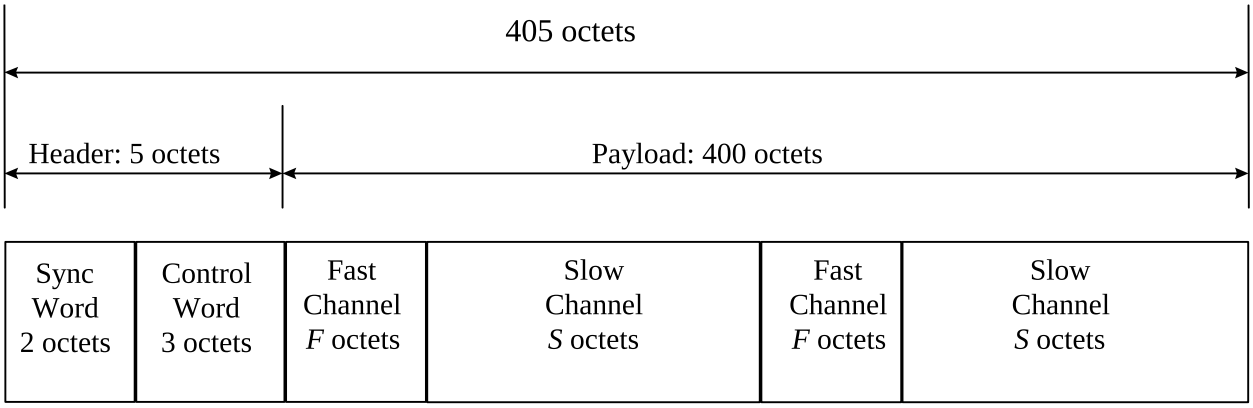


Figure 36: Transmission Frame Format

The transmission frame payload consists of two fields for the Fast channel and two fields for the Slow channel which are alternated as shown in figure 36.

Each Fast channel field (*F*-octets) transports one Reed-Solomon codeword with no interleaving. Each Slow channel field (*S*-octets) transports one Reed-Solomon codeword which shall pass through a convolutional interleaver before transmission onto the line.

Both F and S values are even and depend on the applied Transport Class, as defined in table 26, set during the system configuration. If the Transport Class 1 (single latency) is applied, the setting is $F = 0$, $S = 200$.

All frame octets are transmitted MSB first. The MSB of the first transmitted frame octet corresponds to the beginning of the frame.

6.5.1.1 Fast codeword structure

The structure of a Fast codeword is as shown in figure 37. The codeword consists of a Fast Payload field of *PF* octets and Fast FEC field of *RF* octets so that ($PF + RF = F$). The maximum length of the Fast codeword is 180 octets, the minimum length is 0 octets.

Nonzero values of *PF* and *RF* are *optional*; the valid nonzero *PF* values (Transport Class 2) can be derived from table 26. The number of *RF* octets may get values 0, 2, 4 or 16. The value 0 provides an uncoded data transmission over the Fast channel. The first Fast codeword octet occurring in figure 36 corresponds to the first Fast Payload octet shown in figure 37.

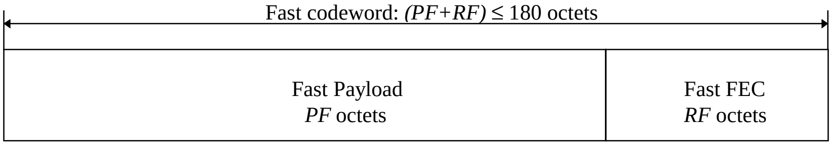


Figure 37: Structure of Fast Codeword

NOTE: For an uncoded implementation of the Fast channel the standard method of the line-related error monitoring verification (by using corrupted FEC as described in clause 6.5.3) is not applicable. The verification method in this case shall be proprietary and may be done on the transport protocol layer (by the corresponding TPS-TC) or on the application layer.

6.5.1.2 Slow codeword structure

The structure of a Slow codeword (prior to interleaving) is presented in figure 38. The codeword consists of 3-octet Operations Channel (OC) field, a Slow Payload field of *PS* octets, and a Slow FEC field of 16 octets so that ($OC + PS + 16 = S$). The maximum length of the Slow codeword is 200 octets, the minimum length is 20 octets. The valid values of *PS* can be derived from table 26. The first Slow codeword octet occurring in figure 38 corresponds to the first OC octet shown in figure 39. The individual octets of the Slow codeword are subject to convolutional interleaving prior to transmission onto the line.

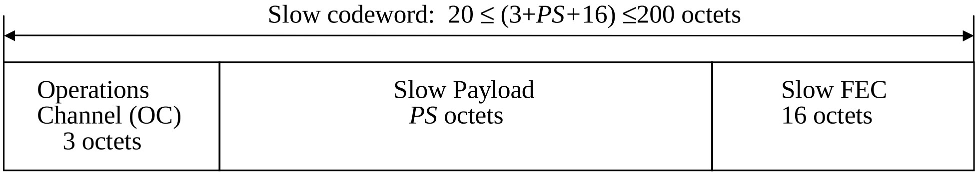


Figure 38: Structure of Slow Codeword

The structure of the OC field is shown in figure 39. The first OC octet is OPCODE, the second and third are DATA octets. The OPCODE indicates the transmitted OC message; the DATA octet supplies the corresponding data. The OC field is shared between the embedded operations channel (eoc) and the VDSL Overhead Control (VOC) channel as described in clause 6.2.3.

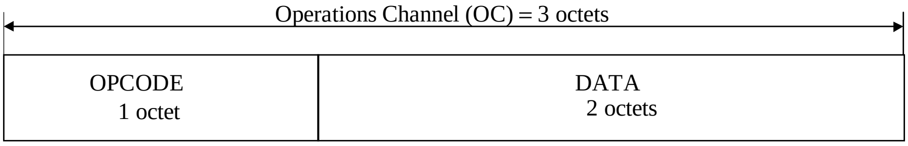


Figure 39: Structure of the Operations Channel Field

6.5.1.3 Frame header octet definition

The transmission frame header includes a 2-octet Syncword and a 3-octet Control field. The Syncword contains frame alignment information. The Control field is intended to convey the following delay sensitive synchronisation, management, and service information:

- NTR marker (*NTR*);
- link activation support flags (*r_trig/o_trig*, *r_flag*);
- far-end PMD layer defects/failures (*flos*, *flos_cr1*, *flos_cr2*);
- far-end PMS-TC layer defects/failures (*fsef*);
- far-end TPS-TC layer defects/failures (*fp*);
- VTU-R power loss (*flpr*, *FPO*);
- reserved for future application;
- reserved for proprietary use.

The header also includes the header cyclic redundancy check, providing Control field error detection.

The header octet description is presented in table 22. In all header octets bit 7 is the MSB. Bit 7 of octet 0 shall be transmitted first.

Table 22: Allocation of the Frame Header Octets

Octet	Name	Description	Value
0	Sync 1	SyncWord, octet 1	0xF6
1	Sync 2	SyncWord, octet 2	0x28
2	Control 1	Control and Management information, word 1	Variable
3	Control 2	Control and Management information, word 2	
4	Control 3	Control and Management information, word 3	

6.5.1.3.1 Syncword octets

The SyncWord is intended for transmission frame delineation at both the VTU-O and VTU-R. It shall consist of two octets with fixed values:

- Sync 1 = 0xF6;
- Sync 2 = 0x28.

6.5.1.3.2 Control 1 octet

The Control 1 octet shall contain the *NTR*-bit, the *o/r_trig* and *o/r_flag* bits, used for the link activation support and the first five Indicator Bits (IB), intended for the far end monitoring. The Control 1 octet description is presented in table 23. All IB are coded "0" for normal operation, "1" for abnormal operation (defect or failure condition).

Table 23: Control 1 Octet Description

Bit	Name	Description	Value	Note
7	*trig*	"o_trig" signal in downstream direction "r_trig" signal in upstream direction	"0" for normal state, "1" for the active state	see clause 8.3.7
6	*flag*	"o_flag" signal in downstream direction "r_flag" signal in upstream direction	"0" for normal state, "1" for the active state	see clause 8.3.7
5	*IB-1 (fp_1)*	Far-end TPS_TC #1 defect/failure	"0" for normal state, "1" for the relevant TPS-TC failure condition	see notes 1, 2 and 3
4	*IB-2 (fp_2)*	Far-end TPS_TC #2 defect/failure		
3	*IB-3 (fp_3)*	Far-end TPS_TC #3 defect/failure		
2	*IB-4 (fp_4)*	Far-end TPS_TC #4 defect/failure		
1	*IB-5*	Reserved for additional defects/failures		
0	*NTR*	NTR marker	"1" if NTR marker is transmitted, "0" otherwise	see clause 6.5.1.3.6

NOTE 1: Far-end pass defect/failure indicators (*fp*) shall be used for path-related primitives for possible paths numbered from #1 to #4. Additional path failures can be indicated using spare bits of the Control octets 1 and 2. The dedicated *fp* shall be specified in accordance with the applied path (applied TPS-TC).

NOTE 2: The definition of any *fp* shall coincide with the relevant path-related defect/failure primitive definition in clause 7.3. Particularly, for the ATM path, the *fp* shall indicate the *Far-end Loss of Cell Delineation* defect (*flcd)*, as it defined in clause 7.3.2.

NOTE 3: If ATM is applied in a single latency mode, the *fp_1* shall be used to indicate the *flcd* defect for the Slow ATM_TC. In a dual latency mode, the *fp_2* shall be additionally used to indicate the *flcd* defect for the Fast ATM_TC.

6.5.1.3.3 Control 2 octet

The Control 2 octet shall contain the first and the second CRC bits and the next six IB. The Control 2 octet description is presented in table 24. All IB are coded "0" for normal operation, "1" for abnormal operation (defect or failure condition). The *CRC_1* and *CRC_2* bits shall be assigned as described in clause 6.5.1.3.5.

Table 24: Control 2 Octet Description

Bit	Name	Description	Value	Note
7	*CRC_1*	Frame header CRC check	As defined in clause 6.5.1.3.5	First bit
6	*IB-6*	IB reserved for further applications		
5	*IB-7 (flos_cr1)*	Far-end Loss of Carrier 1 energy	"0" for normal state, "1" for the loss state	See clause 7.7.1
4	*IB-8 (flos_cr2)*	Far-end Loss of Carrier 2 energy	"0" for normal state, "1" for the loss state	See clause 7.7.1
3	*IB-9 (rdi)*	Far-end Remote defect indication	"0" for normal state, "1" for the loss state	See clause 7.3.1.4
2	*IB-10*	IB reserved for further applications		
1	*IB-11*	IB reserved for further applications		
0	*CRC_2*	Frame header CRC check	As defined in clause 6.5.1.3.5	Second bit

6.5.1.3.4 Control 3 octet

The Control 3 octet shall contain the third and the fourth *CRC* bits, two IB bits and four bits for proprietary use. The Control 3 octet description is presented in table 25. All IB are coded "0" for normal operation, "1" for abnormal operation (defect or failure condition). The *CRC_3* and *CRC_4* bits shall be assigned as described in clause 6.5.1.3.5.

Table 25: Control 3 Octet Description

Bit	Name	Description	Value	Note
7	*CRC_3*	Frame header CRC check	As defined in clause 6.5.1.3.5	Third bit
6	*IB-12 (fpo)*	Far-end Power-off failure	"0" for normal state, "1" for the power failure state	See clause 7.3.3
5	*IB-13 (flpr)*	Far-end Loss-of-Power defect ("dying gasp")	"0" for normal state, "1" for the power failure state	See clause 7.3.3
1 to 4		Reserved for proprietary applications		
0	*CRC_4*	Frame header RC check	As defined in clause 6.5.1.3.5	Fourth bit

6.5.1.3.5 CRC-bits

The *CRC* bits *CRC_1* to *CRC_4* are computed as a remainder of multiplying the polynomial:

$$m_0 D^{23} + m_1 D^{22} + \ldots + m_{23} \text{ by } D^4 \text{ and then dividing by } D^4 + D + 1 .$$

The polynomial coefficient m_0 is the MSB of the first Control 1octet, m_{23} is the LSB of Control 3 octet and $m_8, m_{15}, m_{16}, m_{23} = 0$. The *CRC_1* is the MSB of the remainder; the *CRC_4* is the LSB of the remainder.

6.5.1.3.6 NTR transport and NTR marker generation

An 8 kHz NTR is conveyed from the VTU-O to VTU-R by synchronising the downstream transmission frame boundaries with NTR and transmitting an NTR marker in the frame header, as described in clause 6.5.1.3.2. The NTR is reconstructed at the VTU-R using the received NTR marker. An NTR marker for the transmission profile with the bit rate of N x 67,5 kb/s shall be generated every 384/Q NTR periods (i.e. every 48/Q ms the NTR marker will transition from low to high level), where Q is the greatest common divisor of 384 and N.

NOTE: The NTR marker shall be set the the value 1 once every N/Q transmission frames. For example, for N = 48 (TR = 3,24 Mb/s) the number of transmission frames between two adjacent NTR markers equals 1, and the number of NTR periods between two adjacent NTR markers equals 8. Correspondingly, the NTR marker is inserted every 1 ms.

6.5.1.4 Frame transport classes

The transmission frame transport class defines the number of ***S***, ***F*** and ***RF*** octets in the transmission frame. The *mandatory* Class 1 provides a single latency transport. The *optional* Class 2 provides a dual latency transport.

A Class 1 frame includes two Slow codewords of 200 octets each. A Class 2 frame is defined by the values *F* and *RF*, and respectively denoted as [*F/RF*], where *RF* could be 2, 4 or 16, *F* is even and less than 180. In the same manner, Class 1 frame is denoted as [0/0].

NOTE: A Class 2 frame denoted [12/8], for example, defines a frame which contains two Fast codewords with 4 Fast Payload octets, 8 Fast FEC octets and a Slow codeword with 200-12 = 188 octets (3 OC octets, 169 Slow Payload octets and 16 Slow FEC octets).

The transmission frame structure of a single and dual latency transport classes is summarised in table 26.

Table 26: Frame Transport Classes

Class	Slow Data ***S*, octets**	Fast Data ***F*, octets**	Fast Redundancy ***RF*, octets**	Symbol	Mode	Notes
1	200	0	0	[0/0]	Single latency	Mandatory
2	200-F	F = 2 to 180	RF = 2, 4, 16	[F/RF]	Dual latency	Optional

6.5.1.5 Frame delineation algorithm

The frame delineation algorithm shall be left to the discretion of the vendor. The recommended algorithm and frame delineation state machine is based on Syncword detection at the expected locations (Sync_Events) and is described in annex B.1.

6.5.2 Data randomisation and de-randomisation

Randomisation shall be performed in both transmission directions by the same randomisation algorithm before the RS encoding. Data de-randomisation shall be performed after the RS decoding. Randomisation/de-randomisation shall be performed on the frame header, except Sync1, Sync2 octets, and on the frame payload, except RS redundancy octets. The header, Fast codewords and Slow codewords (except RS redundancy octets) transmitted in the same direction are randomised separately by the same randomisation algorithm.

NOTE: The randomiser/de-randomiser is supposed to be self-synchronising by the implementation.

The randomisation algorithm in both VTU-O and VTU-R shall comply to:

$$D_{out}^{n} = D_{in}^{n} \oplus D_{out}^{n-18} \oplus D_{out}^{n-23}$$

The de-randomisation algorithm shall reconstruct the randomised data. The block diagram of the randomiser is presented in figure 40.

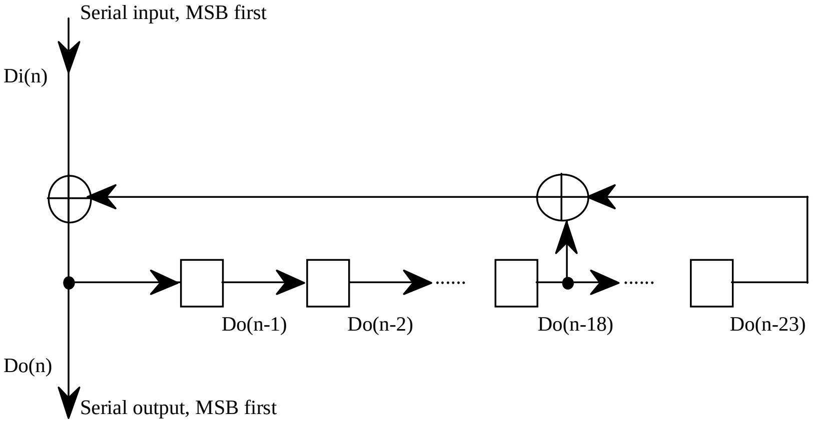


Figure 40: Randomiser

6.5.3 Forward error correction

Reed-Solomon (RS) error correction coding shall be used for FEC implementation. RS codes operate on octet-based data streams. The applied code RS(N,K) is expressed by convention as two numbers, the first indicating the total codeword length (N), and the second indicating the number of data octets (K). The difference between these two numbers (N-K) is the number of FEC octets (redundancy octets).

The error correcting power of an RS code is related to the number of FEC octets N-K. The number of corrected octets *t* per codeword equals $\lfloor(N-K)/2\rfloor$, where $\lfloor x \rfloor$ denotes truncating to the lower integer.

The RS codes applied for downstream and upstream data protection shall use as generator polynomial:

$$g(x) = \prod_{i=0}^{N-K-1} (x + \mu^{i}),$$

where μ is a root of the binary primitive polynomial:

$$x^{8} + x^{4} + x^{3} + x^{2} + 1.$$

A data octet is identified within the Galois Field (256), the finite field with 256 elements as:

$$(d_7 d_6 d_5 d_4 d_3 d_2 d_1 d_0) \Leftrightarrow \sum_{n=0}^{7} d_n \mu^n \Leftrightarrow \mu^p \qquad (\mu\text{=02hex}),$$

with a one-to-one mapping of octet values (d_0 remains the LSB of the octet, d_7 remains the MSB; the MSB shall be transmitted first).

An RS(N,K) codeword shall be defined as a function of the K data octets as:

$$[x^{N-K}(\sum_{i=0}^{K-1} \mu^{p(i)} x^i)] + [x^{N-K}(\sum_{i=0}^{K-1} \mu^{p(i)} x^i)] \ MOD\, g(x)$$

where the K most significant octets (coefficients of x^n, n=N-K..N-1) correspond to the K input data octets, and the N-K least significant octets (coefficients of x^n, n=0..N-K-1) correspond to the N-K output FEC octets.

Because the data octet identification is defined within the Galois Field with 256 elements, RS(N,K) encoding/decoding shall be implemented as a shortened RS(255,255-N+K) code. At the encoder side, 255-N octets, all set to 0, shall be appended before the K data octets at the input of the RS(255,255-N+K) encoder. These appended octets shall be discarded after the encoding procedure.

It shall be possible to introduce an intentional corruption of the RS codeword to enable verification of the VDSL link error monitoring. The corruption shall be introduced when requested by the management system (clause 7.2.3) into a single octet of the FEC redundancy field of either the Slow channel or Fast Channel.

NOTE: The values of N and K in RS(N, K) correspond to (OC + *PS* + 16, OC + *PS*) for the slow code word and to (*PF* + *RF*, *PF*) for the fast code word.

6.5.4 Interleaving

Interleaving improves the error-correcting power of the RS codes in the presence of impulse noise. Slow codewords of the transmission frame shall be interleaved before transmission by a convolutional interleaver, defined by the following parameters:

- *N* = *S* - incoming codeword length defined by the transmission frame format in table 26;
- *I* - interleaver block length, octets;
- *D* - interleaving depth, octets;
- *M* - interleaving depth index;
- *E* - erasure correction, octets.

The incoming codeword of N octets is divided into interleaver blocks of I octets. The interleaver block length I shall be normally equal to *N/8*. Optionally, it may be equal to *N/4* or *N/2*. The octets within the interleaver blocks are numbered from *j* = 0 to *j* = *I - 1*.

The interleaver shall perform by the following rule:

Each octet *j* of any interleaver block is delayed at the interleaver output by (*D - 1*) × *j* octets, where *j* = 0, 1, 2, … (*I - 1*) is the octet number within the interleaver block, *D* is the interleaving depth. For example, the first octet of any block shall be not delayed, the third octet of any block will be delayed by 2 × (*D - 1*) octets and so on.

The value of interleaving depth *D* shall be chosen in according with the required impulse noise protection (erasure correction). The value *D-1* characterises the number of octets separating two sequential octets of the same RS codeword at the output of the interleaver. For all settings the value of (*D - 1*) shall be kept as a multiple of the interleaver block length *I*:

$D = M \times I + 1$, where the value of M shall be programmable to any integer in the range of 0 to 64.

The main characteristics of the interleaver are summarised in table 27.

Table 27: Interleaver Characteristics

Parameter	Value	Notes
Block Length (I)	$I = N/8$, $N/4$ or $N/2$, octets	$N = PS+19$, octets
Depth (D)	$D = M \times I + 1$, octets	$M = 0 \rightarrow 64$, programmable
Erasure Correction (E)	$E = \lfloor t \times I / N \rfloor \times (M \times I + 1)$, octets	$t = 8$ (RS error correction ability)
End-to-End Delay (DL)	$DL = M \times I \times (I - 1)$, octets	
Interleaver Memory Size	$MEM = M \times I \times (I - 1) / 2$, octets	
NOTE 1: The interleaver erasure correction E defines the maximum number of corrupted sequential octets could be corrected by RS algorithm when interleaving is applied. Correspondingly, the duration of noise pulses the system is protected from could be calculated as $E \times 8/R$, where R is the bit rate of the transmit signal over the line. NOTE 2: The $\lfloor \rfloor$ symbols indicates the truncation of the value to the lower integer.		

The maximum value of M required for the given transmission profile shall provide an erasure correction capability up to 500 µs. An example of interleaver/de-interleaver implementation is presented in annex C.

7 Operations and maintenance

7.1 OAM reference model

7.1.1 OAM framework

In order to be manageable by operators, a VDSL system needs to comply with the network management framework. A number of items are imposed by this framework:

- the components involved by the OAM framework;
- the functionality provided by the OAM;
- the fault and performance monitoring process;
- the type of entities to monitor.

7.1.2 Components of the OAM framework

This network management framework contains at least four components:

- the managed nodes (e.g. a switch), each containing one agent;
- at least one network management system that monitors and controls the nodes;
- a network management protocol used by the NMS to exchange management information;
- the Management Information Base (MIB) containing all management information related to one agent.

In the VDSL system there is one agent located on the VTU-O side but none on the VTU-R; this object presents a MIB to the Network Management Stations containing the consolidated OAM information related to the VDSL link. As all MIB objects reside on the VTU-O side, when VTU-R information is required by the NMS, the VTU-O is responsible for the retrieval of this information from the VTU-R, using the VDSL OAM dedicated communication channels. (According to the expected expansions of the VDSL systems, an agent could be located either in a single VTU-O or a common equipment handling multiple VTU-Os; in this latest case, one multi-line MIB is accessible by the NMS.) Figure 41 illustrates the components of the VDSL OAM framework.

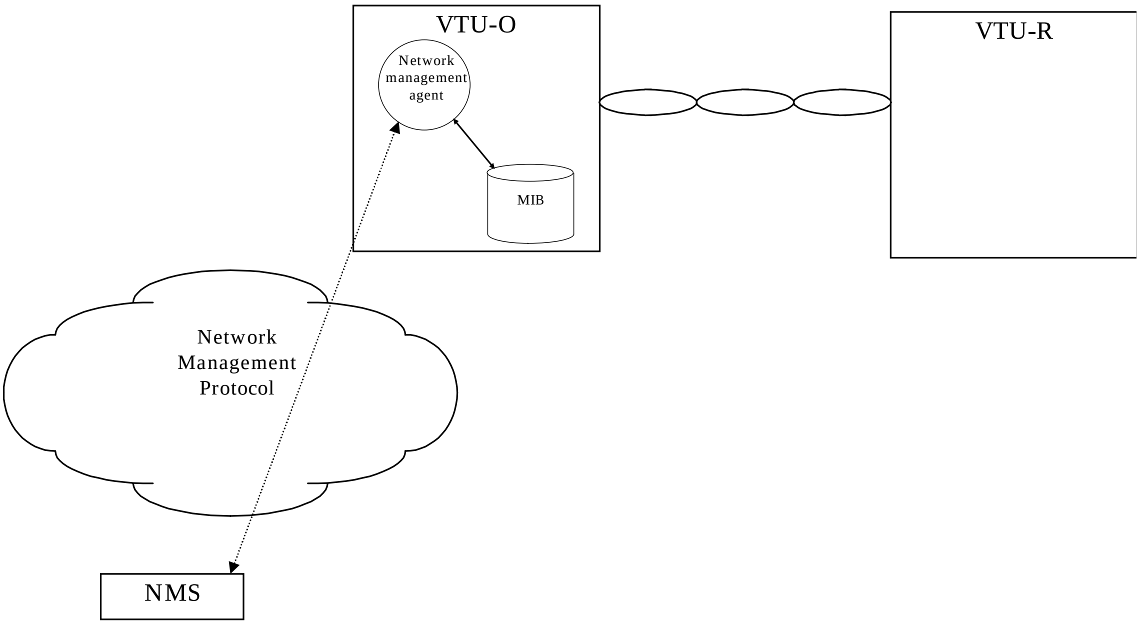


Figure 41: Components of the OAM framework for the VDSL link

Definition of the MIB and the network management protocol are out of scope of the present document.

7.1.3 OAM functionality

According to ITU-T Recommendation X.700 [7], OAM functions to be supported by a managed system are classified by five functional categories:

- Configuration management:
  - Configuration management relates to the topology of the resources within the managed system. Configuration management is responsible for the provision, modification and cessation of capabilities within the system.
- Performance management:
  - Performance management enables the behaviour of resources and the effectiveness of communication activities to be evaluated.
- Fault management:
  - Fault management encompasses fault detection, isolation and the correction of abnormal operation of the managed system.
  - Faults cause open systems to fail to meet their operational objectives and they may be persistent or transient.
  - Faults manifest themselves as particular events (e.g. errors) in the operation of an open system.
- Security management:
  - Security management relates to the integrity of the data in the system and fallback arrangements. This category relates to who or what can access the system and its resources.
- Accounting management:
  - Accounting management enables charges to be established for the use of resources and for costs to be identified for the use of those resources.

Components involved by the management of a VDSL link must support Configuration management, Performance management and Fault management. Security and Accounting management are not applicable to a VDSL link.

7.1.4 Fault and performance monitoring process

The general process applicable by an agent for monitoring fault and performance is shown in figure 42.

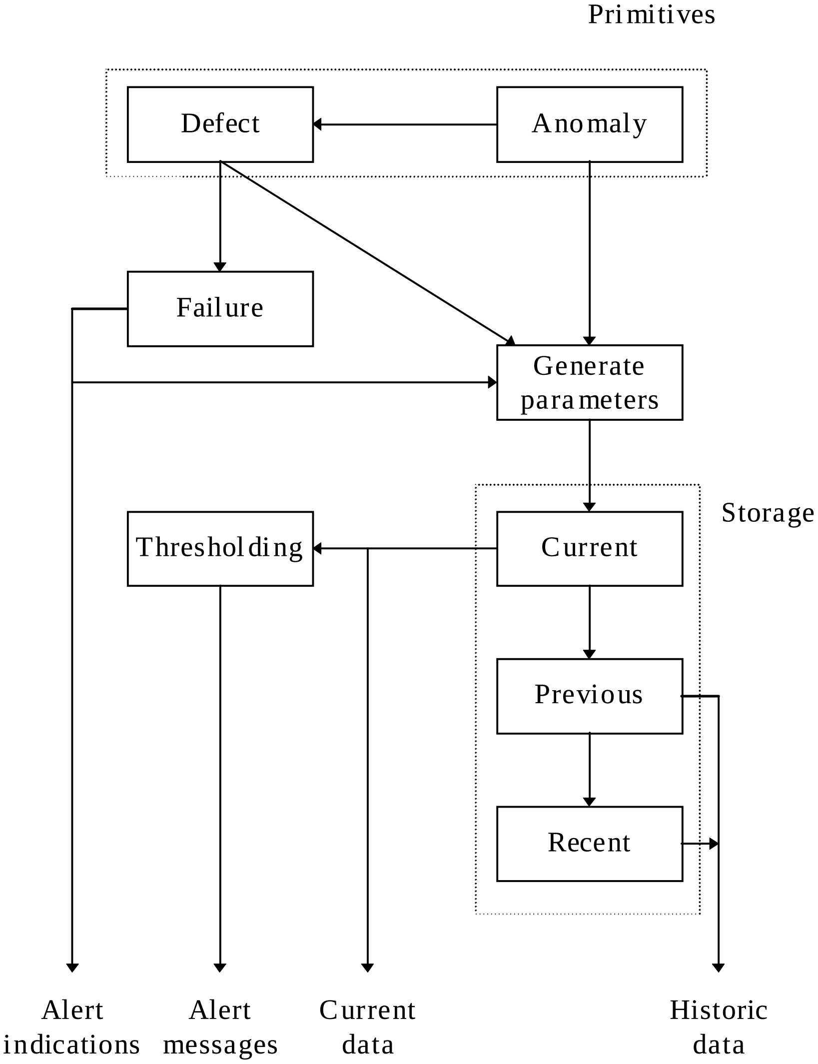


Figure 42: Performance monitoring process

The following definitions are applicable:

- Primitives: Primitives are basic measures of performance. Performance primitives include anomalies and defects. Primitives may also be basic measures of other quantities (e.g., ac or battery power), usually obtained from equipment indicators;
- Near-end primitives are usually detected by monitoring the local line codes and frame formats;
- Far-end primitives are detected by reading fields in the overhead that are defined to report the nature and number of basic error events or other performance-related occurrences detected at the far-end;
- Anomalies: An anomaly is a discrepancy between the actual and desired characteristics of an item. The desired characteristic may be expressed in the form of a specification. An anomaly may or may not affect the ability of an item to perform a required function;
- Defects: A defect is a limited interruption in the ability to perform a required function. It may or may not lead to maintenance action depending on the result of additional analysis. Successive anomalies causing a decrease in the ability of an item to perform a required function are considered as a defect;

- Failures: A failure is the termination of an item's ability to perform a required function. At a network element, both local and remote failures can be observed. Local failures include near-end signal failures. Remote failures are those that occur and are recognised elsewhere, and are reported within the transmission signal;
- Parameters: These parameters are counts of the various impairment events detected during the accumulation period. Performance parameters are directly derived from the corresponding performance primitives;
- Thresholding: All performance parameters (e.g. errored seconds) have associated thresholds, which may be set, read, or changed by the Network Management System (NMS) that is doing performance monitoring. A threshold crossing for performance parameters may be autonomously reported to the NMS by the VTU-O.

Figure 43 describes graphically the near-end and far-end concepts applied to a VDSL link.

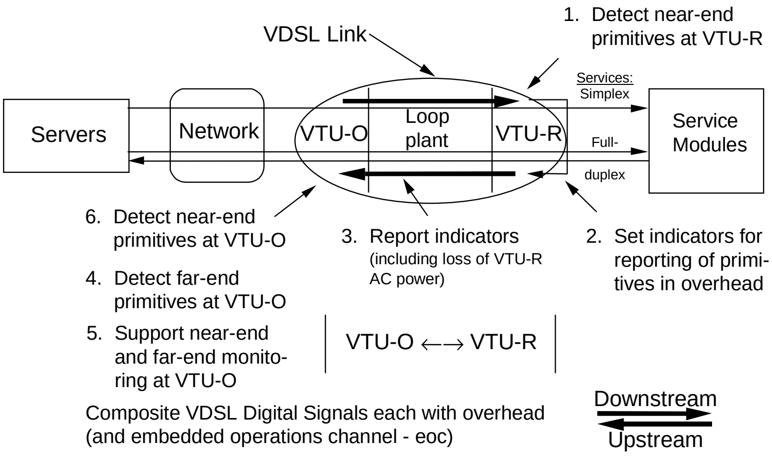


Figure 43: In-service surveillance of the VDSL link shown from the VTU-O's standpoint

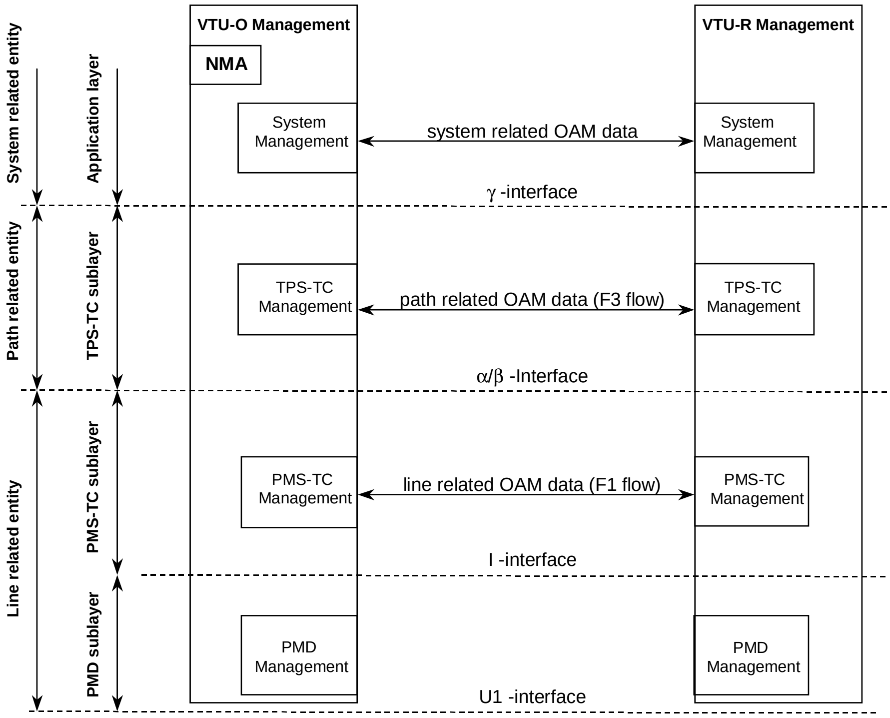
Primitives and messages applicable to the VDSL link are defined in clause 7.3.

7.2 OAM entities

7.2.1 OAM functional model

From the OAM point of view, the VDSL link is a system containing several transmission layers, which shall be managed. The VDSL link OAM functional model (figure 44) contains OAM entities intended to manage the following transmission entities:

- *VDSL Line entity*: the physical transport vehicle provided by PMD and PMS-TC transmission sub-layers.
- *VDSL Path entity*: the applied transport protocol path, provided by TPS-TC sub-layer. 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.



NOTE: The system-related OAM data flow is currently under study.

Figure 44: OAM Functional Model

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

7.2.2 OAM communication channels

To provide the OAM data transfer between the VTU-O and the VTU-R, the following OAM dedicated communication channels shall be arranged:

- Indicator Bits (IB) channel;
- VDSL Overhead Control (VOC) channel;
- embedded operation channel (eoc).

These 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 control;
- maintenance.

The interface between the OAM channel and the corresponding OAM entity 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 clause 7.2.3.

7.2.2.1 Indicator Bits (IB)

The transport of the IB is supported by the PMS-TC sub-layer. The IB are used to arrange an OAM communication channel between the peer OAM entities intended to transfer all the 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, for which timing is critical. The IB may also transfer other line-related and path-related primitives.

7.2.2.2 VDSL Overhead Control (VOC)

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

The VOC channel works in bi-directional mode, hence both transmission directions are required to provide communication for the VOC. The VOC protocol description and the summary of VOC messages are defined in clauses 7.4 and 7.5.

7.2.2.3 Embedded operation channel (eoc)

The eoc is supported at the VDSL system (application) layer. The eoc is a clear channel to provide exchange of VDSL 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.

The eoc, except in some special cases, works in bi-directional mode using an echoing protocol. Both transmission directions are required to provide communication for the eoc. The eoc interface is equal for both the VTU-O and VTU-R. It is defined at the γ-reference point (clause 6.2.3.1). The eoc protocol is defined in clause 7.6.

7.2.3 Partitioning of OAM data

The OAM data at both the VTU-O and VTU-R after being collected is stored in the corresponding part of the MIB and then can be transferred to the far-end over the corresponding OAM channel. Partitioning of the OAM data between different OAM communication channels is summarised in table 28.

Table 28: OAM Data Partitioning

OAM Data	Transferred to the far-end by:	Notes
Primitives		
Line-related, time-sensitive	IB	PMD and PMS-TC defects
Path-related, time-sensitive		TP-specific defects/failures (see 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 (see note 1)	TP-specific anomalies, separately for each TPS-TC
System-related primitives	IB or eoc (see note 2)	Power loss primitives
Parameters		
Line-related, performance	None	Calculated from retrieved line related and path-related primitives
Path-related, performance		
Path-related, testing	eoc	For some TPS-TC
Line-related, testing		ATT, SNR margin and other local measurements
Self-test		For some VTU blocks or completely
VTU Identification		Vendor ID, revision number, serial number
Service modules parameters		Proprietary (SM performance, test or other parameters)
Configuration		
Line-related parameters	VOC	Frame structure, interleaving depth etc.
Path-related parameters	eoc	With respect to the applied TP.
System-related parameters	eoc	Proprietary, with respect to the applied SM
Maintenance		
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.
Loopback activation		At TPS-TC and application layers
Performance monitoring supervision		Request for FEC corruption test, Notify FEC corruption test
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 the certain active path are monitored by the corresponding TPS-TC management function and delivered to the other side by the standard means of the applied TP, IB or eoc. NOTE 2: eoc is preferable for system-related time-insensitive primitives.		

7.3 OAM primitives and parameters

7.3.1 Line-related primitives

Each of the detected line-related primitives is represented by a corresponding indicator at the OAM interface at the $\alpha(\beta)$ reference point. The indicator shall be coded 0 if no anomaly, defect or failure has been registered since the previous transmission period, and shall be coded 1 to indicate that at least one anomaly, defect or failure has been registered since the previous transmission period.

All the near-end anomalies, defects and failures shall be represented at both the VTU-O and VTU-R. Representation of far-end anomalies, defects and failures at the VTU-R is optional.

7.3.1.1 Near-end anomalies

- *Forward Error Correction (fec-f)*: a fec-f anomaly occurs when a received FEC code for the fast data stream indicates that errors have been corrected.
- *Forward Error Correction (fec-s)*: a fec-s anomaly occurs when a received FEC code for the slow data stream indicates that errors have been corrected.
- *Block Error (be-f)*: a be-f anomaly occurs when uncorrected errors have been detected in the received block of fast data.
- *Block Error (be-s)*: a be-s anomaly occurs when uncorrected errors have been detected in the received block of slow data.

7.3.1.2 Far-end anomalies

- *Far-end Forward Error Correction (ffec-f)*: a ffec-f anomaly occurs when a fec-f anomaly detected at the far end is reported. A ffec-f anomaly terminates when the received fecc-f indicator is set to 0.
- *Far-end Forward Error Correction (ffec-s)*: a ffec-s anomaly occurs when a fec-s anomaly detected at the far end is reported. A ffec-s anomaly terminates when the received fecc-s indicator is set to 0.
- *Far-end Block Error (febe-f)*: a febe-f anomaly occurs when a be-f anomaly detected at the far end is reported. A febe-f anomaly terminates when the received be-f indicator is set to 0.
- *Far-end Block Error (febe-s)*: a febe-s anomaly occurs when a be-s anomaly detected at the far end is reported. A febe-s anomaly terminates when the received be-s indicator is set to 0.

7.3.1.3 Near-end defects

- *Loss-of-signal (los):* A los defect occurs when the level of the received VDSL signal power averaged over a TL second period, is lower than the threshold, and terminates when this level, measured in the same way, is at or above the threshold.
- *Severely Errored Frame (sef)*: The sef defect is managed in accordance with the transmission state diagram. A sef defect occurs with a transition out of the SYNCH state and terminates with a transition into the SYNCH state.

NOTE: The value of TL is for further study.

7.3.1.4 Far-end defects

- *Far-end Loss-Of-Signal (flos)*: a flos defect occurs when a los defect detected at the far-end and is reported in 4 or more out of 6 contiguously received indicators. A flos defect terminates when more than 4 indicators out of 6 contiguously received indicators are set to 0.
- *Far-end Remote Defect Indication (rdi)*: a rdi defect occurs when a sef defect detected at the far-end and is reported. An rdi defect terminates when the received indicator is set to 0.

7.3.1.5 Near-end failures

- *Loss-Of-Signal (LOS)*: A LOS failure is declared after TS1 ± 0,5 s of contiguous los defect, or, if los defect is present when the criteria of LOF failure declaration have been met. A LOS failure is cleared after TS2 ± 0,5 s of no los defect.
- *Loss-Of-Frame (LOF)*: A LOF failure is declared after TF1 ± 0,5 s of contiguous sef defect, except when a los defect or failure is present. A LOF failure is cleared when LOS failure is declared, or after TF2 ± 0,5 s of no sef defect.
- *Loss-of-power (LPR)*: A LPR failure is declared after TP1 ± 0,1 s of contiguous occurrence of the *lpr* primitive. A LPR failure is cleared after TP2 ± 0,1 s following power restoration.
- *Power Off (PRO)*: A PRO failure is declared when the VTU power switch is turned off. The VTU shall be fully operable for at least TP3 seconds after its power switch is turned off.

NOTE: The values of TS1, TS2, TF1, TF2, TP1, TP2 and TP3 may be transmission technology-dependent and are for further study.

7.3.1.6 Far-end failures

- *Far-end Loss-Of-Signal (FLOS):* a FLOS failure is declared after TS1 ± 0,5 s of contiguous *flos* defect, or, if a *flos* defect is present when the criteria for LOF failure declaration have been met. A FLOS failure is cleared after TS2 ± 0,5 s of no *flos* defect.
- *Far-end Remote Failure Indication (FRFI):* an FRFI failure is declared after TR1 ± 0,5 s of contiguous *rdi* defect, except when a *flos* defect or FLOS failure is present. An FRFI failure is cleared when FLOS failure is declared, or after TR2 ± 0,5 s of no *rdi* defect.
- *Far-end Loss-of-PoweR (FLPR):* a far-end LPR failure is declared after the occurrence of a *flpr* primitive followed by TP1 ± 0,5 s of contiguous near-end *los* defect. A FLPR failure is cleared after TP2 ± 0,1 s of no near-end *los* defect.

NOTE: The values of TR1 and TR2 may be transmission technology-dependent and are for further study.

7.3.2 Path-related primitives

All path-related primitives are defined separately for each dedicated path, terminated by the corresponding TPS-TC block. The anomalies, defects and failures are different for each transport protocol and so for each dedicated transport protocol (e.g. ATM, SDH, IP etc) they shall be represented by OAM indicators specific to the TP. The indicators shall be represented at the OAM interface of γ_O (γ_R) reference points. The indicators shall be coded 0 if no primitive has been registered during the monitoring period and shall be coded 1 to indicate that the primitive has been registered at least once during the monitoring period.

All the near-end primitives shall be represented at both the VTU-O and VTU-R. Representation of the far-end primitives at the VTU-R is *optional*.

7.3.2.1 Anomalies, defects and failures for ATM transport

The set of anomalies, defects and failures for the ATM transport complies with the ITU-T recommendation I.432 [3]. The ATM transport anomalies, defects and failures shall be supported by ATM-TC. If both the Fast and Slow ATM transport is established, the two corresponding ATM-TC shall be represented by two equal and independent sets of anomalies, defects and failures.

7.3.2.1.1 Near-end anomalies

- *No Cell Delineation (ncd)*: a *ncd* anomaly occurs immediately after ATM Cell TC start-up as long as the cell delineation process is in the HUNT or PRESYNC state as defined in ITU-T Recommendation I.432 [3]. Once cell delineation is acquired, subsequent loss of cell delineation shall be considered as *ocd* anomalies;

- *Out of Cell Delineation (ocd)*: an *ocd* anomaly occurs when the cell delineation process transitions from the SYNC to the HUNT state as defined in ITU-T Recommendation I.432.1 [3]. An *ocd* anomaly terminates when the cell delineation process transitions from the PRESYNC to the SYNC state or when the *lcd* defect is entered.

- *Header Error Check (hec)*: a *hec* anomaly occurs when an ATM cell header error check fails.

NOTE: The *ncd* anomaly indication is optional. If it is not applied then the *ocd* anomaly shall be used instead.

7.3.2.1.2 Far-end anomalies

- *Far-end No Cell Delineation (fncd)*: a *fncd* anomaly occurs when either an *ncd* or *ocd* anomaly is detected at the far end and is reported by the *fncd* indicator. The *fncd* anomaly always occurs immediately after VTU start-up. The *fncd* anomaly terminates when the received *fncd* indicator is coded 0.

- *Far-end Out of Cell Delineation (focd)*: a *focd* anomaly occurs when an *ocd* anomaly is detected at the far-end and no *fncd* anomaly is present. A *focd* anomaly terminates if the received *focd* indicator is coded 0.

- *Far-end Header Error Check (fhec)*: a *fhec* anomaly occurs when a *hec* anomaly is detected at the far end and is reported by the *fhec* indicator. The *fhec* anomaly terminates when a received *fhec* indicator is set to 0.

NOTE: Both the *focd* and *fhec* anomaly indicators are optional.

7.3.2.1.3 Near-end defects

- *Loss of Cell Delineation (lcd)*: an *lcd* defect occurs when at least one *ocd* anomaly has persisted for more than TD1 ms and no *sef* defect is present. An *lcd* defect terminates when no *ocd* anomaly is present for more than TD2 ms.

7.3.2.1.4 Far-end defects

- *Far-end Loss of Cell Delineation (flcd):* an *flcd* defect occurs when an *lcd* is detected at the far-end. An *flcd* defect occurs when either a *focd* or *fncd* anomaly has persisted for more than TD1 ms and no *rdi* defect is present. An *flcd* defect terminates if neither a *focd* nor a *fncd* anomaly is present for more than TD2 ms.

NOTE: The values of TD1 and TD2 are for further study.

7.3.2.1.5 Near-end failures

- *No Cell Delineation (NCD)*: an *NCD* failure is declared when an *ncd* anomaly persists for more than TN1 ± 0,5 s. An *NCD* failure terminates when no *ncd* anomaly is present for more than TN2 ± 0,5 s.

- *Loss of Cell Delineation (LCD)*: an *LCD* failure is declared when an *lcd* defect persists for more than TL1 ± 0,5 s. An *LCD* failure terminates when no *lcd* anomaly is present for more than TL2 ± 0,5 s.

NOTE: The values of TN1, TN2, TL1 and TL2 are for further study.

7.3.2.1.6 Far-end failures

- *Far-end No Cell Delineation (FNCD)*: an *FNCD* failure is declared when an *fncd* anomaly persists for more than TN1 ± 0,5 s. An *FNCD* failure terminates when no *fncd* anomaly is present for more than TN2 ± 0,5 s.
- *Far-end Loss of Cell Delineation (FLCD)*: an *FLCD* failure is declared when an *flcd* defect persists for more than TL1 ± 0,5 s. An *FLCD* failure terminates when no *flcd* anomaly is present for more than TL2 ± 0,5 s.

7.3.2.2 Anomalies, defects and failures for STM transport

This is for further study.

7.3.3 Power-related primitives

Power related primitives shall be represented by the corresponding indicators at the system level. The indicators shall be coded 0 if no power primitive has been registered during the monitoring period and shall be coded 1 to indicate that at least once a power primitive has been registered during the monitoring period.

The near-end primitives shall be represented at both the VTU-O and VTU-R. The far-end primitives shall be represented at the VTU-O only.

7.3.3.1 Near-end primitives

- *Loss-of-power (lpr)*: an *lpr* primitive occurs when the VTU power supply (mains) voltage drops to a level equal to or below the manufacturer-determined level required for proper VTU operation. An *lpr* primitive terminates when the voltage level exceeds the manufacturer-determined minimum level.
- *Power-off (po)*: a *po* primitive occurs when the VTU power supply is going to be switched off by the operator to terminate the service. The *po* primitive terminates when the VTU power supply is switched on.

NOTE: The *po* primitive is optional.

7.3.3.2 Far-end primitives

- *Far-end Loss-of-power (flpr)*: a *flpr* primitive occurs when an *lpr* primitive is detected at the VTU-R. A *flpr* primitive terminates after TP1 s of no far-end *lpr* indicator is received and no near-end *los* defect is present.
- *Far-end Power-off (fpo)*: a *fpo* primitive occurs when a *po* primitive is detected at the VTU-R and reported by the *po* indicator. A *fpo* primitive terminates after TP2 s of no far-end *po* indicator and no near-end *los* defect is present.

NOTE 1: The *fpo* indicator is optional.

NOTE 2: The values of TP1 and TP2 are for further study.

7.3.4 Far-end indicators

Far-end indicators deliver the far-end primitives between the VTU-O and the VTU-R. All indicators shall be transmitted periodically to update the information on far-end primitives while the system is in a Steady-State Transmission state. Indicators of far-end loss of signal (*flos*) and the far-end power related primitives (*flpr, fpo*) still have to be transmitted when the system is in Deactivated Power Save (Idle) state. The transfer mechanism of the indicators depends on the applied transmission technology. The minimum set of required far-end indicators is presented in table 29.

Table 29: A minimum set of far-end indicators

Indicator	Description	Note
Line-Related		
febe-s	Reports non-corrected errors in the slow data stream	
febe-f	Reports non-corrected errors in the fast data stream	
fecc-s	Reports corrected errors in the slow data stream	
fecc-f	Reports corrected errors in the fast data stream	
flos	Reports a loss of received signal energy	Applicable in the power saving state
rdi	Reports severe frame errors	
Power-related (System-related)		
flpr	Reports that the supply voltage has dropped below a pre-defined level	Applicable in the power saving state
fpo	Reports that the power on/off switch has been turned off	Optional. Applicable in the power saving state
ATM path-related		
fncd	Reports a loss of cell delineation anomaly	
fhec	Reports HEC errors	Optional
SDH path-related		
	Reserved	
Other path-related		
	Reserved	

7.3.5 Performance parameters

The defined set of performance parameters shall describe both line-related and path-related parameters at the VTU-O and VTU-R.

7.3.5.1 Defect and failure counters

Counters shall be provided for each near-end and far-end defect and failure. A particular defect or failure count is the number of occurrences of that event, where that event occurs when the defect or failure is declared and ends when the defect or failure clears.

7.3.5.2 Line-related performance parameters

The line-related performance parameters are calculated using the related anomalies. The calculation method is for further study.

7.3.5.3 Path-related performance parameters

The path-related performance parameters are calculated for each applied TP separately, in accordance with the corresponding definitions for that TP. If the same TP is applied for both the fast and slow channels, separate performance parameters for each shall be calculated.

7.3.5.3.1 ATM path-related performance parameters

- *HEC violation count (hec_vc)*: the *hec_vc* performance parameter is a count of the number of occurrences of a *hec* anomaly.
- *HEC total cell count (hec_tcc)*: the *hec_tcc* performance parameter is a count of the total number of cells that have passed through the cell delineation process while in the SYNC state.
- *User total cell count (tcc)*: the *tcc* performance parameter is a count of the total number of cells delivered at the γ-O (for the VTU-O) or γ-R (for the VTU-R) interface.

7.3.5.3.2 SDH path-related performance parameters

The path-related performance parameters for SDH transport are for further study.

7.3.6 Test parameters

The near-end test parameters shall be provided at both the VTU-O and VTU-R; the far-end test parameters shall be provided at the VTU-O only.

7.3.6.1 Near-end test parameters

- *Line attenuation (ATN)*: the *ATN* is the difference in dB between the power received at the near-end and that transmitted from the far-end. The *ATN* ranges from 0 dB to 63,75 dB with 0,25 dB steps.
- *Signal-to-noise ratio margin (SNR_M)*: the *SNR_M* represents the amount of increased received noise (in dB) relative to the noise power that the system is designed to tolerate and still meet the target BER of 10^{-7}, accounting for all coding gains included in the design. The *SNR_M* margin ranges from -31,75 dB to +31,75 dB with 0,25 dB steps.

7.3.6.2 Far-end test parameters

- *Far-end line attenuation (FATN)*: the *FATN* is measured at the VTU-R and reported back to the VTU-O. The attenuation ranges from 0 dB to 63,75 dB in 0,25 dB steps.
- *Far-end signal-to-noise ratio margin (FSNR_M)*: the *FSNR_M* is the signal-to-noise ratio margin measured at the VTU-R and reported back to the VTU-O. The *SNR_M* ranges from -31,75 dB to +31,75 dB in 0,25 dB steps.

NOTE: The *ATN* and *SNR_M* test parameters shall be provided "on-demand" at any time following the initialisation of the system. There is no requirement to continuously monitor them.

7.3.6.3 Self-test results

Both near-end and far-end self-tests are performed "on-demand". A self-test can be defined for any VTU block as well as the whole unit. The result of any type of self-test is stored and can be accessed as an "on demand" test parameter. This is for further study.

7.4 Multi-carrier VDSL overhead channel (VOC)

7.4.1 VOC bandwidth

A VDSL overhead control channel shall be included to support overhead functions. The raw VOC channel data rate is specified as $8f_sV$ kbps where f_s is the DMT symbol rate expressed in kHz and V is the number of VOC octets per frame (clause 5.1.2.2). The mechanism used to support the VOC channel is described in detail in clause 7.4.2.

7.4.2 VOC protocol

All VOC messages shall be transmitted five consecutive times to improve the probability of proper reception and decoding. A transceiver unit shall only act on a VOC message if it has received three identical messages in a time period spanning five of that particular message. When an unrecognisable command is received (less than three identical values in any sequence of five), no action shall be taken. Between two consecutive messages, at least 20 idle octets shall be transmitted. The idle octets have a value of 0x00.

7.4.3 High-level on-line adaptation

7.4.3.1 Bit-swapping

Bit-swapping enables a VDSL system to change the number of bits assigned to a sub-channel, or change the transmit energy of a sub-carrier without interrupting the data flow. Bit-swapping is a mandatory feature.

Either VTU may initiate a bit-swap. The swapping procedures in the upstream and downstream directions are independent.

The "receiver" is defined as the modem that initiates the bit swap. It will transmit the bit swap request message and receive the bit swap acknowledge message. The "transmitter" receives the bit swap request and transmits the bit swap acknowledge.

There shall be a maximum of one pending bit swap request at any time in the downstream direction. There shall be a maximum of one pending bit swap request at any time in the upstream direction.

7.4.3.2 Bit-swap channel

Bit-swaps are conducted using the VOC channel, using the protocol described in clause 7.4.2.

7.4.3.3 Bit-swap co-ordination

Bit-swapping is conducted with respect to synchronised counters at the VTU-O and VTU-R. The counters increment by one after each bit-swap frame interval. A bit-swap frame interval is defined as the duration of 16 DMT symbols. The counters are started and incremented as follows:

- The VTU-O and VTU-R transmitters shall start their counters immediately after transitioning from initialisation to steady-state operation or from dynamic power save state to steady-state operation. The value of the counter for the first superframe shall be zero;
- Each transmitter shall increment its counter after each bit-swap frame;
- Correspondingly, each receiver shall start its counter immediately after transitioning from initialisation to steady-state, and then increment it after receiving each bit-swap frame.

Counting of bit-swap frames shall be performed modulo 256.

Any form of restart that requires a transition from initialisation to steady-state shall reset the counter.

7.4.3.4 Bit-swap request

Upon detecting that the SNR of one or more sub-channels is degraded, the receiver shall initiate a bit-swap by sending a bit-swap request to the transmitter via the VOC channel. It shall be up to the receiver to determine what is considered to be degradation. This request tells the transmitter which sub-channels are to be modified. The bit-swap request message contains the following:

- a VOC message header consisting of 8 binary ones to indicate the ensuing bit-swap request;
- four message fields, each of which consists of an eight-bit command followed by a related 12-bit sub-channel index. Valid eight-bit commands for the bit-swap message are shown in table 30. The 12-bit sub-channel index is counted from low to high frequencies with the lowest frequency sub-carrier assigned the number zero (clause 5.1.2.1.1).

Table 30: Bit-swap request commands

Value	Interpretation
00000000	Do nothing
00000001	Increase the allocated number of bits by one
00000010	Decrease the allocated number of bits by one
00000011	Change the transmitted power by the factor +1 dB
00000100	Change the transmitted power by the factor +2 dB
00000101	Change the transmitted power by the factor +3 dB
00000110	Change the transmitted power by the factor -1 dB
00000111	Change the transmitted power by the factor -2 dB
00001xxx	Reserved for vendor-specific commands

For a g_i update of Δ dB, the new value of g_i shall be calculated as:

$$g_i' = \frac{1}{512} \times round(512 \times g_i \times 10^{\frac{\Delta}{20}})$$

The bit-swap request message (the header plus the four message fields) consists of a total of 11 octets.

7.4.3.5 Bit-swap acknowledge

After a VTU (the transmitter) has received a bit-swap request (three identical bit-swap request messages within the span of five message-times) the transmitter shall act on the request. Within 400 ms, the transmitter shall first send a bit-swap acknowledge, which contains the following:

- a VOC message header containing 8 binary ones, indicating receipt of the request message;
- one message field that consists of eight binary ones followed by the eight-bit bit-swap frame counter number, which indicates after how many bit-swap frame intervals the bit-swap shall occur. This number shall be at least 200 greater than the value of the counter when the bit-swap request was received. This corresponds to a minimum time delay of 800 ms.

Specifically, the new bit and/or transmit energy table(s) shall take effect starting from the first symbol of the VDSL bit-swap frame specified by the bit-swap frame counter number. In other words, if the bit-swap frame counter number contained in the bit-swap acknowledge message is *n*, then the new table(s) shall take effect starting from the first applicable symbol of the *n*th bit-swap frame.

When the transmitter correctly receives the message, but is unable to perform the requested action, it shall transmit an Unable-To-Comply message (UTC). This message consists of a single octet with a value of 0xF0 (repeated five times as described in clause 7.4.2).

7.4.3.6 Bit-swap - Receiver

The receiver shall start a timer from the moment it sends the bit-swap request. If no acknowledgement has been received after 500 ms, the receiver can retransmit the request. After a number of unsuccessful retries, the modem can take vendor discretionary action to accomplish bit-swap.

The receiver shall act on a bit-swap request when it has received three identical bit-swap acknowledge messages within a span of five message-times. The receiver shall then wait until the bit-swap frame counter equals the value specified in the bit-swap acknowledge. Then, beginning with the first symbol in the next bit-swap frame, the receiver shall:

- change the bit assignment of the appropriate sub-channels, and, if necessary (clause 5.1.2.7), perform tone re-ordering based on the new sub-channel bit assignment;
- update applicable receiver parameters of the appropriate sub-channels to account for any changes in their transmitted energy.

7.4.3.7 Bit-swap - Transmitter

After the bit-swap acknowledge has been transmitted, the transmitter shall wait until the bit-swap frame counter equals the value specified in the bit-swap acknowledge. Then, beginning with the first symbol in the next bit-swap frame, the transmitter shall:

- change the bit assignment of the appropriate sub-channels and, if necessary (clause 5.1.2.7), perform tone re-ordering based on the new sub-channel bit assignment;
- change the transmitter energy in the appropriate sub-channels by the desired factors.

7.4.3.8 Express swapping

Express swapping enables a VDSL system to change the number of bits assigned to a sub-channel, or change the transmit energy of a sub-carrier without any acknowledgements. Express swapping is an option to augment the performance of bit-swapping.

Express swapping:

- increases the speed of execution for a swap significantly;
- requires the use of a more sophisticated receiver to monitor the received signal to determine if an express swap request has been implemented correctly by the transmitter.

7.4.3.9 Express swap request

Upon detecting changes in a sub-channel's SNR, the receiver shall initiate an express swap by sending an express swap request to the transmitter via the VOC channel.

An express swap command is sent only once and allows alteration of the bit distribution (or gain distribution) on *n* tones through the transmission of a command as shown in table 31.

Table 31: Express swap request command

VOC message Headers	VOC message field total length including message header (octets)	Interpretation
11110010	2,5 n + 5 for *n* even 2,5 n + 4,5 for *n* odd	Implement express bit-swap request for a total of n tones on the *next* bit-swap frame
11110011	2,5 n + 5 for *n* even 2,5 n + 4,5 for *n* odd	Implement express bit-swap request for a total of n tones on the bit-swap frame after the next one

An express swap request command contains the following:

- A VOC message header consisting either the pattern 11110010 or 11110011 to indicate the ensuing express swap request. The header pattern 11110010 means the express swap shall be executed in the next bit-swap frame while the pattern 11110011 means the express swap shall be implemented in the frame following the next bit-swap frame;
- A 12 bit message field to indicate the total number of tones (*n)* whose bit/gain distributions need to be updated;
- *n* message fields, each of which is 20 bits long. The first 12 bits indicate the sub-channel index. In the next 8 bits, the upper nibble of 4 bits encodes the new absolute number of bits, which is a number between 0 and a maximum of 15, according to 0000 for no bits, 0010 for 2 bits, up to 1111 for 15 bits. The lower nibble of 4 bits, with the most significant bit as the sign bit, encodes the relative gain by a 2's complement 4-bit quantity between -4 dB and +3,5 dB (with 0,5 dB increments);
- 4 dummy bits if *n* is even;
- An internal 16-bit CRC protection for error detection.

Table 32: Express swap request command

Message Header	**ES control**	**1^{st} tone index**	**1^{st} tone total bits/gain**	**…**	**n^{th} tone index**	**n^{th} tone total bits/gain**	**Dummy bits**	**CRC**
1111001x (1 octet)	Tone count (12 bits)	Tone number (12 bits)	# of bits/gain (1 octet)	…	tone number (12 bits)	# of bits/gain (1 octet)	0 - *n* odd 4 - *n* even	16 bits

There is no Express-Swap Acknowledge command. The receiver that initiates an express swap shall be responsible for monitoring the returned DMT signal to determine if the command has been implemented by the transmitter. If the swap has not been detected on the correct superframe, then the receiver assumes that the request has not implemented by the transmitter. The express-swap initiating DMT receiver may then elect to repeat the express-swap command, to send another VOC command, or to retrain. The express swap command is only sent once to improve speed. The CRC at the end of the command follows the same octet CRC protocol as used in initialisation for confirmation of correct receipt of message fields. The polynomial used is $g(Z) = Z^{16} + Z^{12} + Z^{5} + 1$ where Z is an advance of one bit period.

7.4.4 Dynamic rate adaptation

Dynamic rate adaptation is not allowed.

7.5 Single carrier VDSL overhead control (VOC) channel

A VDSL Overhead Control (VOC) is intended to provide the VDSL link maintenance, performance monitoring and modification of its transmission parameters at the physical layer. The VOC messages are always originated from the VTU-O; the VTU-R replies to the VTU-O on a successful message reception.

7.5.1 VOC message types

A VOC message contains an OPCODE octet followed by two DATA octets. The OPCODE value distinguishes the OC field contents and indicates the transmitted VOC message.

Three types of VOC messages are specified:

- COMMAND-type message, which is sent from the VTU-O to convey information to the VTU-R (WRITE command) or to request information from the VTU-R (READ command).
- ECHO-type message, which is a reply from the VTU-R to acknowledge receipt of a COMMAND-type message.
- STATUS-type message, which could be an IDLE message, an EOC message or an Unable-To-Comply (UTC) message.

7.5.2 VOC message transport

The VOC messages are carried through the VDSL link by the 3-octet OC field present in each Slow codeword of the transmission frame (see clause 6.5). The OC field is also used to the eoc stream as described in clause 6.2.3.2. The VOC communication should be highly reliable to avoid an execution of unintended commands in the presence of transmission errors. Two layers of protection shall be used in the VOC message transport:

- FEC and interleaving of the OC field in the transmission frame;
- special handshake between the VTU-O and VTU-R for COMMAND-type messages.

7.5.2.1 VOC handshake

The VOC handshake shall only start after the reception of at least four IDLE messages and use the following algorithm. At the start of the handshake, both the VTU-O and VTU-R transmit IDLE messages. When a COMMAND message is to be sent, the VTU-O begins sending the message and repeats it continuously. The VTU-R shall accept the transmitted command after it has received identical messages in three transmission frames in a row. The VTU-R shall then respond by sending an ECHO message that corresponds to the command received and repeats it continuously. If the VTU-R is unable to comply with the received message, it shall send UTC messages instead of the ECHO message.

NOTE 1: At either receiver under-sampling of received frames may occur (i.e. not every received frame need be sampled during the VOC handshake).

After the VTU-O receives the correct ECHO or UTC message responses in three frame samples in a row, it shall respond to the VTU-R by sending an IDLE message and repeats it continuously. When the VTU-R receives an IDLE message it shall cease sending the ECHO or UTC messages and start sending IDLE messages for at least the next four consecutive messages.

The VTU-O shall continue to send the COMMAND message until it detects the correct ECHO or UTC message three samples in a row. Similarly, the VTU-R shall continue to send ECHO or UTC message until it receives the IDLE message from the VTU-O. The total time taken to perform this handshake at both the VTU-O and VTU-R shall be limited to 0,9 s.

NOTE 2: The VOC handshake process is considered complete when both the VTU-O and the VTU-R have resumed sending IDLE messages.

An example of the handshake process (assuming that the VTU-R can comply with the command) is illustrated in figure 45. The solid arrows indicate the COMMAND messages sent by the VTU-O, the dashed arrows represent the ECHO message response from the VTU-O and the dotted arrows represent the IDLE messages sent by both ends. Each message is sent for a period of time corresponding to the number of transmission frames (prior to interleaving) where the OC field contains the indicated message. Because of interleaving and handshake there may be a considerable delay between VOC message transitions.

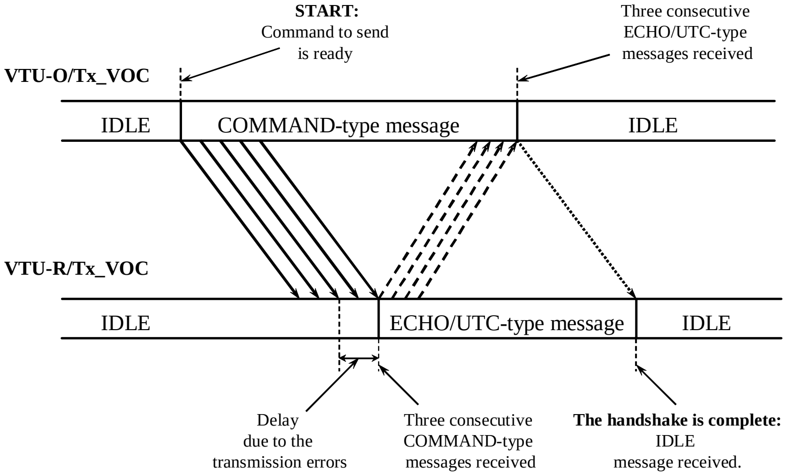


Figure 45: Example of a Handshake for a Successfully Communicated Command

7.5.2.2 VOC handshake flow charts

The full VOC handshake process at the VTU-O shall meet the flow chart presented in figure 46, at the VTU-R it shall meet the flow chart presented in figure 47.

NOTE: The following denominations are used in figures 46 and 47:

- Rx_VOC, Tx_VOC: received and transmitted VOC message respectively;
- Echo_Count: counter of sampled ECHO/UTC messages (at the VTU-O);
- Msg_Count: counter of sampled COMMAND-type messages (at the VTU-R).

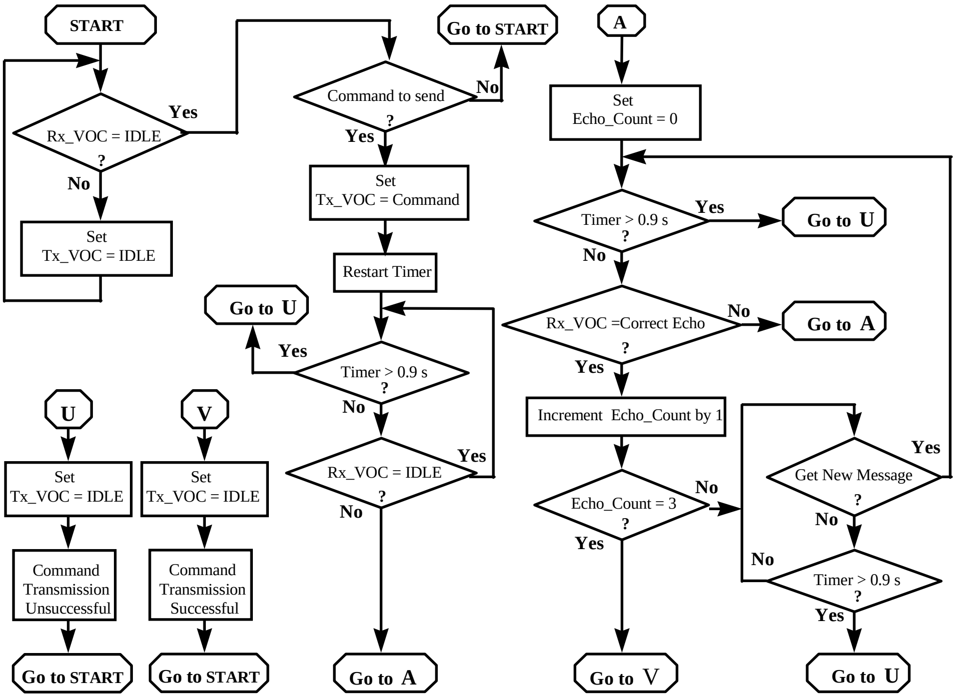
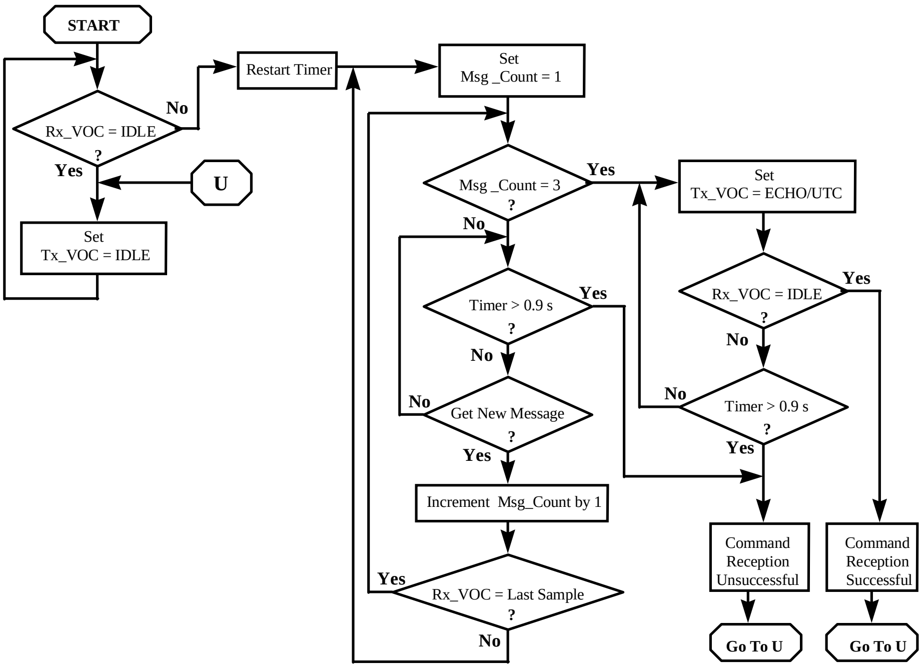


Figure 46: VTU-O Handshaking Flow Chart



NOTE: "Correct Echo" in figure 46 is an ECHO-type message, which corresponds with the sent COMMAND-type message, or a UTC message.

Figure 47: VTU-R Handshaking Flow Chart

7.5.2.3 Multiple word communication

A standard VOC message carries two octets of data, which in some cases is not sufficient. The number of data octets carried by a VOC message can be extended by using NEXT_WORD commands as described in clause 7.5.3.4. There are two types of multiple word messages:

- WRITE, to send information from the VTU-O to the VTU-R;
- READ, to retrieve information from the VTU-R for the VTU-O.

A multiple word message consists of a VOC header (the same as a standard VOC message) followed by multiple NEXT_WORD messages that include the data. The format of READ and WRITE messages is described in table 40.

7.5.3 VOC message set

All VOC messages are grouped according to their overall functionality into four groups: STATUS-type messages (table 33), messages used for VDSL performance monitoring (table 34), messages used for VDSL link configuration/transmission parameters modification (table 36 and 39) and control messages (table 40). The tables provide indication of the message status, which is *mandatory* (M) or *optional* (O).

Any ECHO-type messages use the same OPCODE value as the COMMAND-type message that is being echoed. The DATA field of an ECHO-type message contains either the same data as sent in a COMMAND-type "WRITE" message or the data requested by a COMMAND-type "READ" message.

A group of predefined OPCODES is reserved for vendor proprietary messages.

7.5.3.1 Status messages

Status messages are presented in table 33.

Table 33: STATUS - type VOC Messages

Name	Type	OPCODE	DATA field	Description	Status
IDLE	STATUS	0xFF	0x0000	An IDLE message. Sent by both VTU-O and VTU-R when VOC is inactive.	M
EOC	STATUS	0xFC	*eoc* message	An *eoc* message sent by both VTU-O and VTU-R when OC is used for *eoc* transport (VOC inactive)	M
UTC	STATUS	0xF0	Same as the COMMAND message being UTC'ed	Unable-To-Comply message. Sent by the VTU-R when the received command couldn't be executed by some reason	M
NOTE: The UTC message from the VTU-R is a valid response to a COMMAND-type message only if support for that command by the VTU-R is optional.					

7.5.3.2 Performance-monitoring messages

Performance-monitoring messages are intended to deliver far-end line related primitives, detected in PMD and PMS-TC sub-layers, and path related primitives, detected in different TPS-TC. The OPCODES from 0x90 to 0x9F are reserved for proprietary use.

The following 2-bit combinations shall be used for coding of the US and DS carriers:

- 00 - Carrier 1D;
- 01 - Carrier 2D;
- 10 - Carrier 1U;
- 11 - Carrier 2U.

For commands which deal with both carriers of the same direction only the second bit shall be set to 0 at the transmit side and omitted at the receive side.

Table 34: Performance Monitoring VOC Messages

Name	Type	OPCODE	DATA Field	Description	Status
	Line-related	**PMD**			
SNR_REQ	COMMAND (READ) and ECHO	0x01	COMMAND: 2 MSB = DS carrier code; the rest = 0 ECHO: 2 MSB = DS carrier code; 8 LSB = SNR in dB, the rest = 0 LSB weight = 0,25 dB	Requests VTU-R to send the specified DS carrier SNR in dB	M
SNR_REP	COMMAND (WRITE) and ECHO	0x02	COMMAND and ECHO: 2 MSB = US carrier code; 8 LSB = SNR in dB, the rest = 0. LSB weight = 0,25 dB	Send by VTU-O to indicate the specified US carrier SNR in dB	O
ATT_REQ	COMMAND (READ) and ECHO	0x03	COMMAND: 2 MSB = DS carrier code; the rest = 0 ECHO: 2 MSB = DS carrier code; 9 LSB = attenuation in dB, the rest = 0 LSB weight = 0,25 dB	Requests VTU-R to send the specified DS carrier attenuation in dB	M
ATT_REP	COMMAND (WRITE) and ECHO	0x04	COMMAND and ECHO: 2 MSB = US carrier code; 9 LSB = attenuation in dB, the rest = 0. LSB weight = 0,25 dB	Send by VTU-O to indicate the specified US carrier attenuation in dB	O
Reserved	COMMAND and ECHO	0x05-0x0F			O
	Line-related	**PMS-TC**			
FECS_REQ	COMMAND (READ) and ECHO	0x10	COMMAND: 0x0000 ECHO: VTU-R *fec-s* data as a 16-bit number of erred octets (1)	Requests VTU-R to send the number of octets corrected by FEC in the Slow channel since the last FECS_REQ command	M
FECS_REP	COMMAND (WRITE) and ECHO	0x11	COMMAND and ECHO: VTU-O *fec-s* data as a 16-bit number of erred octets (1)	Reports the number of octets corrected by FEC in the VTU-O Slow channel since the last FECS_REP command	O
FECF_REQ	COMMAND (READ) and ECHO	0x12	COMMAND: 0x0000 ECHO: VTU-R *fec-f* data as a 16-bit number of erred octets (1)	Requests VTU-R to send the number of octets corrected by FEC in the Fast channel since the last FECF_REQ command	O (2)

Name	Type	OPCODE	DATA Field	Description	Status
	Line-related	**PMD**			
FECF_REP	COMMAND (WRITE) and ECHO	0x13	COMMAND and ECHO: VTU-O *fec-f* data as a 16-bit number of erred octets (1)	Reports the number of octets corrected by FEC in the VTU-O Fast channel since the last FECF_REP command	O
ERRS_REQ	COMMAND (READ) and ECHO	0x14	COMMAND: 0x0000 ECHO: VTU-R *err-s* data as a 16-bit number of erred codewords (1)	Requests VTU-R to send the number of octets that were un-correctable by FEC codewords in the Slow channel since the last ERRS_REQ command	M
ERRS_REP	COMMAND (WRITE) and ECHO	0x15	COMMAND and ECHO: VTU-O *err-s* data as a 16-bit number of erred codewords (1)	Reports the number of octets that were un-correctable by FEC codewords in the VTU-O Slow channel since the last ERRS_REP command	O
ERRF_REQ	COMMAND (READ) and ECHO	0x16	COMMAND: 0x0000 ECHO: VTU-R *err-f* data as a 16-bit number of erred codewords (1)	Requests VTU-R to send the number of octets that were un-correctable by FEC codewords in the Fast channel since the last ERRF_REQ command	O (2)
ERRF_REP	COMMAND (WRITE) and ECHO	0x17	COMMAND and ECHO: VTU-O *err-f* data as 16-bit number of erred codewords (1)	Reports the number of octets that were un-correctable by FEC codewords in the VTU-O Fast channel since the last ERRF_REP command	O
Reserved	COMMAND and ECHO	0x18-0x1D			O
VTUO_INFO	COMMAND (WRITE) and ECHO	0x1E	COMMAND and ECHO: first two octets of the VTU-O INFO data field (note 3)	Reports the VTU-O INFO to the VTU-R	M
VTUR_INFO	COMMAND (READ) and ECHO	0x1F	COMMAND: 0x0000 ECHO: first two octets of the VTU-R INFO data field (note 3)	Reports the VTU-R INFO to the VTU-O	M

NOTE 1: The error count saturates at 65 535.
NOTE 2: Turns to mandatory if Fast channel is supported.
NOTE 3: The VTUR_INFO and VTUO_INFO data fields carries a combination of data from the modem including the vendor ID, revision number and configuration registers (clause 7.7.2). The format of the VTUR_INFO and VTUO_INFO data fields is identical and consists of the following data:

- vendor ID (4 octets);
- revision number (2 octets);
- spectral plan/band support (2 octets);
- PSS or BSS indicator (1 octet).

The first two octets of the vendor ID are transferred by the command, further octets are communicated using the NEXT_WORD commands.

7.5.3.3 Configuration messages

The configuration VOC messages are intended to configure and reconfigure the VDSL link by modifying its transmission parameters during the steady-state transmission. Two types of messages are defined for link configuration. The Parameter Setting messages (table 36) deliver the configured parameter value from the VTU-O to the VTU-R Activation database (clause 8.3). The Trigger messages (table 39) execute the change of link transmission parameters to a new setting.

7.5.3.3.1 Parameter setting messages

The VDSL link configuration is performed by setting/modification of at least one of three different STP (WS_STP, CR_STP or I_STP), as described in clause 8.3.2. The set of link transmission parameters (STP) is presented in table 89. A VOC configuration message includes the targeted upstream/downstream carrier code, the targeted STP code, and the applied parameter value. A PROFILE message changes the profile by switching all the parameters of the targeted STP at the same time to standard values, defined by a corresponding transmission profile.

All Parameter Setting messages are of COMMAND WRITE type; the COMMAND and the ECHO DATA fields are equal and contains the parameter value to be set at the VTU-R.

For any Parameter_Setting message a complimentary Read-back message of COMMAND read type could be built to verify the configured parameter value or read the recommended parameter value. All Read-back messages are of COMMAND READ type. A Read-back message shall be built from the corresponding Parameter_Setting message by the following rule:

- the OPCODE of a Read-back message equals to OPCODE of the corresponding Parameter Setting Message increased by 0x20;
- the DATA field of a Read-back message differs from the corresponding Parameter_Setting message by the parameter value only. The latest is set to zero for the COMMAND and equals to the actual parameter value setting at the VTU-R for the ECHO.

The DATA field format for both Parameter_Setting and Read-back messages is presented in table 35.

Table 35: DATA Field Format for Parameter_Setting and Read-back Messages

D15	**D14**	**D13**	**D12**	**D11-D0**
STP Code (1)		US or DS	Carrier 1 or 2	Parameter Value
		Carrier Code (2, 3)		

NOTE 1: The following 2-bit combinations shall be used for STP coding:
00 - for I_STP;
01 - for WS_STP;
10 - for CR_STP;
11 - recommend for CR_STP.

NOTE 2: For DS and US carriers coding shall be used the 2-bit combinations presented in clause 7.5.3.2.

NOTE 3: For commands which deal with both carriers of the same direction only (PROFILE, INTERLV, FRAME, PSDMASK) bit D12 shall be set to 0 at the transmit side and omitted at the receiving side.

The OPCODEs from 0x29 to 0x3F are reserved for proprietary use.

The OPCODEs from 0x40 to 0x5F are reserved for Readback messages.

Table 36: Parameter Setting Messages

Name	Type	OPCODE	Parameter Value	Description	Status
PROFILE	COMMAND (WRITE) and ECHO	0x20	12-bit transmission profile code (1)	Selects the VTU-R transmission profile for the specified direction and STP	M
INTERLV	COMMAND (WRITE) and ECHO	0x21	2 MSB = $\log_2$(S/I) or 0 to disable interleaving, 8 LSB = M (M = 0 disables interleaving) all other bits = 0	Selects the VTU-R interleaving depth for the specified direction and STP	M
FRAME	COMMAND (WRITE) and ECHO	0x22	8 MSB = *F*, 4 LSB = *RF/2*, (2)	Selects the VTU-R frame format for the specified direction and STP	M
PSDMASK	COMMAND (WRITE) and ECHO	0x23	12-bit PSD mask code, (3)	Selects the VTU-R transmit PSD mask for the specified STP	M
PSDLEVEL	COMMAND (WRITE) and ECHO	0x24	4 MSB = 0, 8 LSB = PSD[dBm/Hz] +100, LSB weight = 0,25 dBm/Hz	Selects the VTU-R transmit PSD level for the specified US carrier and STP	M
PSDLEVEL_REP	COMMAND (WRITE) and ECHO	0x25	4 MSB = 0, 8 LSB = PSD[dBm/Hz] +100, LSB weight = 0,25 dBm/Hz	Reports the VTU-O transmit PSD level for the specified DS carrier and STP	O
SMBLRATE	COMMAND (WRITE) and ECHO	0x26	4 MSB = 0, 8 LSB = symbol rate profile *S*, (5)	Selects the VTU-R symbol rate profile for the specified carrier and STP	O
CONSTEL	COMMAND (WRITE) and ECHO	0x27	8 MSB = 0, 4 LSB = $\log_2$(constellation size)	Selects the VTU-R constellation size for the specified carrier and STP	O
CENFREQN	COMMAND (WRITE) and ECHO	0x28	2 MSB = 0, 10 LSB = centre frequency profile *K*, (6)	Selects the VTU-R centre frequency profile for the specified carrier and STP	O
Reserved	COMMAND and ECHO	0x29 - 0x3F			O

NOTE 4: The frame format is defined by the total number of octets ($F \leq 180$) and the number of redundancy octets ($RF \leq 16$) in the Fast codeword. The valid nonzero values for *F* and *RF* are presented in clause 6.5.1.

NOTE 5: The symbol rate profile is calculated as $S = SR/BSR$, where *SR* is the required symbol rate in kBaud and *BSR* is defined in clause 5.2.5.

NOTE 6: The centre frequency profile is calculated as $K = 2f_C/\mathrm{BSR}$, where f_C is the required centre frequency in kHz and BSR = 33,75 kBaud as defined in clause 5.2.5.

NOTE 7: Transmission profile code bears the profile name, as defined in clause 5.2.5, in the following format:

Table 37: Transmission profile code

Bit	D11	D10 - D8	D7 - D6	D5 - D4	D3	D2	D1	D0
Profile name character	X	Y	X_1	X_2	-	X_3	X_4	X_6
Coding rules	1 ↔ S 0 ↔ A	001 ↔ A1/S1 010 ↔ A2/S2 (note 9) 011 ↔ A3/S3 100 ↔ A4/S4 110 ↔ A2/S2 (note 9) 000 ↔ vendor proprietary	00 ↔ 0 01 ↔ 1 10 ↔ 2 11 ↔ 3	00 ↔ 0 01 ↔ 1 10 ↔ 2 11 ↔ 3	See note 8	1 ↔ N 0 ↔ O	1 ↔ A 0 ↔ N	1 ↔ VDSL band allocation 0 ↔ Optional regional specific band allocation

NOTE 8: The constellation size is forced to C = 4 for both carriers in both directions when the value of bit D3 = 1. In the PROFILE-ECHO message bit D3 may be overwritten by the VTU-R. If it is set then the VTU-R is only capable of operating with a fixed constellation size of 4 with the current channel conditions.

NOTE 9: The code 110 shall be used for A2/S2 when the PSD mask is FTTCab variant A and code 010 shall be used when the PSD mask is FTTCab variant B.

NOTE 10: The PSD mask code bears the PSD mask specification, as defined in clause 5.2.4.2, in the following format:

Table 38: PSD mask code

Bit	D11	D10 - D9	D8 - D6	D5	D4	D3	D2	D1	D0
Parameter	Mask	Mask type	0	notch1	notch2	notch3	notch4	notch5	notch6
Coding rules	0 ↔ M1 1 ↔ M2	00 ↔ Pcab 01 ↔ Pex.P1 10 ↔ Pex.P2 11 ↔ N/A	N/A	Amateur bands notches setup 0 ↔ OFF 1 ↔ ON					

NOTE 11: Default frequency values for notches 3 to 6 are defined in TS 101 270-1 [1] (first 4 rows of table 16). Notch 6 is the lowest frequency notch and notch 3 is the highest frequency notch within the band plan. Other characteristics of the notches are for further study.

7.5.3.3.2 Trigger messages

All Trigger messages are of type COMMAND WRITE. Both the COMMAND and the ECHO DATA fields contain 0xAAAA.

Table 39: Trigger Messages

Name	Type	OPCODE	Description	Status
CHANGE	COMMAND (WRITE) and ECHO	0xA0	Requests the VTU-R to be ready to change the CR_STP for a new parameter setting upon the following trigger handshake.	M
IDLEREQ	COMMAND (WRITE) and ECHO	0xA1	Requests the VTU-R to be ready to change the CR_STP for I_STP upon the following trigger handshake.	M
BTSERV	COMMAND (WRITE) and ECHO	0xA2	Requests the VTU-R to be ready to change the CR_STP for WS_STP upon the following trigger handshake.	M

7.5.3.4 Control messages

Control VOC messages are intended for system maintenance in some special cases and allow the management system to override some of the system routine processes.

The OPCODEs from 0xE3 to 0xEF are reserved for proprietary use.

Table 40: Control Messages

Name	Type	OPCODE	DATA Field	Description	Status
USPB_RESET	COMMAND (WRITE) and ECHO	0xE0	COMMAND and ECHO: 2 MSB = US carrier code; the rest = 0	Requests VTU-R to renew US power back-off process for the specified US carrier	M
THRPUT	COMMAND (WRITE) and ECHO	0xE1	COMMAND and ECHO: 8 MSB = data throughput, 8 LSB = EOC throughput (0x00 = set, 0xFF = reset)	Sets or resets data throughput and EOC throughput at the VTU-R (1)	M
THRPUT_REQ	COMMAND (READ) and ECHO	0xE2	COMMAND: 0x0000 ECHO: 8 MSB = data throughput, 8 LSB = EOC throughput (0x00 = set, 0xFF = reset)	Requests VTU-R to send the status of data throughput and EOC throughput at the VTU-R	O
NEXT_WORD_W	COMMAND (WRITE) and ECHO	0xE3	COMMAND and ECHO: next two octets of data (note 1)	Conveys next two octets of data requested by the last WRITE command	M
NEXT_WORD_R	COMMAND (READ) and ECHO	0xE4	COMMAND: 0x0000 ECHO: next two octets of data (note 1)	Requests VTU-R to send next two octets of data requested by the last READ command	M
TX_FILTER_REP	COMMAND (WRITE) and ECHO	0xE5	COMMAND and ECHO: 4 MSB = STP code and carrier code, 8 LSB = first octet of the VTU-O TX_FILTER register to be sent to the VTU-R (see note 2)	Sent by the VTU-O to transfer the parameters of the VTU-O transmit filter to the VTU-R. This command shall preceed any change of the transmit filter parameters (i.e. before it takes effect after a restart).	M
TX_FILTER_REQ	COMMAND (READ) and ECHO	0xE6	COMMAND: 4 MSB = STP and carrier code. ECHO: 8 MSB = 8 MSB of command, 8 LSB = first octet of the VTU-R TX_FILTER register to be sent to the VTU-O (see note 2)	Requests the transfer of the VTU-R transmit filter parameters.	M
QUIET	COMMAND (WRITE) and ECHO	0xE7	COMMAND and ECHO: D10 = mode of the non-silent transceiver, D9 = 1 reports silenced VTU-O, D8 = 1 requests silent VTU-R, 4 LSB = maximum quiet period in seconds (max is 10) (see note 3)	Requests the VTU-R to silence its transmitter and reports whether the VTU-O will also go silent. Either transmitter shall be silenced for the specified time period which starts immediately after the completion of the VOC handshake. Following the silent period, both modems enter the *Cold-Start* activation. (see note 4)	M

Name	Type	OPCODE	DATA Field	Description	Status
COPY_STP	COMMAND (READ) and ECHO	0xE8	COMMAND and ECHO: 8 MSB = source STP, 8 LSB = destination STP. STP encoding:- 0x00 = CR_STP; 0x01 = DF_STP; 0x02 = WS_STP; 0x03 = WR_STP; 0x04 = RE_STP; 0x05 = I_STP; 0xFF = all STP except DF_STP	Requests the VTU-R to copy the parameter values from the specified source STP to the specified destination STP. (DF_STP is allowed only as a source)	M
Reserved	COMMAND and ECHO	0xE9-0xEF			O

NOTE 1: Transmission of the NEXT_WORD_R and NEXT_WORD_W commands always refers to the last VOC opcode (other than NEXT_WORD_W/R and IDLE) which was successfully communicated by the VOC. If the last opcode (other than NEXT_WORD_R and IDLE) that was successfully communicated was a READ command, subsequent NEXT_WORD_R commands shall transfer the next two octets of data from the VTU-R. If the last opcode (other than NEXT_WORD_W and IDLE) that was successfully communicated was a WRITE command, subsequent NEXT_WORD_W commands shall transfer the next two octets of data to the VTU-R. NEXT_WORD_R or NEXT_WORD_W commands which attempt to read or write beyond the end of the data field length defined for that command shall get a UTC response from the VTU-R. Receipt of a new opcode other than NEXT_WORD_R/W or IDLE by the VTU-R shall terminate the processing of the previous command. Receipt of a single NEXT_WORD_R/W which does not correspond with the preceeding command (either NEXT_WORD_R following a WRITE command or vice-versa) shall get a UTC response from the VTU-R.

NOTE 2: The TX_FILTER command communicates the parameters of the transmit filter corresponding to the selected STP and carrier. The first octet of TX_FILTER is the number of octets to be sent or received using NEXT_WORD commands.

NOTE 3: Bits D8 and D9 of the data field specify that one or both modems shall silence their transmitters for the quiet period specified by bits D3-D0. If both modems are silenced, after the specified time period both modems will initiate *Cold-Start* activation. If only one modem is silenced, the other modem shall continue to transmit as it was before the command (D10 = 0) or may transmit any other signal that complies with the PSD limits (D10 = 1), excluding the QUIET signal.

NOTE 4: The non-silent modem can request to terminate the quiet period at any time by transmitting the QUIET signal for at least 100 ms followed by DF_STP, thereby initiating *Cold-Start* activation. The silent modem may remain so until the specified time period has elapsed or it can optionally terminate the quiet period early once it has detected the DF_STP signal at its receiver.

7.6 VDSL embedded operations channel (eoc)

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

The "internal" *eoc* channel, except where specified, works in bi-directional mode using an echoing protocol. Both transmission directions are necessary to provide full communication over the *eoc*.

7.6.1 eoc functional model

The *eoc* functional model is presented in figure 48. 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 stream 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 as either a part of the VTU-O or as a common base 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 shall be supported by the VME_O. If the MIB is shared then the VME_O accesses the MIB directly or, if necessary via the Q-interface. At the VTU-R the MIB and external interface support are optional.

7.6.2 VME functionality

VME 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.

NOTE: This part of VME functionality is beyond the scope of the present document.

The VME provides management functions at the remote end via *eoc* in accordance with table 28 and clauses 7.3.2, 7.3.3, 7.3.5 and 7.3.6.

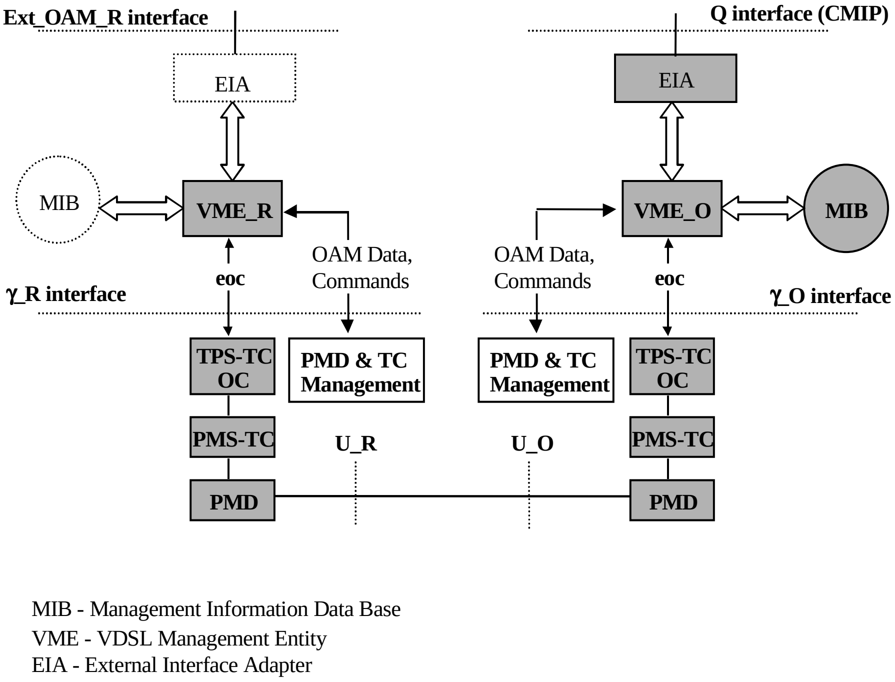


Figure 48: eoc functional model

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.

7.6.3 eoc protocol format

The same *eoc* protocol format shall be used at both sides of the link. The *eoc* protocol format shall implement the HDLC protocol as defined in ITU-T Recommendation G.997.1 [8]. The use of the information payload of the HDLC frame is defined in the following clauses.

Within the HDLC protocol the VME shall multiplex internal *eoc* and external messages received via the Q-interface. All external messages to be transported over the VDSL link shall have an HDLC address field value of 0xFF. The internal *eoc* messages may use an HDLC address field with a value of 0x11. Other address field values are for further study.

NOTE: In the rest of this clauses the term *"eoc"* is used to refer to the internal *eoc* except where indicated.

7.6.3.1 External message format

The information payload of the HDLC frame carrying an external message shall not exceed 510 octets. The external message encapsulation method and the contents of external messages are beyond the scope of the present document.

7.6.3.2 Internal message format

The information payload of the HDLC frame carrying an internal message (further called "*eoc* message") shall contain at least 2 octets sent from the VME_O to the VME_R and vice versa. Use of internal messages with more than two octets is for further study (the number of octets shall always be even).

7.6.3.3 eoc organisation and message types

The *eoc* allows the VTU-O (acting as master) to invoke certain management functions at the VTU-R by sending *eoc* command messages. The VTU-R (acting as slave) shall acknowledge a command message it has received without error by sending a response *eoc* message and perform the requested function. However, *autonomous* messages may be sent from the VTU-R independently (as soon as the appropriate data is available) but not as a response on a VTU-O message.

There are three types of *eoc* messages:

- bi-directional messages (d/u): these are originated by the VTU-O, and echoed by the VTU-R to indicate the correct reception of each message;
- downstream messages (d): these are originated by the VTU-O and acknowledged by the VTU-R;
- upstream messages (u): these are originated by the VTU-R and may be in response to a downstream message or autonomous.

NOTE: Acting as a master, the VTU-O usually determines the rate of the *eoc* communication, as the VTU-R responds with only one message on each received *eoc* message.

7.6.3.3.1 *eoc* message structure

The 16 bits of an *eoc* message are partitioned among six fields, which are summarised in table 41 and defined in the following clauses.

NOTE: Only the first 13 MSB of the 2-octet *eoc* data shall be used for the *eoc* message starting from Bit#1. The last three LSB shall be reserved.

Table 41: eoc Message Fields

Field #	Bit #	Description	Notes
1	1-2	ADDRESS field	Can address up to 4 locations
2	3	DATA (0) or OPCODE (1) field	Data used for both read and write
3	4	PARITY field Odd (1) or even (0)	Octet order indication for multi-octet transmission
4	5	MESSAGE/RESPONSE field Message/Response (1) or Autonomous message (0)	Currently autonomous messages are defined for the VTU-R only
5	6-13	INFORMATION field	One out of 58 opcodes or 8 bits of data
6	14-16	Reserved	For further use

7.6.3.3.1.1 ADDRESS field (# 1)

The two bits of the address field can address up to four locations. Only two locations are presently defined:

- 00: VTU-R address;
- 01: Reserved for future applications; presently invalid;
- 10: Reserved for future applications; presently invalid;
- 11: VTU-O address.

The VTU-O shall address messages to the VTU-R by setting the ADDRESS field equal to the VTU-R address (00). When responding to a message received from the VTU-O, the VTU-R shall keep the ADDRESS field equal to the VTU-R address (00). The VTU-R shall set the ADDRESS field equal to the VTU-O address (11) only when sending an autonomous message to the VTU-O.

7.6.3.3.1.2 DATA or OPCODE field (# 2)

This field is set to false (0) when the information field of the *eoc* message contains a data octet and is set to true (1) when it contains an opcode.

7.6.3.3.1.3 PARITY field (# 3)

This bit helps to speed up the multi-octet reads and writes of data by eliminating the intermediate messages to indicate to the far end that the previous octet was successfully received.

For the first octet of the sent read/write data, this bit shall be set to true (1) to indicate "odd" octet. For the next octet, it shall be set to false (0) to indicate "even" octet and so on, alternately.

The PARITY field shall always be set to 1 if the information field carries an opcode different from the "Next Octet" opcode. If a "Next Octet" opcode is applied, the PARITY field is toggled for multi-octet data transfer.

7.6.3.3.1.4 MESSAGE/RESPONSE field (# 4)

When set to true (1) this field indicates that the current *eoc* message is an *eoc* command message or an *eoc* response message (echo); a false (0) value indicates that it is an autonomous message.

NOTE: For the VTU-O this field shall always be set to true. For the VTU-R this field shall also be set to true except the autonomous messages.

7.6.3.3.1.5 INFORMATION field (# 5)

Up to 58 different 8-bit opcodes or an 8-bit data value may be transported in the information field.

The opcode set is restricted to codes that provide a minimum Hamming distance of 2 between all opcodes, and a minimum distance of 3 between certain critical codes and all other codes.

7.6.3.3.2 eoc Message Set

The VTU-O shall send command messages to perform certain functions at the VTU-R. Some of these functions require the VTU-R to activate changes in the circuitry (e.g. to send corrupted CRC/FEC bits). Other functions are to read from and to write into the MIB data registers at the VTU-R. These functions are used by the VTU-O to read the VTU-R status or performance parameters, or for limited maintenance extensions to the service modules.

Some of *eoc* commands are "latching", meaning that a subsequent *eoc* command shall be required to release the VTU-R from that state. Thus, multiple VDSL *eoc*-initiated functions can be in effect simultaneously. To maintain the latched state, the command "Hold State" shall be sent.

A command, "Return-To-Normal", is used to unlatch all latched states. This command is also used to bring the VDSL system to the Idle state, when no *eoc* command is active in the VTU-R.

All the *eoc* messages and their opcodes are summarised in table 42.

Table 42: The eoc Message Set List

Opcode (HEX)	OPCODE meaning	Direction	Abbreviation and notes
01	Hold state	d/u	HOLD
F0	Return-To-Normal	d/u	RTN
02	Perform "self-test"	d/u	SLFTST
04	Unable-to-comply	u	UTC
07	Request for corrupted CRC/FEC	d/u	REQCOR (latching)
08	Request end of corrupted CRC/FEC	d/u	REQEND
0B	Notify corrupted CRC/FEC	d/u	NOTCOR (latching)
0D	Notify end of corrupted CRC/FEC	d/u	NOTEND
0E	End of data	d/u	EOD
10	Next octet	d	NEXT
13	Request test parameters update	d/u	REQTPU
14	Error	d/u	ERR
20, 23, 25, 26, 29, 2A, 2C, 2F, 31, 32, 34, 37, 38, 3B, 3D, 3E	Write data register. Register number specified by opcode value (e.g. opcode 0x23 specifies register 1, see table 43).	d/u	WRITE
40, 43, 45, 46, 49, 4A, 4C, 4F, 51, 52, 54, 57, 58, 5B, 5D, 5E	Read data register. Register number specified by opcode value (e.g. opcode 0x45 specifies register 2, see table 43)	d/u	READ
19, 1A, 1C, 1F	Vendor proprietary protocols	d/u	Four opcodes are reserved for vendor proprietary use.
15, 16, 80, 83, 85, 86, 89, 8A, 8C, 8F	Undefined codes		These codes are reserved for future use and shall not be used for any purpose.

NOTE 1: The Opcode values are given as MSB left, LSB right with the MSB mapping to the eoc bit 13 and the LSB to the eoc bit 6.

NOTE 2: The given Opcode values guarantee a minimum Hamming distance of:
2 - between all opcodes (by requiring odd parity for all but two critical codes);
3 - between the "Return to Normal" (or "idle") code and all other codes.

7.6.3.3.3 Bi-directional *eoc* messages

Each bi-directional message sent by the VTU-O shall be echoed by the VTU-R if received correctly. The following messages are specified as bi-directional (with their abbreviated names and hex opcodes in parentheses):

- *Hold State*: (HOLD, 0x01) This message tells the VME-R to maintain the VTU-R eoc processor and any active VDSL eoc-controlled operations (such as latching commands) in their present state;
- *Return to Normal* (Idle Code): (RTN, 0xF0) This message releases all outstanding eoc-controlled operations (latched conditions) at the VTU-R and returns the VDSL eoc processor to its initial state.;
- *Request Corrupt CRC/FEC*: (REQCOR , 0x07) This message requests the VTU-R to send corrupt CRC/FEC-s to the VTU-O until cancelled by the "Request End of Corrupt FEC" or "Return-To-Normal" message. In order to allow multiple VDSL eoc-initiated actions to be in effect simultaneously, the "Request corrupt FEC" command shall be latching;
- *Request End of Corrupt CRC/FEC*: (REQEND, 0x08) This message requests the VTU-R to stop sending corrupt CRC/FEC-s toward the VTU-O;
- *Notify Corrupted CRC/FEC*: (NOTCOR, 0x0B) This message notifies the VTU-R that intentionally corrupted CRC/FEC-s will be sent from the VTU-O until cancellation is indicated by "Notify End of Corrupted CRC/FEC";
- *Notify End of Corrupted CRC/FEC*: (NOTEND, 0x0D) This message notifies the VTU-R that the VTU-O has stopped sending corrupted CRC/FEC-s;
- *Perform Self-Test*: (SLFTST, 0x02) This message requests the VTU-R to perform a self-test. The result of the self-test shall be stored in a register at the VTU-R. After the VTU-R self test, the VTU-O reads the test results from the VTU-R register. This is for further study;
- *Receive/Write Data (Register #)*: (WRITE, see clause 7.6.3.5.3.2) This message directs the VTU-R to enter the Data Write Protocol state, receive data, and write it in the register specified by the opcode;
- *Read/Send Data (Register #)*: (READ, see clause 7.6.3.5.3.1) This message directs the VTU-R to enter the Data Read Protocol state, read data from the register specified by the opcode, and transmit it to the VTU-O;
- *End of Data*: (EOD, 0x0E). This message is sent by the VTU-O after it has sent all octets of data to the VTU-R. The message is send by the VTU-R in either of the following cases:
  - in response to a "Next Octet" message from the VTU-O that is received after all octets have been read from the currently addressed VTU-R register;
  - in response to a message from the VTU-O that contains a data octet after all octets have been written to the currently addressed VTU-R register.
- *Vendor Proprietary Opcodes*: (VPC, 0x19, 0x1A, 0x1C, 0x1F). Four opcodes have been reserved for vendor proprietary use. The VTU-O shall read the Vendor ID code register of the VTU-R to ensure compatibility between the VTU's before using proprietary opcodes;
- *Request Test Parameters Update*: (REQTPU, 0x13). This message requests the VTU-R to update the test parameters set as defined in clause 7.3.6. Test parameters supported by the VTU-R shall be updated within 10 s after the request is received. Updated test parameters may be read by the VTU-O thereafter;
- *Error*: (ERR, 0x14). This message requests the VTU-O or VTU-R to repeat the last message. The message is send after a non-correctable error has been detected in the received HDLC frame.

7.6.3.3.4 Downstream messages

There is one message that may be sent only by the VTU-O:

- *Next Octet:* (NEXT, 10) This message is sent repeatedly by the VTU-O (toggling bit four for multi-octet data until all data has been sent) while it is in Data Read protocol state. The message is echoed by the requested octet of the VTU-R data with toggling of the bit four for multi-octet data or by the *End-of-Data* message.

7.6.3.3.5 Upstream messages

The messages that may be sent only by the VTU-R are:

- *Unable-to-Comply (UTC):* (UTC, 04), acknowledgement. The VTU-R shall send this message when it receives a command *eoc* message that it cannot perform for either reason:
  - it does not recognise the command;
  - it cannot implement the command;
  - the command is unexpected for the current state of the *eoc* protocol.
- *Autonomous messages:* for further study. All autonomous messages have bit 5 set to 0 and bit 3 set to 1 to indicate that the message contains an opcode. The information field shall contain the opcode of the corresponding message (table 42).

7.6.3.4 VTU-R Data Registers

The VTU-R data registers shall be defined as:

- *VTU-R Vendor ID code (4 octets):* The format of the VTU-R Vendor ID code is for further study.
- *VTU-R Revision number*: The VTU-R Revision Number register shall be at least one octet long; longer registers shall be vendor discretionary. The most significant bit of the VTU-R Revision number definition is for further study.
- *VTU-R Serial number (32 octets)*: The format of the VTU-R Serial Number shall be vendor discretionary.
- *Self Test Results*: The most significant octet of the Self-Test Results shall be 0x00 if the self test passed, and 0x01 if it failed (the meaning of "failure" is vendor discretionary); other values are reserved for future use. The length and syntax of the remainder shall be vendor discretionary.
- *Line attenuation (1 octet)*: The line attenuation is defined in clause 7.3.6.2.
- *SNR Margin (1 octet)*: The SNR margin is defined in clause 7.3.6.2.
- *VTU-R configuration (≥30 octets)*: The VTU-R configuration registers may contain data for both TPS-TC sub-layer, and application layer and external service module configuration. For further study.

NOTE 1: The VDSL link configuration (applied for the PMD and PMS-TC sub-layer) is delivered by the VOC. Table 43 summarises the VTU-R data registers and their applications.

Table 43: VTU-R Data Registers

REG # (HEX)	USE	LENGTH	DESCRIPTION
0	Read	4 octets	VTU-R vendor ID
1		Vendor discretionary	VTU-R revision number
2		32 octets	VTU-R serial number
3		Vendor discretionary	Self test results
4	Read/Write	Vendor discretionary	Vendor discretionary
5		Vendor discretionary	Vendor discretionary
6	Read	4 octets	Line attenuation
7		4 octets	SNR margin
8		≥ 30 octets	VTU-R Configuration
9-F	reserved	reserved	For future use (see note 2)
NOTE 1: Registers shall be read MSB first. NOTE 2: The VTU-R shall respond UTC if requested to write into one of these registers.			

7.6.3.5 eoc protocol states

7.6.3.5.1 Message/echo-response protocol state (idle state)

To initiate an action at the VTU-R, the VTU-O shall begin sending *eoc* messages with the Data/Opcode set to true and with the appropriate message opcode in the information field. The VTU-R shall initiate the action only when an error-free and properly addressed *eoc* message has been received. The VTU-R shall respond to all the received messages. If either the VTU-R or VTU-O detects a non-correctable error in the received HDLC frame it shall send the corresponding *Error* message. The combination of the VTU-O sending a message and the VTU-R echoing the message back comprises the message/echo-response protocol state.

NOTE 1: The time it takes to complete an *eoc* message transmission under both error and error-free conditions will depend on the vendor's implementation.

NOTE 2: If the *eoc* message was one of the latching commands, then the VTU-R shall maintain the condition until the VTU-O issues the appropriate command to end the specific latched condition or until the VTU-O issues the "Return-to-Normal" command.

7.6.3.5.2 Message/unable-to-comply response protocol state (UTC state)

When the VTU-R does not support the function requested by a message that it has properly received, it shall respond with the UTC message with its own address and switch to the UTC state.

The reception by the VTU-O of a properly addressed UTC message constitutes notification to the VTU-O that the VTU-R does not support the requested function.

7.6.3.5.3 Message/data-response protocol state

The VTU-O may either write data into, or read data from the VTU-R MIB memory.

7.6.3.5.3.1 Data read protocol

To read data from the VTU-R, the VTU-O shall send a "Send Data" opcode message to the VTU-R that specifies the register to be read. After receiving the acknowledgement, the VTU-O shall request the first octet to be sent from the VTU-R by sending "Next Octet" message with bit four set to true, indicating a request for an "odd" octet. The VTU-R shall respond to this "Next Octet" message by sending the first octet of the requested data in the information field of an *eoc* message with bit four set to true to indicate "odd octet" and with bit 3 set to false to indicate the *eoc* data message. If there is more data to be read, the VTU-O shall request the second octet of data by sending "Next Octet" messages with bit four set to false ("even octet"). The VTU-R responds to the message by sending *eoc* message containing the second octet of the register with bit four set to "even octet". The process continues for the third and all subsequent octets with the value of bit four toggling from "odd octet" to "even octet" or vice versa, on each succeeding octet. Each time bit four is toggled, the VTU-R responds by sending the next data octet. The process ends only when all of the requested data in the register are read.

To continue reading data, once the VTU-R is in the Data Read odd or even State, the only message that the VTU-O is allowed to send is "Next Octet" with bit four toggling. To end the data read mode abnormally, the VTU-O sends either "Hold State" or "Return-to-Normal", depending on whether any latched states are to be retained. If the VTU-R receives any other message while it is in Data Read odd or even State, it shall go into the UTC State.

If, after all octets have been read from the VTU-R register, the VTU-O continues to send the "Next Octet" message with bit four toggled, then the VTU-R shall send an "End-of-Data" message.

For the VTU-O, the data read mode ends either when the VTU-O has received the last requested data octet or when the VTU-O has received "End-of-Data" message. The VTU-O shall then switch both itself and the VTU-R into the Idle State (by sending a "Hold State" or a "Return-to-Normal" message), and the VTU-R shall release the register and leave the Data Read State after receiving either "Hold State" or "Return-to-Normal" message.

7.6.3.5.3.2 Data write protocol

To write data into the VTU-R MIB memory, the VTU-O shall send a "Write Data" opcode message to the VTU-R that specifies the register to be written to. When the VTU-R acknowledges (echoing), the VTU-O sends the first octet of data. The VTU-R shall acknowledge the receipt of the octet with an echo of the message. After the VTU-O receives the echo response, it shall send the next octet of data. Each time the VTU-O receives echo response, it shall switch to sending the next octet of data. It shall also toggle the "odd/even" bit accordingly. ("Next Octet" messages are not used in the Data Write mode). The VTU-O shall end the write mode with the "End of Data" message indicating to the VTU-R to release the register and return to the Idle State.

To continue writing data once the VTU-R is in the Data Write odd or even state, the only message that the VTU-O is allowed to send is the "Data Octet" message with bit 3 set to false and with bit four toggling. To end the Data Write state abnormally, the VTU-O may switch to the "*End-of-Data*" message. If the VTU-R receives any other message while it is in Data Write state, it shall go into the UTC state.

If, after all octets have been written to the VTU-R register, the VTU-O continues to send the data, then the VTU-R shall send an "*End-of-Data*" message.

7.7 Single carrier specific OAM objects

7.7.1 Line related primitives

7.7.1.1 Near-end defects

- *Loss-of-carrier* (los_cr) defect occurs when the received carrier signal power, averaged over a 0,5 s period, is lower than the set threshold. It terminates when the signal power exceeds the set threshold.

- *Loss-of-signal* (los) defect occurs when the *los_cr* defect occurs for any of the carriers specified by the applicable transmission profile. It terminates when *loc_cr* for all carriers is cleared.

7.7.1.2 Far-end defects

- *Far-end loss-of-carrier* (flos_cr) defect occurs when a *los_cr* defect is reported in four or more out of six contiguous received far-end indicator reports. The *flos_cr* is terminated when less than two far-end *los_cr* indicators are reported out of six contiguous received far-end indicator reports.

- *Far-end loss-of-signal* (flos) defect occurs when a *flos_cr* defect is reported for any carrier specified by the applicable transmission profile. It terminates when *flos_cr* for all carriers is cleared.

7.7.2 VTU-R configuration register

The register consists of 57 octets and shall include the data specified in table 44.

Table 44: VTU-R configuration register

Octet number (hex)	Parameter description	Format
Line-related		
0x00-0x01	Profile	PROFILE command, table 36
0x02-0x03	Transmit PSD limit	PSDMASK command, table 36
0x04-0x05	Frame configuration	FRAME command, table 36
0x06-0x07	Symbol rate, carrier US1	SMBLRATE command, table 36
0x08-0x09	Symbol rate, carrier US2	
0x0A-0x0B	Symbol rate, carrier DS1	
0x0C-0x0D	Symbol rate, carrier DS2	
0x0E-0x0F	Constellation, carrier US1	CONSTEL command, table 36
0x10-0x11	Constellation, carrier US2	
0x12-0x13	Constellation, carrier DS1	
0x14-0x15	Constellation, carrier DS2	
0x16-0x17	Centre frequency, carrier US1	CENFREQN command, table 36
0x18-0x19	Centre frequency, carrier US2	
0x1A-0x1B	Centre frequency, carrier DS1	
0x1C-0x1F	Centre frequency, carrier DS2	
0x40-0x41	Interleaver configuration	INTERLV command, table 36
0x42-0x43	Spectral plan/band support	See note 1
0x44-0x45	Transmit PSD level, carrier US1	PSDLEVEL command, table 36
0x46-0x47	Transmit PSD level, carrier US2	
0x48-0x49	Transmit PSD level, carrier DS1	
0x4A-0x4B	Transmit PSD level, carrier DS2	
0x4C-0x4F	reserved	0xFF
Path-related		
0x20	TPS-TC configuration	See note 2
0x21	reserved	0xFF
0x22-0x23	ATM-TC configuration	For further study
0x24-0x25	STM-TC configuration	For further study
0x26-0x27	PTM-TC configuration	For further study
0x28-0x2F	reserved	0xFF
System-related		
0x30-0x33	Vendor ID	See note 3
0x34-0x35	Revision number	
0x36	PSS or BSS flag	0x0F = PSS, 0x00 = BSS
0x37-0x3F	reserved	0xFF

NOTE 1: The spectral plan code format shall be as defined in table 45, the band support code format shall be as defined in table 46. A value of 1 indicates support for the specified spectral plan or band, a value of 0 indicates no support.

NOTE 2: Bits D0 (LSB) and D1 relate to the ATM-TC, bit D2 is reserved, bits D3 and D4 relate to the STM-TC, bit D5 is reserved, bits D6 and D7 (MSB) relate to the PTM-TC. The bits use the following coding:

00 - not installed;
11 - installed and active;
10 - installed and disabled;
01 - invalid option.

NOTE 3: Use the standard 4-octet coding for vendor ID.

Table 45: Spectral plan support code

D7 (MSB)	D6	D5	D4	D3	D2	D1	D0 (LSB)
-	-	-	-	FTTCab variant B	FTTCab variant A	VDSL band allocation	Optional regional specific band allocation

Table 46: Band support code

D7 (MSB)	D6	D5	D4	D3	D2	D1	D0 (LSB)
-	-	2U	2D	1U	1D	25-138 kHz DS	25-138 kHz US

7.7.3 VTU-R performance registers

The registers shall include the data specified in table 47.

Table 47: VTU-R performance registers

Octet number (hex)	Parameter description	Format
Loop attenuation register		
0x00	Carrier DS1	See clause 7.3.6
0x01	Carrier DS2	
0x02	Carrier US1	
0x03	Carrier US2	
0x04	Electrical length, US	
0x05	Electrical length, DS	
SNR margin register		
0x00	SNR, carrier DS1	See clause 7.3.6
0x01	SNR, carrier DS2	
Self-test results register		
0x00-0x0F	Reserved	0xFF
Reserved register		
0x00-0x0F	Reserved	0xFF

7.7.4 VTU transmit filter register

The transmit filter register at both the VTU-O and VTU-R shall include the data specified in table 48. The data only relates to the section of filtering operating at the symbol rate.

Table 48: Transmit filter register

Octet number (hex)	Parameter description	Format
0x00	Length of the register, L in octets	0x01 to 0xFF, see note 1
0x01	Number of zeros, NZ	See note 2
0x02-0x03	First zero, real part	
0x04-0x05	First zero, imaginary part	
0x06-0x07	Second zero, real part	
0x08-0x09	Second zero, imaginary part	
…	…	
(4*NZ* - 2)-(4*NZ* - 1)	Last zero, real part	
(4*NZ*)-(4*NZ* + 1)	Last zero, imaginary part	
(4*NZ* + 2)-(4*NZ* + 3)	First pole, real part	
(4*NZ* + 4)-(4*NZ* + 5)	First pole, imaginary part	
…	…	
(4(*NZ*+*NP*) - 2)-(4(*NZ*+*NP*) - 1)	Last pole, real part	
(4(*NZ*+*NP*))-(4(*NZ*+*NP*) + 1)	Last pole, imaginary part	
NOTE 1: The length of the register, L, equals the total number of octets required to specify *NZ* zeros and *NP* poles. L = 4(*NZ*+*NP*)+2. If the parameters of the filter are not available, the value of L shall be set to zero. NOTE 2: The real and imaginary parts of the poles and zeros shall be represented by 16-bit, 2's compliment numbers scaled such that 2^{14} corresponds to a value of 1.		

8 Link activation and de-activation

8.1 Link state and timing diagram

8.1.1 Overview

Activation and deactivation may be the result of a command from network management, autonomous action caused by transmission anomalies or application/removal of power. Where connection information is available activation may be linked to transitions in the connection state. Connection information is not applicable to SDH applications and is not currently supported by ATM applications. Further developments are expected to enable the transmission performance advantages for VDSL to be exploited by ATM applications.

During the initial installation or upon demand of the network operator the start-up of a VDSL transceiver may be subject to an installation procedure. This may be needed to check the spectral compatibility of the transceiver. Such a test procedure is for further study.

The activation procedures begin following a successful initial installation. Three activation procedures shall be supported: Cold start, Resume on error, and Warm start. In addition to the three activation procedures, a de-activation procedure and a power-down procedure shall be supported.

The various required and optional activation, steady state, and de-activation states and procedures are illustrated in figure 49.

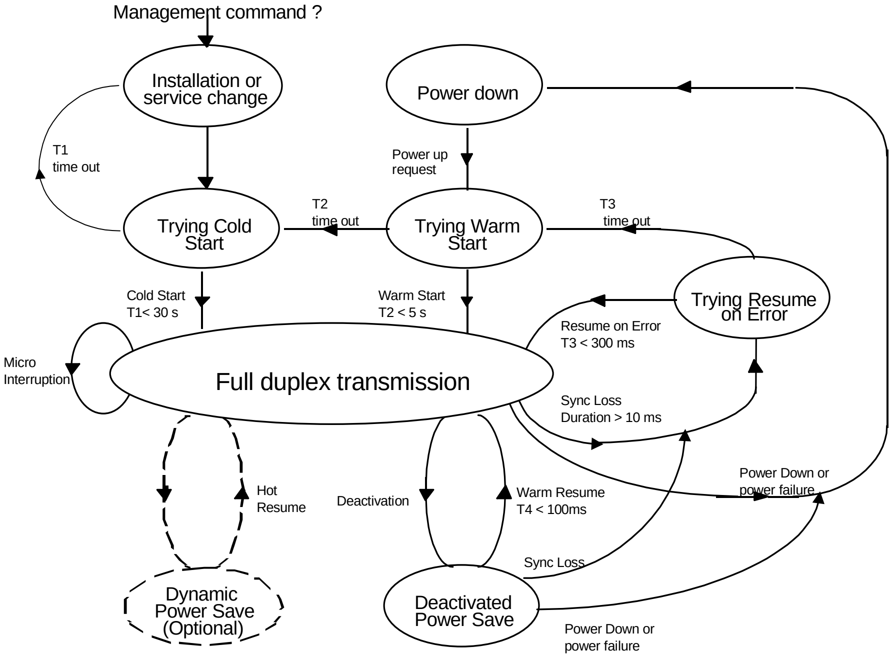


Figure 49: Activation/de-activation state and timing diagram

8.1.2 Activation procedures

8.1.2.1 Cold start

Cold start occurs when power is first applied to the transceiver after intrusive maintenance or if there has been significant change in line characteristics (for example, due to thermal effects). Cold start also occurs when transmission rates and other transmission parameters (such as noise margin, spectral masks, class of service, etc.) are altered. The duration of the cold start phase shall be less than 30 s.

8.1.2.3 Warm start

Warm start occurs when both transceivers start from the power down state. Power down is reached after a transceiver has its AC power removed on purpose (by the customer) via the power down procedure. Warm start occurs only if there have been few or no changes in line characteristics. This procedure may also apply when there is an accidental AC removal or failure at the customer, provided the transceiver can store all necessary data and parameters to avoid the cold start. The duration of the warm start procedure shall be less than 5 s.

8.1.2.4 Resume on error

Resume on error is the start-up process that applies to transceivers that lose synchronisation during steady state transmission, such as after a large impulse hit or an interruption longer than the specified micro-interruption. Resume on error applies only if there have been no changes in line characteristics, and if the clock-frequency recovery circuits can still predict the sample timing. Events leading to loss of synchronisation are longer than a micro-interruption (> 10 ms) and relate to the loss of frequency lock. Completion of the resume on error procedure shall require less than 300 ms.

8.1.2.5 Warm resume

A warm resume is the start-up process that applies to transceivers that after having achieved synchronisation have subsequently responded to a deactivation request. A warm resume is the usual method of activating the VDSL transmission system on receipt of a first incoming or outgoing broadband call request. Warm resume can only be initiated after a de-activation procedure such as the power saving state that keeps both LT and NT VDSL transceivers in a power-saving sleeping mode. A warm resume shall take place in less than 100 ms.

Following completion of one of the activation states, steady-state transmission is achieved.

8.1.3 Steady-state transmission

A transceiver supporting steady-state transmission has completed all start-up processes, including full clock and frame synchronisation. Steady-state also implies that DSP filter adaptations have been completed.

8.1.4 De-activation procedures

8.1.4.1 Introduction

De-activation is the process that places the VDSL transceiver into a power-saving state to reduce ONU heat dissipation and reduce unwanted RF emissions. Both the UNI and the network side must confirm that the VDSL transmission has stopped. De-activation assumes that all broadband traffic has ceased and all calls are closed.

8.1.4.2 Void

8.1.4.3 Power-down procedure

The power-down procedure takes fully operational transceivers at the VTU-O and VTU-R to a power-down state. It can be used when the customer wants to turn off the transceiver AC power, or when the LT cannot support any other power-saving deactivation. To support the use of the normal start activation procedure, VDSL transceivers engaged in the power-down procedure might store transmission-related data such as equaliser states, line characteristics and service-related parameters.

8.1.4.4 Hot resume procedure

Hot resume is the implied immediate power-on procedure to resume transmission whenever the VDSL transceiver alternates between steady state and the optional dynamic power save state.

8.1.5 De-activated power-saving state

This places the digital transmission system in a low power consumption mode when no calls are in progress. The NT and LT consume less power but are capable of detecting a wake up signal from the network side and/or from the UNI and executing a warm resume. When enabled by the Network Management System, this state may be entered automatically after a programmable time following the last broadband call. While in this state the transceivers could continue some (modulation-dependent) form of synchronisation on some of the following levels: clock-sync, frame-sync, equaliser checking and trimming, etc.

8.1.6 Power-down state

The power-down state follows full removal of power at the NT or LT, or the state at the LT when the de-activated power saving state cannot used and VDSL transmission must be halted, such as for maintenance (hardware and/or software).

8.1.7 Dynamic power-save state

The optional dynamic power-save state is intended to reduce the overall power consumption of the VDSL LT transceiver and to reduce the crosstalk level and RF egress from the VDSL system. It may be used when ATM or some other application links are active but not consuming the full bandwidth of the VDSL link. The dynamic power-save state alternates with steady state transmission. No loss of application data shall be tolerated when the VDSL transceiver alternates between steady-state transmission and dynamic power-save state. Support of the dynamic power-save state requires the support of the hot resume procedure.

8.2 Multi-carrier activation/de-activation

8.2.1 Overview

Initialisation of a VTU-O/VTU-R pair includes a variety of tasks. The set of tasks is:

- Definition of a common mode of operation;
- Synchronisation (sample clock alignment and symbol alignment);
- Transfer of frequency band allocation and PSD mask information from the VTU-O to the VTU-R;
- Channel identification;
- Noise identification;
- Calculation of bit and energy tables;
- Exchange of parameters (RS settings, interleaver parameters, VOC settings, bit loading and energy tables).

Information such as PSD mask, frequency band allocation, HAM & RFI bands, bit rate symmetry ratio are initially available at the VTU-O side. The initial value of the cyclic extension is set during handshake and the initial value for the timing advance is set to the default value corresponding to a loop length of 1,5 km.

The time line in figure 50 provides an overview of the initialisation protocol. Following the initial handshake procedure, a full duplex link between the VTU-O and the VTU-R is established. During the training phase, timing advance and upstream power back-off shall be refined. During the channel analysis & exchange state, the two modems measure the characteristics of the channel and agree on a contract that thoroughly defines the communication link.

VTU-O

Activation: Handshake procedures (clause 8.2.3)	Training (clause 8.2.4)	Channel analysis and Exchange (clause 8.2.6)

VTU-R

Activation: Handshake procedures (clause 8.2.3)	Training (clause 8.2.4)	Channel analysis and Exchange (clause 8.2.6)

Figure 50: Overview of initialisation

Transitions between states or various operations are made following completion of the current state or the specific task rather than at fixed times.

During initialisation (but not in the initial handshake phase) a special operation channel (SOC) is defined to exchange information.

8.2.2 SOC protocol

8.2.2.1 Message Format

The SOC uses an HDLC-like format with octet stuffing to delineate the messages as specified in ITU-T Recommendation G.994.1 [6]. Reliable transmission is insured by using either an automatic repeat (AR) mode or a repeat request (RQ) mode. The maximum length of an SOC message shall be 1026 octets. This is the size of the payload before octet stuffing and addition of any flags.

In the AR mode, the message encapsulated in the HDLC frame is automatically repeated. At least four idle flags (0x7E) are inserted in between frames.

In the RQ mode, the messages encapsulated in HDLC frame are sent once. However, the VTU expecting the message can request that the remote side repeat it by sending a REPEAT_REQUEST message. This operation is necessary when the expected message contains bit errors detected by the CRC or when a timeout has expired. After two unsuccessful REPEAT_REQUEST messages, the initialisation is aborted. This means the initiating side will restart the handshake after a silent period. After a number of unsuccessful attempts, the modems shall stop all further attempts. The number of attempts made before the initialisation is aborted shall be chosen by the initiating modem.

A SOC message contains an integer number of octets (8-bits per octet). The octets are sent least significant bit first. A message is subdivided into fields that can contain more than one octet. In the case of multi-octet fields the octet containing the most significant bits is sent first. For example, a field of 16 bits m15,…,m0 is segmented into a first octet B0 = m15,…,m8 and a second octet B1 = m7,…,m0. Some fields can be merged together to form a logical entity called a macro-field, such as "Mask Descriptor".

The structure of an HDLC frame is illustrated in figure 51.

Meaning	**Value** ← 1 octet →
Flag	0x7E
Address Field	Address
Control Field	Control
Information Payload	Payload Octets
Check Sequence	FCS
Check Sequence	FCS
Flag	0x7E

Figure 51: Structure of an HDLC frame

8.2.2.2 O/R IDLE

When the VTU-O is in the idle state (i.e. it has no SOC message to send), it sends O-IDLE. The VTU-R sends R-IDLE when in the idle state.

O-IDLE and R-IDLE correspond to the idle state of the HDLC protocol: 0x7E. This octet is transmitted repeatedly (i.e. there is no HDLC framing).

8.2.2.3 O/R REPEAT_REQUEST

This message requests the remote side to repeat the last unacknowledged message. Note that due to the structure of the initialisation sequence, all messages are acknowledged either by another message or by a symbol type transition. The information payload of the message is one octet: 0x55. In AR mode, REPEAT_REQUEST messages shall be ignored.

When messages are segmented, the REPEAT_REQUEST messages shall be able to ask for the retransmission of a particular segment of a message.

8.2.2.4 Message codes

The information payload of every SOC message starts with a field (of 1 octet) containing a unique code to identify the message and to allow fast and easy recognition of each SOC message. The codes of all the messages used during the initialisation sequence are shown in table 49 in hexadecimal notation. They are arranged and numbered in the order in which they appear. The messages originating at the VTU-O have the MSB set to zero while the messages originating at the VTU-R have the MSB set to one. Some single octet messages have special codes.

Table 49: Message codes used by the SOC

SOC Message	Message code
O/R-REPEAT_REQUEST	0x55 (see note)
R-ACK	0x00 (see note)
R-NACK	0xFF (see note)
O/R-ACK-SEG	0x0F (see note)
O-SIGNATURE	0x01
O-UPDATEn	0x02
O-MSG1	0x03
O-MSG2	0x04
O-CONTRACTn	0x05
O-B&G	0x06
R-MSG1	0x81
R-MSG2	0x82
R-CONTRACT1	0x83
R-MARGINn	0x84
R-B&G	0x85
NOTE: This is the entire payload of the message.	

8.2.2.5 Message fields

Typically, the information contained in an SOC message will be subdivided into a number of fields. It is possible in the future that additional fields may be defined. To ensure backward compatibility, new fields will be appended to the currently defined fields. The modem shall ignore any extra fields following the currently defined fields in a message.

8.2.2.6 Segmentation of messages

Some messages could potentially be large and exceed the maximum allowed frame size of an HDLC frame (1 026 octets). Messages can therefore be segmented before transmission. In order to do this, all messages transmitted during initialisation shall contain a sequence number. The sequence number is stored in one octet. The zero value is reserved (see later). This means that sequence number 255 is followed by sequence number 1.

The sequence number is transmitted in the Address Field of the HDLC frame (see figure 51). The sequence number is used to detect lost messages and to request the retransmission of a particular message. The sequence number is initially set to one and is incremented by one after the transmission of a message. The sequence number is not incremented in response to a REPEAT-REQUEST. The counting of messages starts when the transmission starts using RQ mode instead of automatic repeat mode.

A segmentation index (1 octet) is included in the Control Field of the HDLC frame. The four MSB's of this field indicate the number of segments that make up the total message. The four LSB's indicate the index of the current segment. For instance a value 0x93 indicates the third segment of a total of nine. When the message is not segmented, the value of the field shall be 0x11.

The REPEAT-REQUEST message will behave differently from the other messages. The meaning of the sequence number and the segmentation index is different in this case.

The sequence number field of the REPEAT-REQUEST message shall contain the sequence number of the message to be retransmitted. The default value of zero indicates that the last unacknowledged message shall be resent. If this message contains several segments, only the last segment shall be retransmitted.

Likewise, the segmentation field will contain the number of the segment that shall be retransmitted. The Information payload of the REPEAT-REQUEST message will still consist of one octet with a value 0x55.

During the initialisation procedure a transmitter shall not send a second message without receiving an acknowledgement of the first message. It shall always receive a message from the other side before transmitting again. Therefore, an acknowledgement shall be sent for all but the last segment. Typically, the last segment signals the end of the message and it will therefore be acknowledged by the reply to this message. The ACK-SEG-message (see table 49) shall be used to acknowledge the reception of the other segments. The ACK-SEG-message will have its own sequence number and segment index and does not refer to the segmented message that is being sent.

Once acknowledged, messages (or segments) are not expected to be retransmitted again.

Any REPEAT-REQUEST received with a sequence number ahead of the current sequence number shall be ignored.

In AR mode, segmentation shall be done in the same way, but there will be no acknoledgements (ACK-SEG) between different segments of the same message. Segments shall be sent in order.

8.2.3 Handshake procedure

The handshake procedure is based on ITU-T Recommendation G.994.1 [6] (G.hs). It uses the 4,3125 kHz signalling family and the duplex transmission mode. The initial handshake transmission shall use all carrier sets as defined in ITU-T Recommendation G.994.1 [6] clause 6.1.1. Annex E contains provisional values that will be superseded by ITU-T Recommendation G.994.1 [6]. All carrier frequencies within a carrier set and all carrier sets are simultaneously modulated with the same data bits using Differentially encoded binary Phase Shift Keying (DPSK), as defined in ITU-T Recommendation G.994.1 [6]. During the handshake procedure, the following parameters shall be transmitted:

- The size of IDFT/DFT (note that the size of the (I)FFT is twice the number of tones N_{SC};
- The initial length of the cyclic extension;
- Flags indicating the use of the optional band, 25 kHz ~ 138 kHz.

The parameters above shall be encoded using the Standard information fields defined for VDSL.

The handshake procedure is followed by a silent period after which the VTU-O enters the training state.

The 4,3125 kHz signalling family as defined in ITU-T Recommendation G.994.1 [6] clause 6.1.1 shall be used.

8.2.3.1 Message coding format

The message information field consists of three components: an identification field, a standard information field, and an optional non-standard information field as shown in figure 52. The overall message composition is specific for each message type in the identification field.

Identification (I) field	Standard information (S) field	Non-standard information (NS) field

Figure 52: Information field structure

8.2.3.1.1 Identification field (I)

The identification field specifies the type of message and provides vendor identification and service or application related information. The identification field coding shall be as defined in ITU-T Recommendation G.994.1 [6]. The message type and its field format shall also be as defined in ITU-T Recommendation G.994.1 [6].

8.2.3.1.2 Standard information field (S)

The NPar(1) and SPar(1) coding of the standard information field shall be as defined in ITU-T Recommendation G.994.1 [6]. The coding of NPar(2), SPar(2) and Npar(3) is listed in tables 50 to 54 and are defined in clause 8.2.3.2.

Table 50: Standard information field - ETSI MCM VDSL NPar(2) coding

Bits								
8	7	6	5	4	3	2	1	NPar(2)s
x	x	x	x	x	x	x	1	Upstream use of lower band
x	x	x	x	x	x	1	x	Downstream use of lower band
x	x	x	x	x	1	x	x	Reserved
x	x	x	x	1	x	x	x	STM
x	x	x	1	x	x	x	x	ATM
x	x	1	x	x	x	x	x	G.997.1 - Clear EOC OAM
x	x	0	0	0	0	0	0	No parameters in this octet

Table 51: Standard information field - ETSI MCM VDSL SPar(2) coding

Bits								
8	**7**	**6**	**5**	**4**	**3**	**2**	**1**	SPar(2)s
x	x	x	x	x	x	x	1	Sub-channel information (see note)
x	x	x	x	x	x	1	x	Reserved
x	x	x	x	x	1	x	x	Reserved
x	x	x	x	1	x	x	x	IDFT/DFT size
x	x	x	1	x	x	x	x	Initial length of CE
x	x	1	x	x	x	x	x	Reserved
x	x	0	0	0	0	0	0	No parameters in this octet

NOTE: The use of this bit is for further study and shall be set to zero in CLR, CL, and MS messages. This bit specifies the supported bearer channels for VDSL upstream/downstream transmissions in the TPS-TC sub-layer. The bearer channels are for further study.

Table 52: Standard information field - ETSI MCM VDSL NPar(3) coding for IDFT/DFT size

Bits								
8	7	6	5	4	3	2	1	NPar(3)s
x	x	n_5	n_4	n_3	n_2	n_1	n_0	IDFT/DFT size (n × 256 points)

Table 53: Standard information field - ETSI MCM VDSL NPar(3) coding for CE length - Octet 1

Bits								
8	7	6	5	4	3	2	1	NPar(3)s - Octet 1
x	x	0	0	ce_9	ce_8	ce_7	ce_6	Initial sample length of cyclic extension (high order bits)

Table 54: Standard information field - ETSI MCM VDSL NPar(3) coding for CE length - Octet 2

Bits								
8	7	6	5	4	3	2	1	NPar(3)s - Octet 2
x	x	ce_5	ce_4	ce_3	ce_2	ce_1	ce_0	Initial sample length of cyclic extension (low order bits)

8.2.3.2 Handshake procedures and Message field settings

8.2.3.2.1 Handshake - VTU-O

The detailed procedures for handshake at the VTU-O are defined in ITU-T Recommendation G.994.1 [6]. A VTU-O, after power-up, loss of signal or recovery from errors during the initialisation procedure, shall enter the initial ITU-T Recommendation G.994.1 [6] state C-SILENT1. The VTU-O may transition to the Initialisation Reset Procedure under instruction from the network. From either state, operation shall proceed according to the procedures defined in ITU-T Recommendation G.994.1 [6].

If ITU-T Recommendation G.994.1 [6] procedures select VDSL as the mode of operation, the VTU-O shall transition to state O-QUIET at the conclusion of ITU-T Recommendation G.994.1 [6] operation.

8.2.3.2.1.1 CL messages

A VTU-O wishing to indicate VDSL capabilities during an ITU-T Recommendation G.994.1 [6] CL message shall do so by setting to one the Level 1 SPar(1) ETSI MCM VDSL bit as defined in table C.5. The NPar(2) and SPar(2) fields corresponding to the VDSL Level 1 bit are defined in table 50 and table 51, respectively. For each Level 2 SPar(2) bit that is set to one, a corresponding NPar(3) field shall also be present. These NPar(3) fields are defined in tables 52 through 54. The Level 2 bits in a CL message are defined in tables 55 and 56.

Table 55: VTU-O CL message NPar(2) bit definitions

NPar(2) bit	Definition
Upstream use of lower band	If set to one signifies that the VTU-O is capable of using the band between 25 kHz and 138 kHz and that the band can be used for the upstream transmission.
Downstream use of lower band	If set to one signifies that the VTU-O is capable of using the band between 25 kHz and 138 kHz and that the band can be used for the downstream transmission.
STM	If set to one signifies that the VTU-O can be configured for STM bit synchronous transport.
ATM	If set to one signifies that the VTU-O can be configured for ATM cell transport.
EOC-Clear	If set to one signifies that the VTU-O supports transmission and reception of ITU-T Recommendation G.997.1 [8] OAM frames.

Table 56: VTU-O CL message SPar(2) bit definitions

SPar(2) bit	Definition
IDFT/DFT size	Always set to one in a CL message. It indicates the maximum IDFT/DFT size that the VTU-O can support. The value shall be present in the corresponding NPar(3) field.
Initial length of CE	If set to zero, it indicates that the VTU-O can only support the mandatory CE length of $40x2^n$ with the number of tones equal to $256x2^n$. If set to one, it indicates the initial sample length of the cyclic extension that the VTU-O can support. It also signifies that the VTU-O can support CE lengths other than the mandatory length. The value shall be present in the corresponding NPar(3) field. If one of the modems only supports the mandatory value, then this value shall be used.

At least one of the STM and ATM bits shall be set to one in a CL message.

8.2.3.2.1.2 MS messages

A VTU-O selecting VDSL operation in an ITU-T Recommendation G.994.1 [6] MS message shall do so by setting to one the Level 1 SPar(1) ETSI MCM VDSL bit as defined in table C.5. The NPar(2) and SPar(2) fields corresponding to this bit are defined in tables 50 and 51 respectively. For each Level 2 SPar(2) bit set to one, a corresponding NPar(3) field shall also be present as defined in tables 52 through 54. The Level 2 bits in an MS message from the VTU-O are defined in tables 57 and 58.

Table 57: VTU-O MS message NPar(2) bit definitions

NPar(2) bit	Definition
Upstream use of lower band	If this bit was set to one in the last CL message and the last CLR message then it shall be set to one. It signifies that the band between 25 kHz and 138 kHz shall be used for the upstream transmission.
Downstream use of lower band	If this bit was set to one in the last CL message and the last CLR message then it shall be set to one. It signifies that the band between 25 kHz and 138 kHz shall be used for the downstream transmission.
STM	If this bit was set to one in the last CL message and the last CLR message then it shall be set to one. It signifies that the VTU-O and VTU-R shall be configured for STM bit synchronous transport.
ATM	If this bit was set to one in the last CL message and the last CLR message then it shall be set to one. It signifies that the VTU-O and VTU-R shall be configured for ATM cell transport.
EOC-Clear	If this bit was set to one in the last CL message and the last CLR message then it shall be set to one. It signifies that the VTU-O and VTU-R may transmit and receive ITU-T Recommendation G.997.1 [8] OAM frames.

Table 58: VTU-O MS message SPar(2) bit definitions

SPar(2) bit	Definition
IDFT/DFT size	Always set to one in an MS message. It indicates the maximum IDFT/DFT size that the VTU-O and VTU-R can support. The value shall be present in the corresponding NPar(3) field.
Initial length of CE	If set to zero, it indicates that the VTU-O can only support the mandatory CE length of $40x2^n$ with the number of tones equal to $256x2^n$. If set to one, it indicates the initial sample length of the cyclic extension that the VTU-O can support. It also signifies that the VTU-O can support CE lengths other than the mandatory length. The value shall be present in the corresponding NPar(3) field. If one of the modems only supports the mandatory value, then this value shall be used.

If "Upstream use of lower band" and "Downstream use of lower band" are both set to one in the CL and CLR messages, only one of the bits shall be set to one in an MS message sent from the VTU-O and the VTU-O shall choose the transmission direction of the lower band. If the VTU-O and VTU-R have no common usage of the lower band, both bits shall be set to zero in an MS message sent from the VTU-O.

Only one of the STM and ATM bits shall be set to one in an MS message sent from the VTU-O. If both bits are set in the CL and CLR messages, the VTU-O shall choose the transport mode.

8.2.3.2.2 Handshake - VTU-R

The detailed procedures for handshake at the VTU-R are defined in ITU-T Recommendation G.994.1 [6]. A VTU-R, after power-up, loss of signal or recovery from errors during the initialisation procedure, shall enter the initial ITU-T Recommendation G.994.1 [6] state R-SILENT0. Upon command from the host controller, the VTU-R shall initiate handshaking by invoking the Initialisation Reset Procedure. Operation shall then proceed according to the procedures defined in ITU-T Recommendation G.994.1 [6].

If ITU-T Recommendation G.994.1 [6] procedures select VDSL as the mode of operation, the VTU-R shall transition to state R-QUIET at the conclusion of ITU-T Recommendation G.994.1 [6] operation.

8.2.3.2.2.1 CLR messages

A VTU-R wishing to indicate VDSL capabilities during in an ITU-T Recommendation G.994.1 [6] CLR message shall do so by setting to one the Level 1 SPar(1) ETSI MCM VDSL bit as defined in table C.5. The NPar(2) and SPar(2) fields corresponding to the VDSL Level 1 bit are defined in tables 50 and 51 respectively. For each Level 2 SPar(2) bit set to one a corresponding NPar(3) field shall also be present. These NPar(3) fields are defined in tables 52 through 54. The Level 2 bits in a CLR message are defined in tables 59 and 60.

Table 59: VTU-R CLR message NPar(2) bit definitions

NPar(2) bit	Definition
Upstream use of lower band	If set to one signifies that the VTU-R is capable of using the band between 25 kHz and 138 kHz and that the band can be used for the upstream transmission.
Downstream use of lower band	If set to one signifies that the VTU-R is capable of using the band between 25 kHz and 138 kHz and that the band can be used for the downstream transmission.
STM	If set to one signifies that the VTU-R can be configured for STM bit synchronous transport.
ATM	If set to one signifies that the VTU-R can be configured for ATM cell transport.
EOC-Clear	If set to one signifies that the VTU-R supports transmission and reception of ITU-T Recommendation G.997.1 [8] OAM frames.

Table 60: VTU-R CLR message SPar(2) bit definitions

SPar(2) bit	Definition
IDFT/DFT size	Always set to one in a CLR message. It indicates the maximum IDFT/DFT size that VTU-R can support. The value shall be present in the corresponding NPar(3) field.
Initial length of CE	If set to zero, it indicates that the VTU-O can only support the mandatory CE length of $40x2^n$ with the number of tones equal to $256x2^n$. If set to one, it indicates the initial sample length of the cyclic extension that the VTU-O can support. It also signifies that the VTU-O can support CE lengths other than the mandatory length. The value shall be present in the corresponding NPar(3) field. If one of the modems only supports the mandatory value, then this value shall be used.

At least one of the STM and ATM bits shall be set to one in a CLR message.

8.2.3.2.2.2 MS messages

A VTU-R selecting VDSL operation in an ITU-T Recommendation G.994.1 [6] MS message shall do so by setting to one the Level 1 SPar(1) ETSI MCM VDSL bit as defined in table C.5. The NPar(2) and SPar(2) fields corresponding to this bit are defined in tables 50 and 51 respectively. For each Level 2 SPar(2) bit set to one a corresponding NPar(3) field shall also be present, as defined in tables 52 through 54. The Level 2 bits in an MS message from the VTU-R are defined in tables 61 and 62.

Table 61: VTU-R MS message NPar(2) bit definitions

NPar(2) bit	Definition
Upstream use of lower band	If this bit was set to one in the last CL message and the last CLR message then it shall be set to one. It signifies that the band between 25 kHz and 138 kHz shall be used for the upstream transmission.
Downstream use of lower band	If this bit was set to one in the last CL message and the last CLR message then it shall be set to one. It signifies that the band between 25 kHz and 138 kHz shall be used for the downstream transmission.
STM	If this bit was set to one in the last CL message and the last CLR message then it shall be set to one. It signifies that the VTU-O and the VTU-R shall be configured for STM bit synchronous transport.
ATM	If this bit was set to one in the last CL message and the last CLR message then it shall be set to one. It signifies that the VTU-O and the VTU-R shall be configured for ATM cell transport.
EOC-Clear	If this bit was set to one in the last CL message and the last CLR message then it shall be set to one. It signifies that the VTU-O and the VTU-R may transmit and receive ITU-T Recommendation G.997.1 [8] OAM frames.

Table 62: VTU-R MS message SPar(2) bit definitions

SPar(2) bit	Definition
IDFT/DFT size	Always set to one in an MS message. It indicates the maximum IDFT/DFT size that the VTU-O and the VTU-R can support. The value shall be present in the corresponding NPar(3) field.
Initial length of CE	If set to zero, it indicates that the VTU-O can only support the mandatory CE length of $40x2^n$ with the number of tones equal to $256x2^n$. If set to one, it indicates the initial sample length of the cyclic extension that the VTU-O can support. It also signifies that the VTU-O can support CE lengths other than the mandatory length. The value shall be present in the corresponding NPar(3) field. If one of the modems only supports the mandatory value, then this value shall be used.

If "Upstream use of lower band" and "Downstream use of lower band" are both set to one in the CL and CLR messages, only one of the bits shall be set to one in an MS message sent from the VTU-R and the VTU-R shall choose the transmission direction of the lower band. If the VTU-O and VTU-R have no common usage of the lower band, both bits shall be set to zero in an MS message sent from the VTU-R.

Only one of the STM and ATM bits shall be set to one in an MS message sent from the VTU-R. If both bits are set in the CL and CLR messages, the VTU-R shall choose the transport mode.

8.2.4 Training state

Figure 53 gives an overview of the sequence of SOC messages and symbol types that are transmitted by the VTU-O and VTU-R during the training phase.

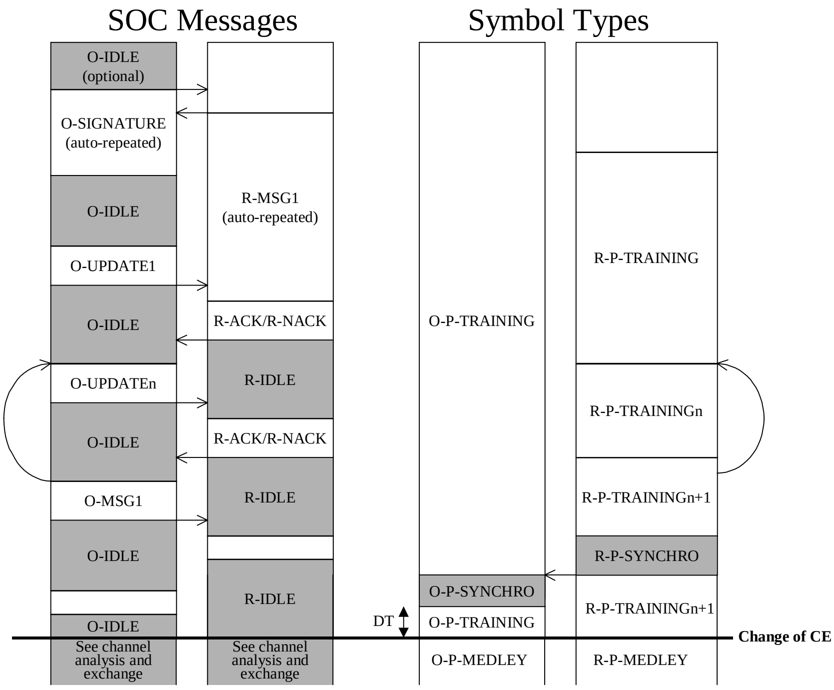


Figure 53: Timeline of training phase

8.2.4.1 Sequence of messages and symbols during training.

The sequence of messages is illustrated in figure 53.

The VTU-O initiates the start of the training phase by transmitting O-SIGNATURE using the symbol type O-P-TRAINING. The message O-SIGNATURE is sent over the SOC using AR mode. During this first phase, the modems synchronise.

Once the VTU-R is synchronised and has successfully decoded the O-SIGNATURE message, it transmits the symbol R-P-TRAINING. The SOC will transmit the message R-MSG1. The VTU-O keeps transmitting the O-P-TRAINING symbol and the O-SIGNATURE message. Optionally the VTU-O can transmit the O-IDLE message (since O-SIGNATURE has already been decoded at the VTU-R). During this phase the VTU-O can optimise timing advance and measure the received PSD at the VTU-O side. Once this is completed the VTU-O can initiate the next phase by transmitting the SOC message O-UPDATE1.

In this last phase, the transmit PSD of the VTU-R is tuned in an iterative procedure. The VTU-O sends a change request by sending the O-UPDATEn message. The VTU-R responds to each message by sending an R-ACKn or R-NACKn reply. Five symbols after the R-ACK message is sent, the VTU-R transmits the symbol R-P-TRAININGn+1.

If R-NACK is sent the VTU-O continues the iterative process by sending O-UPDATEn+1 or ends the process by sending O-MSG1.

This last phase shall be terminated by the VTU-O by sending the SOC message O-MSG1. Upon detection of O-MSG1, the VTU-R shall transmit the symbol R-P-SYNCHRO1. The VTU-O shall reply with O-P-SYNCHRO1. Both sides shall simultaneously update the *CE*, reset the quadrant scramblers and enter the next state (channel analysis and exchange) *DT* seconds after the last symbol of O-P-SYNCHRO1 has been sent. *DT* shall correspond to 15 DMT symbols (using the initial value for the cyclic extension).

8.2.4.2 Messages and symbols sent by the VTU-O

8.2.4.2.1 SOC messages

During the training phase, the VTU-O will send the SOC messages O-SIGNATURE, O-UPDATEn and O-MSG1 as well as the idle message O-IDLE.

Clause 8.2.4.2.2 describes how the messages are modulated onto the transmit symbol.

8.2.4.2.1.1 O-SIGNATURE

This message contains nine fields:

- message descriptor;
- the bands used in the downstream direction;
- the bands used in the upstream direction;
- the bands notched for RFI ingress/egress reduction;
- transmit PSD in the downstream direction;
- whether the VTU-O shall specify a maximum allowed receive PSD or a maximum allowed transmit PSD;
- the PSD mask in the upstream direction;
- the reference PSD or maximum allowed transmit PSD in the upstream direction;
- the overall length of the window at the transmitter (β).

O-SIGNATURE is repeated automatically using the AR mode.

Table 63: Description of message O-SIGNATURE

Field content	Field or Macro-field type
Message descriptor	Message code (1 octet)
Band used in downstream	Band descriptor
Band used in upstream	Band descriptor
Bands notched for RFI reduction	Band descriptor
Transmit PSD in downstream	PSD descriptor
Receive or transmit PSD mask selector	1 octet
PSD mask in upstream	PSD descriptor
Maximum allowed receive PSD in upstream direction	PSD descriptor
Length of the window at the transmitter	1 octet

Fields two, three and four contain a "band descriptor". The first octet of these fields contains the number of bands being described. After the first octet, groups of 3 consecutive octets describe each band. The first 12 bits (0-11) contain the index of the tone that resides at the lower edge of the band. The last 12 bits (12-23) contain the index of the tone at the upper edge of the band. The starting and ending tones are included in the band. For example, a field value 0x400200 means that all tones from 0x200 = 512 to 0x400 = 1 024 are used, including tones 512 and 1 024.

Table 64: Band descriptor

Octet	Content of field
1	Number of bands to be described
2 to 4	Bits 0 to 11: Start tone index of band 1 Bits 12 to 23: Ending tone index of band 1
5 to 7 (if applicable)	Bits 0 to 11: Start tone index of band 2 Bits 12 to 23: Ending tone index of band 2
etc.	etc.

Fields five, seven and eight contain a "PSD descriptor". The first octet of this field contains the number of tones being specified. After the first octet, groups of 3 consecutive octets describe the PSD. The first 12 bits (0-11) contain the index of the tone being described. The last 12 bits (12-23) contain the PSD level. The PSD level is an integer multiple of 0,5dB with an offset of -140dBm/Hz. For example a field value of 0x0A0400 means a PSD of 0x0A0 x 0,5 - 40 = -60 dBm/Hz on tone index 0x400 = 1 024. The PSD level of intermediate unspecified tones is obtained using a linear interpolation between the given PSD points (in dBm/Hz) with the frequency axis on a linear scale.

The sixth field of O-SIGNATURE is a flag indicating whether the transmit PSD at the VTU-R shall be calculated from the maximum receive PSD (field eight) or not. If this field has the value 0xFF, the upstream transmit PSD shall be calculated using the reference PSD given in field eight. If this field has a value of 0x00, the transmit PSD at the VTU-R shall be determined from the maximum upstream PSD only (field seven).

Table 65: PSD descriptor

Octet	Content of field
1	Number of tones to be described
2 to 4	Bits 0 to 11: Index of first tone being described Bits 12 to 23: PSD level in steps of 0,5 dB with an offset of -140 dBm/Hz
5 to 7 (if applicable)	Bits 0 to 11: Index of second tone being described Bits 12 to 23: PSD level in steps of 0,5 dB with an offset of -140 dBm/Hz
etc.	etc.
NOTE: The index *n* refers to frequencies used in the definition of the PSD mask.	

The last field in the O-SIGNATURE message contains the length of the transmit window, in samples at the sampling rate corresponding to the selected value of N. This sampling rate is given by $2N_{SC}\Delta f$ (i.e. two times the Nyquist frequency of an N_{SC}-tone multi-carrier signal.

8.2.4.2.1.2 O-UPDATEn

This message instructs the VTU-R to tune its transmit PSD to optimise the power back-off and allows the VTU-O to optimise the timing advance. O-UPDATEn is repeated only at the request of the VTU-R (see R-REPEAT_REQUEST in clause 8.2.2.3). This message contains a single "update descriptor" field. The first octet of the update descriptor contains the number of specified tones. Each specified tone is described using 3 octets and contains the gain level (12bits) at a given tone index (12 bits). The gain level is the amplification applied on one tone. It is specified in 2's complement format using 0,25 dB steps. For example a field value of 0x030400 means a PSD amplification of 0x030 x 0,25 = 12 dB on the tone index 0x400 = 1 024. The gain on unspecified tones is derived by linear interpolation between tones specified using a dB gain scale and a linear frequency scale.

The last field defines the timing advance correction in samples at the sampling rate corresponding to the negotiated value of N. The value is encoded in a 16 bit field using 2's complement format.

Table 66: Description of message O-UPDATEn

Field content	Field or Macro-field type
Message descriptor	Message code (1 octet)
Gain update	Update descriptor
Timing advance correction	2 octets

Table 67: Update descriptor

Octet	Content of field
1	Number of tones to be described
2 to 4	Bits 0 to 11: Index of first tone being described Bits 12 to 23: Gain level adjustment in 2's complement in steps of 0,25 dB
5 to 7 (if applicable)	Bits 0 to 11: Index of second tone being described Bits 12 to 23: Gain level adjustment in 2's complement in steps of 0,25 dB
etc.	etc.

8.2.4.2.1.3 O-MSG1

This message contains the final length of the CE expressed in samples at the sampling frequency corresponding to the negotiated value of N. The message is described in table 68. The O-MSG1 message is sent once but can be repeated if the VTU-R sends a repeat request.

Table 68: Description of message O-MSG1

Field content	Field or Macro-field type
Message descriptor	Message code (1 octet)
Final length of CE	2 octets

The final CE length shall be applied from the beginning of the channel analysis state.

8.2.4.2.2 Symbol types transmitted by the VTU-O

During the entire training phase the VTU-O modem shall transmit the O-P-TRAINING symbol. To signal the end of the training phase, O-P-SYNCHRO1 shall be transmitted.

8.2.4.2.2.1 O-P-TRAINING

O-P-TRAINING is a wideband signal that allows the VTU-R to synchronise and to measure the attenuation over the channel. It uses all of the allowed downstream tones (determined by management parameters) modulated in 4QAM. The symbol length is N + CE samples. N and CE are negotiated during the initial ITU-T Recommendation G.994.1 [6] phase. Windowing is applied at the transmitter, with the overall window length β set by OAM. The transmitter PSD is defined by the network management. O-P-TRAINING carries one octet of information per DMT symbol. The information mapping is summarised in table 69, where the constellation labels correspond to the points in figure 7.

Table 69: O-P-TRAINING bit mapping

Tone index	Constellation point (see note)
Even	00
1, 11, 21, …	SOC message bits 0 and 1
3, 13, 23, …	SOC message bits 2 and 3
5, 15, 25, ...	SOC message bits 4 and 5
7, 17, 27, ….	SOC message bits 6 and 7
9, 19, 29, …	00

NOTE 1: If the two SOC message bits *i* and *i+1* are denoted as S_i and S_{i+1} respectively, the constellation point is (S_i, S_{i+1}).

The selected constellation points are pseudo-randomly rotated by 0, π/2, π, 3π/2 depending on a 2-bit pseudo-random number. The DC component is not rotated. The rotation is equivalent to the following transformation of the (X, Y) co-ordinates:

Table 70: Pseudo-random transformation

d_{2n}, d_{2n+1}	Angle of rotation	Final co-ordinates
0 0	0	(X,Y)
0 1	π/2	(-Y,X)
1 1	π	(-X, -Y)
1 0	3π/2	(Y, -X)

NOTE 2: (X,Y) is the original constellation point.

The 2-bit sequence is the output of a pseudo-random bit generator defined by the following equation:

$$d_n = d_{n-9} \oplus d_{n-11}.$$

Two bits of the bit generator are mapped onto each tone including those at DC, however the bits for DC are overwritten by zeros. The bit generator is illustrated in figure 54.

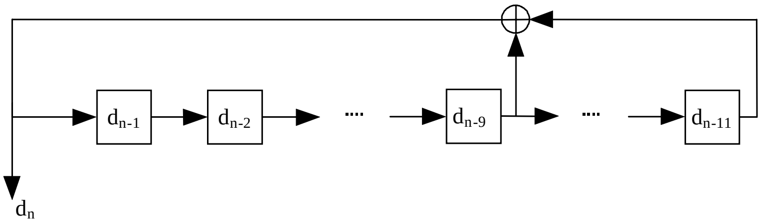


Figure 54: Pseudo-random bit generator

For a VDSL system that uses *N* tones, 2*N* bits shall be generated by the scrambler every DMT symbol (d_0 d_1 d_2 … d_{2N-2} d_{2N-1}). These 2*N* bits are generated in both transmission directions. The first two bit (d_0 d_1) correspond to tone 0, the next two bits (d_2 d_3) to tone 1 etc. In general, bits (d_{2j} d_{2j+1}) correspond to tone j. Although not all tones are used for transmission all 2*N* bits shall be generated.

Initially, all the registers are set to one. During the training phase the scrambler is reset at the start of every symbol (meaning that all registers are reset to one) and therefore the same 2*N* bits will be used every symbol. This means that each tone always has the same two bits assigned to it for successive DMT symbols.

In the channel analysis state the scrambler will not be reset but keeps running from one symbol to the next. The sequence shall be random in time for one single tone. There shall be no correlation between the two bits that are mapped on tone j during symbol m and the two bits that are mapped on the same tone during symbol m+1. In order to guarantee this for all allowed values of *N*, a number of output bits from the quadrant scrambler will be skipped when going from symbol m to symbol m+1. The number of bits skipped shall be four.

8.2.4.2.2.2 O-P-SYNCHRO1

O-P-SYNCHRO1 is a wideband signal that allows the VTU-O and the VTU-R to simultaneously step into the Channel Analysis & Exchange State. It shall use all of the allowed downstream tones modulated using 4QAM. The symbol length is N+CE samples, where the values of N and CE are set to the values specified during the initial handshake. Windowing shall be applied at the transmitter and the overall window length β is set to the value specified in O-SIGNATURE (clause 8.2.4.2.1.1). The PSD mask is defined by network management. The overall duration of O-P-SYNCHRO1 is 15 DMT symbols. The value 11 shall be mapped on all the allowed downstream tones for the first five and the last five DMT symbols. The value 00 shall be mapped on the allowed downstream tones for the five remaining DMT symbols. The selected constellation points shall be pseudo-randomly rotated by 0, $\pi/2$, π or $3\pi/2$ depending on the 2-bit random number provided by the pseudo-random bit generator defined in clause 8.2.4.2.2.1. The scrambler is reset every symbol.

8.2.4.3 Messages and symbols sent by the VTU-R

8.2.4.3.1 SOC messages

During the training phase the VTU-R sends the SOC messages R-MSG1, R-ACKn and R-NACKn as well as the idle message R-IDLE.

Clause 8.2.4.3.2 describes how the messages are modulated onto the transmit symbol.

8.2.4.3.1.1 R-MSG1

This message contains the description of the transmit PSD of the VTU-R. This PSD is encoded in one macro-field "PSD Descriptor" as described in clause 8.2.4.2.1.1. The PSD level on unspecified tones is derived using a linear interpolation between the PSD in dBm/Hz of the specified tones, using a linear frequency axis.

The method used to provide an initial estimate for the transmit PSD depends on the value of the selector flag octet in O-SIGNATURE. If the flag indicates that the modem shall obey a reference PSD mask at the VTU-O, it is computed by dividing the maximum allowed receive PSD by the estimate of the upstream channel insertion loss. Otherwise the transmit PSD is set to the upstream PSD mask that is transferred from the VTU-O to the VTU-R in the O-SIGNATURE message.

R-MSG1 also indicates whether the optional echo canceller state shall be entered or bypassed. R-MSG1 is repeated automatically until the VTU-R detects O-UPDATE.

Table 71: Description of R-MSG1

Field content	**Field or Macro-field type**
Message descriptor	Message code (1 octet)
Transmit PSD in upstream	PSD descriptor
Echo canceller training flag	0x00: no echo canceller training 0xFF: echo canceller training required

8.2.4.3.1.2 R-ACKn

This message is an acknowledgement of the O-UPDATEn message. It is sent only once unless the VTU-O requests a re-transmission. The message contains the octet 0x00. Five symbols after sending this message the VTU-R changes its symbol type from R-P-TRAININGn to R-P-TRAININGn+1. On reception of this message the VTU-O could decide to ask for a new update by sending O-UPDATEn+1 or to end the iterative VTU-R PSD optimisation by sending O-MSG1.

If the VTU-R receives a REPEAT_REQUEST message on this message, it takes the following actions to repeat the message:

- Return to the symbol type R-P-TRAININGn;
- Send back R-ACKn;
- Return to the symbol type R-P-TRAININGn+1.

8.2.4.3.1.3 R-NACKn

This message is sent when the VTU-R is unable to apply the update encoded in O-UPDATEn. It is sent only once unless the VTU-O requests a re-transmission. The message contains one octet 0xFF. Upon reception of this message the VTU-O can decide to continue the initialisation by sending either O-UPDATEn or O-MSG1 or to abort the initialisation.

8.2.4.3.2 Symbol types transmitted by the VTU-R

During the training phase the VTU-R shall transmit various R-P-TRAININGn symbols. The transition from training to channel analysis and exchange is triggered by the transmission of R-P-SYNCHRO1.

8.2.4.3.2.1 R-P-TRAININGn

R-P-TRAININGn is a wideband signal that allows the VTU-O to optimise the VTU-R timing advance (TA) and the VTU-R transmitted PSD mask in order to be compliant with the power back-off requirement. R-P-TRAINING uses all of the upstream tones modulated in 4QAM. The symbol length is N + CE samples. N and CE are specified during the initial handshake phase. Windowing is applied at the transmitter, with the window length β as specified in O-SIGNATURE. The PSD mask is chosen to be compliant with the power-back-off requirement defined in O-SIGNATURE (clause 8.2.4.2.1.1). Afterward the VTU-O instructs the VTU-R to tune the upstream transmit PSD based on information in O-UPDATEn (clause 8.2.4.2.1.2). At the first iteration (R-P-TRAINING1) the timing advance is set to a value corresponding to the maximum loop length (1,5 km or 7,5 μs). Afterwards the timing advance is updated as per the instructions transmitted by the VTU-O by means of O-UPDATEn (clause 8.2.4.2.1.2). R-P-TRAINING carries one octet of information per DMT symbol. The information mapping is summarised in table 72.

Table 72: R-P-TRAINING bit mapping

Tone index	Constellation point
Even	00
1, 11, 21, …, 10n+1, …	SOC message bits 0 and 1
3, 13, 23, …, 10n+3, …	SOC message bits 2 and 3
5, 15, 25, …, 10n+5, …	SOC message bits 4 and 5
7, 17, 27, …, 10n+7, …	SOC message bits 6 and 7
9, 19, 29, …, 10n+9, …	00

The selected constellation points are pseudo-randomly rotated by 0, π/2, π, 3π/2 depending on a 2-bit pseudo-random sequence provided by the pseudo-random generator described in clause 8.2.4.2.2.1. The DC component is not rotated. The generator is reset at the start of every symbol.

8.2.4.3.2.2 R-P-SYNCHRO1

R-P-SYNCHRO1 is a wideband signal that allows the VTU-O and the VTU-R to simultaneously step into the Channel analysis & Exchange State. It uses all of the allowed upstream tones modulated in 4QAM. The symbol length is N + CE samples. N and CE are specified during the initial ITU-T Recommendation G.994.1 [6] phase. Windowing is applied at the transmitter and the overall window length β is set to the value specified in O-SIGNATURE. The transmitter PSD mask meets the power back-off requirements. The timing advance is applied and corresponds to the loop length. The duration of R-P-SYNCHRO1 is 15 DMT symbols. A fixed phase value of 11 is mapped on all the upstream tones for the first five and last five symbols. A fixed phase value of 00 is mapped on all the upstream tones for the middle five symbols. The selected constellation points are pseudo-randomly rotated by 0, π/2, π, 3π/2 depending on the 2-bit random number generated by a pseudo-random bit generator defined in clause 8.2.4.2.2.1. The generator is reset at the start of every symbol.

8.2.5 Echo canceller training state (optional)

The echo canceller state is optional in the sense that it will be skipped when modems do not need to train an echo canceller. Any modem that requires this state shall be able to demand that it is included in the initialisation sequence.

Some modems may use an (analog) echo canceller that will have to be trained at some point during the initialisation sequence. During the training of an echo canceller, the other side should be completely quiet.

Such a silent period exists for the VTU-O at the beginning of the training state. Here, the VTU-R will be quiet until it has decoded O-SIGNATURE correctly. This period could be used by the VTU-O to train its echo canceller. It could even make the available period longer by delaying the transmission of O-SIGNATURE and sending IDLE messages instead.

The VTU-R does not have a convenient echo canceller training state however. Therefore, the modems can follow two different paths after the PSD training. It is signalled in R-MSG1 whether an echo canceller training state is required for the VTU-R. If so, both modems will go to the echo canceller training state at the end of the PSD training state.

In the echo canceller training state, the VTU-O will go completely silent after transmission of O-MSG1 and perform no operations, other than listening to the signal on the line. After reception of O-MSG1, the VTU-R will keep transmitting the same signal as during the last phase of the training state.

In this state, the VTU-R can train its echo canceller with a proprietary algorithm. After completion of this task, the VTU-R will go completely silent. This transition (no power on the line) should be detected by the VTU-O, which will react by returning to the beginning of the training state (synchronisation). Note that the situation is now identical to that at the beginning of initialisation: the VTU-R is quiet and the VTU-O starts the communication.

After performing an echo canceller training, R-MSG1 should be changed such that at the second pass through the PSD training state, the sequence will continue with the channel analysis state and not perform another echo canceller training.

At the second pass, the VTU-R already knows its correct transmit PSD, so the training phase will be automatically shortened. There is no need to explicitly bypass any stages.

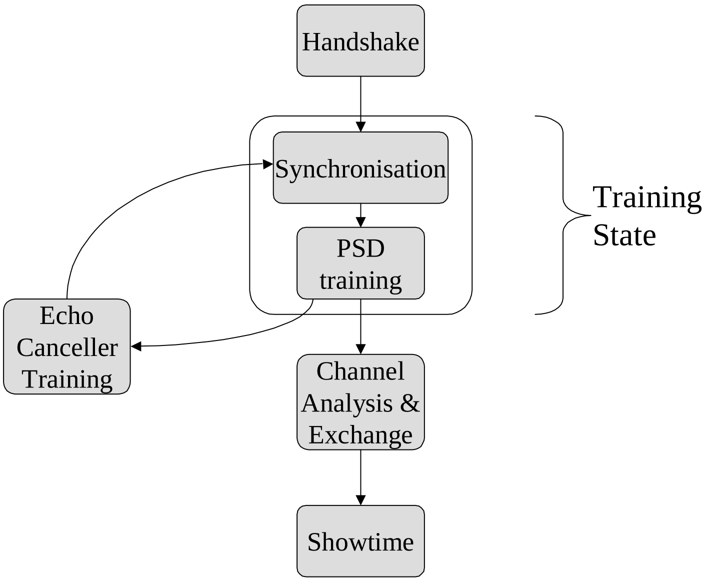


Figure 55: Position of (optional) echo canceller training state in the initialisation procedure

8.2.6 Channel analysis and exchange

Figure 56 gives an overview of the sequence of SOC messages and symbol types during the channel analysis and exchange phase.

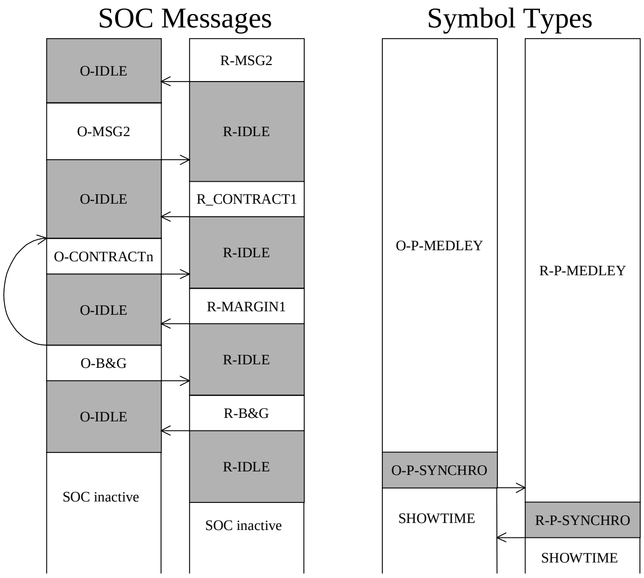


Figure 56: Timeline of the channel analysis and exchange phase

8.2.6.1 Sequence of messages and symbols during channel analysis and exchange

The sequence of SOC messages and symbols is depicted in figure 56. Upon entering the channel analysis and exchange state the VTU-R transmits symbol type R-P-MEDLEY, while the VTU-O transmits O-P-MEDLEY. The VTU-R sends the R-MSG2 message to transfer information about its bit allocation capabilities and other features. After receiving this message the VTU-O will do the same by sending the O-MSG2 message.

After receiving O-MSG2 the VTU-R sends the R-CONTRACT1 message. The VTU-O and VTU-R then enter an iterative procedure to agree on a contract for the transmission. At the n-th iteration, the VTU-O will send O-CONTRACTn. The VTU-R will reply with R-MARGINn.

To end the contract negotiations, the VTU-O transmits the message O-B&G. After receiving this message, the VTU-R sends the message R-B&G. After receiving R-B&G, the VTU-O initiates the transition to showtime by sending the symbol O-P-SYNCHRO2, which allows a simultaneous transition at both sides in the downstream direction. The VTU-R will reply by sending the message R-P-SYNCHRO2, which allows a simultaneous transition in the upstream direction.

8.2.6.2 Messages and symbols send by the VTU-O

8.2.6.2.1 SOC messages

During the channel analysis and exchange phase the VTU-O will send the SOC messages O-MSG1, O-CONTRACTn and O-B&G as well as the idle message O-IDLE.

Clause 8.2.6.2.2 describes how the messages are modulated onto the transmit symbols.

The sequence in which the messages are sent is illustrated in figure 56.

During this state, all messages are sent in RQ-mode (clause 8.2.2.1).

8.2.6.2.1.1 O-MSG2

This message contains information about the capabilities of the VTU-O to negotiate a contract.

Table 73: Description of O-MSG2

Field content	Field or macro-field type	Remark
Message descriptor	1 octet	See table 49
Minimum Margin	1 octet	In units of 0,5 dB
Maximum constellation size in downstream	1 octet	Maximum number of bits per tone
RS settings supported by VTU-O	1 octet	0x00: only mandatory settings 0xFF: all settings (see note 1)
Interleaver setting supported by VTU-O	1 octet	0x00: only mandatory settings 0xFF: all settings 0xNN: NN = number of settings (0x00 < NN < 0xFF)
Detailled interleaver setting description	0 octets if NN = 0x00 0 octets if NN = 0xFF NN x 4 octets otherwise	Interleaver description see table 74
Maximum power in downstream	1 octet	In units of 0,25 dBm
Required interleaver delay	1 octet	In units of 0,5 ms (see note 2)
Maximum number of EOC octets per frame in downstream	1 octet	Number of EOC octets per frame
Maximum number of VOC octets per frame in downstream	1 octet	Number of VOC octets per frame
Support of express swapping	1 octet	0x00: Not supported 0xFF: Supported
j_{max}	1 octet	Maximum value of j_{max} supported by the VTU-O (see note 3)
NOTE 1: All settings means the values (for the redundancy) that are specified in clause 6.4.2. NOTE 2: This field can be set to zero in order to emulate the fast channel. This field is used for the creation of R-CONTRACT1 even if dual latency is used later. NOTE 3: Specification of j_{max} = k means that all values from 0 to k are supported.		

The structure of the interleaver description is shown in table 74. It lists the parameters of the interleaver. A number of these macrofields (depending on the value of NN) can be included in O/R-MSG2.

Table 74: Interleaver description

Field	Field or macrofield type
I	1 octet
Q	1 octet
M_{min}	1 octet
M_{max}	1 octet
NOTE: The four fields are repeated for each interleaver setting.	

8.2.6.2.1.2 O-CONTRACTn

This message consists of a proposal for an upstream and downstream contract and the EOC and VOC capacity, based on the EOC and VOC capabilities of both modems (exchanged during O-MSG1 and R-MSG1). The downstream contract is based on the information carried by R-CONTRACT1. Ideally the downstream contract is the same as the one proposed in R-CONTRACT1.

Table 75 describes O-CONTRACTn. Both upstream and downstream values are encoded in a macro-field called "Contract Descriptor". The contract descriptor is defined in table 73. This macro-field contains all the necessary data for the setting of the framing.

Table 75: Description of O-CONTRACTn

Field	Field or macro-field type
Message descriptor	Message code (1 octet)
Downstream contract	Contract Descriptor
Upstream contract	Contract Descriptor
EOC capacity	Number of EOC octets per frame (1 octet)
VOC capacity	Number of VOC octets per frame (1 octet)

Table 76: Contract Descriptor

Field	Field or macro-field type	Remark
Rate in fast channel	2 octets	In multiple of 64 kbps
RS setting in fast channel	2 octets	b15 → b8: RS overhead b7 → b0: RS codeword length
Rate in slow channel	2 octets	In multiple of 64 kbps
RS setting in slow channel	2 octets	b15 → b8: RS overhead b7 → b0: RS codeword length
Interleaver setting	2 octets	b15 → b8: M (see note 1) b7 → b0: I
NOTE: The value *I* must be a divider of the RS codeword length.		

8.2.6.2.1.3 O-B&G

O-B&G shall signal the end of the contract negotiation and shall be used to transmit to the VTU-R the bits and gains information for the upstream direction.

The number of bits to be coded onto carrier *i* is denoted as b_i. The gain scale factor that shall be applied to carrier *i* (relative to the gain used during the transmission of R-P-MEDLEY) is denoted as g_i.

The b_i and g_i values are only defined for those tones that are used during the transmission of R-P-MEDLEY (i.e. the upstream tones indicated in O-SIGNATURE). Because no bits or energy will be transmitted at the other frequencies (at least in the opposite direction) the corresponding b_i and g_i values are all presumed to be set to zero and shall not be transmitted.

The b_i and g_i values shall be transmitted in ascending order (i.e. from lowest to highest tone). In case all b_i values above a certain tone are zero, the remaining zero values do not have to be transmitted. The VTU-R shall assume that any missing values after the last received value correspond to tones that carry no bits.

Each b_i shall be represented as an unsigned 4-bit integer with a value in the range of zero to B_{max_u} which is the maximum number of bits that the modem is prepared to modulate onto any sub-carrier.

Each g_i shall be represented as an unsigned 12-bit fixed-point quantity with the binary point assumed just to the right of the third most significant bit. For example a g_i with binary representation (most significant bit listed first) $001,010000000_2$ would instruct the modem to scale the constellation for carrier *i* by a gain of 1,25 so that the power in that carrier shall be 1,94 dB higher than it was during R-P-MEDLEY.

The whole spectrum may be split up into groups of adjacent tones such that the number of bits allocated to the carriers of a group is constant. The number of carriers in each group need not be constant but cannot exceed 256 carriers. The scale factor for each carrier within a group is defined by a polynomial interpolation. Only the parameters of the polynomial shall be transmitted. This polynomial is specified by means of the values of (j_{max}+1) defined tones where j_{max} is the order of the polynomial. The (j_{max}+1) tones are chosen to be equidistant. In the case of a group of carries $[x_n, x_{n+1}]$ where x_n and x_{n+1} are the index of the lowest and highest tones respectively of the n-th group of carriers the (j_{max}+1) X_{nj} positions are defined as:

$$X_{nj} = x_n + \left\lfloor \frac{j \times (x_{n+1} - x_n)}{j_{\max}} \right\rfloor \text{for } j = 0 \ldots j_{\max}$$

At the VTU-O the value of j_{max} is chosen based on the values supported by the VTU-R as specified in R-MSG2.

An O-B&G message is defined as:

Table 77: Description of O-B&G messages

Field content	Field or Macro-field type
Message descriptor	1 octet
j_{max}	1 octet
b_i and g_i information	B&G descriptor

Table 78: B&G descriptor j_{max}=0

Octet	Content of field
2n + 1 → 2n + 2	Specification of tone n+1 for n = 0 to N - 2 (see note) Bits 0 - 3: number of bits b_n Bits 4 - 15: scale gain g_n.
NOTE: If tone *n* is not used in the upstream direction the specification is not transmitted.	

Table 79: B&G descriptor j_{max}>0 and odd

Octet	Content of field
1-2	N_{gr} Number of group of tones
3 + n x(1,5 x j_{max} + 3,5) → 3 + (n +1) x (1,5 x j_{max} + 3,5) - 1	Specification of tone in group n + 1 for n = 0 to N_{gr} - 1 Bits 0 - 3: number of bits Bits 4 - 15: number of carriers of group *n* Bits 16 + 12i → 27 + 12i: $g_{X_{nj}}$ for tone X_{nj} j = 0 to j_{max}.

Table 80: B&G descriptor j_{max}>0 and even

Octet	Content of field
1-2	N_{gr} Number of group of tones
3 + n x (1,5 x j_{max} + 3) → 3 + (n + 1) x (1,5 x j_{max} + 3) - 1	Specification of tone in group n + 1 for n = 0 to N_{gr} - 1 Bits 0 - 3: number of bits Bits 4 - 11: number of carriers of group *n* Bits 12 + 12i → 23 + 12i: $g_{X_{nj}}$ for tone X_{nj} j = 0 to j_{max}.

8.2.6.2.2 Symbol types transmitted by the VTU-O

8.2.6.2.2.1 O-P-MEDLEY

O-P-MEDLEY is a wideband signal used for estimation at the VTU-R of the downstream SNR. O-P-MEDLEY uses all of the downstream tones modulated in 4QAM. The symbol length is N + CE samples. N shall be set to the value specified during the handshake procedure and CE shall be set to the value specified in O-MSG1 (clause 8.2.4.2.1.3). The change in CE shall be made after transmission of O-P-SYNCHRO2. Any change in CE shall be made at the beginning of the DMT symbol (i.e. by changing the number of samples in L_{CP}). Windowing is applied at the transmitter, with the window length β set to the value specified in O-SIGNATURE (clause 8.2.4.2.1.1). The PSD mask is defined by network management. O-P-MEDLEY carries 2 octets of information ($b_{15}b_{14}$ .. b_0) per DMT symbol mapped as described in table 81. The mapping of bits is as shown in figure 7.

Table 81: O-P-MEDLEY bit mapping

Tone index	Constellation point
5, 10, 15, …, 5n, …	00
1, 11, 21, …, 10n+1, …	SOC message bits 0 & 1
2, 12, 22, …, 10n+2, …	SOC message bits 2 & 3
3, 13, 23, …, 10n+3, …	SOC message bits 4 & 5
4, 14, 24, …, 10n+4, …	SOC message bits 6 & 7
6, 16, 26, …, 10n+6, …	SOC message bits 8 & 9
7, 17, 27, …, 10n+7, …	SOC message bits 10 & 11
8, 18, 28, …, 10n+8, …	SOC message bits 12 & 13
9, 19, 29, …, 10n+9, …	SOC message bits 14 & 15

The selected constellation points are pseudo-randomly rotated by 0, π/2, π, 3π/2 depending on the 2-bit random sequence provided by the pseudo-random bit generator defined in clause 8.2.4.2.2.1. Two bits are mapped onto each tone including DC. The pseudo-random bit sequence continues from one symbol to the next. The generator is reset only when the VTU-O enters the channel analysis and exchange state.

8.2.6.2.2.2 O-P-SYNCHRO2

O-P-SYNCHRO2 is a wideband signal that allows the VTU-O and the VTU-R to simultaneously step into the Showtime State. It uses all of the allowed downstream tones modulated in 4QAM. The symbol length is N + CE samples. N shall be set to the value specified during the handshake procedure and CE shall be set to the value specified in O-MSG1 (clause 8.2.4.2.1.3). Windowing is applied at the transmitter, with the overall window length β set to the value specified in O-SIGNATURE (clause 8.2.4.2.1.1). The PSD mask is defined by network management. The duration of O-P-SYNCHRO2 is 15 DMT symbols. A fixed phase value of 11 is mapped on all the downstream tones for the first five and last five symbols. A fixed phase value of 00 is mapped on all the allowed downstream tones for the middle five symbols. The selected constellation points are pseudo-randomly rotated by 0, π/2, π, 3π/2 depending on the 2-bit random sequence provided by the pseudo-random bit generator defined in clause 8.2.4.2.2.1. The pseudo-random bit sequence continues from one symbol to the next. The generator is never reset. In the downstream direction, the scrambler shall be disabled after the transmission of O-P-SYNCHRO1.

8.2.6.3 Messages and symbols sent by the VTU-R

8.2.6.3.1 SOC messages

During the channel analysis and exchange phase the VTU-R sends the SOC messages R-MSG2, R-CONTRACT1, R-MARGIN1 and R-B&G as well as the idle message R-IDLE.

Clause 8.2.6.3.2 describes how the messages are modulated onto the transmit symbol.

8.2.6.3.1.1 R-MSG2

This message contains information about the capabilities of the VTU-R for bit allocation.

Table 82: Description of R-MSG2

Field	Field or macro-field type	Remark
Message descriptor	1 octet	See table 49
Maximum constellation size in upstream	1 octet	Maximum number of bits per tone
RS setting supported by VTU-R	1 octet	0x00: only mandatory settings 0xFF: all settings (see note 1)
Interleaver setting supported by VTU-R	1 octet	0x00: only mandatory settings 0xFF: all settings 0xNN: NN = number of settings (0x00 < NN < 0xFF)
Detailed interleaver setting description	0 octets if NN = 0x00 0 octets if NN = 0xFF NN x 4 octets otherwise	See table 74
Maximum power transmitted	1 octet	In units of 0,25 dBm
Maximum interleaver memory	3 octets	In octets (see note 2)
Maximum number of EOC octets per frame in upstream	1 octet	Number of EOC octets per frame
Maximum number of VOC octets per frame in upstream	1 octet	Number of VOC octets per frame
Support of express swapping	1 octet	0x00: Not supported 0xFF: Supported
j_{max}	1 octet	Maximum value of j_{max} supported by the VTU-R (see note 3)
NOTE 1: All settings means the values (for the redundancy) that are specified in clause 6.4.2. NOTE 2: The interleaver memory is computed as M×I×(I-1). NOTE 3: Specification of j_{max} = k means that all values from 0 to k are supported.		

8.2.6.3.1.2 R-CONTRACT1

This message contains the contract based on the maximum number of bits specified in O-MSG2. The contract is encoded in a "Contract Descriptor" macro-field with all fields related to the fast channel set to 0x00.

8.2.6.3.1.3 R-MARGINn

This message contains the margin computed by the VTU-R for the downstream contract proposed in O-CONTRACTn. Upon reception of R-MARGINn the VTU-O can decide to choose this contract by sending O-B&G or to propose a new contract by sending O-CONTRACTn.

Table 83: Description of R-MARGINn

Field	Field or macro-field type	Remark
Message descriptor	1 octet	
Margin	1 octet	In units of 0,5 dB

8.2.6.3.1.4 R-B&G

R-B&G shall be used to transmit to the VTU-O the bits and gains information to be used in the downstream direction.

The number of bits to be coded onto carrier *i* is denoted as b_i. The gain scale factor that shall be applied to carrier *i* (relative to the gain used during the transmission of O-P-MEDLEY) is denoted as g_i.

The b_i and g_i values are only defined for those tones that are used during the transmission of O-P-MEDLEY (i.e. the downstream tones indicated in O-SIGNATURE). Because no bits or energy will be transmitted at the other frequencies (at least in the opposite direction) the corresponding b_i and g_i values are all presumed to be set to zero and shall not be transmitted.

The b_i and g_i values shall be transmitted in ascending order (i.e. from lowest to highest tone). In case all b_i values above a certain tone are zero, the remaining zero values do not have to be transmitted. The VTU-R shall assume that any missing values after the last received value correspond to tones that carry no bits.

Each b_i shall be represented as an unsigned 4-bit integer with a value in the range of zero to B_{max_d} which is the maximum number of bits that the modem is prepared to modulate onto any sub-carrier.

Each g_i shall be represented as an unsigned 12-bit fixed-point quantity with the binary point assumed just to the right of the third most significant bit. For example a g_i with binary representation (most significant bit listed first) $001{,}010000000_2$ would instruct the modem to scale the constellation for carrier *i* by a gain of 1,25 so that the power in that carrier shall be 1,94 dB higher than it was during O-P-MEDLEY.

If use of a dedicated pilot tone, k, is required (see clause 5.1.2.3.1), the VTU-R shall indicate this requirement to the VTU-O by sending the value "2" in the position of b_k in the bit table in R-B&G. In the gain table, it shall transmit a value of zero for the gain scaling of tone k. Receipt by the VTU-O of "2" in a bit table entry and zero in the corresponding gain scaling table entry indicates that tone has been selected as a dedicated pilot and shall be loaded with the 4QAM constellation point 00 during every symbol.

The whole spectrum is split up into groups of adjacent tones such that the number of bits allocated to the carriers of a group is constant. The number of carriers in each group need not be constant but cannot exceed 256 carriers. The scale factor for each carrier within a group is defined by a polynomial interpolation. Only the parameters of the polynomial shall be transmitted. This polynomial is specified by means of the values of (j_{max}+1) defined tones where j_{max} is the order of the polynomial. The (j_{max}+1) tones are chosen to be equidistant. In the case of a group of carries $[x_n, x_{n+1}]$ where x_n and x_{n+1} are the index of the lowest and highest tones respectively of the n-th group of carriers the (j_{max}+1) X_{nj} positions are defined as:

$$X_{nj} = x_n + \left\lfloor \frac{j \times (x_{n+1} - x_n)}{j_{\max}} \right\rfloor \text{for } j = 0 \ldots j_{\max}$$

At the VTU-O the value of j_{max} is chosen based on the values supported by the VTU-R as specified in R-MSG2. At the VTU-R the value of j_{max} is chosen based on the values supported by the VTU-O which are specified in O-MSG2.

An R-B&G message is defined as:

Table 84: Description of R-B&G messages

Field content	Field or Macro-field type
Message descriptor	1 octet
j_{max}	1 octet
b_i and g_i information	B&G descriptor

Table 85: B&G descriptor j_{max}=0

Octet	Content of field
2n + 1 → 2n + 2	Specification of tone n + 1 for n = 0 to N - 2 (see note) Bits 0 - 3: number of bits b_n Bits 4 - 15 scale gain g_n
NOTE: If tone *n* is not used the specification is not transmitted.	

Table 86: B&G descriptor j_{max}>0 and odd

Octet	Content of field
1-2	N_{gr} Number of group of tones
3 + 1,5n x (j_{max}+1) → 3 + (n +1) x 1,5 x (j_{max}+1)	Specification of tone in group n + 1 for n = 0 to N_{gr} - 1 Bits 0 - 3: number of bits Bits 4 - 15: number of carriers of group *n* Bits 16 + 12i → 27 + 12i: $g_{X_{nj}}$ for tone X_{nj} j = 0 to j_{max}

Table 87: B&G descriptor j_{max}>0 and even

Octet	Content of field
1-2	N_{gr} Number of group of tones
3 + 1,5n x (j_{max}+3) → 3 + (n + 1) x 1,5 x (j_{max}+3)	Specification of tone in group n + 1 for n = 0 to N_{gr} - 1 Bits 0 - 3: number of bits Bits 4 - 11: number of carriers of group *n* Bits 12 + 12i → 23 + 12i: $g_{X_{nj}}$ for tone X_{nj} j = 0 to j_{max}

8.2.6.3.2 Symbol types transmitted by the VTU-R

8.2.6.3.2.1 R-P-MEDLEY

R-P-MEDLEY is a wideband signal used for estimation at the VTU-O of the upstream SNR. It uses all of the available upstream tones modulated in 4QAM. The symbol length shall be N + CE samples. N shall be set to the value specified during the handshake procedure and CE shall be set to the value specified in O-MSG1 (clause 8.2.4.2.1.3). Any change in CE shall be made at the beginning of the DMT symbol (i.e. by changing the number of samples in L_{CP}). Windowing is applied at the transmitter, with the overall window length β as specified in O-SIGNATURE (clause 8.2.4.2.1.1). The transmitter PSD mask shall meet the power back-off requirements. The timing advance is applied and corresponds to the loop length. R-P-MEDLEY carries two octets of information ($b_{15}b_{14}$ .. b_8) & (b_7b_6 .. b_0) per DMT symbol mapped as described in table 88.

Table 88: R-P-MEDLEY bit mapping

Tone index	Constellation point
5, 10, 15, …, 5n, …	00
1, 11, 21, …, 10n+1, …	SOC message bits 0 and 1
2, 12, 22, …, 10n+2, …	SOC message bits 2 and 3
3, 12, 23, …, 10n+3, …	SOC message bits 4 and 5
4, 13, 23, …, 10n+4, …	SOC message bits 6 and 7
6, 16, 26, …, 10n+6, …	SOC message bits 8 and 9
7, 17, 27, …, 10n+7, …	SOC message bits 10 and 11
8, 18, 28, …, 10n+8, …	SOC message bits 12 and 13
9, 19, 29, …, 10n+9, …	SOC message bits 14 and 15

The selected constellation points are pseudo-randomly rotated by 0, π/2, π, 3π/2 depending on the 2-bit random sequence provided by the pseudo-random bit generator defined in clause 8.2.4.2.2.1. Two bits are mapped onto each tone including DC. The pseudo-random bit sequence continues from one symbol to the next. The generator is reset only when the VTU-O enters the channel analysis & exchange state.

8.2.6.3.2.2 R-P-SYNCHRO2

R-P-SYNCHRO2 is a wideband signal that allows the VTU-O and the VTU-R to simultaneously step into the Showtime State. It shall use all of the allowed upstream tones modulated using 4QAM. The symbol length is N+CE samples where CE is set to the value specified in O-MSG1 (clause 8.2.4.2.1.3) and N is negotiated during the handshake procedure. Windowing is applied at the transmitter and the overall window length β is set to the value specified in O-SIGNATURE (clause 8.2.4.2.1.1). The PSD shall conform with the UPBO requirements. The overall duration of R-P-SYNCHRO2 is 15 DMT symbols. The value 11 is mapped on all the allowed downstream tones for the first five and the last five DMT symbols. The value 00 is mapped on the allowed downstream tones for the five remaining DMT symbols. The selected constellation points are pseudo-randomly rotated by 0, π/2, π and 3π/2 depending on the 2-bit random sequence provided by the pseudo-random bit generator defined in clause 8.2.4.2.2.1. The pseudo-random bit sequence continues from one symbol to the next.

The scrambler keeps free-running during the transmission of this R-P-SYNCHRO2. In the upstream direction the quadrant scrambler shall be disabled after the transmission of R-P-SYNCHRO2.

8.3 Single carrier activation/deactivation

8.3.1 Link states and timing

The Link State and Timing diagram presented in figure 57 is an implementation of the generic diagram presented in figure 49. It includes five states (rounded blocks), four types of link activation (rectangular blocks) and two types of link deactivation. Link activation and deactivation is initiated by Control signals described in clause 8.3.5. Both the VTU-O and VTU-R shall support *all* types of link activation and deactivation.

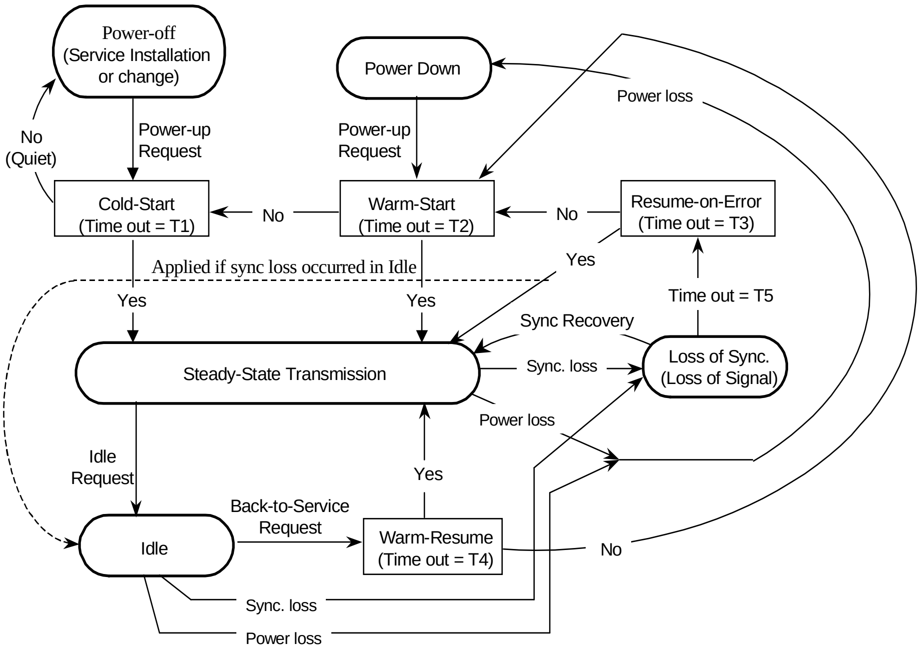


Figure 57: Link State and Timing Diagram

8.3.1.1 States

- *Power-off* is the initial state intended for service installation and modification prior to the first power-up process;
- *Steady-State Transmission* (full duplex transmission) is a state achieved after the link activation process is completed. In this state the link shall transport user information with standard performance characteristics;
- *Loss of Sync (Loss of Signal)* is a state achieved if frame synchronisation loss occurs (also as a result of signal energy loss or symbol timing loss). During this state the link is interrupted. The link shall return from this state back to *Steady-State Transmission* if frame synchronisation is recovered in a short period of time (T5). Otherwise, the *Resume-on-Error* activation procedure will be invoked;
- *Power Down* is a state achieved after a guided power removal, power failure or *QUIET* deactivation at either the VTU-O or VTU-R. During this state the link is terminated. The link shall move from this state into the *Warm-Start* procedure by applying a Power-up request;
- *Idle* state (deactivated power save) provides an environment with a low generated crosstalk and a reduced power consumption when no broadband calls are in progress. After the VTU-O or VTU-R detects a broadband call wake-up signal (Back-to-Service request) from the network or from the CPE respectively, a *Warm-Start* procedure is executed.

NOTE: If the link connection is maintained during the *Idle* state, at least data frame synchronisation, VOC transparency and Sync Loss event monitoring shall be provided. The user data channels and EOC transparency is *optional*. If the link connection is not maintained during the *Idle* state, the Sync Loss event in the *Idle* state is not monitored.

8.3.1.2 Activation

- *Cold-Start* shall be applied after the first power-up or after an unsuccessful *Warm-Start* activation. If finished unsuccessfully, some changes in the installed service shall be made to simplify the link establishment.
- *Warm-Start* shall be applied after an unsuccessful *Resume-on-Error* activation or an unsuccessful *Warm-Resume* activation or after either Power-down/Power failure or a link deactivation (*QUIET*) event. If finished unsuccessfully the *Cold-Start* activation is applied.
- *Resume-on-Error* shall be applied after a link interruption due to loss of synchronisation, which was not self-recovered during the defined time out (T5). If finished unsuccessfully the *Warm-Start* activation is applied.
- *Warm-Resume* shall be applied on receipt of a broadband call wake-up signal (Back-to-Service request command) if the link resides in the *Idle* mode. If finished unsuccessfully the *Warm-Start* activation is applied.

NOTE 1: Unsuccessful *Cold-Start* activation occurs usually if the activated link environment (attenuation, noise etc) can't provide the desired service.

NOTE 2: Unsuccessful *Warm-Start* activation occurs usually after significant change of line characteristic (for example a connection to a new line with unknown parameters).

NOTE 3: Unsuccessful *Resume-on-Error* activation occurs usually due to a temporary change of noise conditions in the loop or due to modification of the transmission parameters.

NOTE 4: Unsuccessful *Warm-Resume* activation occurs usually due to a temporary change of noise conditions in the loop.

NOTE 5: Back-to-Service request command may be applied at both the VTU-O and the VTU-R.

Any of the defined activation processes conceptually includes the following steps:

- Upstream and downstream channel equalisers convergence (PMD sub-layer activation);
- Upstream and downstream channel transmission frame synchronisation (PMS-TC sub-layer activation);
- Open the steady-state data communication between the VTU-O and VTU-R (TPS-TC sub-layer activation).

In some particular cases of *Resume-on-Error* and *Warm-Resume* activation the equaliser convergence may be skipped.

8.3.1.3 De-activation

- *QUIET* shall terminate the link. *QUIET* shall be applied if power failure occurs, or if a transceiver restart is desired, or as a part of the power-down process. *QUIET* may be initiated while the link resides in any state or during any activation process. In any case, except the Cold-Start, after *QUIET* de-activation the link shall be moved into the Power-Down state. *QUIET* de-activation during the Cold-Start moves the link into the initial (Power-off) state.
- *Idle Request* shall move the link into the *Idle* state. *Idle Request* may be applied on receipt of a broadband call release while the link resides in the *Steady-State Transmission* state only.

NOTE: The *Warm-Resume* activation procedure is applied to return the link from the *Idle* state back to a *Steady-State Transmission* state.

8.3.2 Set of transmission parameters

The required link transmission capabilities and characteristics are provided by the Set of Transmission Parameters (STP) presented in table 89. The STP applied at the VTU-O and VTU-R shall be the same, regardless of the state they reside in or the activation process they pass through. When the STP is modified in one VTU, the same change shall occur in the other one as well.

Table 89: Set of Transmission Parameters

Parameter	Downstream carrier-1	Downstream carrier-2	Upstream carrier-1	Upstream carrier-2	Parameter Range
Symbol Rate	1D_SR	2D_SR	1U_SR	2U_SR	67,5 kBaud x N (N=1, 2, …)
Constellation	1D_C	2D_C	1U_C	2U_C	D_C = 4 to 1 024 U_C = 4 to 1 024
Centre Frequency	1D_CF	2D_CF	1U_CF	2U_CF	In accordance with the applied transmission profile
Transmit PSD	1D_PSD	2D_PSD	1U_PSD	2U_PSD	
Interleaving Parameters	D_ M, D_I		U_ M, U_I		In accordance with tables 26 and 27 of clause 6.5.
Frame Format	D_ FR		U_ FR		

For the purpose of the present document a *Current STP* and a *Standard STP* are defined.

8.3.2.1 Current STP

The *Current STP* (CR_STP) contains transmission parameters currently in use by the upstream and downstream transmitters.

8.3.2.2 Standard STPs

The following five standard STPs are defined to provide interoperability between transceivers from different vendors. The standard STPs are permanently stored in both the VTU-O and VTU-R local Activation Data Base and shall be applied to perform the corresponding activation/deactivation procedures.

- *Default STP* (DF_STP) shall be applied to perform a *Cold-Start* activation. Usually DF_STP parameter values are set by the network operator at the VTU-O prior to system installation and may be delivered to the remote side by the handshaking procedure. Alternatively, the DF_STP may be set prior to system installation at the both sides. The DF_STP shall be kept constant until the link is returned into *Power-off* state to change the type of service. The parameter values for DF_STP providing interoperability for either the VDSL band allocation or the optional regional specific band allocation are shown in table 90. The nominal PSD value of the default STP (DF_STP) shall meet the requirements specified in TS 101 270-1 [1].

Table 90: Default values of DF_STP

Parameter	1D	2D	1U	2U
Symbol Rate (MBaud)	0,57375 (17x0,03375)	0	0,7425 (22 x 0,03375)	0
Constellation	4		4	
Centre Frequency (MHz)	1,45125 (86x0,016875)		4,455 (264 x 0,016875)	
Transmit PSD (dBm/Hz)	-61		< -61 (note 1)	
Interleaver	Disabled			
Frame Format	Type [0/0] (single latency)			
NOTE: The value will be decreased upon application of upstream power back-off.				

- *Warm-Start STP* (WS_STP) shall be applied to perform a *Warm-Start* activation. WS_STP initially shall be set equal to the DF_STP. A VOC communication may be used to negotiate changes to WS_STP.

- *Warm-Resume STP* (WR_STP) shall be applied to perform a *Warm-Resume* activation. As the link enters *Steady-State Transmission* state WR_STP shall be automatically set equal to the currently applied CR_STP. The WR_STP settings shall be complete prior to an *Idle* deactivation.

- *Resume-on-Error STP* (RE_STP) shall be applied to perform a *Resume-on-Error* activation. As the link enters either *Steady-State Transmission* state or *Idle* state and during these states RE_STP is automatically set equal to the currently applied CR_STP. The RE_STP settings shall be complete prior to a *Resume-on-Error* activation.
- *Idle STP* (I_STP) - *optional* - shall be applied to perform a transition to the *Idle* state. The I_STP initially shall be set equal to CR_STP, except for constellation size, which is set to 4, and the transmit PSD level, which may be reduced by the values presented in table 91. A VOC communication may be used to negotiate changes to I_STP. All changes in I_STP shall be complete prior to an *Idle* deactivation.

Table 91: Constellation size at start-up

Steady-state transmission constellation	4	8	16	32	64	128	256	512	1 024
Maximum PSD reduction, dB	3	7	10	12	12	12	12	12	12

NOTE 1: Other DF_STP are for further study.

NOTE 2: If I_STP is not defined, the system could be moved into the *Idle* state by a generic CR_STP modification, as described in clause 8.3.3.2.

8.3.3 Transmission parameters modification

At the discretion of the network operator, transmission parameter settings for CR_STP and all standard STPs, except DF_STP, can be modified, as appropriate for the required service characteristics. The modification of STP can be initiated only by the VTU-O. The VTU-R is not required to accept the requested value of a transmission parameter if it is not a standard setting.

NOTE: DF_STP may be changed during the system re-installation or by re-applying the handshake procedure prior the *Cold-start*, or by some vendor proprietary procedure, which is beyond the scope of the present document.

8.3.3.1 Adjustment of standard STP values

From the standard STPs only WS_STP and I_STP may have individual parameter values modified under the control of the VTU-O. The parameter values for the STP can be modified during the *Steady-State Transmission* state of the link only.

The VTU-O gets the new settings for the intended STP target from the local management system. It shall send to the VTU-R through the VOC a copy of the new STP and a request to make the corresponding changes to its own copy of the corresponding STP. Once accepted by the VTU-R the new STP settings are stored at both the VTU-O and VTU-R.

The RE_STP shall be automatically updated to be equal to the currently applied CR_STP each time the link enters *Steady-State Transmission* state or *Idle* state. Similarly, WR_STP shall be automatically updated to be equal to the currently applied CR_STP each time the link enters *Steady-State Transmission* state.

8.3.3.2 CR_STP adjustment

The CR_STP parameter values may be modified in two different ways.

- The CR_STP shall be automatically overwritten with DF_STP, WS_STP or RE_STP when the link, enters *Cold-Start*, *Warm-Start* or *Resume-on-Error*, respectively. During these changes the link is usually interrupted or disconnected.
- The CR-STP shall be overwritten with a new setting after a successful communication of a VOC trigger message (CHANGE, BTSERVC or IDLEREQ) followed by a trigger handshake. The procedure shall be used both to make generic modifications to CR_STP, and to modify CR_STP to I_STP or to WR_STP upon transition into *Idle* state or entering *Warm-Start* respectively. The CR_STP modification is initiated by a special control signal from the VTU-O (CHNG_PRM, B_SERV or I_REQ) and can be performed only during the *Steady-State Transmission* link state, except for CR_STP to WR_STP modification, which is made during the *Idle* state. The modification of CR_STP is accompanied by corresponding changes in both transmitter/receiver parameters and in transmit signal parameters, as defined by the new CR_STP.

For a generic parameter modification, the STP modification requests and the new parameter settings come to the VTU-R from the VTU-O over the VOC. After all the new parameter settings are successfully communicated, the VTU-O management system uses a CHANGE VOC message to request that CR_STP be overwritten with the new parameter settings. A special trigger handshake activated after the successful communication of the CHANGE message overwrites CR_STP, RE_STP at both the VTU-O and the VTU-R with the new parameter settings and triggers the desired change in their transmitter/receiver parameters.

For transitions into the *Idle* state or for *Warm-Resume* activation, CR_STP and RE_STP are overwritten with I_STP or WR_STP respectively in the same manner, after the successful communication of IDLEREQ or BTSERVC VOC messages followed by a trigger handshake.

If due to the performed parameter change the link moves into the *Loss of Sync* state (caused by symbol rate change, for example), it will either recover synchronisation within time T5 and thereby return to *Steady-State Transmission* state with new parameters in place, or instead it will attempt a *Resume-on-Error* activation with RE_STP equal to the modified CR_STP. If this *Resume-on-Error* activation is successful, the link returns to *Steady-State Transmission* with the successfully accomplished parameter change. If not, the parameter change process has failed, and *Warm-Start* activation is automatically attempted to return the link into the *Steady-State Transmission* state.

NOTE: With some additional delay, a generic CR_STP modification can also be effected without use of the CHANGE VOC command and the trigger handshake. The technique is to use the VOC to set the new desired transmission parameters into WS_STP, then force a *Warm-Start* by deactivating the link through application of the *QUIET* control signal at either end of the link and then activating the link back. Failure to acquire the link with the new parameter values automatically initiates a *Cold-Start* and thus the link will be returned into the *Steady-State Transmission* state for the next parameter modification attempt.

8.3.3.3 STP adjustment summary

A summary of the STP modification rules is presented in table 92.

NOTE: All the listed STP modifications are fully provided by the VTU-O, VTU-R state machines described in clause 8.3.9.

Table 92: Summary of STP Modification Rules

Parameter	Overwritten automatically:	Overwritten by the operator:
DF_STP	N/A	N/A
WS_STP I_STP	N/A	with an arbitrary parameter setting during *Steady-State Transmission* state
WR_STP	with the CR_STP upon entry to *Steady-State Transmission* state.	N/A
RE_STP	with the CR_STP upon entry to either *Steady-State Transmission* or *Idle* state; with the CR_STP, immediately after CR_STP was overwritten with the new parameter settings (I_STP, WR_STP or generic).	N/A
CR_STP	with the DF_STP, WS_STP, or RE_STP at the beginning of a *Cold-Start*, *Warm-Start*, or *Resume-on-Error* activation, respectively.	with an arbitrary transmission parameter setting during the *Steady-State Transmission*, after a successful communication of the CHANGE VOC message followed by a trigger handshake (generic CR_STP modification); with I_STP upon entering *Idle* state after a successful communication of the IDLEREG VOC message followed by a trigger handshake (moving into *Idle* state); with WR_STP upon entry to the *Warm-Start*, after a successful communication of the BTSERVC VOC message followed by a trigger handshake (moving back from *Idle* state to *Steady-State Transmission*);

8.3.4 VTU activation/deactivation

The VTU- activation/deactivation functional diagram is shown in figure 58. The activation/deactivation process is performed by the VTU state machine described in clause 8.3.9. Prior to activation, the VTU state machine shall be supplied with the appropriate CR_STP to be used in the activation. This STP stored in CR_STP Memory (CR_STPM) of the VTU Activation database. The VTU management entity shall load the appropriate standard STP (DF_STP, WS_STP, or RE_STP) or a generic STP into the CR_STPM for the subsequent activation type. Thus it supports the desired link characteristics and all the required activation types, as defined in figure 57.

The activation/deactivation is driven by the Control signals originated by the VTU management entity, which shall also monitor the state machine states and flags.

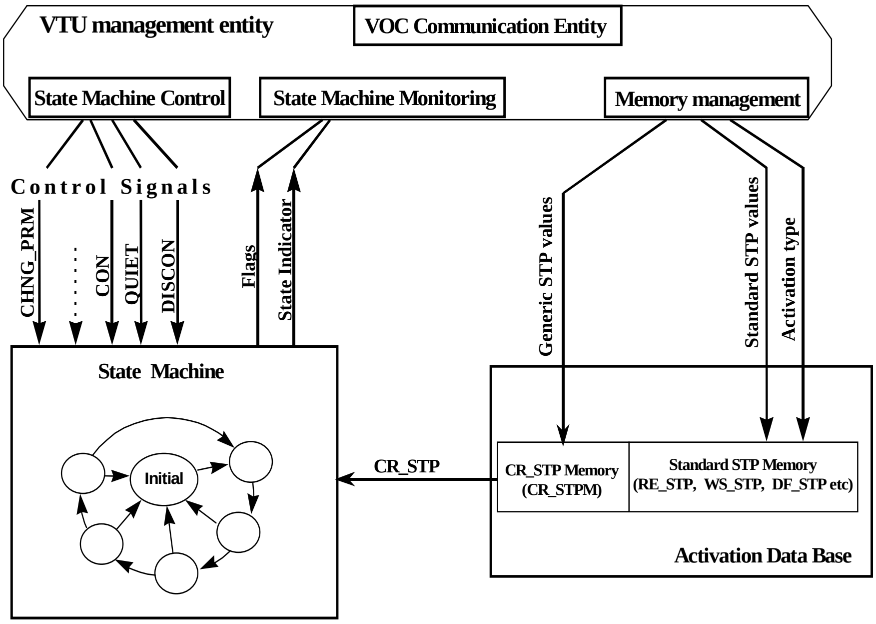


Figure 58: VTU- Activation/Deactivation Functional Diagram

The CR_STPM shall contain the STP for the pending activation process. Identical STP shall be loaded into the CR_STPM at both the VTU-O and VTU-R at the start of the activation and kept constant until the activation process is complete, either successfully or not. If the activation process is successfully completed the loaded CR_STP will be used during the following steady-state transmission until a new parameter modification request. If any activation process fails, a new STP will be automatically loaded into CR_STPM in accordance with the next activation type, as described in figure 57.

8.3.5 Control signals

The VTU activation/de-activation process shall be driven by the following Control signals:

- *Connect (CON)* - to initiate the activation process after the link was disconnected (i.e. initiates either *Cold-Start* or *Warm-Start*). As *Connect* is set, the VTU shall move from the STANDBY state to start the link synchronisation. Applied at the VTU-R in the case of activation from the CPE site, and at the VTU-O in the case of activation from the ONU/CO site. *Connect* is ignored in all states except STANDBY.

- *Quiet (QUIET)* - to terminate the link. As QUIET is set, the activated transceiver shall move from its current state into the POWER_UP state. Applied for transceiver restart or as a part of the power-down process. QUIET is applicable for both the VTU-O and VTU-R.

- *Change parameter (CHNG_PRM)* - to initiate a generic parameter modification process. Applied only at the VTU-O while the link is in a *Steady-State Transmission* state.

- *Idle Request (I_REQ) - optional* - to initiate the link deactivation into the *Idle* state. As *Idle Request* is set, the link shall move from the *Steady-State Transmission* into the *Idle* state. Applied only at the VTU-O while the link is in the *Steady-State Transmission* state.
- *Back-to-Service (B_SERV)* - to initiate a *Warm-Resume* activation. As *Back-to-Service is set* the link shall move from the *Idle* state into the *Steady-State Transmission* state. Applied for both the VTU-O and VTU-R while the link is in the *Idle* state.
- *Disconnect (DISCON) - optional* - to disable the link activation attempt (*CON* signal) from the VTU-R. Used to prevent uncontrolled link activation. Applied at the VTU-O only.

8.3.6 Flags and indicators

The local VTU management entity uses Flags and Indicators to monitor the state machine. The state machine shall provide the following Flags and Indicators for monitoring purposes.

- *State Indicator* (*SI*) - to indicate the current state of the state machine. Used by the VTU management entity to set or reset user data and EOC throughput.
- *Complied Flag* (*CF*) - to indicate that the last command being applied by a certain Control signal was successfully executed.
- *Unable-to-Comply Flag* (*UTCF*) - to indicate that the last command being applied by a certain Control signal was not executed.
- *Remote-Activation-Request Flag* (*RAF*) - to indicate that an activation request from the VTU-R have been received, applicable at the VTU-O while in STANDBY state only.
- *Back-to-Service-Request Flag* (*BTSF*) - indicates that a back-to-service request from the VTU-R have been received, applicable at the VTU-O while the link is in *Idle* state only.

8.3.7 Transmit signals

For each state of the VTU state machine, during both the activation and steady-state transmission, is specified a transmit signal, while residing in that state. All transmit signal types are presented in table 93.

Transmit signals O_QUIET and R_QUIET shall drive the line with zero volts (silence). Other transmit signals shall be formatted as a standard transmission frame (see clause 7.3.1.6) and specified by the contents of the OC field and by the values of *o_trig*, *r_trig* and *r_flag* signals (see table 23), and by the values of indicators IB-7 to IB-9 (see table 24).

Signals O/R_ACQUIRE, O/R_TRIG always carry the IDLE VOC message; signals O/R_DATA can carry both IDLE and valid VOC and EOC messages.

The *o_trig* bits in the downstream transmission frame header are equal one for the O_TRIG signal and zero for all other VTU-O transmit signals. The *r_trig* bit equals 0 for all VTU-R transmit signals, except for R_TRIG, where it is set to 1. The *r_flag* is set to 0 in all signals except R_DATA, in which it is set to 1 once the B_SERV control signal is applied at the VTU-R.

Table 93: Transmit Signals Summary

Signal	OC Field	Control Field	Note
O_QUIET		No transmission	
O_ACQUIRE	OC = IDLE	o_trig = 0, IB-9 = 1	User Data: Denied EOC: Denied
O_TRIG	OC = IDLE	o_trig = 1, IB-9 = 0	User Data: Applicable (see note 1) EOC: Denied
O_DATA	OC = valid message	o_trig = 0, IB-9 = 0	User Data: Applicable (see note 1) VOC: Applicable EOC: Applicable (see note 1)
R_QUIET		No transmission	
R_ACQUIRE	OC = IDLE	r_trig = 0, r_flag = 0, IB-7 = 1	User Data: Denied EOC: Denied Variable transmit level (see note 2)
R_TRIG	OC = IDLE	r_trig = 1, r_flag = 0, IB-7 = 0	User Data: Applicable (see note 1) EOC: Denied
R_DATA	OC = valid message	r_trig = 0, r_flag = 0/1, IB-7 = 0	User Data: Applicable (see note 1) VOC: Applicable EOC: Applicable (see note 1)

NOTE 1: *Optional*, if the link is in *Idle* state.
NOTE 2: To support the upstream Start-up power back-off process during the *Cold-Start*.
NOTE 3: During transmission of signals O/R_DATA the indicator bits IB-7, IB-8, and IB-9 show temporary loss of synchronisation when all are set to 1.

8.3.8 Timers

The following timers, listed in table 94 are involved in the VTU- activation/de-activation process.

Table 94: VTU State-Machine Timers

Timer	Function	Value
t_{P_O}	Duration of the R_QUIET signal detection at VTU-O to complete the O_POWERUP state.	100 ms
t_{P_R}	Duration of the O_QUIET signal detection at VTU-R to complete the R_POWERUP state.	100 ms
t_{1_R}	DS equaliser convergence time-out	4 s
t_{1_O}	US equaliser convergence time-out	4 s
t_{2_O} t_{2_R}	Time-out for VTU-O activation process Time-out for VTU-R activation process	Depends on start-up type: T1 for *Cold-Start*, T2 for *Warm-Start*, T4 for *Warm-Resume*, T3 for *Resume-on-Error*, T3 + T5 following CHANGE VOC message
t_{3_O}	Time-out for VTU-O trigger handshake	1 000 ms
t_{3_R}	Time-out for VTU-R trigger handshake	100 ms
t_{4_O}	Time-out to recover VTU-O frame synchronisation	200 ms
t_{4_R}	Time-out to recover VTU-R frame synchronisation	200 ms

NOTE: T1 to T5 are defined in Part1 of this specification and also appear in figure 49.

8.3.9 VTU-O state machine

The VTU-O state machine is shown in figure 59.

NOTE 1: Each ellipsoid block in figure 59 represents a state which contains the state number (*S1* → *S7*) followed by the state name. The names of the VTU-O transmit signal, while residing in that state, is placed below the state name.

S1: O_POWERUP

This state is the initial state of the state machine. It corresponds to the start of the activation process and shall be entered in the following cases:

- a *QUIET* Control signal or a Power-up request is applied. This is the first step in a pending *Cold-Start* or *Warm-Start* activation, as shown by figure 57.
- Loss of Upstream Signal (*US_LOS*) is detected while in states *S3* - *S4* or time-out of states *S3* - *S4*. This *S1* entry follows a failed activation attempt and is the first step in a pending reactivation attempt of type specified by figure 57.

In state *S1*, the VTU-O shall transmit O_QUIET. The VTU-O transmitter and receiver shall be configured with the STP stored in CR_STPM.

The VTU-O transits into state *S2* if loss of the received upstream signal (US_LOS) is detected for more than t_{P_O} ms.

NOTE 2: The definition for *los* given in clause 7.3.1.3 shall be used for *US_LOS*.

S2: O_STANDBY

In state *S2* the VTU-O shall transmit O_QUIET and wait for an activation request, which could be either the *Connect* Control signal, if the link is activated from the VTU-O, or detection of the upstream received signal energy (*Disconnect* Control signal disabled), if the link is activated from the VTU-R. Once the activation request is performed the timer t_0 shall be started from zero and state *S3* shall be entered.

The *Disconnect* Control signal shall override any activation request from the VTU-R. If *QUIET* is applied while in this state, the VTU-O is returned to state *S1*.

NOTE 3: The timer t_0, started at the beginning of VTU-R activation, is used to monitor the VTU-R synchronisation process.

S3: O_CONVERGE

In state *S3* the VTU-O shall transmit the O_ACQUIRE signal while attempting to converge the upstream equaliser(s). The IB-9(rdi) bit shall be set 1 to indicate that the upstream direction is not synchronised. This state is entered from state *S2* following an activation request, or from state *S6* following a non recovered synchronisation loss (including that due to a change in the current upstream transmission parameters through the CHANGE VOC message). The transition from *S6* to *S3* corresponds to the initiation of a *Resume-On-Error* activation attempt.

NOTE 4: The converging process includes identification of the received US signal shaping type (whether BSS or PSS).

The VTU-O shall converge its upstream equaliser(s) before the timer t_0 reaches $t_{1\text{-}O}$ ms. If convergence is not achieved within this time the VTU-O shall return to state *S1*. If convergence is reached before this time, the VTU-O shall immediately transit to state *S4,* without waiting for the full time-out period to elapse.

If *QUIET* is applied or if *US_LOS* occurs while in this state, VTU-O shall return to state *S1*.

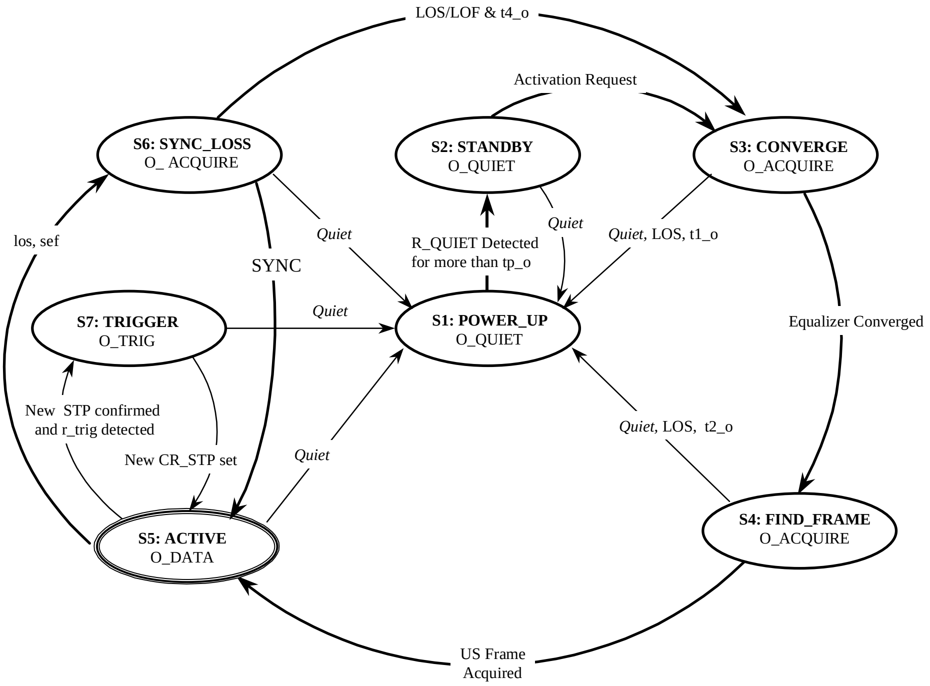


Figure 59: VTU-O Activation/De-activation State Machine

S4: O_FINDFRAME

While in state *S4* the VTU-O shall transmit O_ACQUIRE and o_pmd_rai bit shall be set 1 to indicate that the upstream direction is not synchronised yet. In state *S4* the VTU-O shall process the received upstream bit stream to acquire the upstream transmission frame using the Frame Delineation Algorithm (see clause 6.5.1.5). The VTU-O shall transit to state *S5* as soon as the frame acquisition is complete and stable for at least 100 ms. If frame acquisition is not complete before t_0 reaches $t_{2\text{-}O}$ ms, or if *QUIET* is applied, or if *US_LOS* occurs while in this state, the VTU-O shall return to state *S1*.

S5: O_ACTIVE

The VTU-O shall reside in this state while the upstream channel is acquired. While in *S5* the VTU-O shall transmit O_DATA; the state of the link is either *Steady-State Transmission* or *Idle*.

In *S5* the VTU-O may transmit VOC messages to modify CR_STP, WS_STP or I_STP if required by the VTU-O management entity. If the link state is *Idle*, the VTU-O also tracks the *Back-to-Service* request from the VTU-R by monitoring the r_flag bits in the received transmission frame header. After r_flag = 1 is detected, the VTU-O shall transmit the BTSERV VOC message to confirm the request. If the BTSERV message is transmitted successfully, the B_SERV Control signal shall be applied to initiate the state machine to move the link from the *Idle* state back to the *Steady-State Transmission* state.

To perform a generic CR_STP modification the VTU-O management entity shall apply *CHNG_PRM* Control signal, which causes the VTU-O to transmit VOC messages containing the new desired values of transmission parameters. Once all the necessary new parameter values are successfully transmitted (no ECHO response from the VTU-R on the requested parameter change is UTC), the VTU-O shall transmit a CHANGE VOC message, which confirms that both the VTU-O and VTU-R are ready to change their transmission parameters for a new parameter setting. After the CHANGE message is transmitted successfully, the VTU-O shall wait for reception of the upstream signal R_TRIG by monitoring the r_trig bits in the received transmission frame header. Once the received value r_trig = 1 is detected, the VTU-O shall move to state *S7*.

If the VTU-O is in *Idle* state and a *B_SERV* Control signal is applied (initiated either by the VTU-O or upon r_flag = 1 reception), the VTU-O shall transmit a BTSERVC VOC message, which confirms than both the VTU-O and VTU-R are ready to change their transmission parameters with WR_STP to return the link back to the *Steady-State Transmission* state from the *Idle* state. After the BTSERVC message is transmitted successfully, the VTU-O shall wait for reception of the upstream signal R_TRIG by monitoring the r_trig bits in the received transmission frame header. Once the received value r_trig = 1 is detected, the VTU-O shall move to state *S7*.

If the VTU-O is in *Steady-State Transmission* state and an *I_REQ* Control signal is applied, the VTU-O shall transmit a IDLEREQ VOC message, which confirms than both the VTU-O and VTU-R are ready to change their transmission parameters with I_STP to pull the link into the *Idle* state from the *Steady-State Transmission* state. After the IDLEREQ message is transmitted successfully, the VTU-O shall wait for reception of the upstream signal R_TRIG by monitoring the r_trig bits in the received transmission frame header. Once the received value r_trig = 1 is detected, the VTU-O shall move to state *S7*.

If R_TRIG reception is not achieved in $t_{3\text{-O}}$ ms after any CHANGE, BTSERVC or IDLEREQ message is transmitted successfully the VTU-O shall make no changes in CR_STP and shall remain in ACTIVE state.

If los or sef occurs while in this state, the VTU-O shall transit to state *S6*. If *QUIET* is applied the VTU-O shall return to state *S1*.

S6: O_SYNC LOSS

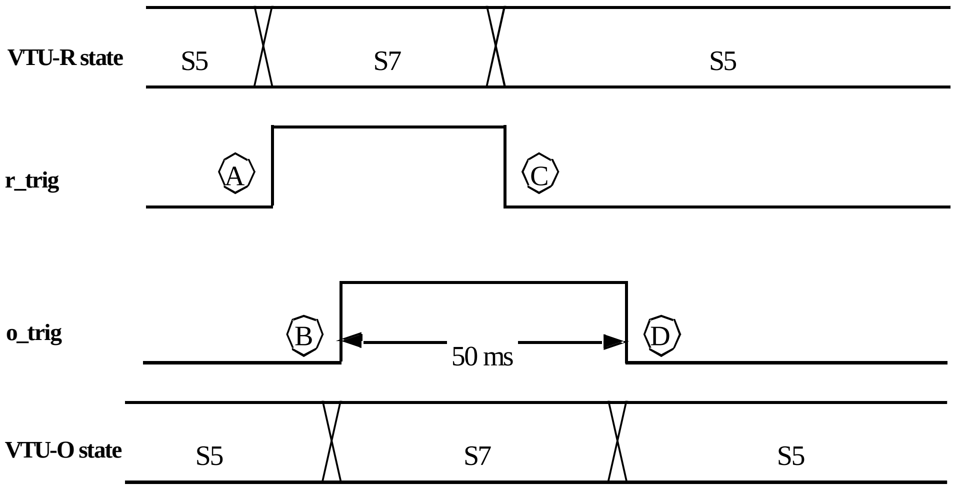
In this state the VTU-O attempts to recover the lost transmission frame synchronisation. After the synchronisation is recovered the VTU-O shall return to state *S5*. If synchronisation is not recovered during the time-out interval of $t_{4\text{-O}}$ ms, the VTU-O shall move to state *S3* to initiate a *Resume-On-Error* activation request. The VTU-O shall move to state *S1* if *QUIET* is applied. During this state O_ACQUIRE shall be transmitted to inform the VTU-R on the VTU-O synchronisation loss by setting IB-9(rdi) = 1.

S7: O_TRIGGER

In state *S7* the VTU-O shall transmit the O_TRIG signal with o_trig = 1 for 50 ms ± 1ms. Following this the VTU-O shall overwrite CR_STP with a new parameter setting, with WR_STP, or with I_STP depending on whether the CHANGE, BTSERVC or IDLEREQ VOC message, respectively, was last transmitted. Then the VTU-O shall make the corresponding changes to it's transmitter/receiver parameters, and returns to state *S5* with a new CR_STP parameter setting. Upon entering *S5* RE_STP shall be automatically overwritten with CR_STP.

If QUIET is applied, the VTU-O shall return to state S1.

NOTE 5: The transmission of o_trig is used to synchronise transmission parameter modification at the VTU-R with the same modification at the VTU-O. The timing diagram of the VTU-O to VTU-R interaction during the O/R_TRIG state is presented in figure 60. In accordance with figure 60, the VTU-R executes the parameter change after the point "C" and the VTU-O executes the parameter change after the point "D". The maximum difference between parameter modification at the VTU-O and VTU-R doesn't exceed 50 ms (omitting execution time).



Trigger Transitions:

A) CHANGE/BTSERVC/IDLEREQ VOC confirmed, VTU-R enters state S7.
B) CHANGE /BTSERVC/IDLEREQ VOC confirmed, VTU-O detects r_trig = 1, VTU-O enters state S7.
C) VTU_R detects o_trig = 1 and enters S5.
D) 50 ms after entering S7, VTU-O enters S5.

Figure 60: Trigger Transitions Following CHANGE/BTSERV/IDLEREQ VOC Message

8.3.10 VTU-R state machine

The VTU-R state machine is shown in figure 61. The conventions for interpreting this figure are the same as those described for figure 59.

S1: R_POWERUP

This state is the initial state of the state machine. It corresponds to the start of the process and shall be entered in the following cases:

- a *QUIET* Control signal or a Power-up request is applied. This is the first step in a pending *Cold-Start* or *Warm-Start* attempt, as shown by figure 57.
- Loss of Downstream Signal (*DS_LOS*) is detected while in states *S3 - S4*, time-out of states *S3 - S4.* This *S1* entry follows a failed activation attempt and is the first step in a pending reactivation attempt of type specified by figure 57.

In state *S1* the VTU-R shall transmit R_QUIET. The VTU-R transmitter and receiver shall be configured with the STP stored in CR_STPM.

The VTU-R transits into state *S2* if loss of the received downstream signal (DS_LOS) is detected for more than in t_{P_R} ms.

NOTE 1: The definition for *los* given in clause 7.3.1.3 shall be used for *DS_LOS*.

S2: R_STANDBY

In state S2 the VTU-R shall transmit R_QUIET and wait for an activation request, which could be either the *Connect* Control signal, if the link is activated from the VTU-R, or detection of the downstream received signal energy, if the link is activated from the VTU-O. Once the activation request is performed the timer t_R shall be started from zero and state *S3* is entered. If *QUIET* is applied while in this state, the VTU-R shall return to state *S1*.

NOTE 2: The timer t_R, started at the beginning of VTU-O activation, is used to monitor the VTU-O synchronisation process.

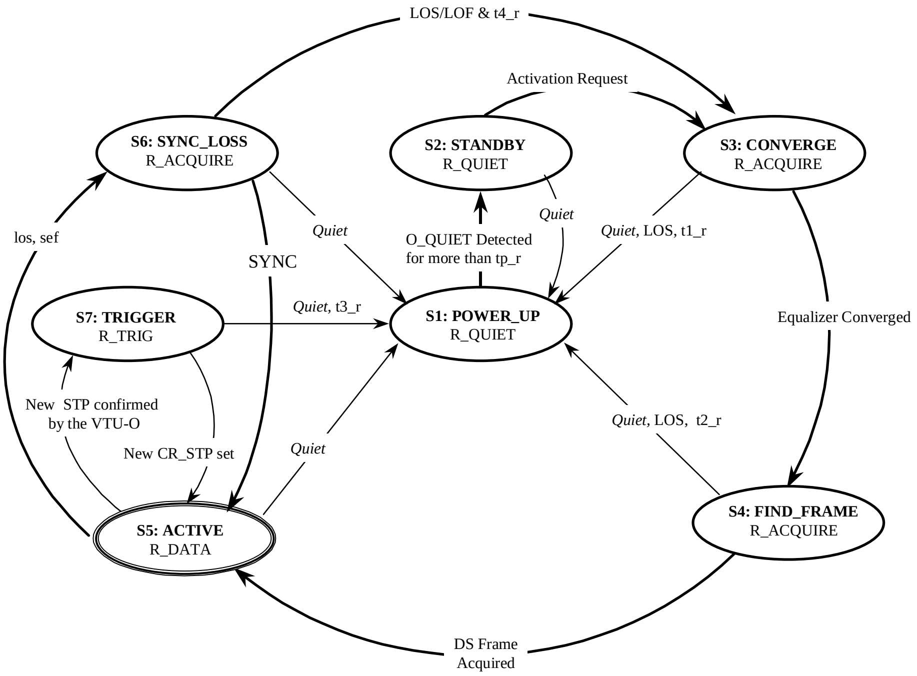


Figure 61: VTU-R Activation/Deactivation State Machine

S3: R_CONVERGE

In state *S3* the VTU-R shall transmit the R_ACQUIRE signal while attempting to converge the downstream equaliser(s). The IB-9(rdi) bit shall be set 1 to indicate that the downstream direction is not synchronised. This state is entered from state *S2* following an activation request, or from state *S6* following a non recovered synchronisation loss (including that due to a change in the current downstream transmission parameters through the CHANGE VOC message). The transition from *S6* to *S3* corresponds to the initiation of a *Resume-On-Error* activation attempt.

NOTE 3: The converging process includes identification of the received DS signal shaping type (whether BSS or PSS).

The VTU-R shall converge its downstream equaliser(s) before the timer t_R reaches $t_{1\text{-}R}$ ms. If convergence is not achieved within this time the VTU-R shall return to state *S1*. If convergence is reached before this time, the VTU-R shall immediately transit to state *S4*, without waiting for the full time-out period to elapse.

If *QUIET* is applied or if *DS_LOS* occurs while in this state, the VTU-R shall return to state *S1*.

If state *S3* is entered from state *S2* upon activation request for a *Cold-Start* an upstream power back-off (US_PBO) procedure shall be applied. Upon entering state *S3* the VTU-R shall start to transmit R_ACQUIRE signal at a reduced power level (the level is for further study). At the start of the downstream equaliser convergence process the received downstream signal will be measured and the R_ACQUIRE signal power level shall be raised to the nominal value, including the upstream power back-off. The functional diagrams describing activation from both the VTU-O and the VTU-R are presented in figures 62 and 63.

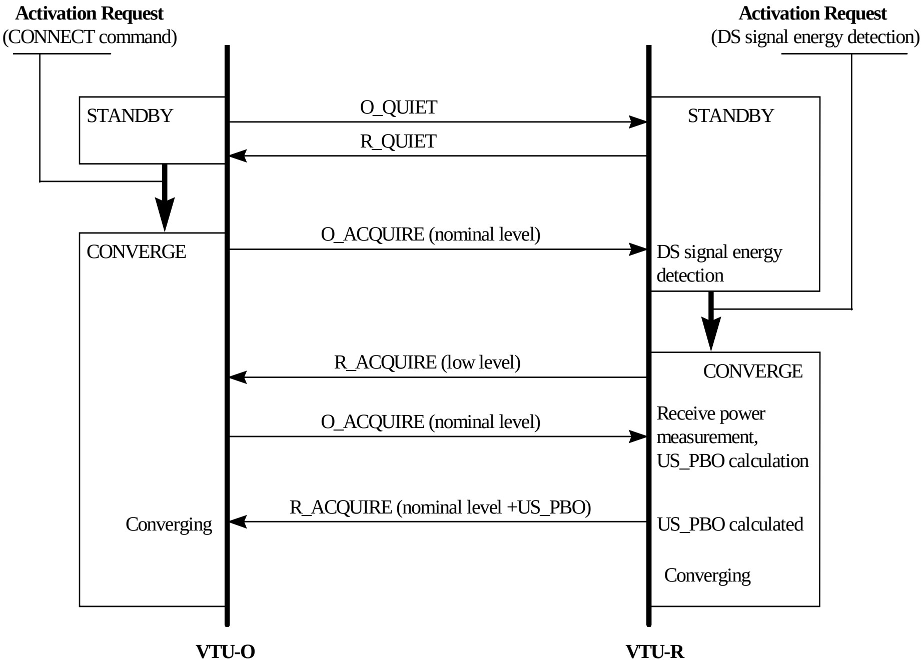


Figure 62: Activation From the VTU-O

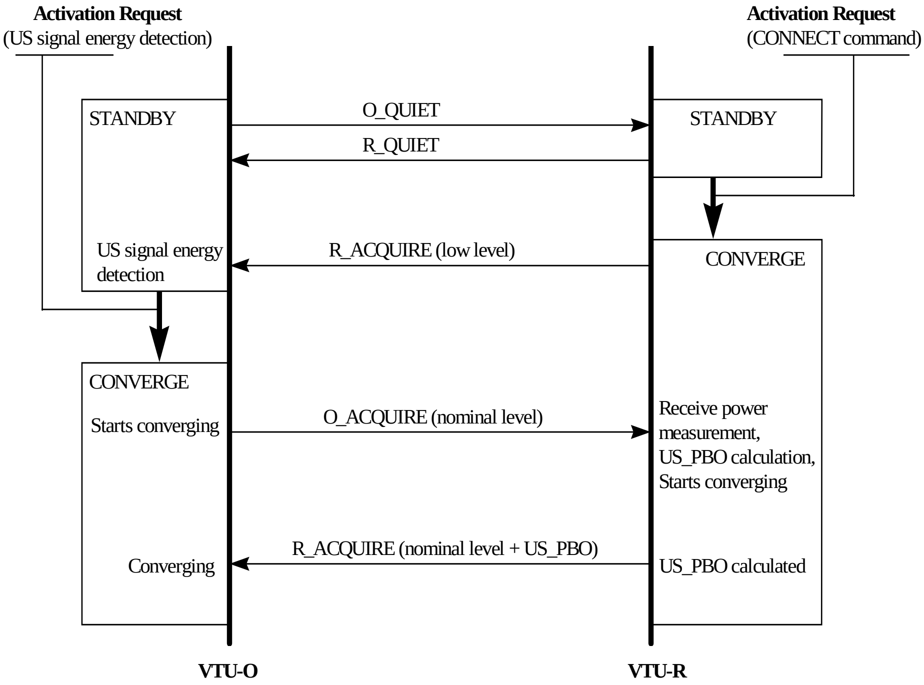


Figure 63: Activation From the VTU-R

S4: R_FINDFRAME

While in state *S4* the VTU-R shall transmit R_ ACQUIRE and IB-9(rdi) bit shall be set 1 to indicate that the downstream direction is not synchronised yet. In state *S4* the VTU-R shall process the received downstream bit stream to acquire the downstream transmission frame using the Frame Delineation Algorithm (see clause 6.5.1.5). The VTU-R shall transit to state *S5* as soon as the frame acquisition is complete and stable for at least 100 ms. If frame acquisition is not complete before t_R reaches t_{2-R} ms, or if *QUIET* is applied, or if *DS_LOS* occurs while in this state, the VTU-R shall return to state *S1*.

S5: R_ACTIVE

The VTU-R resides in this state while the downstream channel is acquired. While in *S5* the VTU-R shall transmit R_DATA, the link state is either *Steady State Transmission* or *Idle*.

In *S5* the VTU-R may receive VOC messages which deliver modified transmission parameters values for CR_STP, WS_STP or I_STP, as directed by the VTU-O. If a *B_SERV* Control signal is applied the VTU-R shall transmit r_flag = 1 and shall wait for the successful reception of the BTSERV VOC message, which confirms that the *B_SERV* signal applied in the VTU-R was received by the VTU-O.

If the VTU-R successfully receives the CHANGE, BTSERVC, or IDLEREQ VOC messages, it shall transit to state *S7*.

If los or sef occurs while in this state, VTU-R shall transit to state *S6*. If *QUIET* is applied VTU-R shall return to state *S1*.

S6: R_SYNC LOSS

In this state the VTU-R attempts to recover the lost transmission frame synchronisation. After the synchronisation is recovered the VTU-R shall return back to state *S5*. If synchronisation is not recovered during the time-out interval of **t4_r** ms, the VTU-R shall move to state *S3* to initiate a *Resume-On-Error* activation request. The VTU-R shall move to state *S1* if *QUIET* is applied. During this state R_ACQUIRE is transmitted to inform the VTU-O on the VTU-R synchronisation loss by setting IB-9(rdi) = 1.

S7: R_TRIGGER

In state *S7* the VTU-R shall transmit the R_TRIG signal with r_trig = 1 and shall monitor the o_trig bit in the received transmission frames. Once o_trig = 1 is detected, the VTU-R shall overwrite CR_STP with a new parameter setting, with WR_STP, or with I_STP, depending on whether the CHANGE, BTSERVC or IDLEREQ VOC message, respectively, was last transmitted. Then the VTU-R shall make the corresponding changes to its transmitter/receiver parameters, and shall return to state *S5* with a new CR_STP parameter setting. Upon entering *S5* RE_STP shall be automatically overwritten to CR_STP. If o_trig = 1 is not detected within the time-out interval of $t_{3\text{-}R}$ ms after entering state *S7*, the VTU-R shall return to state *S1*.

If *QUIET* is applied the VTU-R shall return to state *S1*.

8.3.11 Two-step activation

Both the VTU-O and the VTU-R may support a two-step activation process.

Step 1: Activation with 4-point constellation;

Step 2: Modifying the constellation size using a standard CR_STP procedure.

The standard two-step activation shall use the activation diagram described in clause 8.3 and the standard VTU state machine described in clause 8.3.9. It shall be performed in the following sequence:

7) Start the link and reach steady-state transmission with DF_STP.

8) Select the required transmission profile by sending a PROFILE command with bit D3 set.

9) Change the selected profile from DF_STP to CR_STP using the CHANGE command and reach steady-state transmission.

10) Use the CONSTEL command to specify the desired constellation size.

11) Activate the modified CR_STP profile using the CHANGE command and reach steady-state transmission.

NOTE 1: Performance monitoring VOC messages are allowed to be inserted between the specified parameter setting messages.

NOTE 2: If the VTU-R can only be activated using the two-step approach, the constellation size for the WS_STP profile shall be fixed to QAM-4.

Annex A (informative): UTOPIA Implementation of the ATM-TC Interface

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

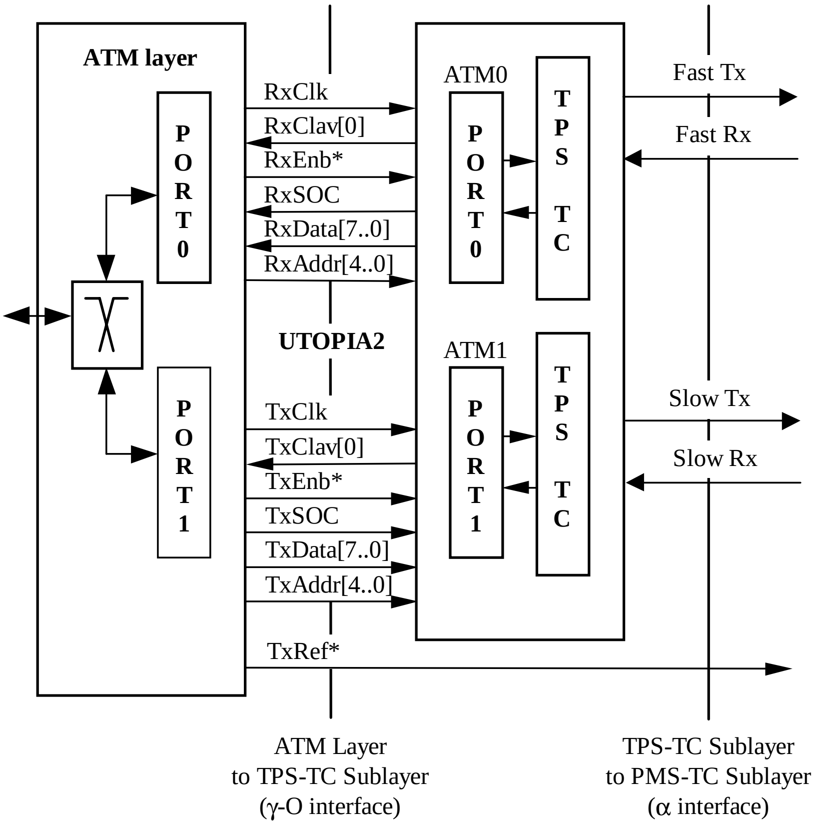


Figure A.1: Interfaces to ATM TPS-TC Sublayer, internal to ATM VTU-O

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. The ATM Layer management configures the cell de-multiplexing process.

An ATM TPS-TC Sublayer is provided for each latency path separately. ATM TPS-TC functionality is described in clause 6.2.1.

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 A.1 and A.2 and shown in figure A.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 A.1: UTOPIA Level 2 ATM Interface Signals for Tx

Signal Name	Direction	Description
Transmit Interface		
TxClk	ATM to PHY	Timing signal for transfer
TxClav[0]	PHY to ATM	Asserted to indicate that the PHY Layer has buffer space available to receive a cell from the ATM Layer (de-asserted 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 A.2: UTOPIA Level 2 ATM Interface Signals for Rx

Signal Name	Direction	Description
Receive Interface		
RxClk	ATM to PHY	Timing signal for transfer
RxClav[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 (de-asserted 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 RxClav 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 the ATM Forum Specification, af-phy-0039.000.

Annex B (informative): TC Example Algorithms

B.1 Frame Delineation Algorithm

The transmission frame delineation algorithm is based on Sync_Events (Syncword detection at the expected locations). The frame delineation state machine, comprising HUNT, PRESYNC and SYNC states, is shown in figure B.1.

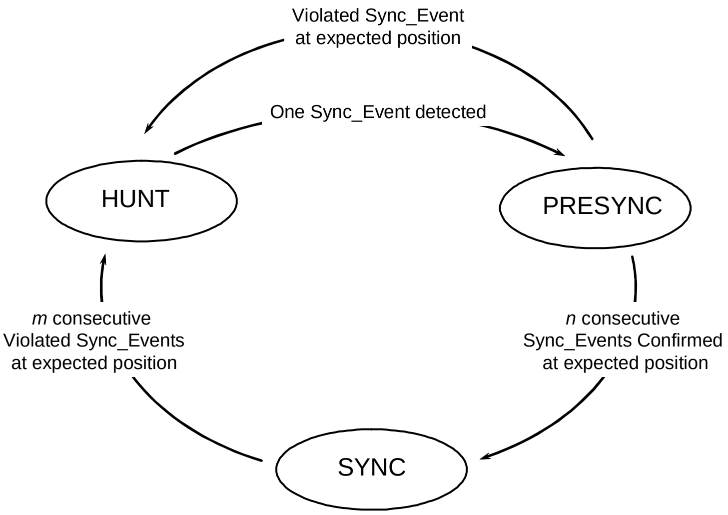


Figure B.1: Frame Delineation State Machine

In HUNT state the frame synchronisation is lost and the state machine attempts to acquire frame synchronisation by searching the frame Sync_Event. After the first Sync_Event occurs the state machine transits from HUNT state to PRESYNC state.

The state machine transits from PRESYNC state to SYNC state when the frame Sync_Event occurs consecutively at least n = 2 times. If a violated Sync_Event occurs during PRESYNC state the state machine transits back to HUNT state.

The state machine transits from SYNC state to HUNT state when the frame Sync_Event is violated consecutively at least m = 6 times for the rates lower than 26 Mb/s and at least m = 8 times for the higher rates.

B.2 Convolutional Interleaver

B.2.1 Implementation Example

The interleaving is performed at the transmitter side by writing the octets of the incoming Reed-Solomon codeword into a bank of I virtual shift registers numbered j = 0, 1, … ($I-1$). The length of virtual shift register j in the interleaving memory is: $M \times j$.

The de-interleaving is performed at the received side by writing the octets of the incoming codeword into a bank of I virtual shift registers numbered j = 0, 1, … ($I -1$). The length of virtual shift register j in the de-interleaving memory is: $M \times (I-1-j)$.

The codeword is input either into the interleaving or de-interleaving memory by blocks of *I* octets at a time. The first octet from the codeword is written into the first shift register, the second octet into the second shift register and so on, up to the register (*I-1*). This process is repeated *N*/*I* times until the complete codeword is input into the bank of shift registers.

The codeword is output from the interleaving or de-interleaving memory by reading blocks of *I* octets at a time. The first octet from the codeword is read from the first shift register, the second octet from the second shift register and so on, up to the register (*I-1*). This process is repeated *N*/*I* times until the complete codeword is extracted from the bank of shift registers.

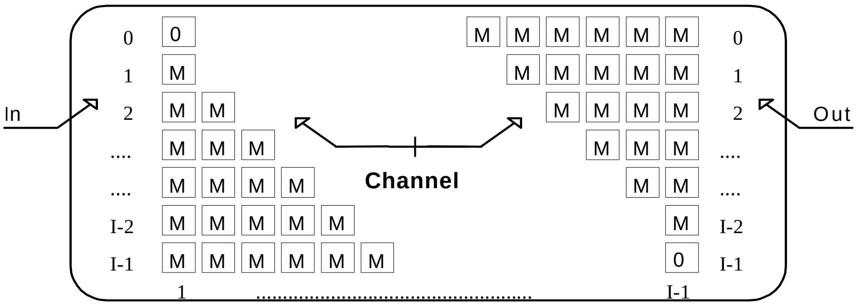


Figure B.2: Interleaver/De-interleaver Implementation example

Figure B.2 shows the structure of the interleaver. The *I* parallel branches, numbered 0, 1. .. (*I-1*) are implemented with a delay increment of *M*I* octets per branch. Each branch is a shift register with the length of 0×*M*×*I*, *M*×*I*, 2*M*×*I*, ..(*I-1*)×*M*×*I* bytes. The de-interleaver is similar to the interleaver, but the branch indexes are reversed so that the largest interleaver delay corresponds to the smallest de-interleaver delay. De-interleaver synchronization is achieved by routing the first octet of an interleaved block of *I* bytes into the branch 0.

B.2.2 Interleaving Parameters - Example

Some typical examples of interleaving parameters values of *M*, *E* and end-to-end delay calculated for *N*/*I* = 8, *t* = 8 and different line rates are presented in table B.1.

Table B.1: Interleaving depth Parameter values

Line Rate, Mb/s		**1,62**	**3,24**	**6,48**	**12,96**	**25,92**	**51,84**
Value of N/I		8					
250 µs of erasure correction	M, octets	2	4	8	16	32	64
	Delay, msec	5,9					
500 µs of erasure correction	M, octets	4	8	16	32	64	128
	Delay, msec	11,8					

Annex C (informative): Provisional handshake parameters

Table C.1: Void

Table C.2: Carrier sets for the 4,3125 kHz signalling family

Carrier set designation	Upstream carrier sets		Downstream carrier sets		Transmission mode
	Frequency indices (N)	Maximum power level/carrier (dBm)	Frequency indices (N)	Maximum power level/carrier (dBm)	
A43	9, 17, 25	-1,65	40, 56, 64	-3,65	duplex only
B43	37, 45, 53	-1,65	72, 88, 96	-3,65	duplex only
C43	7, 9	-1,65	12, 14, 64	-3,65	duplex only
D43	TBD	TBD	TBD	TBD	duplex only

Table C.3: Mandatory carrier sets

xDSL Recommendation(s)	Carrier set designation
ITU-T Recommendation G.992.1 [4], annex A, ITU-T Recommendation G.992.2 [5], annex A/B	A43
ITU-T Recommendation G.992 [5], annex B	B43
ITU-T Recommendation G.992.1 [4], annex C, ITU-T Recommendation G.992.2 [5], annex C, ITU-T Recommendation G.992.1 [4], annex H	C43
ETSI MCM VDSL	D43

Table C.4: Standard information field - SPar(1) coding - Octet 1

Bits 8	7	6	5	4	3	2	1	SPar(1)s - Octet 1
x	x	x	x	x	x	x	1	G.992.1 - annex A
x	x	x	x	x	x	1	x	G.992.1 - annex B
x	x	x	x	x	1	x	x	G.992.1 - annex C
x	x	x	x	1	x	x	x	G.992.2 - annex A/B
x	x	x	1	x	x	x	x	G.992.2 - annex C
x	x	1	x	x	x	x	x	G.992.1 - annex H
x	1	x	x	x	x	x	x	Reserved for allocation by the ITU-T
x	0	0	0	0	0	0	0	No parameters in this octet

Table C.5: Standard information field - SPar(1) coding - Octet 2

Bits 8	7	6	5	4	3	2	1	SPar(1)s - Octet 2
x	x	x	x	x	x	x	1	G.992.1 - annex A
x	x	x	x	x	x	1	x	G.992.1 - annex B
x	x	x	x	x	1	x	x	Committee T1 DMT VDSL
x	x	x	x	1	x	x	x	Reserved for allocation by the committee T1
x	x	x	1	x	x	x	x	ETSI MCM VDSL
x	x	1	x	x	x	x	x	ETSI SCM VDSL
x	1	x	x	x	x	x	x	Reserved for allocation by the ITU-T
x	0	0	0	0	0	0	0	No parameters in this octet

Annex D (informative): MCM Duplexing

D.1 Introduction

In Multi-carrier VDSL, N orthogonal narrow-band channels (or tones) are modulated with QAM symbols at the symbol rate. For each symbol period the N modulated tones are summed to form a time-domain block of 2N (real) samples. These blocks are cyclically extended (to a total length of 2N+CE) before transmission. The most efficient implementation of DMT modulation is through the use of an IFFT.

At the receiving side 2N samples are extracted from the time-domain signal during each symbol period. An FFT is used to demodulate the signal and recover the original QAM symbols on the N tones. Obviously, the receiver has to be symbol-aligned with the transmitter such that the 2N samples that are fed to the FFT belong to the same transmitted DMT symbol. Only when this is the case are the N tones orthogonal. This means that any given tone will not exhibit sidelobe energy on any of the other tones. Put differently: only the energy transmitted on a tone will contribute to the received energy on that tone.

In reality of course, the received signal does not only consist of the useful received signal. The near-end echo and near-end crosstalk from transmissions in the opposite direction will also contribute to the received signal and will therefore be present in the 2N samples that are sent to the FFT. In general this crosstalk signal is not symbol-aligned with the transmitted signal. Usually, the 2N samples that go into the FFT contain contributions from two consecutive "crosstalk symbols". The energy from the crosstalkers is consequently not orthogonal to the useful received signal. This means that the crosstalk energy will also affect the useful received signal, even if the crosstalk was generated by a signal that uses tones in the other transmission direction.

One way of dealing with the NEXT or echo sidelobes is by filtering the transmitted signal, such that the sidelobe energy of the signal (and hence the crosstalk) is reduced.

D.2 MCM duplexing technique

Orthogonal DMT duplexing provides a way to separate the useful signal and the near-end crosstalk or echo.

As explained above, the problem of the sidelobe energy from crosstalk signals is caused by the fact that these "crosstalk symbols" are not aligned with the received symbols. If one aligns all transmit and receive signals, also the near-end crosstalk and the echo are aligned with the received symbols. The crosstalk symbols will then remain orthogonal to the useful signal and there will be no interference on the "receive tones".

Aligning the two transmission directions is easily done at one side of the modem pair (in fact such single-ended alignment is used in some ADSL implementations to simplify the echo-cancelling). In general however, alignment at one side results in a misalignment at the other side of the modem pair. The essence of the duplexing is that it provides a technique to achieve alignment on both sides simultaneously. This is done by the use of the "cyclic suffix" and "timing advance", which are explained in the following sections.

D.2.1 Cyclic Suffix (CS)

Because of the transmission delay of the line, it is normally not possible to align transmit and receive symbol at both sides simultaneously. Assume the one-way delay of the line is denoted as Δ. If transmit and receive symbols are perfectly aligned at the LT side, there will clearly be a misalignment at the NT side. Indeed, for the alignment at the LT to hold, the symbol at the NT has to be transmitted at time $-\Delta$. On the other hand, the symbol from the LT will arrive at the NT at time Δ resulting in a misalignment of 2Δ between transmit and receive at the NT.

This problem can be solved by cyclically extending the transmitted symbols. This is called the cyclic suffix (CS). If for example the symbols are extended by 2Δ it is possible at both sides of the link to chose 2N samples such that these samples contain contributions from only one received DMT symbol and only one crosstalk DMT symbol. At both LT and NT, the crosstalk will then be orthogonal with the received signal. No additional filtering is needed, since the FFT will separate the useful signal and the near-end echo or crosstalk onto different tones.

D.2.2 Timing Advance (TA)

As discussed above, a choice of CS = 2Δ will allow one to keep the signal and the echo (or crosstalk) orthogonal. However, it is not the optimal choice for the cyclic extension. In fact, the transmitted symbols at the LT can be advanced with Δ w.r.t. to received symbols. It is then still possible to select 2N samples at both sides such that signal and noise remain orthogonal. However, an important advantage is that the required cyclic suffix can be kept as low as Δ, the one-way delay of the line (instead of 2Δ).

Conceptually, this corresponds to a situation where LT and NT start transmission of each DMT symbol at different ends of the line at the same absolute moment in time. In a practical implementation it requires that the system is capable of starting its transmission at a suitable time TA before the arrival of the DMT symbol from the opposite transmission direction.

As a conclusion, one can avoid the sidelobes coming from transmissions in the opposite direction by a suitable combination of cyclic extension and timing advance. This only requires operations in the digital domain. No additional filtering is required to obtain the desired orthogonality.

D.3 Synchronous versus asynchronous operation

When the transmit and receive symbols of all systems in a binder are aligned, both the near-end echo and the near-end crosstalk will be orthogonal to the received signal. This obviously requires the synchronisation of all systems is a binder. This may not be always possible in practice. This mode is therefore only optional.

When only transmit and receive symbols of a single system are aligned, the near-end echo will not interfere with the received signal. However, the system will still experience the effect of the NEXT from other MCM VDSL systems in the same binder that are not aligned to the first system. To reduce the effect of the sidelobes coming from non-synchronised systems, all MCM VDSL systems apply windowing at the transmitter. Windowing achieves much steeper sidelobes and lower out-of-band PSD levels.

Annex E (informative): Bibliography

ATM Forum Specification 0039.000: "UTOPIA Level 2". Version 1.0, June 1995.

History

Document history		
V1.1.1	February 2001	Publication
V1.2.1	July 2003	Publication