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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
DTS/TM-06003-2

Keywords
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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 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";

Part 3: "Interoperability specification".

1 Scope

This multi-part ETSI Technical Specification (TS) 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).

The 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 Part 1 to be met.

This specification 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.

[1] ETSI TS 101 270-1 (V1.2.1 onwards): "Transmission and Multiplexing (TM); Access transmission systems on metallic access cables; Very high speed Digital Subscriber Line (VDSL); Part 1: Functional requirements".

[2] ITU Recommendation I.432.1: "B-ISDN user-network interface - Physical layer specification: General characteristics".

[3] ITU Recommendation I.432: "B-ISDN User-Network Interface - Physical layer specification".

[4] ITU-T Recommendation G.992.1: "Asymmetric Digital Subscriber Line (ADSL) transceivers".

[5] ATM Forum Specification 0039.000: "UTOPIA Level 2". Version 1.0, June 1995.

[6] ITU-T Recommendation G.992.2: "Splitterless asymmetric digital subscriber line (ADSL) transceivers".

[7] ITU Recommendation G.994.1: "Handshake procedures for digital subscriber line (DSL) transceivers".

[8] ITU Recommendation X.700: "Management framework for Open Systems Interconnection (OSI) for CCITT applications".

[9] ITU Recommendation G.997.1: "Physical layer management for digital subscriber line (DSL) transceivers".

3 Definitions, symbols 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
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, synchronization of the various data streams, and fixed indicator bits for operations, administration, and maintenance. 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
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 characterized by an average bit rate
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
Broadband typically implies transmission of bit rates greater than 100 kbps.

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

downstream: direction from the ONU to the subscriber premises

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 higher BER in comparison to the slow channel
In contrast to the slow channel the fast channel is not interleaved.

impulse noise: short-duration noise source characterized 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, synchronization, 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 characterizing 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 but lower BER 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
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

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

upstream: In the direction from the subscriber premises to the ONU.

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

3.2 Abbreviations

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

ABR	Available Bit Rate
ADC	Analogue-to-Digital Converter
ADSL	Asymmetric Digital Subscriber Line
ATM	Asynchronous Transfer Mode
ATM-TC	ATM Transmission Convergence sub-layer
ATN	Attenuation
ATP	Access Termination Point
AWG	American Wire Gauge
BER	Bit Error Rate
BSR	Basic Symbol Rate
BSS	Baseband Spectral Shaping
CBR	Constant Bit Rate
CER	ATM Cell Error Ratio
Co	Central Office (or local exchange)
COF	Co-Ordination Function
CP	Customer Premise
CPE	Customer Premises Equipment
DFT	Discrete Fourier Transform
DMT	Discrete Multi-Tone
DR	Data carrying capacity for a single carrier in an SCM system
DS	Downstream
DSA	Distribution Service Area
DSL	Digital Subscriber Line (or loop)
EMC	Electro-Magnetic Compatibility
EMI	Electro-Magnetic Interference
EN	European Norm
EOC	Embedded Operations Channel
FDD	Frequency Division Duplex
FEC	Forward Error Correction
FEQ	Frequency-domain Equalizer
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
IFI	Inter-Frame Interference
ISDN	Integrated Services Digital Network
LT	Line Termination
MIB	Management Information Base
MSB	Most Significant Bit

NEXT	Near-End crosstalk
NID	Network Interface Device
NMP	Network Management Protocol
NMS	Network Management System
NT	Network Termination
NT1	Network Termination of physical layer
NTR	Network Timing Reference
OAM	Operation, Administration and Maintenance
OAMP	Operations, Administration, Maintenance and Provisioning
ONU	Optical Network Unit
P/S	Parallel-to-Serial conversion
PDH	Plesiochronous Digital Hierarchy
PLOAM	Physical Layer OAM cells
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
PRBS	Pseudo-Random Binary Sequence
PRC	Payload Rate Change
PSD	Power Spectral Density
PSS	Passband Spectral Shaping
PSTN	Public Switched Telephone Network
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
RF	Radio-Frequency
RFI	Radio-Frequency Interference
RMS	Root Mean Squared
S/P	Serial-to-Parallel conversion
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
TBC	To Be Confirmed
TBD	To Be Determined
TC	Transmission Convergence
TE	Terminal Equipment
TP	Transmission Parameters
TPS-TC	Transport Protocol Specific Transmission Convergence layer
TR	Total data carrying capacity using both carriers in an SCM system
UBR	Unspecified Bit Rate
UNI	User-Network Interface
UPBO	Upstream Power Back-Off
US	Upstream
UTOPIA	Universal Test & Operations Physical-layer Interface for ATM
UTP	Unshielded Twisted-Pair
VBR	Variable Bit Rate
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
xDSL	generic term for the family of DSL technologies, including HDSL, ISDN, ADSL, VDSL, etc.

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.

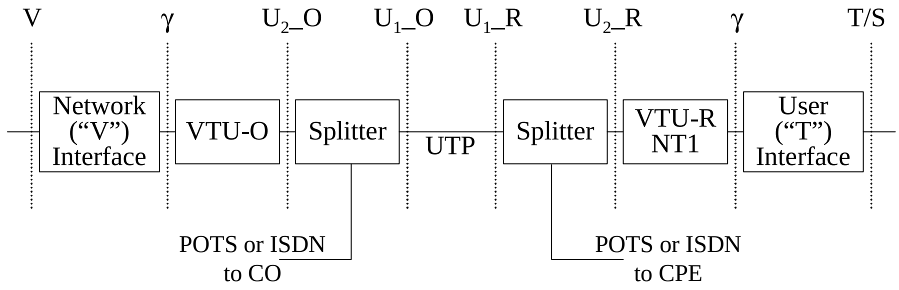


Figure 1: Interface reference model

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.

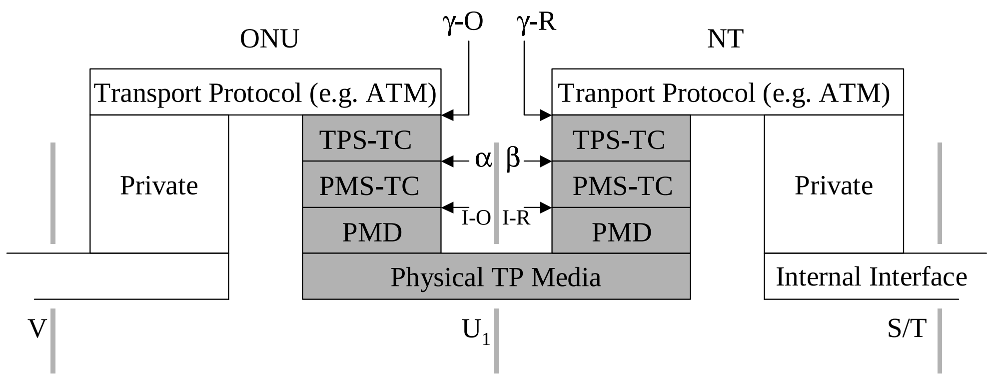


Figure 2: VDSL protocol layer model

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), 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.

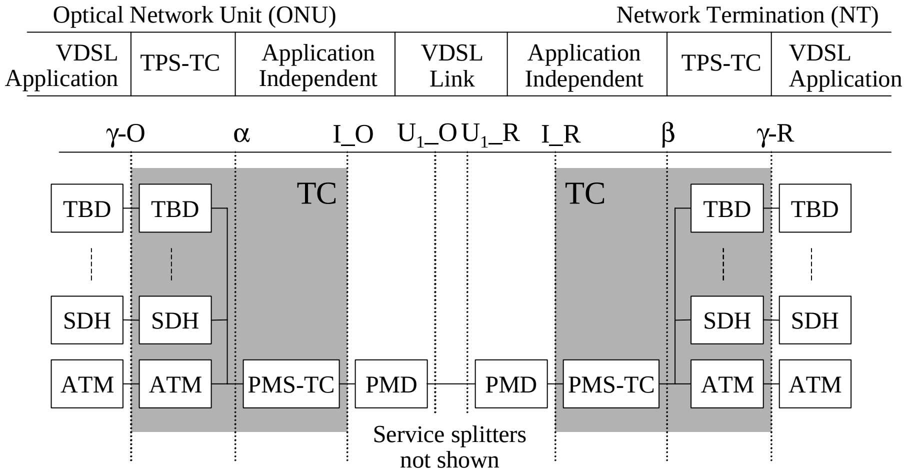


Figure 3: Functional decomposition

4.3 Reference points

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 standardized 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.

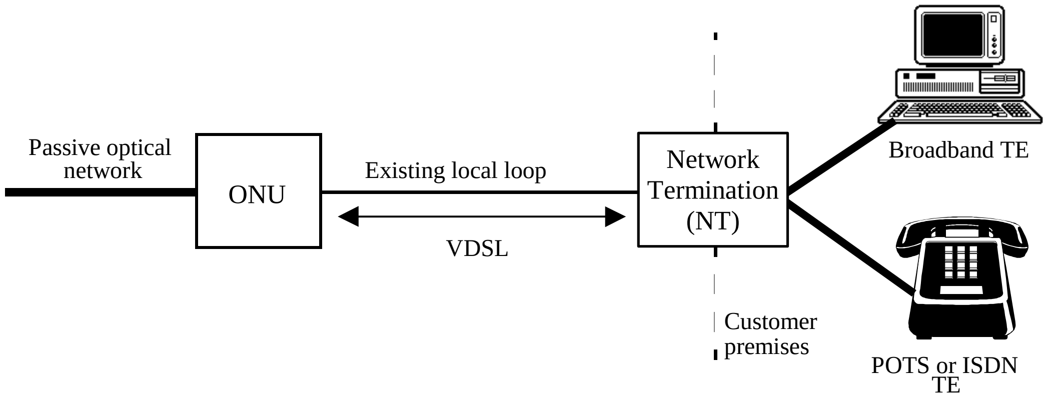


Figure 4: General fibre-to-the-node architecture for VDSL

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 layer (PMD)

5.1 Duplexing Method

VDSL modems shall use Frequency Division Duplexing (FDD). This applies to single carrier and multi-carrier modulation schemes as described in 5.3 and 5.4.

5.1.1 Band Allocation

This clause defines the frequencies allocated for upstream and downstream transmission. The overall frequency boundaries and power limits are defined in TS 101 270-1 [1].

Four bands denoted 1D, 2D, 1U and 2U (two for downstream and two for upstream respectively) are illustrated in figure 5. The actual band allocation is defined by the values of transition frequencies f_1 - f_5.

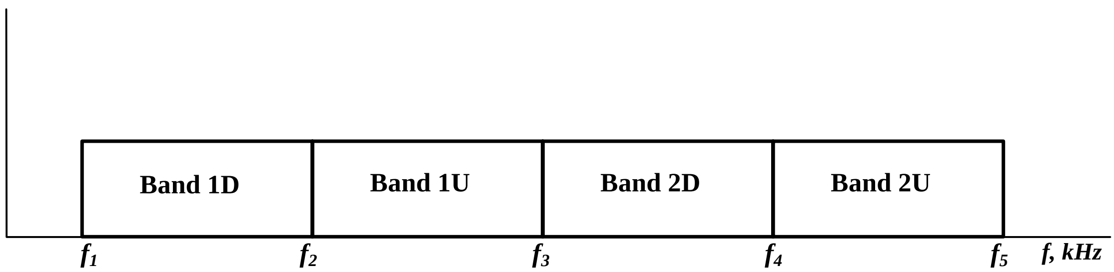


Figure 5: Illustrative VDSL Band Allocation

Table 1: Band transition frequencies

Band Transition Frequencies (kHz)	f_1	f_2	f_3	f_4	f_5
VDSL bands	138	3 000	5 100	7 050	12 000
Optional regional-specific bands	138	3 750	5 200	8 500	12 000
NOTE 1: Use of frequencies above f_5 but within the overall PSD masks is not covered in the present document and is for further study.					
NOTE 2: Use of frequencies below f_1 but within the overall PSD masks is not covered in the present document and is for further study.					

The band allocation for VDSL is shown in figure 6.

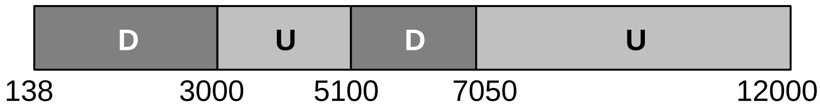


Figure 6: VDSL Band Allocation

Optionally, modems may use the band allocation shown in figure 7 to satisfy alternative regional requirements.

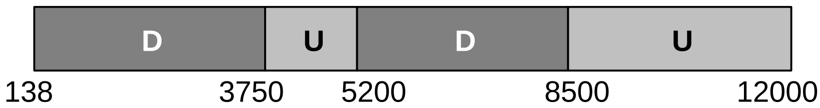


Figure 7: Optional regional-specific VDSL Band Allocation

Other plans are under study as alternatives to figure 7 to satisfy alternative regional requirements.

5.1.2 Out-of-band power limits for the transmit signal

This clause defines the residual transmit power outside of the designated transmit bands described in 5.1.1.

The out-of-band transmit signal is an additional source of noise for the VDSL receiver. It generates NEXT into other pairs in the same cable and correspondingly degrades the performance of other VDSL systems.

The out-of-band PSD mask is based on the requirement that the crosstalk from the out-of-band energy shall not increase the noise floor (assumed to include background noise of –140 dBm/Hz and one FEXT VDSL crosstalker) of receivers on other pairs in the same cable by more than 1 dB.

The out-of-band PSD mask is shown in figure 8.

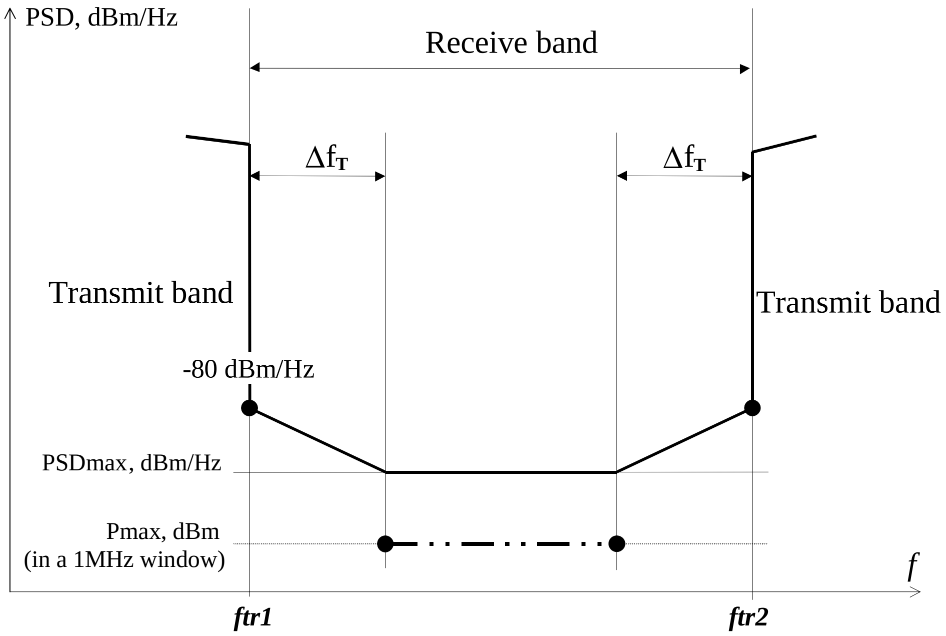


Figure 8: PSD mask definition around the transition band

Two transmit bands are shown, with the receive band in between them. The transmit bands can be either the two upstream or two downstream bands defined in 5.1.1.

Transition bands lie outside the specified transmit bands and are regions in which the transmit signal roll-off occupies part of an adjacent receive band.

The variables *ftr1* and *ftr2* represent band transition frequencies as specified in 5.1.1. The variable Δf_T represents the widths of the transition bands. The value of Δf_T is independent of frequency and is 175 kHz. Between frequency *ftr1* + Δf_T and *ftr2* – Δf_T is the stop band.

Within the transition bands (i.e. from *ftr1* to *ftr1* + Δf_T and from *ftr2* – Δf_T to *ftr2*), the transmit PSD mask either decreases linearly (on a linear scale) from –80 dBm/Hz to a value of PSD_{max}, or increases linearly (on a linear scale) from PSD_{max} to –80 dBm/Hz. Within the stop band, the transmit PSD shall not exceed PSD_{max}. Furthermore, the total transmit power in the stop band, P_{max}, measured in a 1 MHz sliding window, shall be limited.

Table 2 defines the corners of a straight-line graph of the out-of-band PSD mask versus frequency on a linear, linear scale. Table 2 also provides the wide-band power limits that shall be imposed on the out-of-band PSD.

Table 2: The out-of-band PSD mask definition

Frequency (MHz)	Maximum PSD PSD_{max}, (dBm/Hz)	Maximum power in a 1MHz sliding window P_{max}, (dBm)
< 0,12	–120	
0,12 to 0,225	–110	
0,225 to 4,0	–100	
4,0 to 5,0	–100	–50
5,0 to 30,0	–100	–52
> 30,0	–120	
Transition frequency	–80	

NOTE1: The out-of-band transmit PSD shall comply with *both* the maximum PSD limitation, using a measurement resolution bandwidth of 10 kHz, and the maximum power in a 1MHz sliding window limitations presented in table 2.

NOTE 2: The power in a 1 MHz sliding window is measured in a 1MHz bandwidth starting at frequency *ftr1* + Δf_T of the corresponding transmit signal band and finishing at frequency *ftr2* – Δf_T.

NOTE 3: If the value of the stop band, $ftr2 - ftr1 - 2\Delta f_T$, is narrower than 1 MHz, the bandwidth of the measurement device should be set to F, with $F <$ value of the stop band minus $2\Delta f_T$, and the measured result should be recalculated to the 1 MHz sliding window as:

$$\text{Pmax} = \text{P} - 10\log(F),$$

Where P is the measured result in dBm and F is the bandwidth, in MHz, used for the measurement.

5.2 Upstream power back-off

This clause applies to all modulation schemes (single carrier and multi-carrier) and describes how power back-off shall be implemented.

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

i. It shall be possible for the network management system to set the limiting transmit PSD mask for the VTU-R to one of the standard masks specified in TS 101 270-1 [1]. The method to determine this limiting mask is for further study.

ii. The VTU-R shall perform UPBO as described in 5.2.1 autonomously, i.e. without sending any significant information to the VTU-O until the UPBO is applied.

iii. After UPBO has been applied as described in (ii), the VTU-O shall be capable of adjusting the transmit PSD selected by the VTU-R; the adjusted transmit PSD shall be subject to the limitations in 5.2.1.

iv. To enable the VTU-R to initiate a connection with the VTU-O, which will occur before UPBO has been applied, the VTU-R shall be allowed to cause more degradation to other loops than expected when using the mode described in 5.2.1. The mechanism by which the VTU-R initiates a connection and the allowed additional degradation during initiation is for further study.

5.2.1 Upstream transmit PSD mask estimation

The VTU-R shall explicitly estimate the electrical length of its line, kl_0, and use this value to calculate the transmit PSD mask $TxPSD(kl_0,f)$. The VTU-R shall then adapt its transmit signal to conform to this mask while remaining below the PSD limit set by the management system as described in (i) of 5.2.

$$TxPSD(kl_0,f) = PSD_{\text{REF}}(f) + LOSS(kl_0,f) \qquad \text{in dB.}$$

$$LOSS(kl_0,f) = kl_0 \sqrt{f} \qquad \text{in dB.}$$

The *LOSS* function is an approximation of the loop attenuation (insertion loss). More accurate approximations of the *LOSS* function are for further study.

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

kl_0 is the estimate of the electrical length of a line.

5.3 Multi-carrier PMD sub-layer specification

5.3.1 PMD functional model

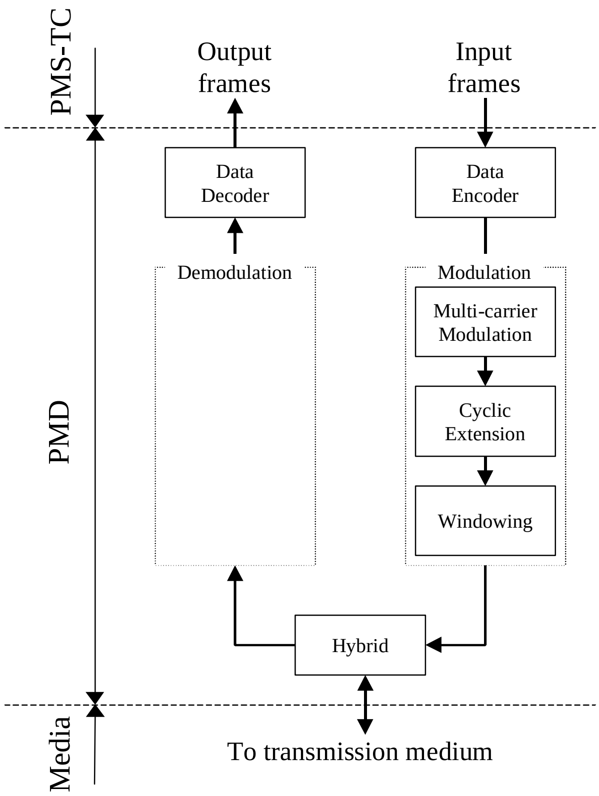


Figure 9: Functional model of PMD Sub-layer

The functional model of the PMD sub-layer is presented in figure 9.

In the transmit direction, the PMD layer receives input frames from the PMS-TC sub-layer. A frame contains exactly the number of octets that will be modulated onto one DMT symbol. This will be an integer number. Each sub-carrier has a number of bits assigned to it during initialization. The bits that are to be transmitted on a sub-carrier are encoded into constellation points according to the rules given in 5.3.2.5. 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.

5.3.2 VTU-O and VTU-R functional characteristics

5.3.2.1 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 (5.1.1). The exact subsets of sub-carriers used to modulate data in each direction are determined during initialization 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.

5.3.2.1.1 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.

5.3.2.1.2 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.

5.3.2.1.3 Modulation by the inverse 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,

$$Z_i' = Z_i,\ i = 0, \ldots, N_{SC}-1; \text{ and}$$

$$Z_i' = conj\,(Z_{2N_{sc}-i}),\ i = 0, \ldots, 2N_{SC}-1$$

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':

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

5.3.2.2 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 5.3.2.1. The windowed parts of consecutive symbols overlap (β samples).

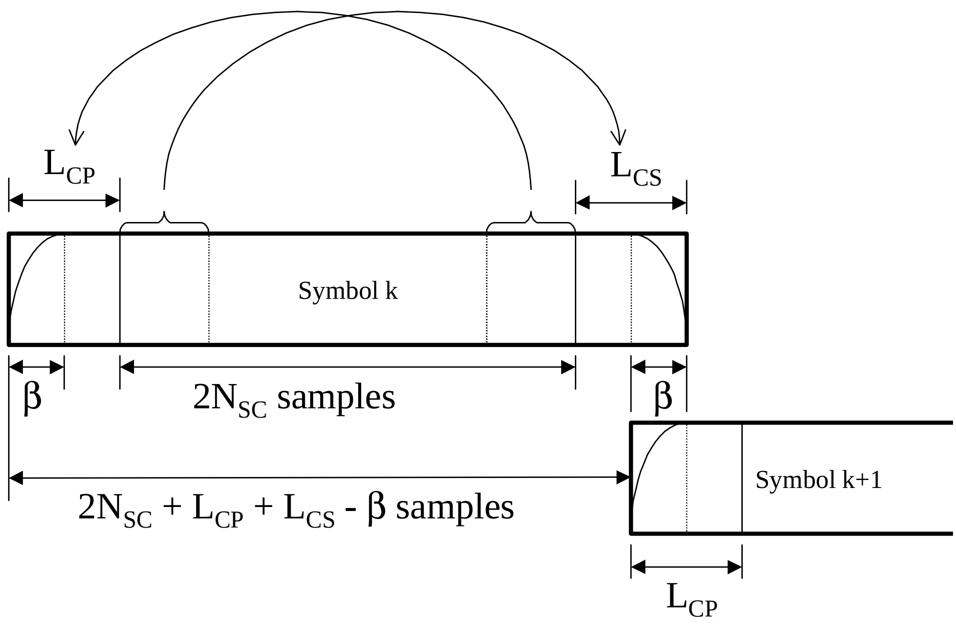


Figure 10: Cyclic extensions, windowing and overlap of DMT symbols

Figure 10 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. It is mandatory that L_{CP}, L_{CS} and β be chosen such that $L_{CP} + L_{CS} - \beta$ can at least take the value 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 3 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 µsec, irrespective of the sampling rate.

Table 3: 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
1024	160
2048	320
4096	640

The symbols shall be transmitted at a rate equal to

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

5.3.2.3 Synchronization

5.3.2.3.1 Pilot tone

Use of a dedicated pilot tone is optional. During initialization, 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 initialization (8.2.6.3.1.4). The VTU-O then transmits the 4QAM value of 00 on that tone during every symbol.

5.3.2.3.2 Loop timing

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

5.3.2.3.3 Timing advance

To maximize efficiency, 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 initialization (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.

5.3.2.3.4 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 (5.3.2.3.3) shall be used to correct the VTU-R symbol timing to synchronize VTU-O and VTU-R transmissions.

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

5.3.2.4 Power back-off in the upstream direction

Transceivers shall be capable of performing frequency-dependent power back-off while complying with 5.2. A maximum allowed receive PSD at the VTU-O will be defined. This PSD will be input via the management interface. This PSD may be defined by the owner of the cable plant, or it may be imposed by a regulatory body.

In the early stages of initialization (8.2.4.3.1.1), the VTU-O will transmit to the VTU-R either:

a) the maximum allowed receive PSD; or

b) the maximum allowed transmit PSD.

In the case of (a), the VTU-R will adjust its transmit PSD such that the PSD received at the VTU-O does not exceed the maximum allowed receive PSD.

In the case of (b), the VTU-R will adjust its transmit PSD such that it does not exceed the maximum allowed transmit PSD.

The result will be used as the initial upstream transmit PSD. Upon receiving signals from the VTU-R, the VTU-O will compare the actual received PSD to the maximum allowed receive PSD. If necessary, it will use O-UPDATEn to instruct the VTU-R to fine-tune its PSD (8.2.4.3.1.2).

5.3.2.5 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 initialization. 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.

5.3.2.5.1 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 11 shows example constellations for b = 2 and b = 4.

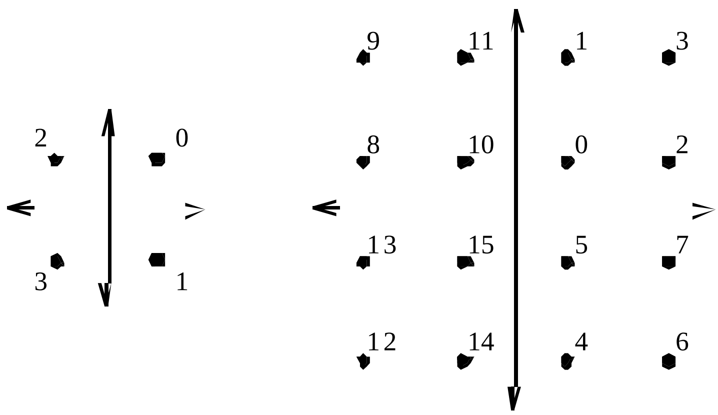


Figure 11: Constellation labels for *b* = 2 and *b* = 4

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.

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

Figure 12 shows the constellations for the cases $b = 1$ and $b = 3$.

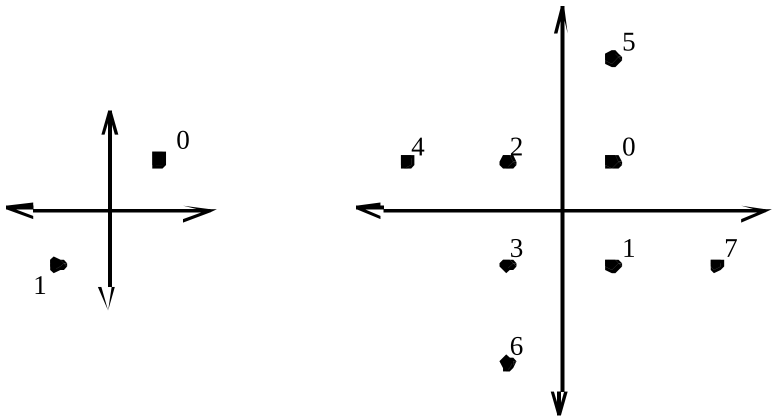


Figure 12: Constellation labels for *b* = 1 and *b* = 3

5.3.2.5.3 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 4.

Table 4: 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 13 shows the constellation for the case $b = 5$.

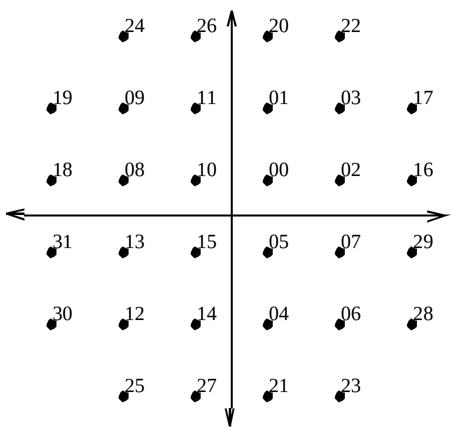


Figure 13: Constellation labels for *b* = 5

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:

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

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

5.3.2.6 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 equalize 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.

5.3.2.7 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 $B_{max\_d \text{ or } u}$

- 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 14 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.

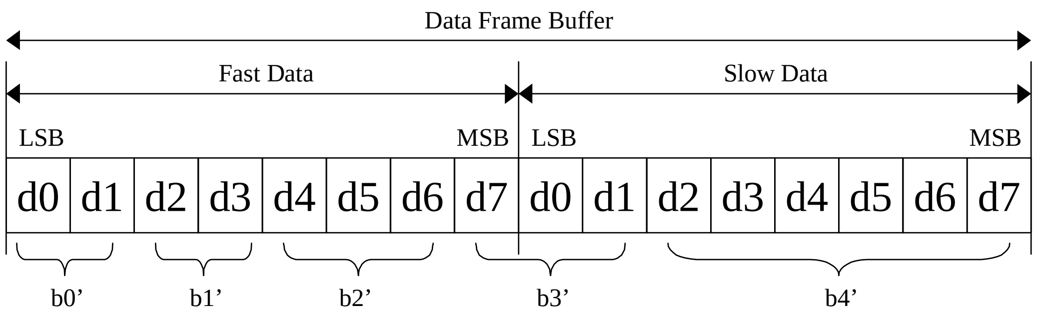


Figure 14: Bit extraction after tone ordering

5.3.2.8 U-interface characteristics

5.3.2.8.1 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.

5.3.2.8.2 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 5.3.2.8.1) 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].

5.3.2.8.3 Aggregate power level

The aggregate power level shall comply with TS 101 270-1 [1].

5.4 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.

5.4.1 Basic principles

5.4.1.1 Functional model

The VDSL transceiver functional model is presented in figure 15. 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 (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.

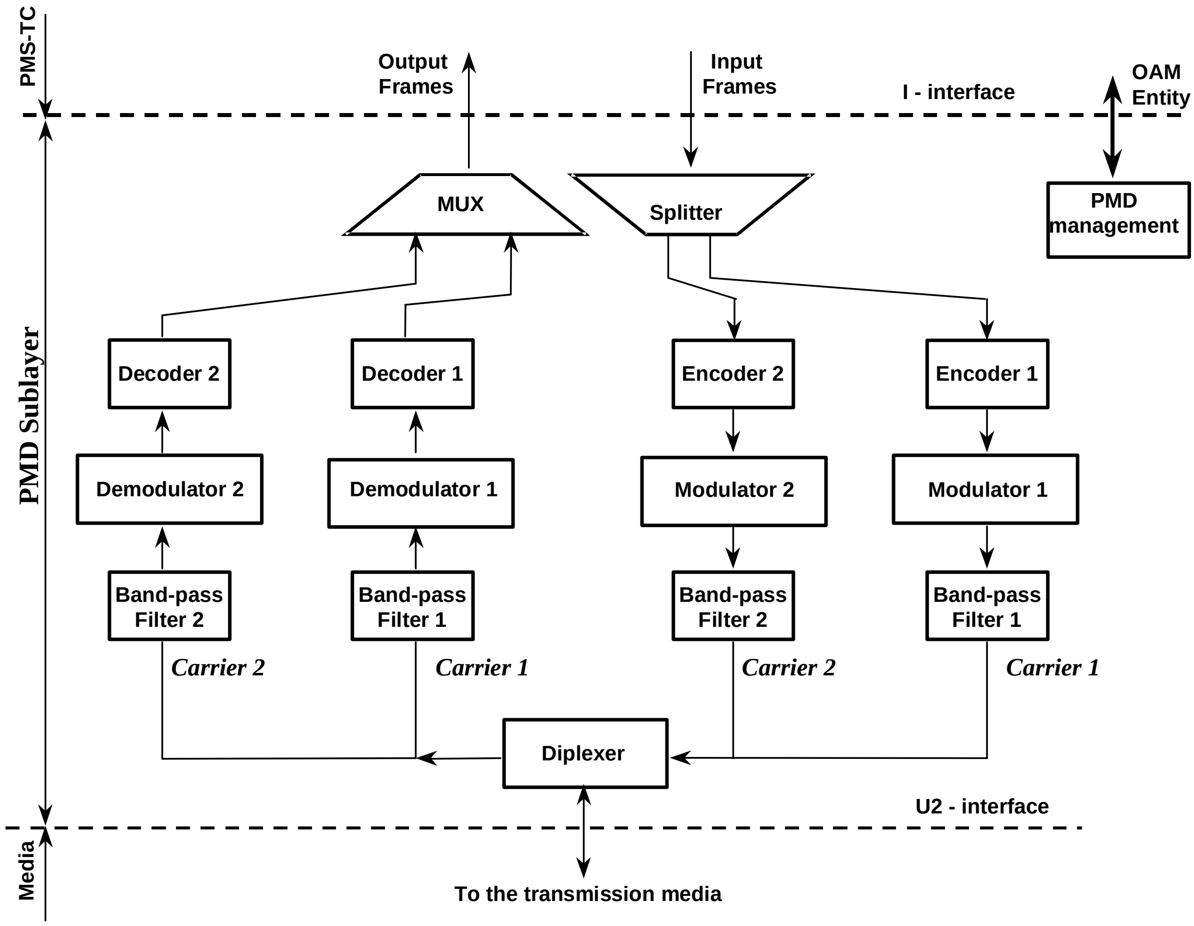


Figure 15: VTU PMD Sub-layer Functional Model

5.4.1.2 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 synchronization. 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.

5.4.2 Transmit Functionality

5.4.2.1 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 15). The same splitting procedure is applied for both the upstream and downstream carriers. The PMD-frame Syncword contains Sync1 and Sync2 octets (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 16. 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 16). 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 (either carrier-1 or 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 16.

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 16 are aligned with the Sync1 octet of the input frame #1.

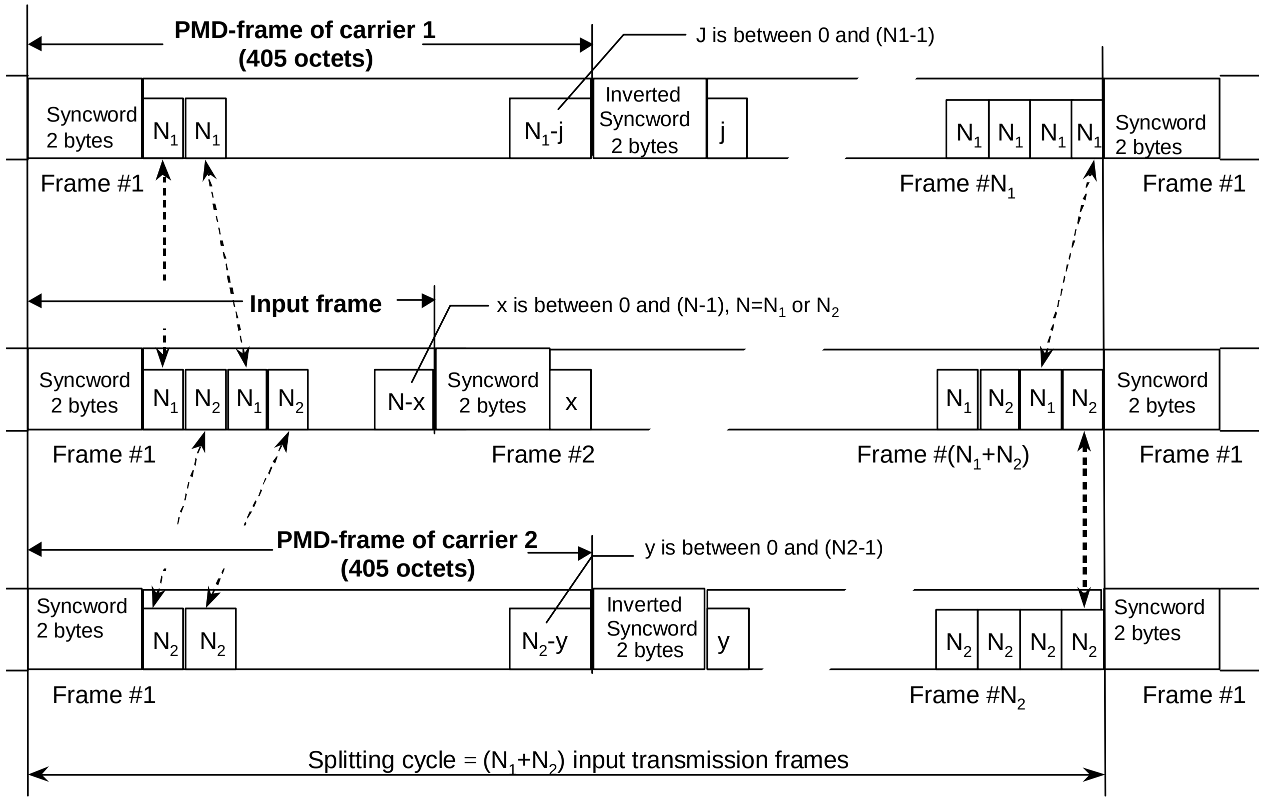


Figure 16: PMD-frame Format

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, should be less than 1 µs.

5.4.2.2 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 both 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 17 and 18 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 n^{th} 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 17 shows the block diagram of an SCM transmitter using PSS while figure 18 shows the block diagram of an SCM transmitter using BSS.

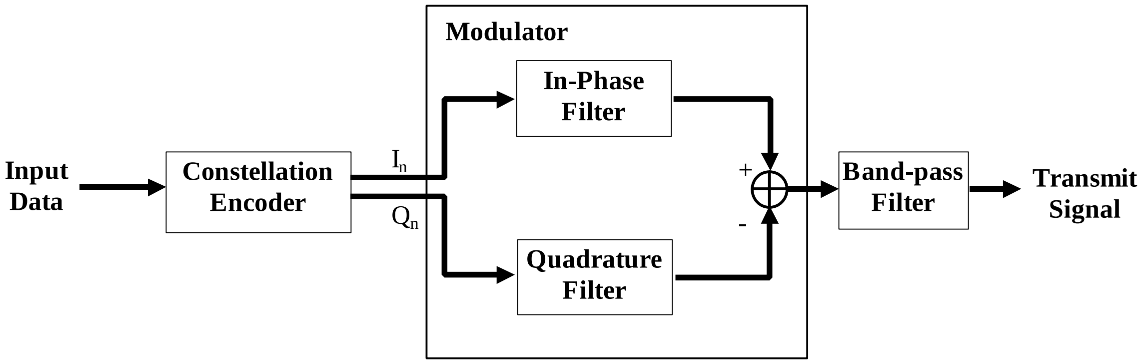


Figure 17: Block Diagram of a SCM Transmitter Using PSS

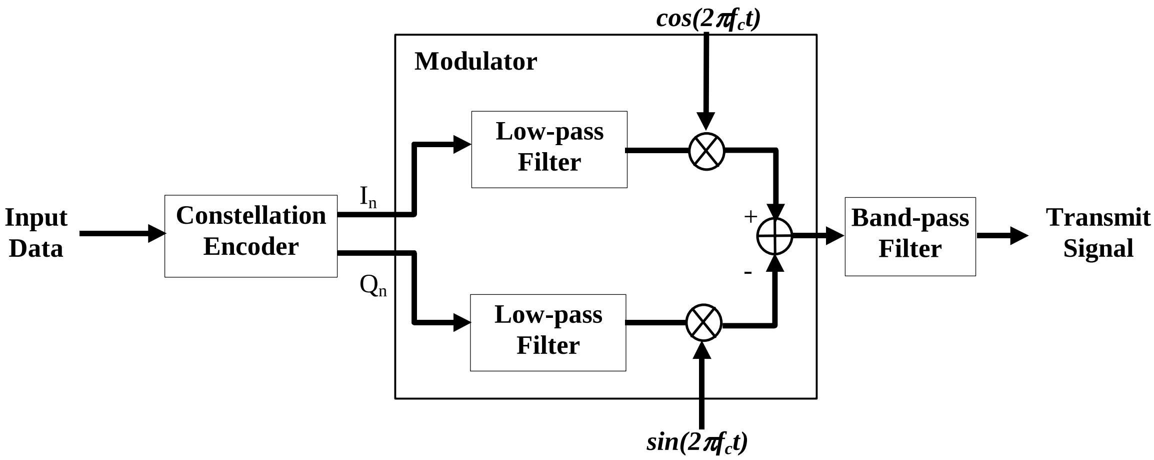


Figure 18: Block Diagram of a SCM Transmitter Using BSS

5.4.2.2.1 Constellation Encoder

The Encoder input data is converted into a serial stream of bits with the most significant bit first. For a given constellation of size 2^M, a group of M bits {b1,b2,…bM} in the bit stream is encoded into one symbol, and consecutive groups of M bits are encoded into consecutive symbols as illustrated in figure 19. Differential quadrant encoding shall be used to encode the first two bits, {b1,b2}, as shown in table 5. The four values of {b1,b2} are represented by the quadrant transition of the symbols. The remaining (M-2) bits shall be encoded in accordance with the corresponding constellation diagrams. The constellation diagrams for 4, 8, 16, 32, 64, 128 and 256 points are given in figures 20 through 26.

In figures 24 through 26 the second, third and fourth quadrant mappings are derived from the mappings in the first quadrant by rotating this quadrant counter-clockwise by 90 degrees, 180 degrees, and 270 degrees, respectively.

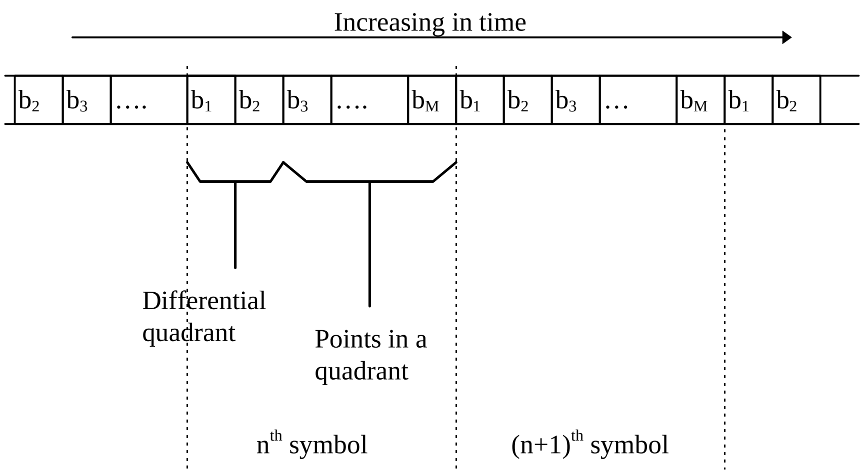


Figure 19: Bit to symbol mapping

Table 5: Differential Encoding of b1, b2

	Previous quadrant	**Sign of previous symbol**	**Current quadrant**	**Sign of current symbol**
b1 b2	number	I_{n-1} Q_{n-1}	number	I_n Q_n
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	– +

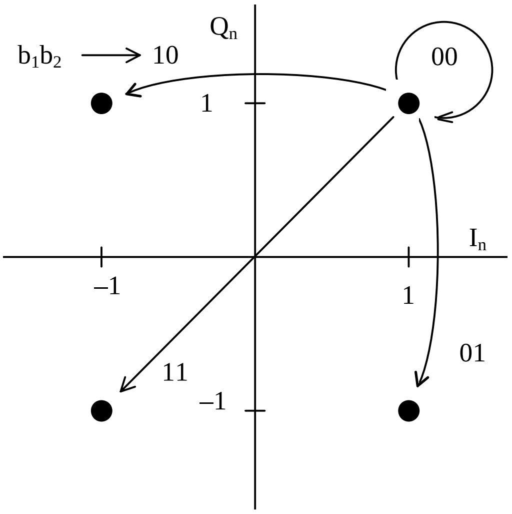


Figure 20: 4-point Constellation with Differential Bit Encoding

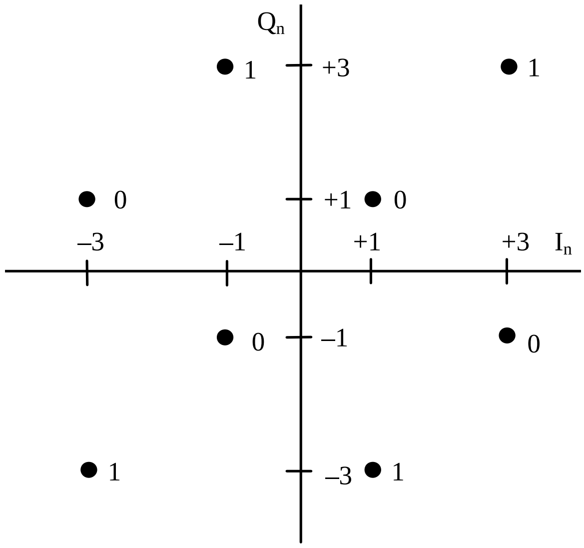


Figure 21: 8-point Constellation and Bit Mapping

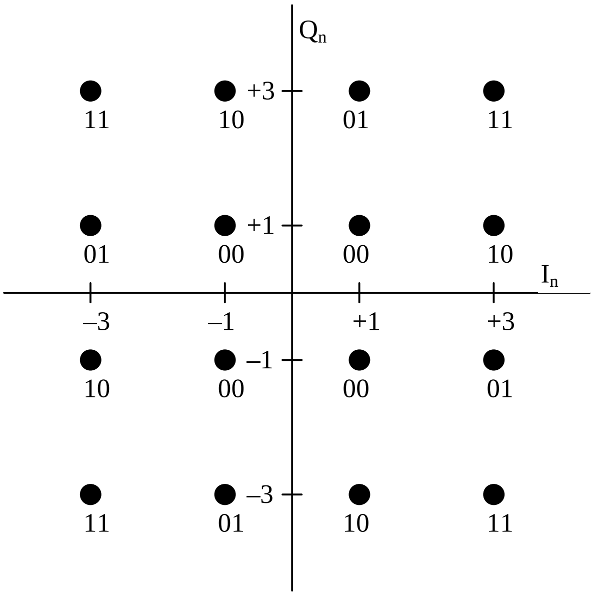


Figure 22: 16-point Constellation and Bit Mapping

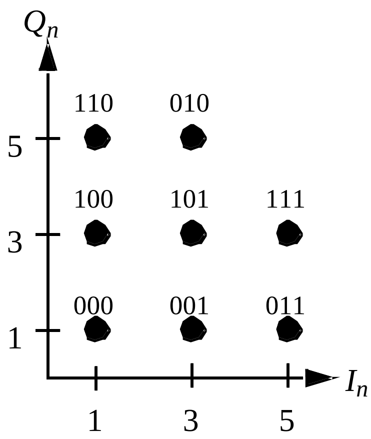


Figure 23: First Quadrant of 32-point Constellation and Bit Mapping

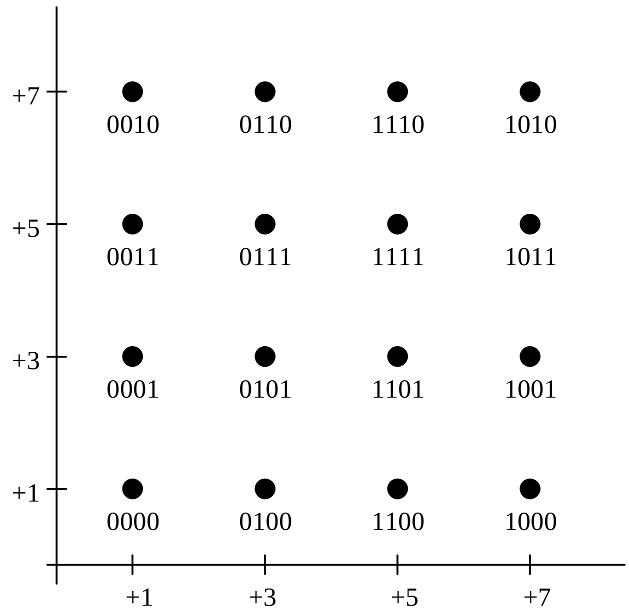


Figure 24: First Quadrant Of 64-Point Constellation and Bit Mapping

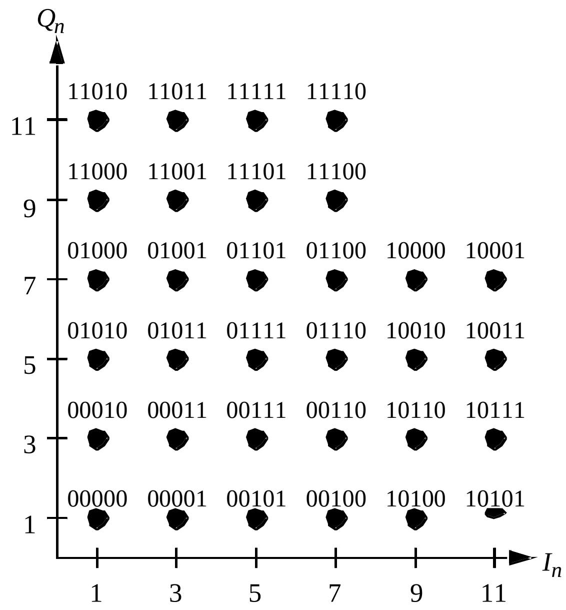


Figure 25: First Quadrant of 128-point Constellation and Bit Mapping

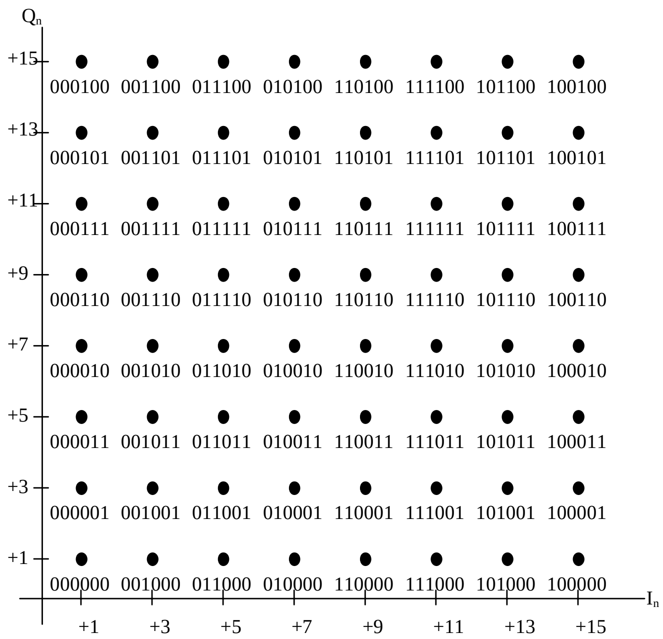


Figure 26: First Quadrant of 256-Point Constellation and Bit Mapping

5.4.2.2.2 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, 11, 13, 15 with a tolerance of ±0,06 relative to these values, as it depicted in the constellation diagrams in figures 20 to 26.

5.4.2.2.2.1 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*):

$$R = s \times BSR,$$

where *s* is an integer, *BSR* = 67,5 kBaud.

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

$$f_C = \tfrac{1}{2}BSR \times k \text{ , [MHz],}$$

where *k* is an integer. The resulting f_C shifting granularity is equal to 33,75 kHz.

NOTE: The value of SR/f_C shall be an exact ratio of two integers under all possible frequency tolerances.

5.4.2.2.2.2 Spectral Shaping Filters

The impulse response, for both BSS and PSS filters, of the in-phase and quadrature filters (see figure 18) shall have an excess bandwidth of α = 0,20.

The square-root raised-cosine approximation of the BSS low-pass filter impulse response shall be as:

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

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

For a PSS filter, the impulse response approximation of the in-phase filter (see figure 17) shall be as:

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

A PSS quadrature filter impulse response approximation shall be as:

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

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.

NOTE: The presented transmit filters' impulse response approximations have an infinite timespan (finite bandwidth filters). The actual impulse responses shall follow the above approximations over a time interval of at least 8T (±4T) with the implementation accuracy less than 2% of the impulse response peak value (8-bit representation).

The in-phase and quadrature impulse response figures of the BSS and the PSS filters are shown in annex B. Also shown in annex B are the equations for transmit signals using both BSS and PSS filters.

5.4.2.3 Power Spectrum Template

The transmit signal of any carrier inside the transmit band (5.1.1) shall meet the power spectrum template defined in table 6. The lower and upper limits of the attenuation are defined as a function of the normalized frequency *x*, where

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

Table 6: Power Spectrum Template

Normalized frequency (x)	Lower Bound (dB)	Upper Bound (dB)
≤ –1,5		< –40
–1,4		< –30
–1,3		< –24
–1,2	–30	–8
–1,1	–12	–5
–1	–5	–3
–0,9	–2,7	–0,7
–0,8	–2	0
0	–2	0
0,8	–2	0
0,9	–2,7	–0,7
1	–5	–3
1,1	–12	–5
1,2	–30	–8
1,3		< –24
1,4		< –30
≥1,5		< –40

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

NOTE 2: The in-band part of the template is defined by $|x| < 1,2$ (20% excess bandwidth).

NOTE 3: The values for the PSD given in table 6 for the out-of-band part of the template ($|x| > 1,2$) may not be sufficient to meet the generic requirements for out-of-band PSD specified in 5.1.2. The band-pass filter should provide additional filtering if necessary.

5.4.3 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 15). 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 recognize 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 16, into the original transmission frame as described in 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 5.4.2.1.

The receiver shall operate with a propagation delay difference between carrier-1 and carrier-2 up to 2 µs.

NOTE: The 2 µs delay difference takes in account only the external elements of the transmission path (twisted pair line, splitters etc). The internal delay difference compensation is the responsibility of the vendor.

5.4.4 Interface Specification

5.4.4.1 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 6.3.2.

5.4.4.2 U1-interface (Transmission Media Interface)

5.4.4.2.1 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].

5.4.4.2.2 Transmit Signal Power Spectral Density

The transmit Power Spectral Density (PSD) comprises a *nominal* PSD and a PSD boost, applicable for certain deployment scenarios. Both shall comply with the masks M1 and M2 defined in TS 101 270-1 [1].

5.4.4.2.3 Transmit PSD Control

All PSD control options should 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.

5.4.4.2.3.1 PSD Boost

The PSD boost option is available for all upstream and downstream carriers in the frequency range up to 12 MHz.

The particular value of the PSD boost for the certain application and deployment scenario is limited by the transmit signal power value, as defined in 5.4.4.2.1, and by the applied PSD mask, as defined in TS 101 270-1 [1] (ETSI PSD masks M1, M2).

5.4.4.2.3.2 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 (7.6.3.3).

5.4.4.2.3.3 Upstream Power Back-off

5.4.4.2.3.3.1 Introduction

Upstream power back-off will be provided by the VTU-R in accordance with the requirements specified in 5.2 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.

5.4.4.2.3.3.2 Start-up Power Back-off

The *Start-up Power back-off* will perform a flat transmit PSD reduction of the upstream carriers transmit PSD at the beginning of the Cold-Start activation. The transmit PSD level of any upstream carrier can be reduced down to -100 dBm/Hz. The granularity of the PSD reduction mechanism will not be more than 1 dB. The VTU-R receiver will resolve the particular value of the required PSD reduction Autonomously (with no assistance from the VTU-O) in accordance with the received downstream signal from the VTU-O.

The VTU-R will reduce the transmit PSD, under requirements specified in 5.2, so that the average FEXT power generated into any US carrier frequency band, either before or after the *Start-up Power back-off* is applied, will not exceed 3 dB over the reference FEXT power. Both the average FEXT power and the reference FEXT power are calculated by an expression:

$$FEXT = d \times \int_{f1}^{f2} PSD(f)\left|H(f)\right|^2 f^2 df$$

where:

f - frequency;
f1, f2 - respectively the low and the high frequency of the considered US carrier frequency band;
d - the length of the loop the considered US is applied;
PSD(f) - the applied US PSD;
H(f) - the loop transfer function between the VTU-O and VTU-R.

To calculate the reference FEXT power the values of *d*, *PSD(f)* and *H(f)* should be set by the operator or resolved by the VTU-R autonomously in accordance with the loop plan under consideration for the particular carrier.

The detailed *Start-up Power back-off* algorithm shall be proprietary.

5.4.4.2.3.3.3 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 5.2. 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.

5.4.4.2.4 Return Loss

The return loss shall comply with the requirements specified in 8.3.2 of Part 1. The return loss mask for any carrier, in both the transmit and receive directions, is shown in figure 27.

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.

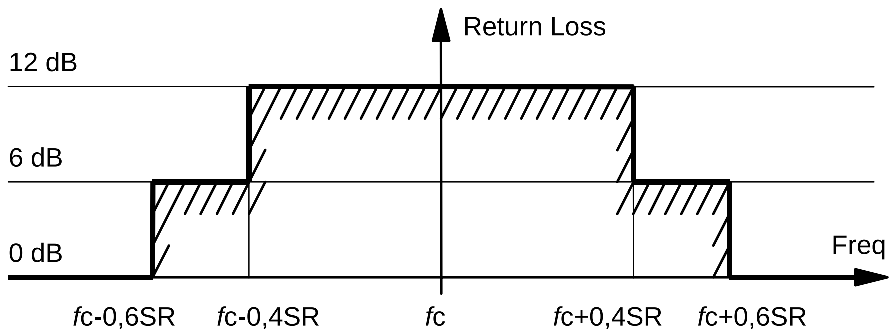


Figure 27: Return Loss Mask

NOTE: See 5.4.5.2 for the particular f_C and *SR* values for standard transmission profiles.

5.4.4.2.5 Output Signal Balance

Output signal balance (OSB) shall comply with the requirements in 8.3.3 of Part 1 in the VDSL band of each transmitted carrier, as defined in 5.4.5.1.3 (from f_C – ½SR to f_C + ½SR).

5.4.5 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.

5.4.5.1 Transmission Profile Specification

5.4.5.1.1 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 Part 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 (5.4.5.2), 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 type using carriers 1D, 1U, 2U.

3) X_3 specifies if 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 if the profile occupies the ADSL frequency band. It shall have a value of N if it occupies the spectrum or A if not.

5) X_5 - *optional* - specifies if 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 utilizing the main band allocation (figure 6);
   - "R1" for profiles utilizing the regional band allocation (figure 7);
   - "R2","R3"… for profiles utilizing other regional band allocations.

5.4.5.1.2 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 $SR = BSR = 67{,}5$ kBaud and the minimum constellation size $C = 4$ are applied. This rate is called Basic Bit Rate $BBR = 135$ kb/s and defines the transmission bit rate granularity.

5.4.5.1.3 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 (5.4.2.2.2.1) and its symbol rate *SR*.

In accordance with the transmit filter characteristics described in 5.4.2.2.2.2, 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:

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

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

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

5.4.5.2 Standard Transmission Profiles

Standard transmission profiles are intended to provide both symmetric and asymmetric classes of operation (services) with the payload rates defined in Part 1. A specific standard profile is defined for each class of operation utilizing either the main (figure 6) or the optional (figure 7) spectral plan. The symbol rates (*SR*), bit rates (*DR*) and band allocation of both carriers for standard asymmetric classes of operation are presented in tables 7 and 8 (main spectral plan) and tables 11 and 12 (optional spectral plan). The same parameters for standard symmetric classes of operation are presented in tables 9 and 10 (main spectral plan) and tables 13 and 14 (optional spectral plan).

NOTE: The symbol rates, constellation sizes and band allocation recommended in tables 7 to 14 are intended for a "regular" environment (regular cable plan, PSD mask M2, both FTTEx and FTTCab compatible). In specific environments (extremely short or long loops, RFI ingress/egress concern, PSD mask M1, powerful crosstalk etc), non-standard profiles may be applied with more suitable values. The values are modified using the procedure described in 8.3.2. The symbol rates and central frequencies of all standard and non-standard transmission profiles are defined in 5.4.2.2.2.1.

5.4.5.2.1 Standard Transmission Profiles - Main Spectral Plan

Table 7: 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	1D	1,62 (24x67,5)	32	8,1	DS	8,1	7,24
	1U	1,215 (18x67,5)	4	2,43	US	2,43	2,172
A2-02OAG-M	1D	1,62 (24x67,5)	64	9,72	DS	9,72	8,688
	1U	1,215 (18x67,5)	4	2,43	US	2,43	2,172
A3-01OAG-M	1D	1,620 (24x67,5)	128	11,34	DS	16,2	14,48
	2D	1,215 (18x67,5)	16	4,86			
	1U	1,215 (18x67,5)	8	3,645	US	3,645	3,258
NOTE: Payload rate is calculated assuming single latency.							

Table 8: Asymmetric Profiles - Band Allocation

Profile code	Carrier	Carrier frequency f_C (MHz)	Lowest frequency f_{LOW} (MHz)	Highest frequency f_{HIGH} (MHz)	Maximum PSD (dBm/Hz)
A1-02OAG-M	1D	1,89 (56x33,75)	0,92	2,86	–60
	1U	3,8475 (114x33,75)	3,12	4,58	
A2-02OAG-M	1D	1,89 (56x33,75)	0,92	2,86	
	1U	3,8475 (114x33,75)	3,12	4,58	
A3-01OAG-M	1D	1,89 (56x33,75)	0,92	2,86	
	2D	6,2775 (186x33,75)	5,55	7,01	
	1U	3,8475 (114x33,75)	3,12	4,58	

Table 9: 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	1D	1,62 (24x67,5)	32	8,1	DS	8,1	7,24
	1U	1,62 (24x67,5)	16	6,48	US	8,1	7,24
	2U	0,81 (12x67,5)	4	1,62			
S2-03OAG-M	1D	1,62 (24x67,5)	64	9,72	DS	9,72	8,688
	1U	1,62 (24x67,5)	16	6,48	US	9,72	8,688
	2U	1,62 (24x67,5)	4	3,24			
S3-00OAG-M	1D	1,62 (24x67,5)	128	11,34	DS	16,2	14,48
	2D	1,215 (18x67,5)	16	4,86			
	1U	1,62 (24x67,5)	32	8,1	US	16,2	14,48
	2U	2,7 (40x67,5)	8	8,1			
NOTE: Payload rate is calculated assuming single latency.							

Table 10: Symmetric Profiles - Band Allocation

Profile Code	Carrier	Carrier frequency f_C (MHz)	Lowest frequency f_{LOW} (MHz)	Highest frequency f_{HIGH} (MHz)	Maximum PSD (dBm/Hz)
S1-03OAG-M	1D	1,89 (56x33,75)	0,92	2,86	–60
	1U	4,1175 (122x33,75)	3,15	5,09	
	2U	8,370 (248x33,75)	7,88	8,57	
S2-03OAG-M	1D	1,89 (56x33,75)	0,92	2,86	
	1U	4,1175 (122x33,75)	3,15	5,09	
	2U	8,8425 (262x33,75)	7,87	9,81	
S3-00OAG-M	1D	1,89 (56x33,75)	0,92	2,86	
	2D	6,2775 (186x33,75)	5,55	7,01	
	1U	4,1175 (122x33,75)	3,15	5,09	
	2U	9,5175 (282x33,75)	7,9	11,14	

5.4.5.2.2 Standard Transmission Profiles - Optional Spectral Plan

Table 11: 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 (28x67,5)	16	7,56	DS	7,56	6,757
	1U	0,81 (12x67,5)	8	2,43	US	2,43	2,172
A2-02OAG-R1	1D	2,16 (32x67,5)	32	10,8	DS	10,8	9,653
	1U	0,81 (12x67,5)	8	2,43	US	2,43	2,172
A3-01OAG-R1	1D	2,16 (32x67,5)	64	12,96	DS	17,28	15,445
	2D	2,16 (32x67,5)	4	4,32			
	1U	0,945 (14x67,5)	16	3,78	US	3,78	3,378
A4-01OAG-R1	1D	2,16 (32x67,5)	128	15,12	DS	25,92	23,168
	2D	2,16 (32x67,5)	32	10,8			
	1U	0,945 (14x67,5)	32	4,725	US	4,725	4,223
NOTE: Payload rate is calculated assuming single latency.							

Table 12: Asymmetric Profiles - Band Allocation

Profile code	Carrier	Carrier frequency f_C (MHz)	Lowest frequency f_{LOW} (MHz)	Highest frequency f_{HIGH} (MHz)	Maximum PSD (dBm/Hz)
A1-02OAG-R1	1D	2,0925 (62x33,75)	0,96	3,23	–60
	1U	4,455 (132x33,75)	3,97	4,94	
A2-02OAG-R1	1D	2,2275 (66x33,75)	0,93	3,52	
	1U	4,455 (132x33,75)	3,97	4,94	
A3-01OAG-R1	1D	2,2275 (66x33,75)	0,93	3,52	
	2D	6,885 (204x33,75)	5,59	8,18	
	1U	4,5225 (134x33,75)	3,96	5,09	
A4-01OAG-R1	1D	2,2275 (66x33,75)	0,93	3,52	
	2D	6,885 (204x33,75)	5,59	8,18	
	1U	4,5225 (134x33,75)	3,96	5,09	

Table 13: 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	1D	1,89 (28x67,5)	16	7,56	DS	7,56	6,757
	1U	0,945 (14x67,5)	32	4,725	US	7,56	6,757
	2U	1,4175 (21x67,5)	4	2,835			
S2-03OAG-R1	1D	2,16 (32x67,5)	32	10,8	DS	10,8	9,653
	1U	0,945 (14x67,5)	32	4,725	US	10,395	9,291
	2U	1,89 (28x67,5)	8	5,67			
S3-00OAG-R1	1D	2,16 (32x67,5)	64	12,96	DS	17,28	15,445
	2D	2,16 (32x67,5)	4	4,32			
	1U	0,945 (14x67,5)	64	5,67	US	16,47	14,721
	2U	2,16 (32x67,5)	32	10,8			
NOTE: Payload rate is calculated assuming single latency.							

Table 14: Symmetric Profiles - Band Allocation

Profile Code	Carrier	Carrier frequency f_C (MHz)	Lowest frequency f_{LOW} (MHz)	Highest frequency f_{HIGH} (MHz)	Maximum PSD (dBm/Hz)
S1-03OAG-R1	1D	2,0925 (62x33,75)	0,96	3,23	–60
	1U	4,5225 (134x33,75)	3,95	5,09	
	2U	10,125 (300x33,75)	9,27	10,98	
S2-03OAG-R1	1D	2,2275 (66x33,75)	0,93	3,52	
	1U	4,5225 (134x33,75)	3,95	5,09	
	2U	10,395 (308x33,75)	9,26	11,53	
S3-00OAG-R1	1D	2,2275 (66x33,75)	0,93	3,52	
	2D	6,885 (204x33,75)	5,59	8,18	
	1U	4,5225 (134x33,75)	3,96	5,09	
	2U	10,53 (312x33,75)	9,23	11,83	

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 28, 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 and STM. 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 28. Both the Fast and Slow multiplexed signals have an application independent format on the $\alpha(\beta)$-interface.

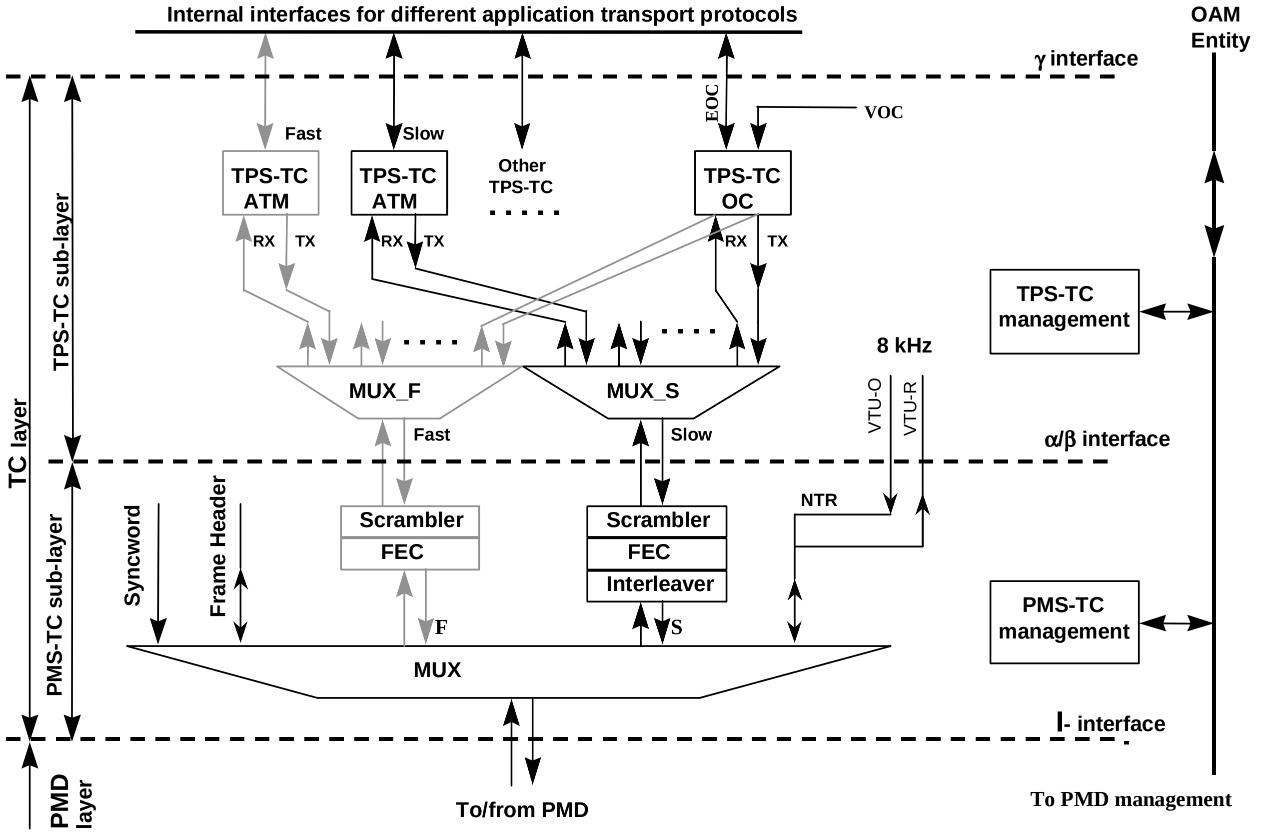
On the PMS-TC sub-layer both the Fast and Slow channels are randomized, protected by FEC and mapped into the transmission frame. The Slow channel protection includes interleaving. The transmission frame contains separate fields for Fast and Slow channels. The frame header carries frame alignment, OAM 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 $\alpha(\beta)$ 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 $\alpha(\beta)$-interface.

The NTR 8 kHz network timing should 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 6.1.4.



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 should be done beyond the TC sub-layer.

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

Figure 28: 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 28 is presented in figure 29. 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), the second ATM_TC is optional.

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

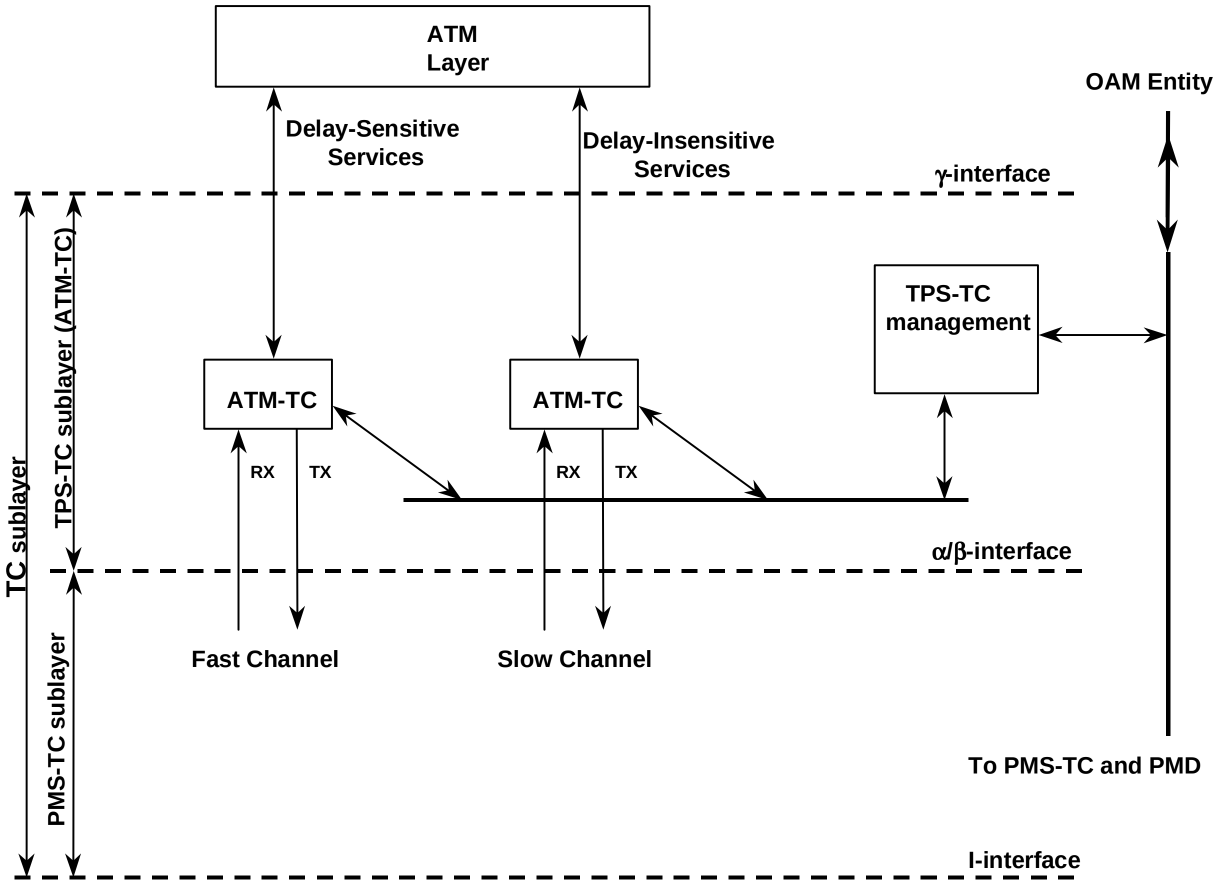


Figure 29: Functional Model of ATM Transport

The γ-interface of both ATM_TC shall interface the ATM Layer as described in 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 channelization of different user payloads into either the Fast or the Slow channel is embedded within the ATM data stream by using different Virtual Paths and/or Virtual Channels. To meet the basic requirements for ATM data transport, 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 28 is presented in figure 30. 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.

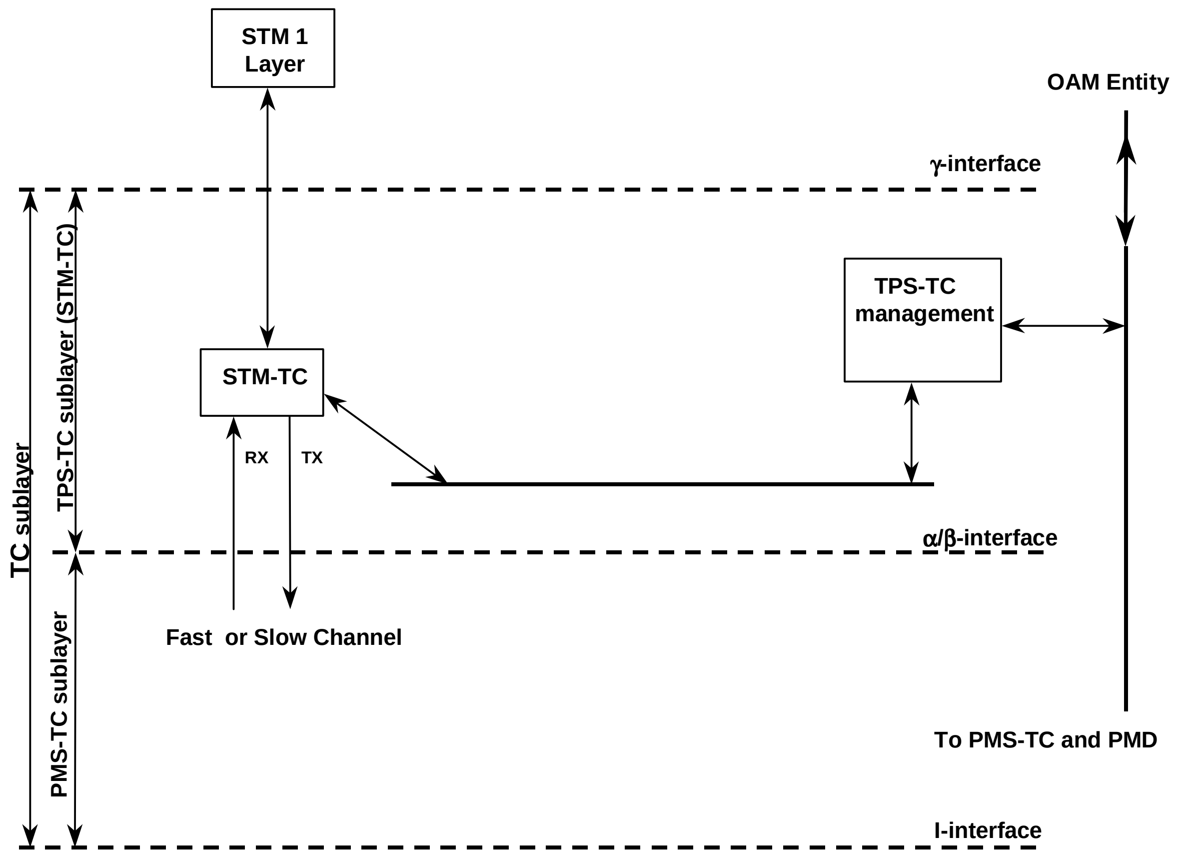


Figure 30: Functional Model of STM Transport

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 6.2. The STM_TC has a standard application-independent format at the α/β-interface as described in 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 clause are for further study.

6.1.4 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 (6.4.4.4.4, 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 29) 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;
- synchronization 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 15.

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 Synchronization flow

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

The synchronization flow comprises the following signals, presented in table 15:

- 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 synchronization 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 15: ATM-TC: γ-interface Data, Synchronization 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 7.3.2.1.

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 should 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 [3]. The single-bit error correction of the cell header shall not be performed.

6.2.1.2.3 Cell payload randomization and de-randomization

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

The ATM cell randomizer shall use a self-synchronizing scrambler polynomial $x^{43} + 1$. The randomization procedure shall be as defined in ITU-T Recommendation I.432 for SDH-based transmission. The corresponding de-randomization process should 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 31:

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

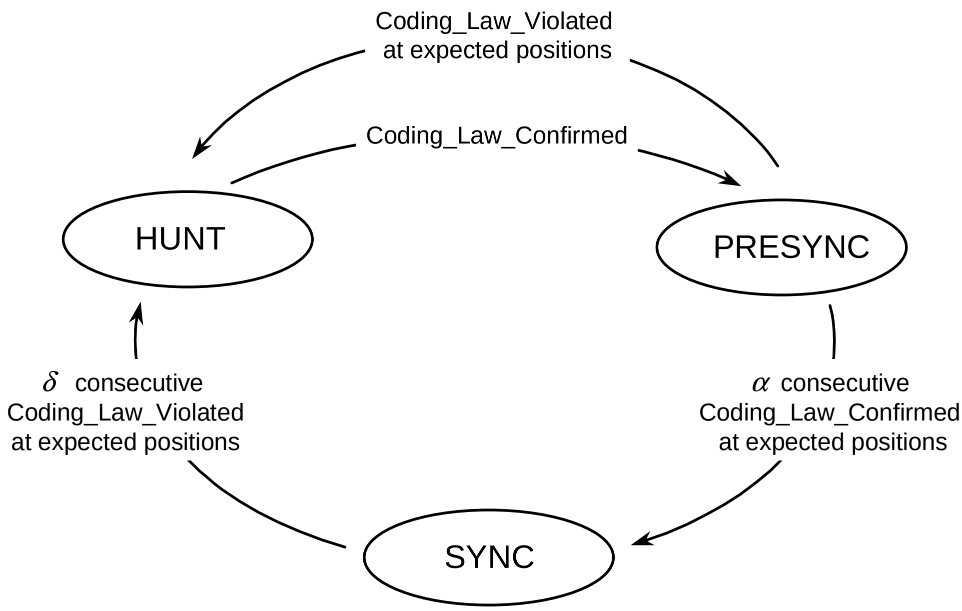


Figure 31: ATM Cell Delineation State Machine

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 30. Both γ-interfaces are functional, identical and shall be defined by the following flows of signals:

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

6.2.2.1.1 Data flow

For further study.

6.2.2.1.2 Synchronization 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 28. Both γ-interfaces are functionally identical and shall be defined by the following flows of signals:

- data flow;
- synchronization 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 16.

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

6.2.3.1.2 Synchronization flow

This flow provides synchronization between the eoc application layer (eoc processor) and the OC_TC. It includes the following synchronization signals, presented in table 16:

- 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 16: OC_TC: γ-interface Data and Synchronization Flow Summary

Signal	Description	Direction	Notes
Data flow			
eoc_tx	Transmit eoc data	eoc → OC-TC	Two octet message
eoc_rx	Receive eoc data	eoc ← OC-TC	
Synchronization flow			
eoc_tx_clk	Transmit clock	eoc → OC-TC	
eoc_rx_clk	Receive clock	eoc → OC-TC	
tx_enbl	Transmit enable flag	eoc ← OC-TC	Active if the transmit OPCODE = IDLE
rx_enbl	Receive enable flag	eoc ← OC-TC	Active if the received OPCODE = IDLE
NOTE 1: Acronym eoc denotes the eoc application layer entity (located above TPS-TC). NOTE 2: All the buffering required to implement the eoc communication protocol, shall be provided by the eoc entity; no buffering for eoc is supposed in 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 (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 a certain Slow codeword, the OC OPCODE octet shall be set to 0xFF ("IDLE" message OPCODE). In this case either the next 2-octets eoc message or 0x0000 may be inserted into the DATA field. When the VOC message has to be sent, eoc transparency shall be interrupted, and the OPCODE octet is set to a value other than 0xFF, indicating transmission of a VOC message other than IDLE. When the VOC message transmission is complete, the OPCODE is set to IDLE and eoc transport over the OC may be enabled again.

6.2.3.2.2 De-multiplexing

An IDLE (0xFF) OC OPCODE indicates that the DATA octets of the received OC field may contain an eoc message. If the received OPCODE equals to 0xFF the contents of the OC DATA field is output via the γ-interface. The eoc processor shall distinguish a valid eoc message in the eoc_rx signal as described in 6.2.3.1.2.

A valid OPCODE other than 0xFF (7.6.3) indicates that OC is used for the VOC message exchange. The received OC field in this case shall be directed to the VOC processor.

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 randomization/de-randomization (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 (7.2).

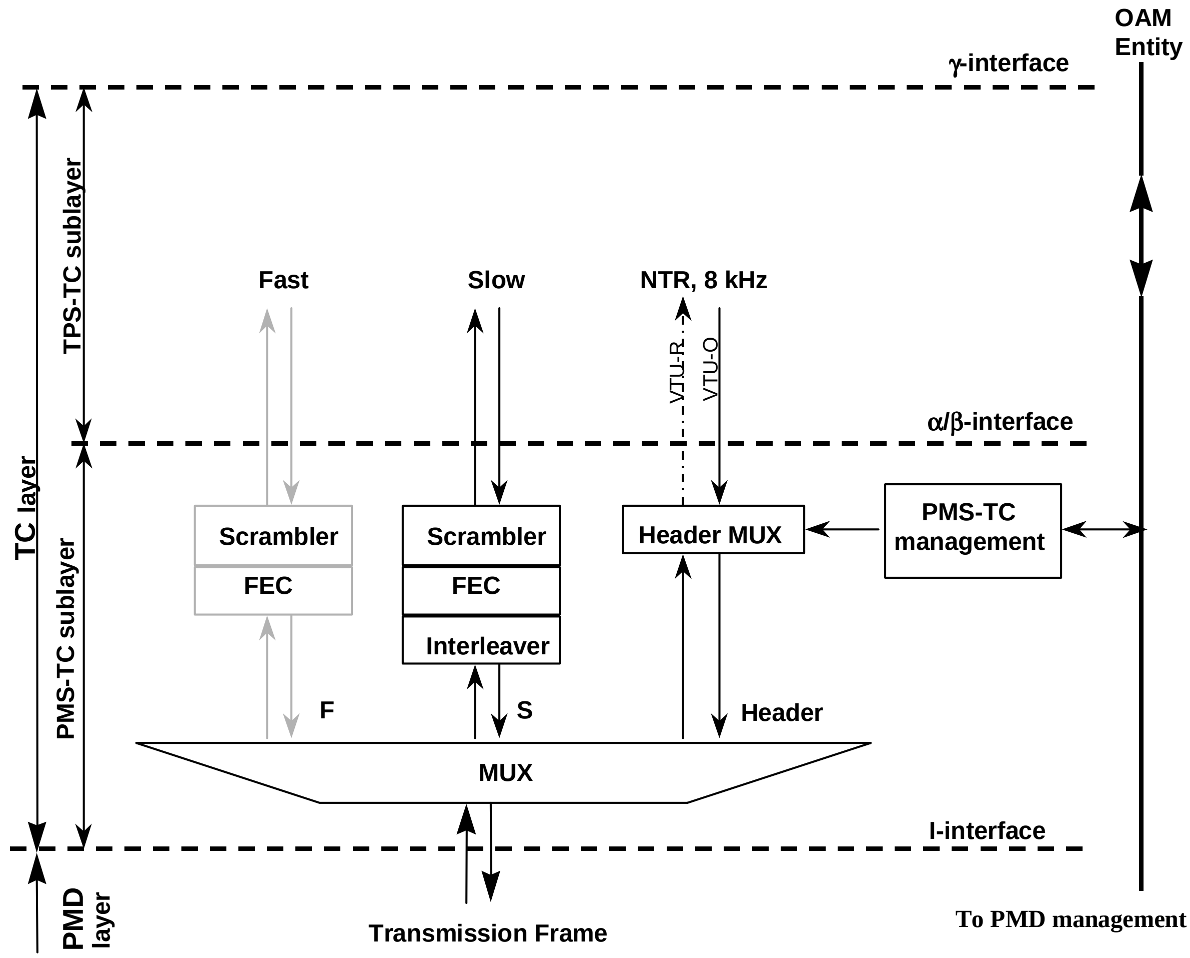


Figure 32: PMS-TC functional model

The data incoming from α(β)-interface of both the Fast and Slow channels is randomized, 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;
- synchronization 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 summarized 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 Synchronization flow

The synchronization flow comprises of up to eight synchronization signals:

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

All synchronization 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 synchronization flow signal description is summarized 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
	Synchronization 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.

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;
- synchronization 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 summarized 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 Synchronization flow

The synchronization flow consists of the transmit and receive data flow bit-synchronization signals (Clkp_t, Clkp_r) and the frame-synchronization signals (Fsync_t, Fsync_r). Both signals are asserted by the PMD and directed towards the PMS-TC. The Synchronization flow signal description is summarized 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	
	Synchronization 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.

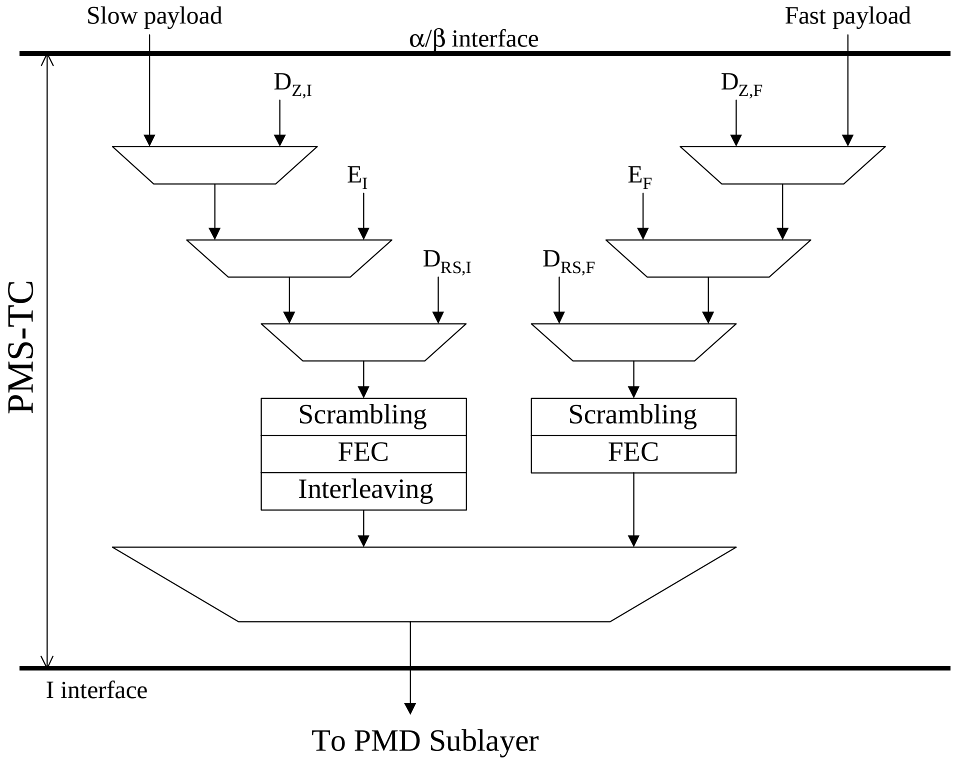


Figure 33: PMS-TC block diagram

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-synchronizing 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 initialized 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

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

is the message polynomial,

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

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	$\lfloor t/q \rfloor$ 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 initialization.

The framing rules described in this clause are summarized in figure 31:

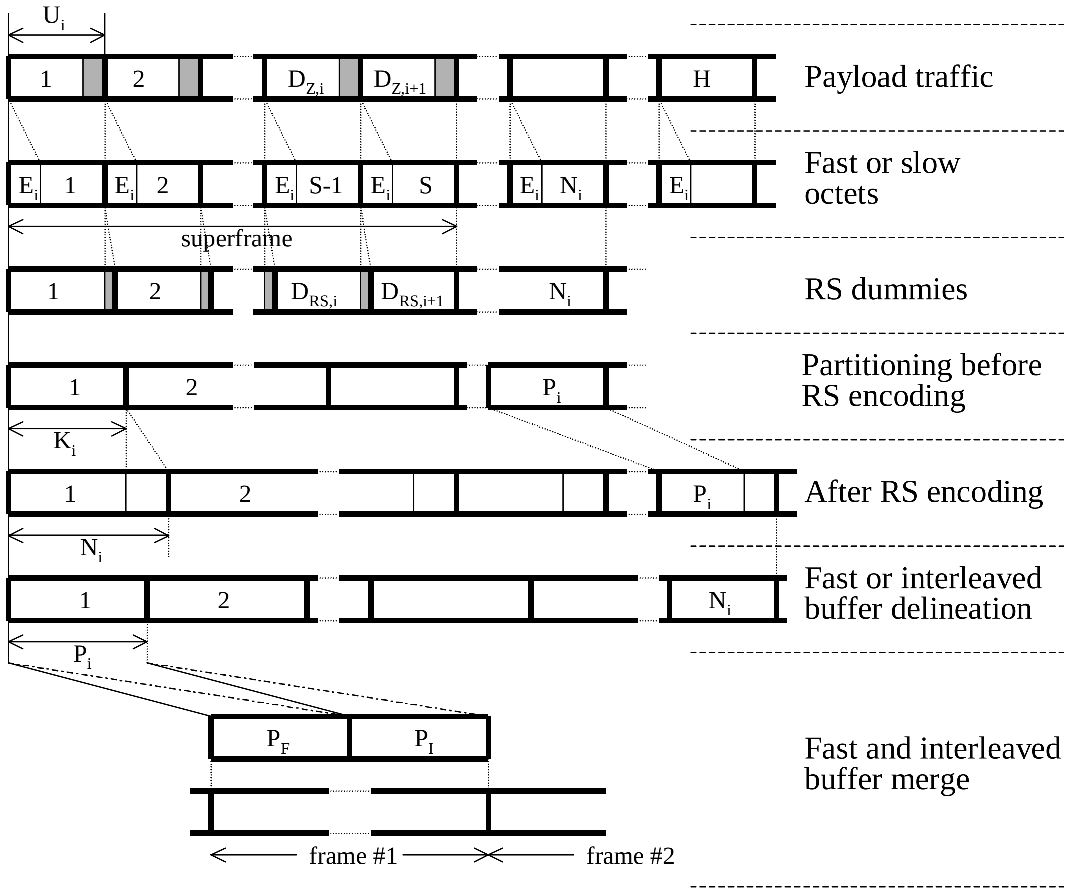


Figure 34: Framing description

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 $n_i \times 8000/f_s$ 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 Fast and interleaved buffers

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 (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

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

Note that the parameter $B_i = P_i\ N_i$ 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 summarized 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.

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
3-5	F-IB	F-EOC	S-IB/dummy	VOC	S-EOC/payload
6	F-NTR	F-EOC	S-NTR/dummy	VOC	S-EOC/payload
7 → 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

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

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

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

D 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 Synchronization octet

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

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 29. 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 – 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-b7	Reserved for future use

The active state of a bit is one (high). Bits that are not used are set to zero (low).

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 2 illustrates this process.

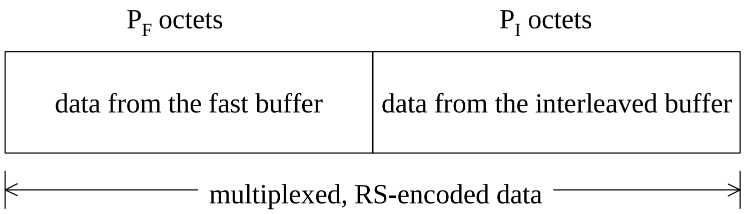


Figure 35: Convergence of the fast and interleaved data into one frame

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.

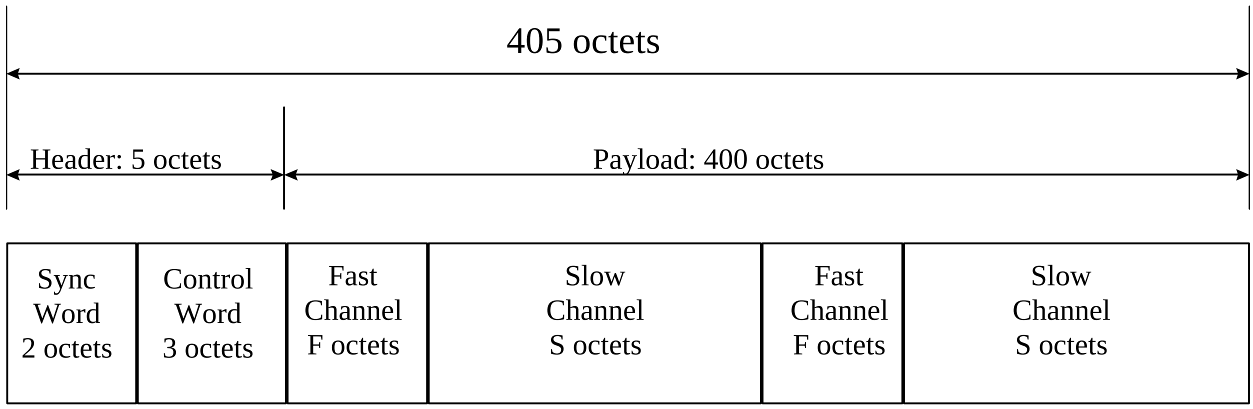


Figure 36: Transmission Frame Format

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.

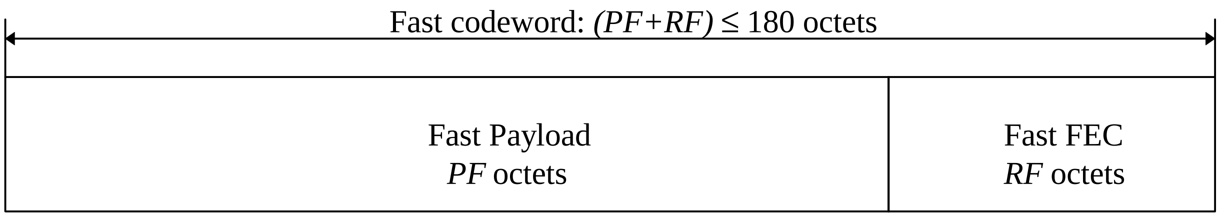
Both *F* and *S* values are even and depend on the applied Transport Class, as defined in table 26, set during the system configuration. If the Transport Class 1 (single latency) is applied, the setting is $F = 0$, $S = 200$.

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.



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 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.

Figure 37: Structure of Fast Codeword

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.

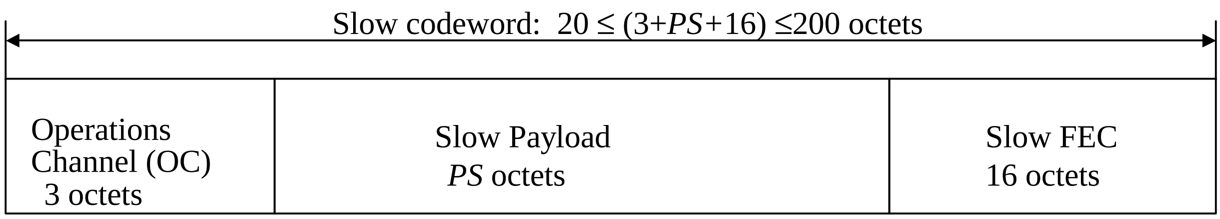


Figure 38: Structure of Slow Codeword

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 6.2.3.

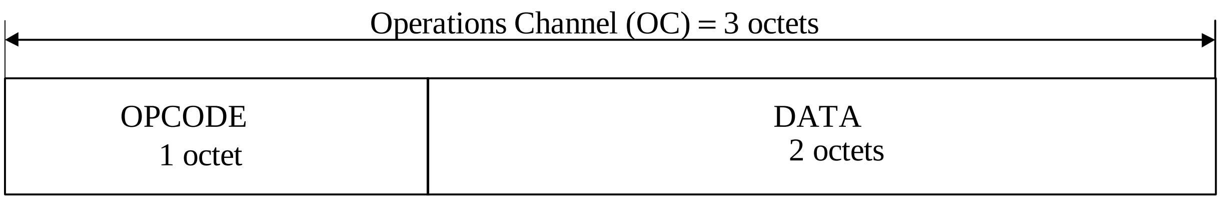


Figure 39: Structure of the Operations Channel Field

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 synchronization, 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 0 = MSB. Bit 0 of octet 0 is 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
0	*trig_1*	"o_trig" signal in downstream direction "r_trig" signal in upstream direction	"0" for normal state, "1" for the active state	
1	*flag_1*	"o_flag" signal in downstream direction "r_flag" signal in upstream direction	"0" for normal state, "1" for the active state	
2	*fp_1*	Far-end TPS_TC #1 defect/failure	"0" for normal state, "1" for the corresponding TPS-TC failure condition	See below
3	*fp_2*	Far-end TPS_TC #2 defect/failure		
4	*fp_3*	Far-end TPS_TC #3 defect/failure		
5	*fp_4*	Far-end TPS_TC #4 defect/failure		
6		Reserved for additional defects/failures		
7	*NTR_1*	NTR marker	"1" if NTR marker is transmitted, "0" otherwise	

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 according with the applied path (applied TPS-TC).

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

NOTE 4: The NTR is transported to the VTU-R by the downstream frame boundaries of those frames, which are marked by a special 2 ms NTR marker, located in the transmission frame header (6.5.1).

6.5.1.3.3 Control 2 octet

The Control 2 octet shall contains the first and the second CRC bits and the second 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 6.5.1.3.5.

Table 24: Control 2 Octet Description

Bit	Name	Description	Value	Note
0	*CRC_1*	Frame header CRC check	As defined in 6.5.1.3.5	First bit
1	*flos*	Far-end Loss-of-Signal defect	"0" for normal state, "1" for the failure condition	
2	*los_cr1*	Far-end Loss of Carrier 1 energy	"0" for normal state, "1" for the loss state	PMD
3	*los_cr2*	Far-end Loss of Carrier 2 energy	"0" for normal state, "1" for the loss state	
4	*fsef*	Far-end Severely Errored Frame defect	"0" for normal state, "1" for the loss state	PMS-TC
5-6		IB reserved for further applications		
7	*CRC_2*	Frame header CRC check	As defined in 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 6.5.1.3.5.

Table 25: Control 3 Octet Description

Bit	Name	Description	Value	Note
0	*CRC_3*	Frame header CRC check	As defined in 6.5.1.3.5	Third bit
1	*FPO*	Far-end Power-off failure	"0" for normal state, "1" for the power failure state	
2	*flpr*	Far-end Loss-of-Power defect ("dying gasp")	"0" for normal state, "1" for the power failure state	VTU-R only
3-6		Reserved for proprietary applications		
7	*CRC_4*	Frame header RC check	As defined in 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

$m_0D^{23} + m_1D^{22} + ... + m_{23}$ by D^4 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 synchronizing the downstream transmission frame boundaries with NTR and transmitting an NTR marker in the frame header, as described in 6.5.1.3.2. The NTR is reconstructed at the VTU-R using the received NTR marker. The NTR marker for the transmission profile with the bit rate of N x 67,5 kb/s shall be generated every 384/N NTR periods (i.e. every 48/N ms the NTR signal will transition from low to high level).

NOTE: The number of transmission frames between two adjacent NTR markers equals N/Q, where Q is the greatest common factor of 384 and N. 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, 8 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 summarized 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	RF	[F/RF]	Dual latency	Optional
NOTE: The valid nonzero values for *F* and *RF* are for further study.						

6.5.1.5 Frame delineation algorithm

The transmission frame delineation algorithm is based on Sync_Events (Syncword detection at the expected locations). The frame delineation algorithm is proprietary. The recommended frame delineation state machine is presented in annex D.

6.5.2 Data randomization and de-randomization

Randomization shall be performed in both transmission directions by the same randomization algorithm before the RS encoding. Data de-randomization shall be performed after the RS decoding. Randomization/de-randomization 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 randomized separately by the same randomization algorithm.

NOTE: The randomizer/de-randomizer is supposed to be self-synchronizing by the implementation.

The randomization 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-randomization algorithm shall reconstruct the randomized data. The block diagram of the randomizer is presented in figure 40.

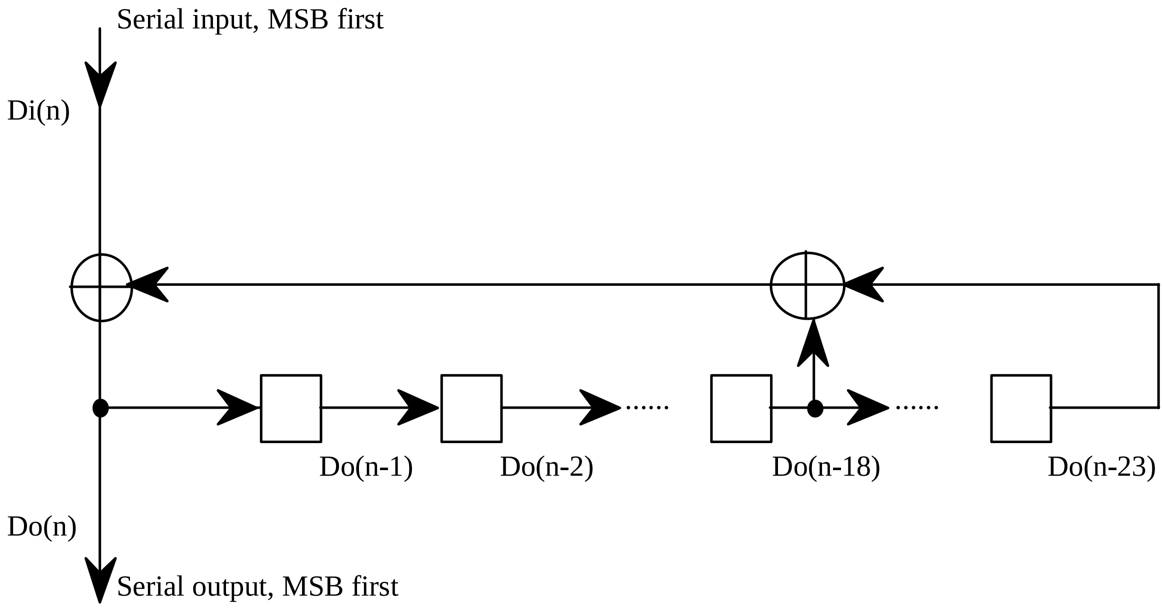


Figure 40: Randomizer

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:

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

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 (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 $j = 0, 1, 2, \ldots (I-1)$ 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 $D-1$ characterizes 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:

$$D = M * I + 1, \text{ where M is any integer.}$$

The value M shall be programmable at least to values 0 or 2^P where $P = 0, 1, \ldots 7$ in the interval from M = 0 (no interleaving) to M = 128. The main characteristics of the interleaver are summarized 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)	$D = M * I + 1$, octets	$M = 0 \div 128$, programmable
Erasure Correction (E)	$E = \lfloor t * I / N \rfloor * (M * I + 1)$, octets	$t = 8$ (RS error correction ability)
End-to-End Delay (DL)	$DL = M * I * (I - 1)$, octets	
Interleaver Memory Size	$MEM = M * I * (I - 1) / 2$, octets	

NOTE: 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 $E*8/R$, where R is the bit rate of the transmit signal over the line.

The maximum value of M required for the given transmission profile shall provide an erasure correction capability up to 500 microseconds. 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.

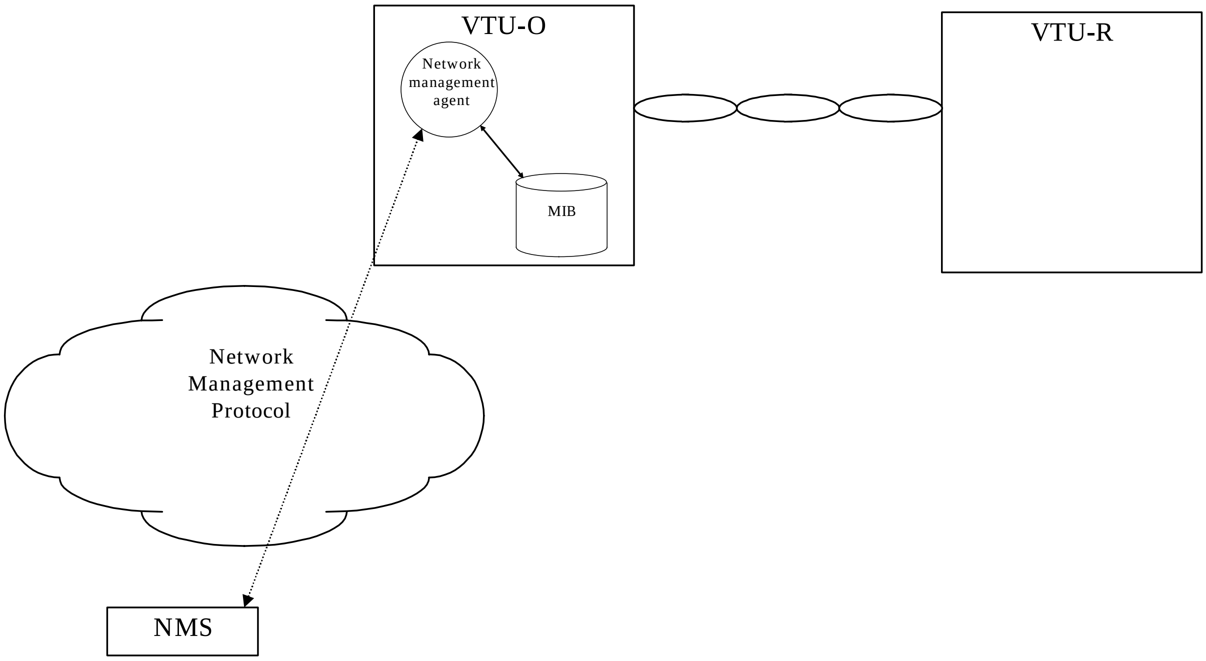


Figure 41: Components of the OAM framework for the VDSL link

Definition of the MIB and the network management protocol are out of scope of this technical specification.

7.1.3 OAM functionality

According to standard ITU-T Recommendation X.700 [8], 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 & performance monitoring process

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

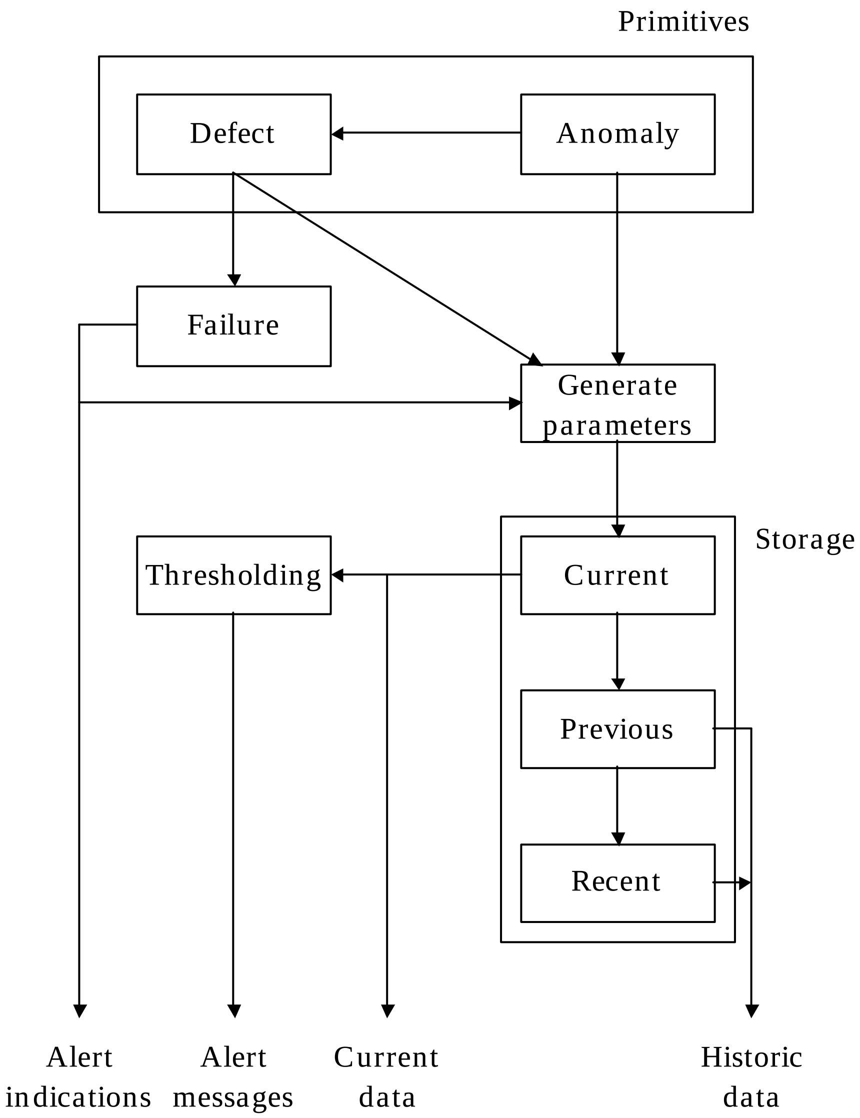


Figure 42: Performance monitoring process

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 recognized 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.

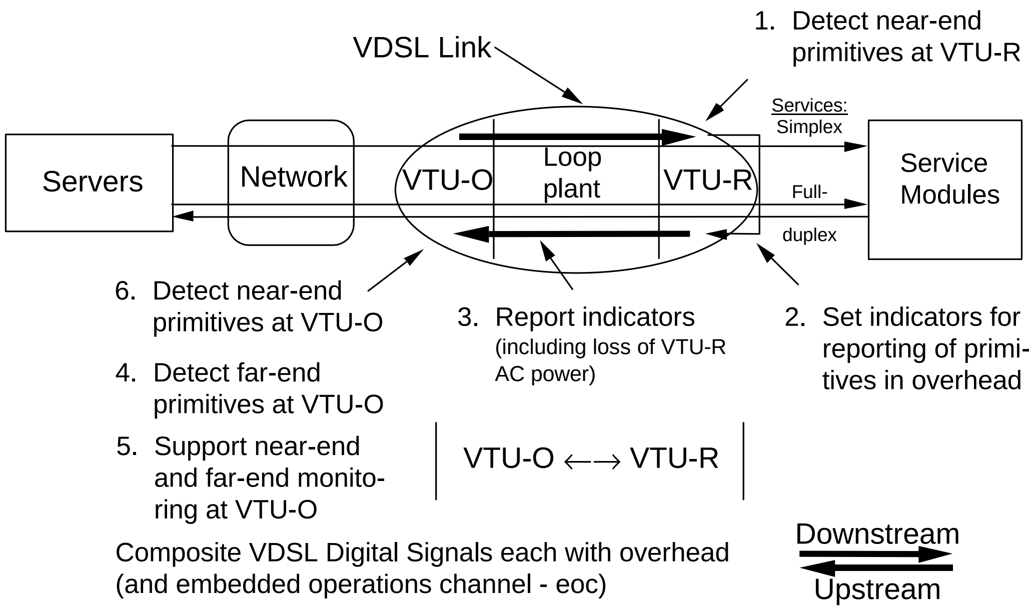


Figure 43: In-service surveillance of the VDSL link shown from the VTU-O's standpoint

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 should 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.

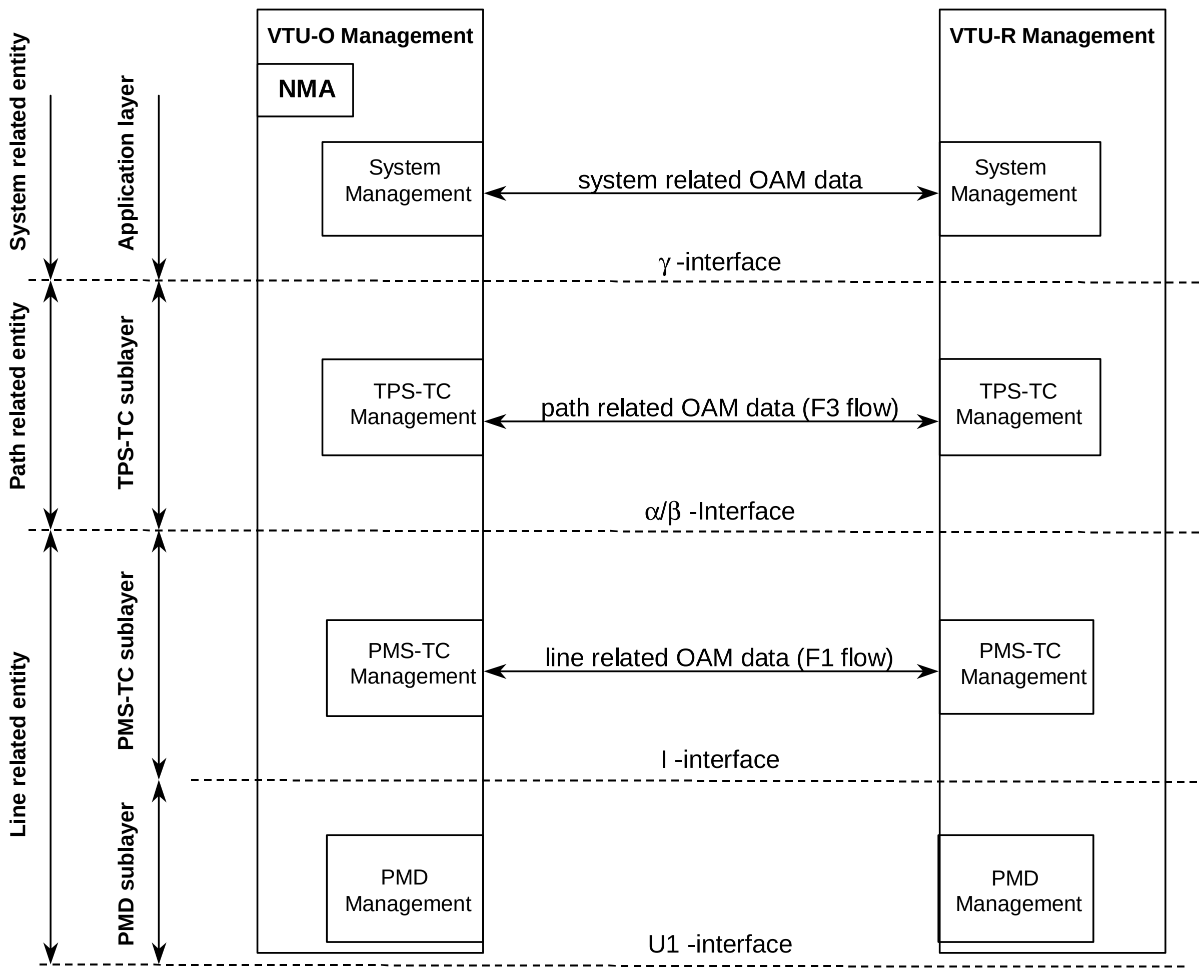


Figure 44: OAM Functional Model

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

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 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 (6.2.3.1). The eoc protocol is defined in 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 summarized 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 (note 1), separately for each TPS-TC
Line-related, time-insensitive	IB or VOC	PMD and PMS-TC anomalies
Path-related, time-insensitive	IB or eoc (note 1)	TP-specific anomalies, separately for each TPS-TC
System-related primitives	IB or eoc (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 α(β) 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 should 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 sec 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 sec of no los defect.
- *Loss-Of-Frame (LOF)*: A LOF failure is declared after TF1 ± 0,5 sec 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 sec of no sef defect.
- *Loss-of-power (LPR)*: A LPR failure is declared after TP1 ± 0,1 sec of contiguous occurrence of the *lpr* primitive. A LPR failure is cleared after TP2 ± 0,1 sec following power restoration.
- *Power Off (PRO)*: A PRO failure is declared when the VTU power switch is turned off. The VTU should be fully operable 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 seconds 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 seconds of no *flos* defect.

- *Far-end Remote Failure Indication (RFI):* an RFI failure is declared after TR1 ± 0,5 seconds of contiguous *rdi* defect, except when a *flos* defect or FLOS failure is present. An RFI failure is cleared when FLOS failure is declared, or after TR2 ± 0,5 seconds 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 seconds of contiguous near-end *los* defect. A FLPR failure is cleared after TP2 ± 0,1 seconds 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 should be represented by OAM indicators specific to the TP. The indicators should be represented at the OAM interface of γ_O (γ_R) reference points. The indicators should 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 should 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 should comply with the ITU-T Recommendation I.432 [3]. The ATM transport anomalies, defects and failures should 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 [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 should 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 seconds. An *NCD* failure terminates when no *ncd* anomaly is present for more than TN2 ± 0,5 seconds.
- *Loss of Cell Delineation (LCD)*: an *LCD* failure is declared when an *lcd* defect persists for more than TL1 ± 0,5 seconds. An *LCD* failure terminates when no *lcd* anomaly is present for more than TL2 ± 0,5 seconds.

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

7.3.2.2 Anomalies, defects and failures for STM transport

This is for further study.

7.3.3 System power-related primitives

Power related primitives should be represented by the corresponding indicators at the system level. The indicators should 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 should be represented at both the VTU-O and VTU-R. The far-end primitives should 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 seconds 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 seconds 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 should 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 should 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

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 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 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 to +31,75 dB in 0,25 dB steps.

NOTE: The *ATN* and *SNR_M* test parameters should be provided "on-demand" at any time following the initialization 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 (5.3.2.2). 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 7.4.2.

7.4.3.3 Bit-swap co-ordination

Bit-swapping is conducted with respect to synchronized 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 initialization to steady-state operation or from dynamic power save state to steady-state operation;
- Each transmitter shall increment its counter after each bit-swap frame;
- Correspondingly, each receiver shall start its counter immediately after transitioning from initialization 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 initialization 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. 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 (5.3.2.1.1).

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 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. 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 should 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 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 (5.3.2.7), 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 (5.3.2.7), 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 the table below.

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 should be executed in the next bit-swap frame while the pattern 11110011 means the express swap should be implemented in the next-to-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 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	1st tone index	1st tone total bits/gain	nth tone index	nth 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 initialization 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 or an Unable-To-Comply (UTC) message.

The IDLE message shall be sent from both the VTU-O and VTU-R when no activity is going over VOC, particularly for eoc transportation. The UTC message is sent by VTU-R to indicate the VTU-R's inability to comply with the received command (WRITE or READ).

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.

7.5.2 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 6.5). The OC field is also used to the eoc stream as described in 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 handshake process under the assumptions that the VTU-R complies with the transmitted VOC command is illustrated in figure 45. The solid arrows indicate the COMMAND-type message sent by the VTU-O, the dashed arrows indicate the VTU-R ECHO, the dotted arrows indicates IDLE message sent by both the VTU-O and the VTU-R. Each message is sent during a time corresponding to the number of transmission frames (prior to interleaving) for which the OC field contains the indicated message. Because of interleaving, channel, and handshake delays, there can be considerable delay in message transitions.

At the start of the handshake both the VTU-O and VTU-R shall transmit the IDLE message. When a certain command has to be sent, the VTU-O begins and continues transmitting the corresponding COMMAND-type message, which the VTU-R eventually detects. The transmitted COMMAND-type message shall be accepted and latched by the VTU-R after it has sampled identical messages in three consequently sampled transmission frames. The VTU-R then responds by beginning and continuing to transmit an ECHO-type message corresponding to the accepted COMMAND-type message. If the VTU-R is unable to comply with the received message, it will transmit an UTC message instead of echoing the COMMAND-type message.

After the VTU-O samples the consecutive arrival of three correct and identical ECHO-type responses or three consecutive UTC messages in three consequently sampled frames, it shall respond to the VTU-R by beginning and continuing to transmit the IDLE message. When the VTU-R receives the IDLE message it shall stop to transmit the ECHO or UTC message and start to transmit IDLE instead.

The VOC handshake process is complete when both the VTU-O and VTU-R have resumed transmitting the IDLE message.

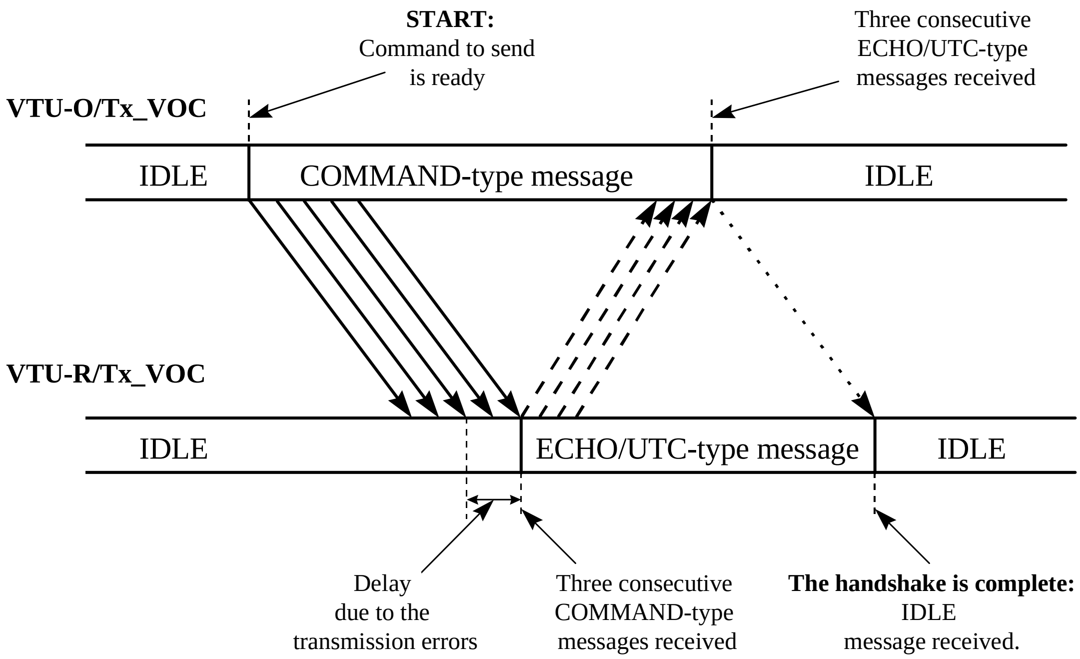


Figure 45: Example of a Handshake for a Successfully Communicated Command

To overcome transmission errors the VTU-O continues to send the COMMAND-type message until it detects the ECHO or UTC message three times in a row. Similarly, the VTU-R continues to send the echoed message until it receives the IDLE message from the VTU-O. The 0,9s timer shall be activated at both the VTU-O and VTU-R to limit the total handshake time, as it is shown in figure 46 and 47 respectively.

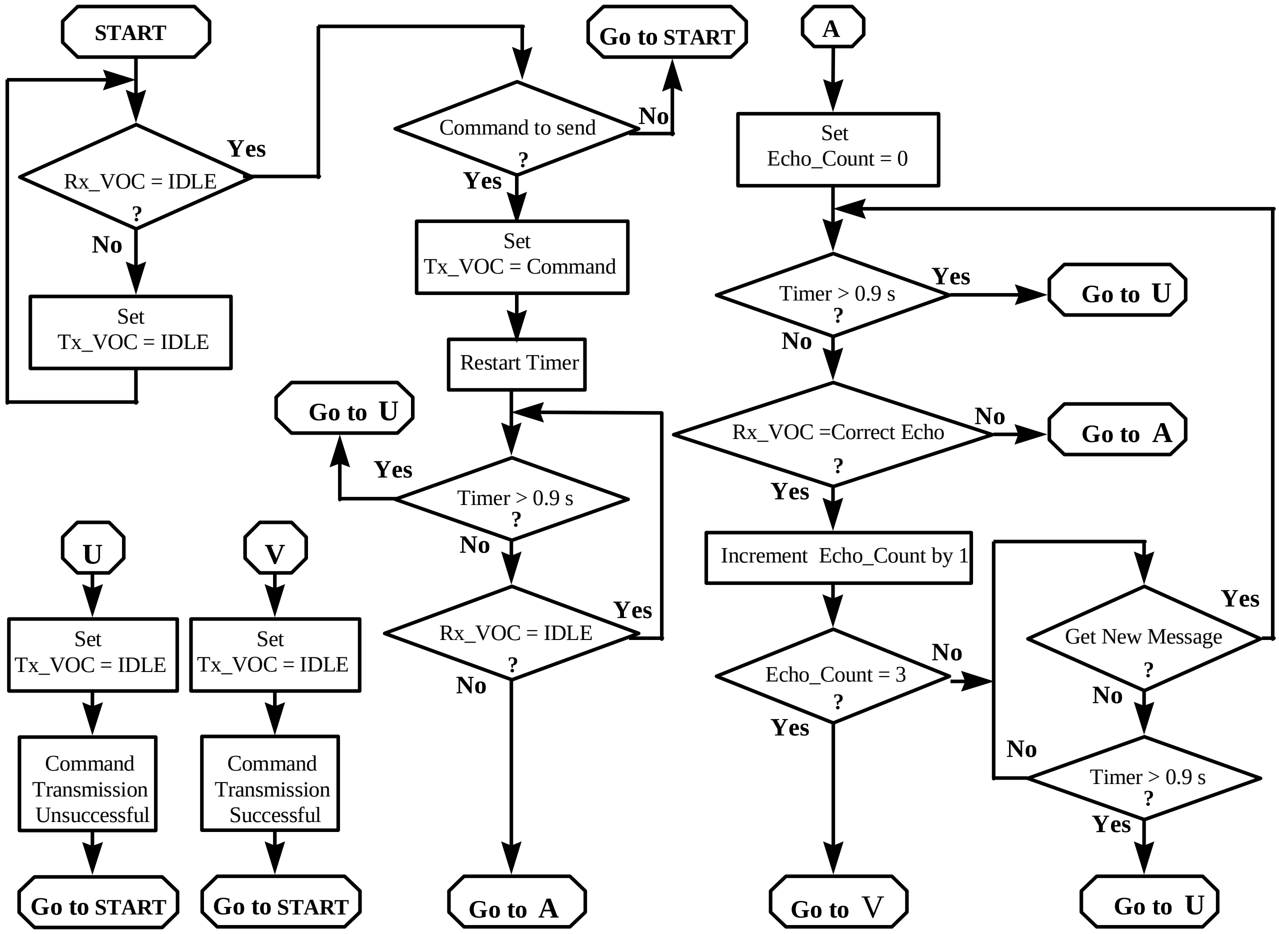
NOTE: Transmission errors delay the handshake process but probably can't cause a false information transport.

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 both 46 and 47:

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



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

Figure 46: VTU-O Handshaking Flow Chart

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 or eoc message	An IDLE message. Sent by both VTU-O and VTU-R when VOC is 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

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 should 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 should 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)
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

Name	Type	OPCODE	DATA Field	Description	Status
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	0x18-0x1F			O
ATM Path-related			**(ATM_TC)**		
HECF_REQ	COMMAND (READ) and ECHO	0x40	COMMAND: 0x0000 ECHO: VTU-R *hec* data as a 16-bit number of erred *hec* (1)	Requests VTU-R to send the number of ATM *hec* errors in the Fast channel since the last HECF_REQ	O
HECF_REP	COMMAND (WRITE) and ECHO	0x41	COMMAND and ECHO: VTU-O *hec* data as 16-bit number of erred *hec* (1)	Reports the number of ATM *hec* errors in the VTU-O Fast channel since the last HECF_REP	O
HECS_REQ	COMMAND (READ) and ECHO	0x42	COMMAND: 0x0000 ECHO: VTU-R *hec* data as a 16-bit number of erred *hec* (1)	Requests VTU-R to send the number of ATM *hec* errors in the Slow channel since the last HECF_REQ	O
HECS_REP	COMMAND (WRITE) and ECHO	0x43	COMMAND and ECHO: VTU-O *hec* data as 16-bit number of erred *hec* (1)	Reports the number of ATM *hec* errors in the VTU-O Slow channel since the last HECF_REP	O
Reserved	COMMAND and ECHO	0x44-0x4F			O
TBD Path-related			**(TBD_TC)**		
TBD	COMMAND (READ) and ECHO	0x50-0x8F			O
NOTE 1: The error count saturates at 65 535. NOTE 2: Turns to mandatory if Fast channel is supported.					

VOC messages for other path-related primitives are for further study.

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 (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 8.3.2. The set of link transmission parameters (STP) is presented in table 84 A VOC configuration message includes the targeted upstream/downstream carrier code, the targeted STP code, and the applied parameter value. A special message allows changing the profile by switching all the parameters of the targeted STP at once 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 could be built a complimentary Read-back message, verifying the configured 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 - reserved.

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

NOTE 3: For commands which deal with both carriers of the same direction only (PROFILE, INTERLV, FRAME) 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	4 MSB = 0, 8 LSB = interleaving depth	Selects the VTU-R interleaving depth for the specified direction and STP	M
FRAME	COMMAND (WRITE) and ECHO	0x22	8 MSB = F, 4 LSB = $\log_2 RF$, (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 US carrier and 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	3 MSB = 0, 9 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: Transmission profile code bears the profile name, as defined in 5.4.5, 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	3-bit service class number	2-bit X_1 value	2-bit X_2 value	Not Used	1 ↔ N 0 ↔ O	1 ↔ A 0 ↔ N	1 ↔ Main 0 ↔ Regional

NOTE 5: 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 6.5.1.

NOTE 6: The PSD mask code bears the PSD mask specification, as defined in 5.4.4.2, in the following format:

Table 38: PSD mask code

Bit	D11 – D10	D9	D8 – D6	D5	D4	D3	D2	D1	D0
Parameter	PSD boost	Mask	-	notch1	notch2	notch3	notch4	notch5	notch6
Coding rules	00 ↔ 0 dBm/Hz 01 ↔ 3 dBm/Hz 10 ↔ 6 dBm/Hz 11 ↔ 9 dBm/Hz	0 ↔ M1 1 ↔ M2	Not Used	Amateur bands notches setup 0 ↔ OFF 1 ↔ ON					

NOTE 7: Default frequency values for notches 3 to 6 are defined in TS 101 270-1 [1] (first 4 rows of table 25). Notch 6 is the lowest frequency notch and notch 3 is the highest frequency notch within the band plan.

NOTE 8: The symbol rate profile is calculated as $S = SR/BSR$, where SR is the required symbol rate in kBaud and BSR = 67,5 kBaud as defined in 5.4.5.

NOTE 9: The centre frequency profile is calculated as $K = ½f_C$/BSR, where f_C is the required centre frequency in kHz and BSR = 67,5 kBaud as defined in 5.4.5.

7.5.3.3.2 Trigger messages

All Trigger messages are of type COMMAND WRITE. Both the COMMAND and the ECHO DATA fields content is equal to 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	O
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)	O
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
Reserved	COMMAND and ECHO	0xE3-0xEF			O

NOTE: When the throughput at the VTU-R is reset, an "all ones" transmission instead of user data or EOC data towards both the PMD via I_R-interface and TPS-TC via β interface is assumed.

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
(*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.

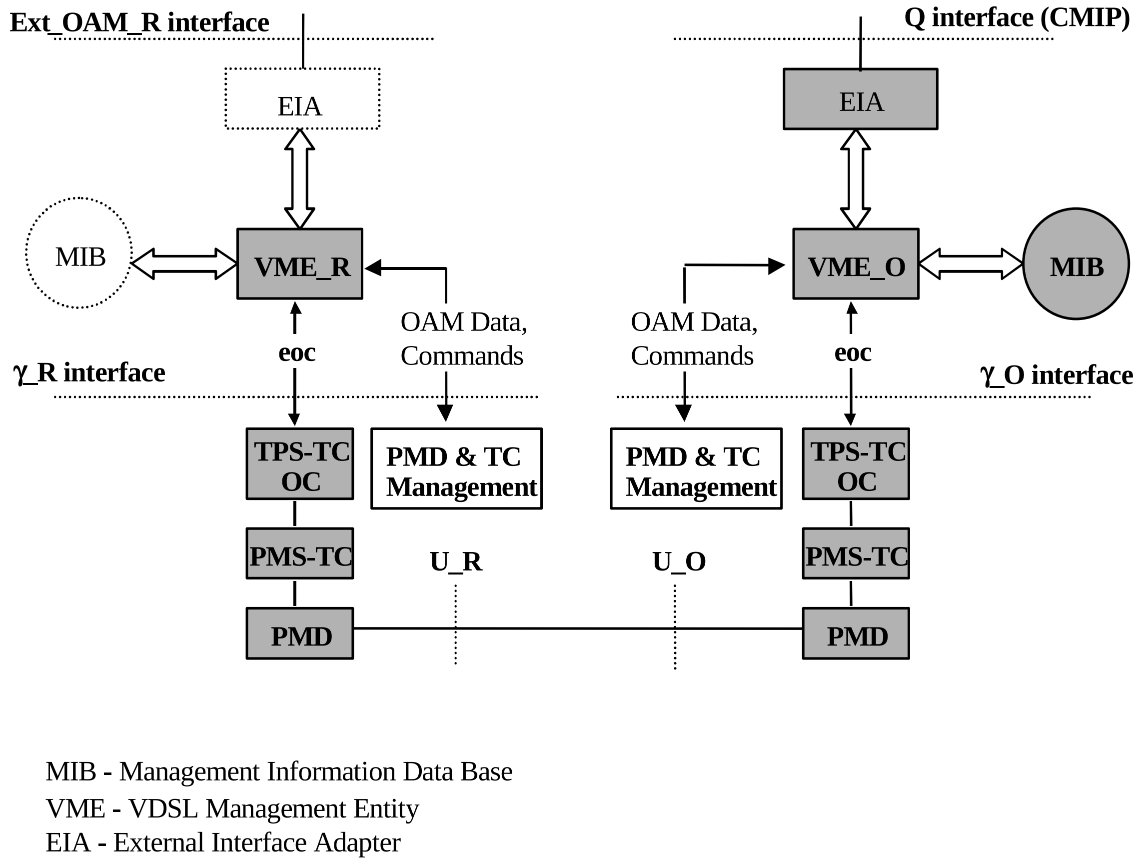


Figure 48: eoc functional model

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 Recommendation G.997.1 [9]. 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 clause 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 organization 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 (echo) 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 echoed by the VTU-R;
- upstream messages (u): these 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 by only one echo message on each received *eoc* command message.

7.6.3.3.1 *eoc* message structure

The 16 bits of an *eoc* message are partitioned among six fields, which are summarized in table 41 and defined in the following sub-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 summarized 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 numbers	d/u	WRITE
40, 43, 45, 46, 49, 4A, 4C, 4F, 51, 52, 54, 57, 58, 5B, 5D, 5E	Read data register numbers	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, 01) 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, F0) This message releases all outstanding eoc-controlled operations (latched conditions) at the VTU-R and returns the VDSL eoc processor to its initial state. This code is also the message sent during idle states;

- *Request Corrupt CRC/FEC*: (REQCOR , 07) 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, 08) This message requests the VTU-R to stop sending corrupt CRC/FEC-s toward the VTU-O;

- *Notify Corrupted CRC/FEC*: (NOTCOR, 0B) 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, 0D) This message notifies the VTU-R that the VTU-O has stopped sending corrupted CRC/FEC-s;

- *Perform Self-Test*: (SLFTST, 02) 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, 0E). 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, 19, 1A, 1C, 1F). 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 VTUs before using proprietary opcodes;

- *Request Test Parameters Update*: (REQTPU, 13). This message requests the VTU-R to update the test parameters set as defined in **7.3.6**. Test parameters supported by the VTU-R shall be updated within 10 seconds after the request is received. Updated test parameters may be read by the VTU-O thereafter;

- *Error*: (ERR, 14). 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 recognize 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 (2 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 **7.3.6.2**.
- *SNR Margin (1 octet)*: The SNR margin is defined in **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: The VDSL link configuration (applied for the PMD and PMS-TC sub-layer) is delivered by the VOC. Table 43 summarizes the VTU-R data registers and their applications.

Table 43: VTU-R Data Registers

REG # (HEX)	USE	LENGTH	DESCRIPTION
0	Read	2 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 (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.

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.

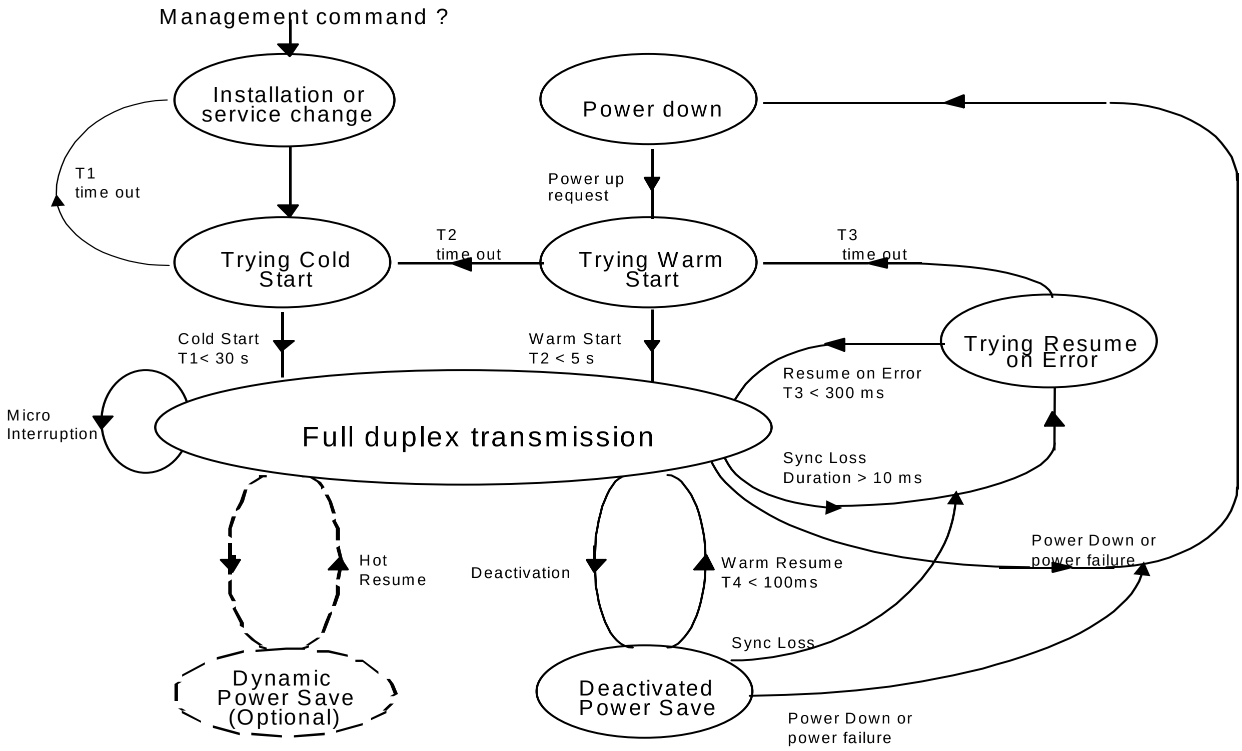


Figure 49: Activation/de-activation state and timing diagram

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 seconds.

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 seconds.

8.1.2.4 Resume on error

Resume on error is the start-up process that applies to transceivers that lose synchronization 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 synchronization 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 synchronization 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 synchronization. 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 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 equalizer states, line characteristics and service-related parameters.

8.1.4.3 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 synchronization on some of the following levels: clock-sync, frame-sync, equalizer 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

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

- definition of a common mode of operation;
- synchronization (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 by default to a value corresponding to the longest possible loop length (1,5 km).

The time line in figure 50 provides an overview of the initialization protocol. Following the initial handshake procedure, a full duplex link between the VTU-O and the VTU-R is established. 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 (8.2.3)	Training (8.2.4)	Channel analysis & Exchange (8.2.6)

VTU-R

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

Figure 50: Overview of initialization

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

During initialization (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 [7]. 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.

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 initialization is aborted.

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, 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 initialization 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.

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 initialization sequence are shown in table 44 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 44: 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 (1026 octets). Messages can therefore be segmented before transmission. In order to do this, all messages transmitted during initialization 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 MSBs of this field indicate the number of segments that make up the total message. The four LSBs 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 will contain the sequence number of the message that should be retransmitted. The default value of zero indicates that the last unacknowledged message should be sent. If this message contains several segments, only the last segment will be retransmitted.

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

During the initialization procedure a transmitter shall not send a second message without receiving an acknowledgement of the first message. It should always receive a message from the other side before transmitting again. Therefore, an acknowledgement should 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 44) 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.

8.2.3 Handshake procedure

The handshake procedure is based on ITU-T Recommendation G.994.1 [7] (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 [7] clause 6.1.1. Annex E contains provisional values that will be superseded by ITU-T Recommendation G.994.1 [7]. 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 [7]. During the handshake procedure, the following parameters shall be transmitted:

- The size of IDFT/DFT
- The initial length of the cyclic extension
- Flags indicating the use of the optional band, 25 ~ 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 [7] 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 [7]. The message type and its field format shall also be as defined in ITU-T Recommendation G.994.1 [7]

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 [7]. The coding of NPar(2), SPar(2) and Npar(3) is listed in tables 45 to 49 and are defined in 8.2.3.28.2.3.2.

Table 45: 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 46: 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 47: 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 $\times$ 256 points)

Table 48: 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 49: 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 [7]. A VTU-O, after power-up, loss of signal or recovery from errors during the initialization procedure, shall enter the initial G.994.1 state C-SILENT1. The VTU-O may transition to the Initialization 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 [7].

If ITU-T Recommendation G.994.1 [7] procedures select VDSL as the mode of operation, the VTU-O shall transition to state O-QUIET at the conclusion of G.994.1 operation.

8.2.3.2.1.1 CL messages

A VTU-O wishing to indicate VDSL capabilities during a G.994.1 CL message shall do so by setting to one the Level 1 SPar(1) ETSI MCM VDSL bit as defined in table E9. The NPar(2) and SPar(2) fields corresponding to the VDSL Level 1 bit are defined in table 45 and table 46, 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 47 through 49. The Level 2 bits in a CL message are defined in tables 50 and 51.

Table 50: 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 G.997.1 OAM frames.

Table 51: 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	Always set to one in a CL message. It indicates the initial sample length of the cyclic extension that the VTU-O can support. The value shall be present in the corresponding NPar(3) field.

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 a G.994.1 MS message shall do so by setting to one the Level 1 SPar(1) ETSI MCM VDSL bit as defined in table E9. The NPar(2) and SPar(2) fields corresponding to this bit are defined in tables 45 and 46 respectively. For each Level 2 SPar(2) bit set to one, a corresponding NPar(3) field shall also be present as defined in tables 47 through 49. The Level 2 bits in an MS message from the VTU-O are defined in 52 and 53.

Table 52: 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 G.997.1 OAM frames.

Table 53: 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	Always set to one in an MS message. It indicates the initial length (in samples) of the cyclic extension. The value is based on the final IDFT/FFT size chosen and shall be present in the corresponding NPar(3) field.

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 [7]. A VTU-R, after power-up, loss of signal or recovery from errors during the initialization procedure, shall enter the initial G.994.1 state R-SILENT0. Upon command from the host controller, the VTU-R shall initiate handshaking by invoking the Initialization Reset Procedure. Operation shall then proceed according to the procedures defined in ITU-T Recommendation G.994.1 [7].

If ITU-T Recommendation G.994.1 [7] procedures select VDSL as the mode of operation, the VTU-R shall transition to state R-QUIET at the conclusion of G.994.1 operation.

8.2.3.2.1.1 CLR messages

A VTU-R wishing to indicate VDSL capabilities during in a G.994.1 CLR message shall do so by setting to one the Level 1 SPar(1) ETSI MCM VDSL bit as defined in table E9. The NPar(2) and SPar(2) fields corresponding to the VDSL Level 1 bit are defined in tables 45 and 46 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 47 through 49. The Level 2 bits in a CLR message are defined in tables 54 and 55.

Table 54: 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 G.997.1 OAM frames.

Table 55: 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	Always set to one in a CLR message. It indicates the initial length (in samples) of the cyclic extension that VTU-R can support. The value shall be present in the corresponding NPar(3) field.

At least one of the STM and ATM bits shall be set to one in a CLR message.

8.2.3.2.1.1 MS messages

A VTU-R selecting VDSL operation in a G.994.1 MS message shall do so by setting to one the Level 1 SPar(1) ETSI MCM VDSL bit as defined in table E9. The NPar(2) and SPar(2) fields corresponding to this bit are defined in tables 45 and 46 respectively. For each Level 2 SPar(2) bit set to one a corresponding NPar(3) field shall also be present, as defined in tables 47 through 49. The Level 2 bits in an MS message from the VTU-R are defined in tables 56 and 57.

Table 56: 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 G.997.1 OAM frames.

Table 57: 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	Always set to one in an MS message. It indicates the initial length (in samples) of the cyclic extension. The value is based on the final IDFT/FFT size chosen and shall be present in the corresponding NPar(3) field.

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.

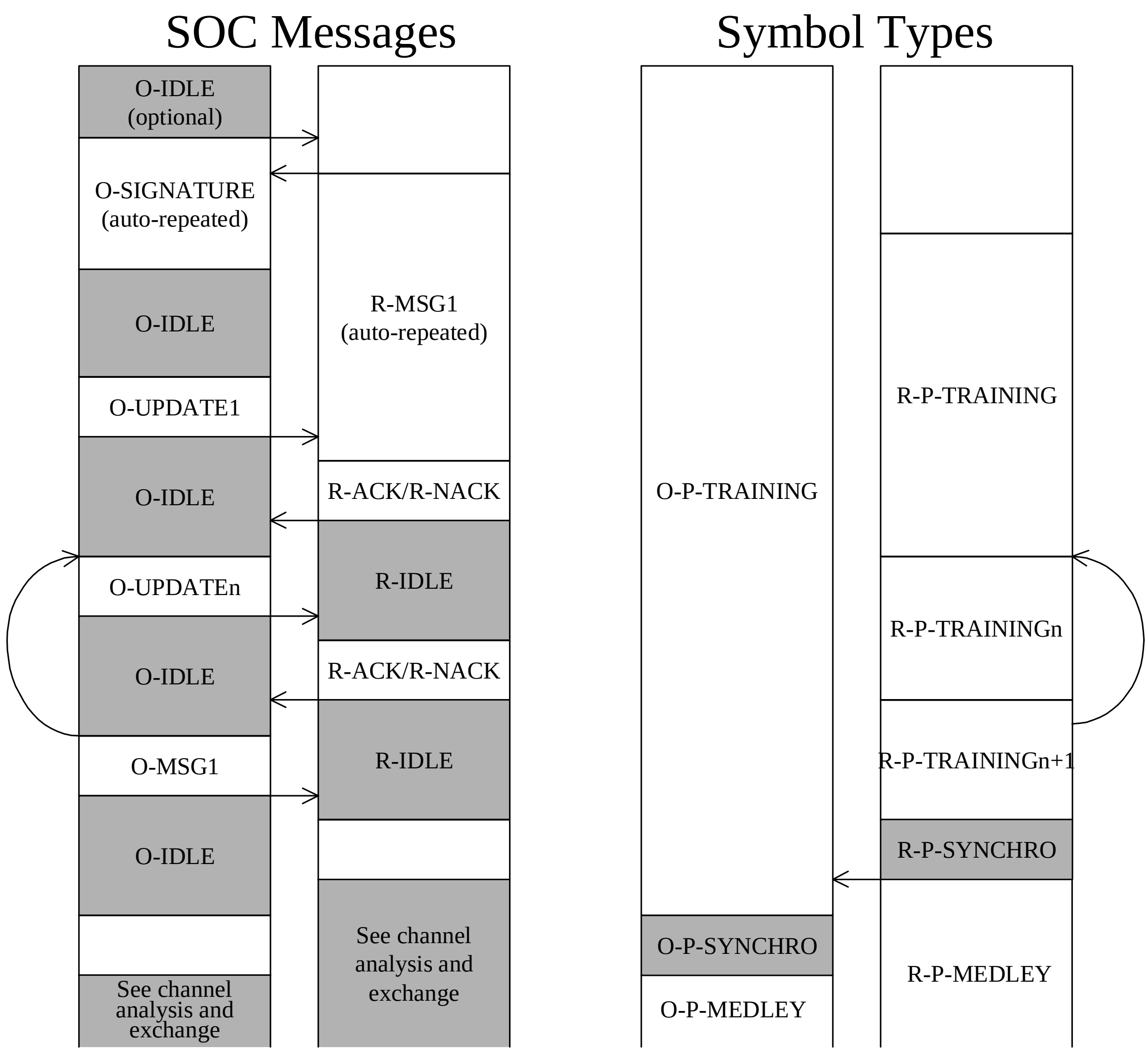


Figure 53: Timeline of training phase

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 synchronize.

Once the VTU-R is synchronized 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 optimize 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.

Training is complete when the VTU-O sends the O-MSG1 message. Upon detection of O-MSG1 the VTU-R transmits the R-P-SYNCHRO symbol type. The VTU-O replies with O-P-SYNCHRO. This allows both sides to simultaneously enter the next state: channel analysis and exchange.

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 maximum allowed receive 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 58: 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	Mask descriptor
Receive or transmit PSD mask selector	1 octet
PSD mask in upstream	Mask descriptor
Maximum allowed receive PSD in upstream direction	Mask 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 = 1024 are used, including tones 512 and 1024.

Table 59: Band descriptor

Octet	Content of field
1	Number of bands to be described
2-4	Bits 0-11: Start tone index of band 1 Bits 12-23: Ending tone index of band 1
5-7 (if applicable)	Bits 0-11: Start tone index of band 2 Bits 12-23: Ending tone index of band 2
etc.	etc.

Fields five, seven and eight contain a "mask 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 – 140 = – 60 dBm/Hz on tone index 0x400 = 1024. 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 logarithmic scale.

The sixth field of O-SIGNATURE is a flag indicating whether the transmit PSD at the VTU-R should 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 so as not to exceed the maximum allowed receive PSD at the VTU-O. 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 60: Mask descriptor

Octet	Content of field
1	Number of tones to be described
2-4	Bits 0-11: Index (n) of first tone being described Bits 12-23: PSD level in steps of 0,5dB with an offset of –140dBm/Hz
5-7 (if applicable)	Bits 0-11: Index (n) of second tone being described Bits 12-23: PSD level in steps of 0,5dB with an offset of –140dBm/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.

8.2.4.2.1.2 O-UPDATEn

This message instructs the VTU-R to tune its transmit PSD to optimize the power back-off and allows the VTU-O to optimize the timing advance. O-UPDATEn is repeated only at the request of the VTU-R (see R-REPEAT_REQUEST in 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 = 1024. The gain on unspecified tones is derived by linear interpolation between tones specified using a dB gain scale and a logarithmic 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 61: 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 62: Update descriptor

Octet	Content of field
1	Number of tones to be described
2-4	Bits 0-11: Index of first tone being described Bits 12-23: Gain level adjustment in 2's complement in steps of 0,25dB
5-7 (if applicable)	Bits 0-11: Index of second tone being described Bits 12-23: Gain level adjustment in 2's complement in steps of 0,25dB
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 63. The O-MSG1 message is sent once but can be repeated if the VTU-R sends a repeat request.

Table 63: Description of message O-MSG1

Field content	Field or Macro-field type
Message descriptor	Message code (1 octet)
Final length of CE	2 octets

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.

8.2.4.2.2.1 O-P-TRAINING

O-P-TRAINING is a wideband signal that allows the VTU-R to synchronize 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 G.hs 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 summarized in table 64, where the constellation labels correspond to the points in figure 11.

Table 64: O-P-TRAINING bit mapping

Tone index	Constellation point (see note)
Even	00
1, 11, 21, …	SOC message bits 0&1
3, 13, 23, …	SOC message bits 2&3
5, 15, 25, ...	SOC message bits 4&5
7, 17, 27, ….	SOC message bits 6&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, $\pi/2$, π, $3\pi/2$ 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 65: Pseudo-random transformation

d_{2n}, d_{2n+1}	Angle of rotation	Final co-ordinates
0 0	0	(X,Y)
0 1	$\pi/2$	(–Y,X)
1 1	π	(–X, –Y)
1 0	$3\pi/2$	(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.

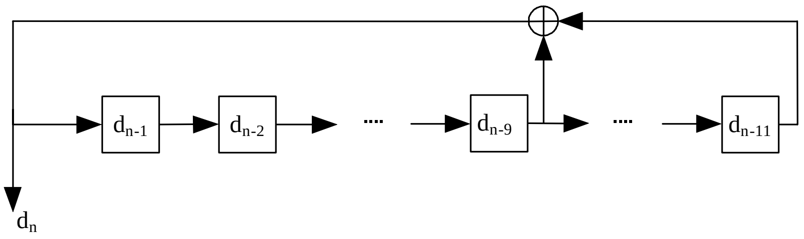


Figure 54: Pseudo-random bit generator

For a VDSL system that uses N tones, $2N$ bits shall be generated by the scrambler every DMT symbol (d_0 d_1 d_2 … d_{2N-2} d_{2N-1}). These $2N$ 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 $2N$ 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 $2N$ 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-SYNCHRO

O-P-SYNCHRO 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 (8.2.4.2.1.1). The PSD mask is defined by network management. The overall duration of O-P-SYNCHRO 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 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 "Mask Descriptor" as described in 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 logarithmic 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 maximum receive 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 should be entered or bypassed. R-MSG1 is repeated automatically until the VTU-R detects O-UPDATE.

Table 66: Description of R-MSG1

Field content	Field or Macro-field type
Message descriptor	Message code (1 octet)
Transmit PSD in upstream	Mask 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 optimization 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 initialization by sending O-MSG1 or to abort the initialization.

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-SYNCHRO.

8.2.4.3.2.1 R-P-TRAININGn

R-P-TRAININGn is a wideband signal that allows the VTU-O to optimize 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 G.hs 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 (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 (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 (8.2.4.2.1.2). R-P-TRAINING carries one octet of information per DMT symbol. The information mapping is summarized in table 67.

Table 67: R-P-TRAINING bit mapping

Tone index	Constellation point
Even	00
1, 11, 21, …, 10n+1, …	SOC message bits 0&1
3, 13, 23, …, 10n+3, …	SOC message bits 2&3
5, 15, 25, …, 10n+5, …	SOC message bits 4&5
7, 17, 27, …, 10n+7, …	SOC message bits 6&7
9, 19, 29, …, 10n+9, …	00

The selected constellation points are pseudo-randomly rotated by 0, $\pi/2$, π, $3\pi/2$ depending on a 2-bit pseudo-random sequence provided by the pseudo-random generator described in 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-SYNCHRO

R-P-SYNCHRO 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 G.hs 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-SYNCHRO 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, $\pi/2$, π, $3\pi/2$ depending on the 2-bit random number generated by a pseudo random bit generator defined in 8.2.4.2.2.1. The generator is reset at the start of every symbol.

8.2.5 Echo canceller training state (optional)

Some modems may use an (analog) echo canceller that will have to be trained at some point during the initialization 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 (synchronization). Note that the situation is now identical to that at the beginning of initialization: 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.

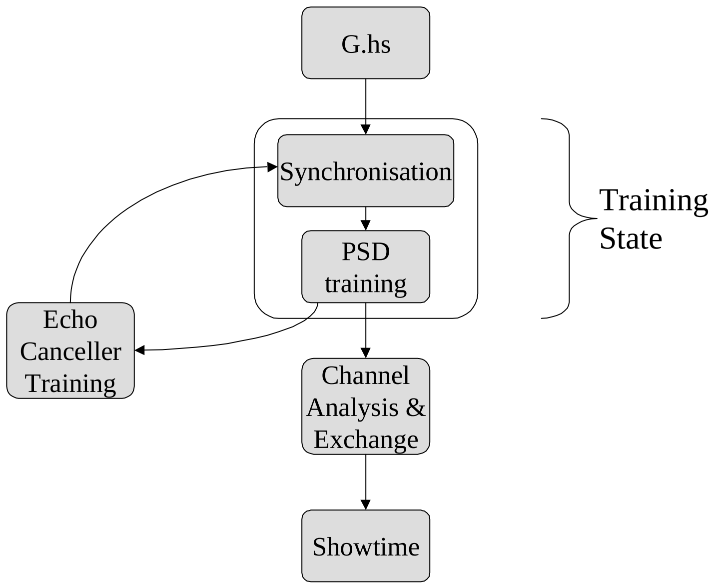


Figure 55: Position of (optional) echo canceller training state in the initialization procedure

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.

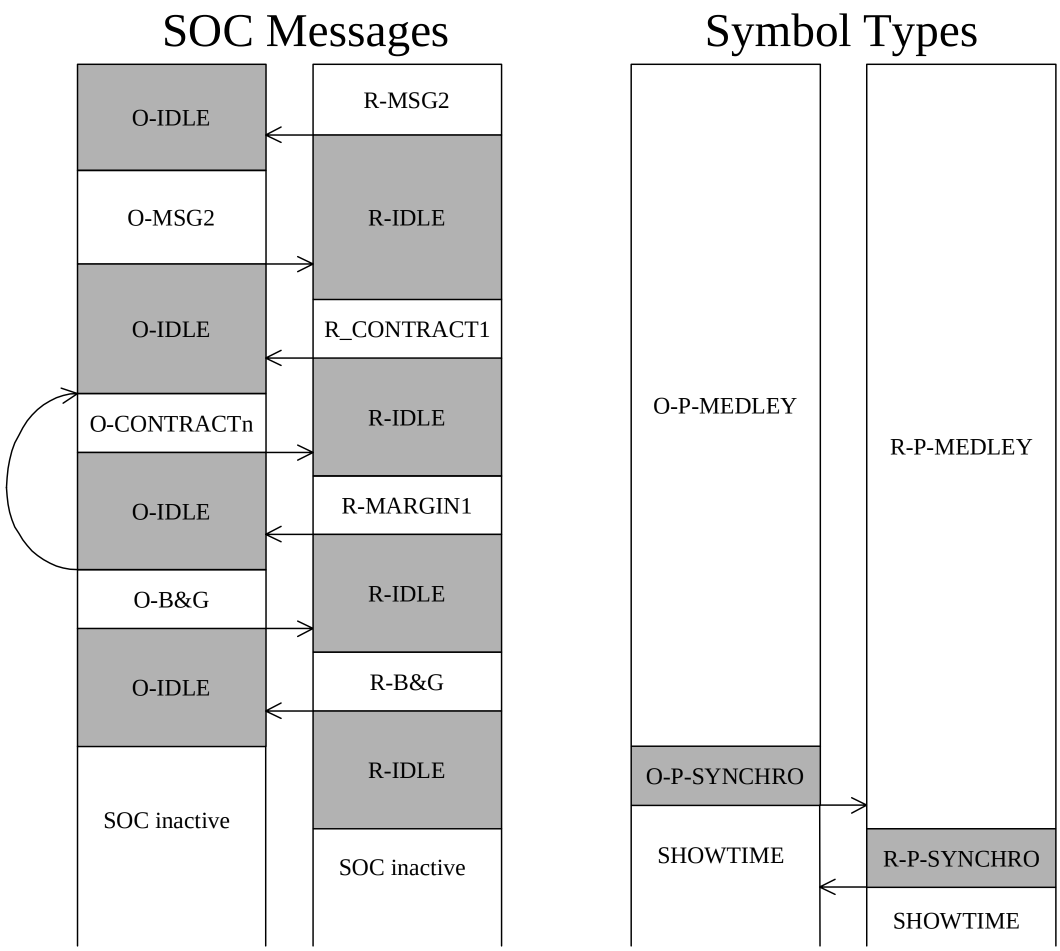


Figure 56: Timeline of the channel analysis and exchange phase

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-SYNCHRO, which allows a simultaneous transition at both sides in the downstream direction. The VTU-R will reply by sending the message R-P-SYNCHRO, 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 (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 68: Description of O-MSG2

Field content	Field or macro-field type	Remark
Message descriptor	1 octet	See table 44
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 (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)
Detailed interleaver setting description	0 octets if NN = 0x00 0 octets if NN = 0xFF NN x 4 octets otherwise	Interleaver description see table 69
Maximum power in downstream	1 octet	In units of 0,5 dBm
Required interleaver delay	1 octet	In units of 0,5 ms (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 (note 3)
NOTE 1: All settings means the values (for the redundancy) that are specified in 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 69. 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 69: Interleaver description

Field	Field or macrofield type
I	1 octet
Q	1 octet
M_{min}	1 octet
M_{max}	1 octet

NOTE 4: 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. 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 70 describes O-CONTRACTn. Both upstream and downstream values are encoded in a macro-field called "Contract Descriptor". The contract descriptor is defined in table 68. This macro-field contains all the necessary data for the setting of the framing.

Table 70: 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 71: 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 (note) 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 72: 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 73: 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 74: 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 75: 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 and CE are set to the values specified in G.hs and O-MSG1 (8.2.4.2.1.3). Windowing is applied at the transmitter, with the window length β set to the value specified in O-SIGNATURE (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 76. The mapping of bits is as shown in figure 11.

Table 76: 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, $\pi/2$, π, $3\pi/2$ depending on the 2-bit random sequence provided by the pseudo-random bit generator defined in 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.

8.2.6.2.2.2 O-P-SYNCHRO

O-P-SYNCHRO 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 and CE are set to the values specified in O-MSG1 (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 (8.2.4.2.1.1). The PSD mask is defined by network management. The duration of O-P-SYNCHRO 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, $\pi/2$, π, $3\pi/2$ depending on the 2-bit random sequence provided by the pseudo-random bit generator defined in 8.2.4.2.2.1. The pseudo-random bit sequence continues from one symbol to the next. The generator is never reset.

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 77: Description of R-MSG2

Field	Field or macro-field type	Remark
Message descriptor	1 octet	See table 44
Maximum constellation size in upstream	1 octet	
RS setting supported by VTU-R	1 octet	0x00: only mandatory settings 0xFF: all settings (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 69
Maximum power transmitted	1 octet	In units of 0,5dBm
Maximum interleaver memory	3 octets	In octets (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 (note 3)
NOTE 1: All settings means the values (for the redundancy) that are specified in 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 78: 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 5.3.1.3.1), 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 should 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 79: 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 80: 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 81: 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 82: 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 is N + CE samples. N and CE are specified in G.hs and O-MSG1 (8.2.4.2.1.3). Windowing is applied at the transmitter, with the overall window length β as specified in O-SIGNATURE (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 83.

Table 83: R-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, 12, 23, …, 10n+3, …	SOC message bits 4 & 5
4, 13, 23, …, 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 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-SYNCHRO

R-P-SYNCHRO 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 (8.2.4.2.1.3). Windowing is applied at the transmitter and the overall window length β is set to the value specified in O-SIGNATURE (8.2.4.2.1.1). The PSD mask is defined by network management. The overall duration of R-P-SYNCHRO 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 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-SYNCHRO.

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 8.3.5. Both the VTU-O and VTU-R should support *all* types of link activation and deactivation.

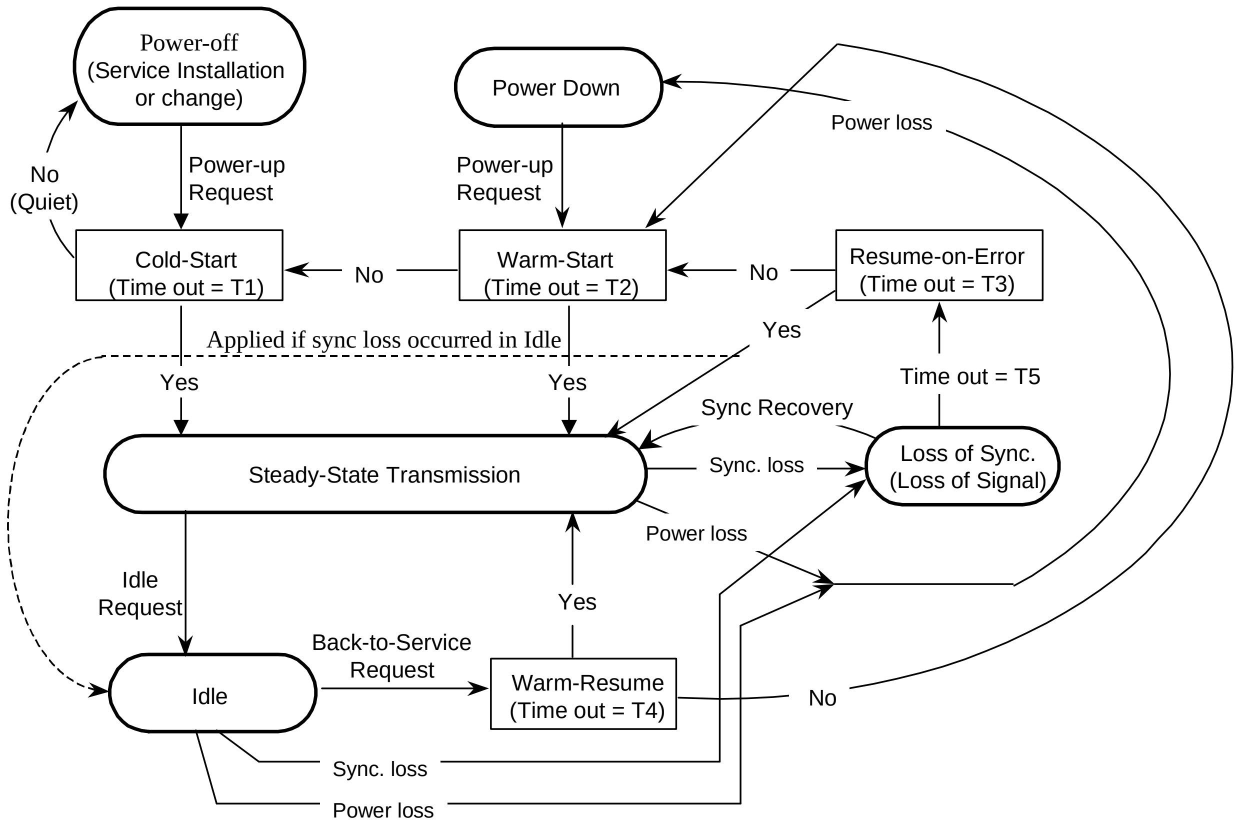


Figure 57: Link State and Timing Diagram

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 synchronization 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 synchronization 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 synchronization, 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 synchronization, 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 equalizers convergence (PMD sub-layer activation);
- Upstream and downstream channel transmission frame synchronization (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 equalizer 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 84. The STP applied at the VTU-O and VTU-R should be the same, regardless of the state they reside in or the activation process they pass through. When an STP is modified in one of them, the same change should occur in the other one as well.

Table 84: 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 – 256, U_C = 4 - 256
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		

The first four STP parameters are defined by the applied transmission profile (5.4.5.2). The last two parameters are service-dependent as defined by the applied service types.

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 should be permanently stored in both the VTU-O and VTU-R local Activation Data Base and 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 recommended parameter values for DF_STP providing interoperability for either the main spectral plan (figure 6) or the optional spectral plan (figure 7) are shown in table 85.

Table 85: Recommended values of DF_STP

Parameter	1D	2D	1U	2U
Symbol Rate (MBaud)	0,675 (10x67,5)	0	0,675 (10x67,5)	0
Constellation	4		4	
Centre Frequency (MHz)	1,35 (40x33,75)		4,455 (132x33,75)	
Transmit PSD (dBm/Hz)	–60		< –60 (note)	
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 should 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 should 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 86. A VOC communication may be used to negotiate changes to I_STP. All changes in I_STP should be complete prior to an *Idle* deactivation.

Table 86: Constellation size at start-up

Steady-state transmission constellation	4	8	16	32	64	128	256
Maximum PSD reduction, dB	3	7	10	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 may not accept the requested value of transmission parameter if it is not standard or if it is an optional 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 Modification 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 modification

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 synchronization 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 modification summary

A summary of the STP modification rules is presented in table 87

NOTE: All the listed STP modifications are fully provided by the VTU-O, VTU-R state machines described in 8.3.9.

Table 87: 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 clauses 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.

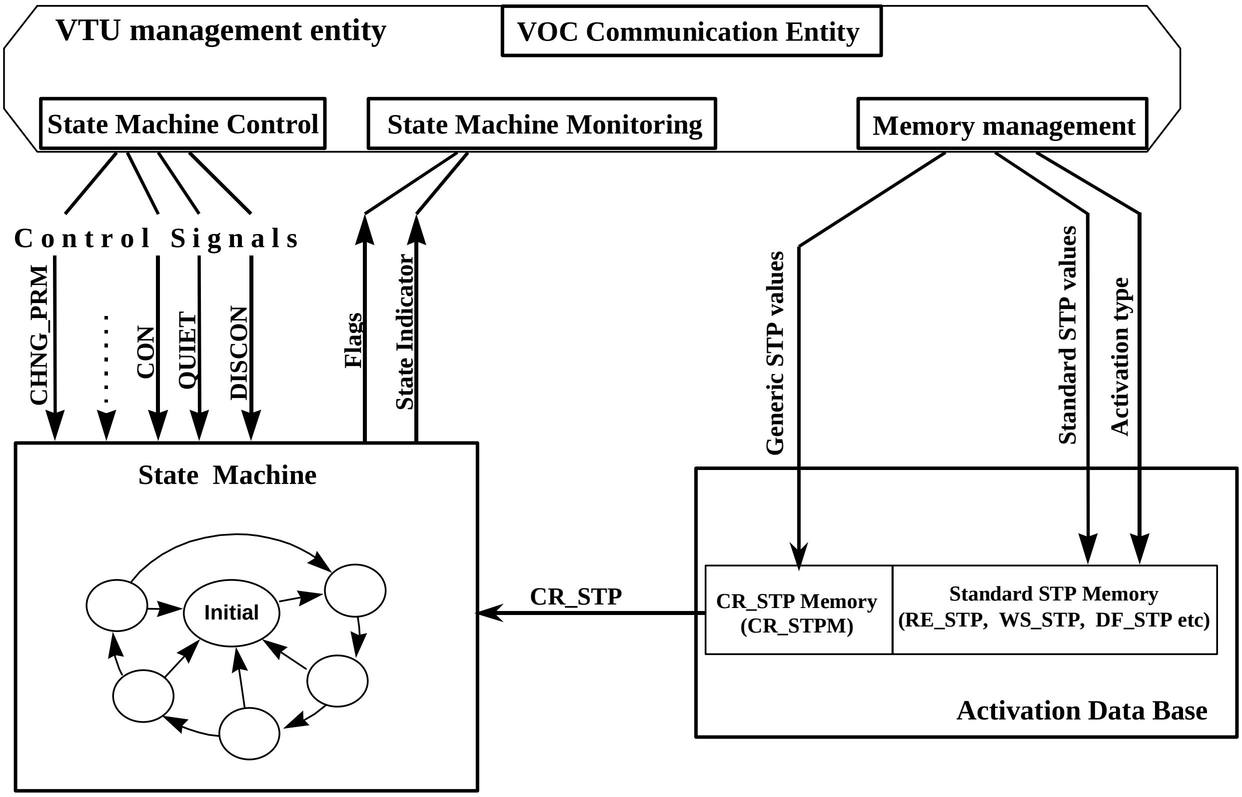


Figure 58: VTU- Activation/Deactivation Functional Diagram

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 synchronization. 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 88.

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 7.3.1.6) specified by the contents of the OC field and by the values of o_trig, r_trig, o_flag and r_flag in the Control 2 octet (6.5.1.3.3) and by the values of r_pmd_rai and o_pmd_rai. The values of r_pmd_rai and o_pmd_rai are calculated for the VTU-R and the VTU-O from a logical OR of *FLOS* and *RFI*, where *FLOS* and *RFI* are defined in 7.3.1.6.

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.

The PMD sub-layer Remote Alarm Indication (pmd_rai) bits o_pmd_rai, r_pmd_rai equal one for the O_ACQUIRE, R_ACQUIRE signals respectively and equal to zero for all the other transmit signals.

Table 88: Transmit Signals Summary

Signal	OC Field	Control Field	Note
O_QUIET		No transmission	
O_ACQUIRE	OC = IDLE	o_trig = 0, o_pmd_rai = 1	User Data: Denied EOC: Denied
O_TRIG	OC = IDLE	o_trig = 1, o_pmd_rai = 0	User Data: Applicable (note 1) EOC: Denied
O_DATA	OC = valid message	o_trig = 0, o_pmd_rai = 0	User Data: Applicable (note 1) VOC: Applicable EOC: Applicable (note 1)
R_QUIET		No transmission	
R_ACQUIRE	OC = IDLE	r_trig = 0, r_flag = 0, r_pmd_rai = 1	User Data: Denied EOC: Denied Variable transmit level (note 2)
R_TRIG	OC = IDLE	r_trig = 1, r_flag = 0, r_ pmd_rai = 0	User Data: Applicable (note 1) EOC: Denied
R_DATA	OC = valid message	r_trig = 0, r_flag = 0/1, r_ pmd_rai = 0	User Data: Applicable (note 1) VOC: Applicable EOC: Applicable (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*.			

8.3.8 Timers

The following timers, listed in table 89 are involved in the VTU- activation/de-activation process.

Table 89: VTU State-Machine Timers

Timer	Function	Value
t_{P_O}	Duration of the O_QUIET signal detection at VTU-O to complete the O_POWERUP state.	10 ms ≤ t_{P_O}, t_{P_R}
t_{P_R}	Duration of the R_QUIET signal detection at VTU-R to complete the R_POWERUP state.	
t_{1_R}	DS equalizer convergence time-out	TBD ($t_{1\_R} \leq t_{2\_R}$)
t_{1_O}	US equalizer convergence time-out	TBD ($t_{1\_O} \leq t_{2\_O}$)
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	1000 ms
t_{3_R}	Time-out for VTU-R trigger handshake	100 ms
t_{4_O}	Time-out to recover VTU-O frame synchronization	T5 ≤ 10 ms
t_{4_R}	Time-out to recover VTU-R frame synchronization	T5 ≤ 10 ms
NOTE: T1 to T5 are defined in TS 101 270-1 [1] 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 absence of the received upstream signal (the VTU-R transmits R_QUIET) is detected for more than t_{P_O} ms.

NOTE 2: The definition for *los* given in 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 synchronization process.

S3: O_CONVERGE

In state *S3* the VTU-O shall transmit the O_ACQUIRE signal while attempting to converge the upstream equalizer(s). The o_pmd_rai bit shall be set 1 to indicate that the upstream direction is not synchronized. This state is entered from state *S2* following an activation request, or from state *S6* following a non recovered synchronization 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 should converge its upstream equalizer(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*.

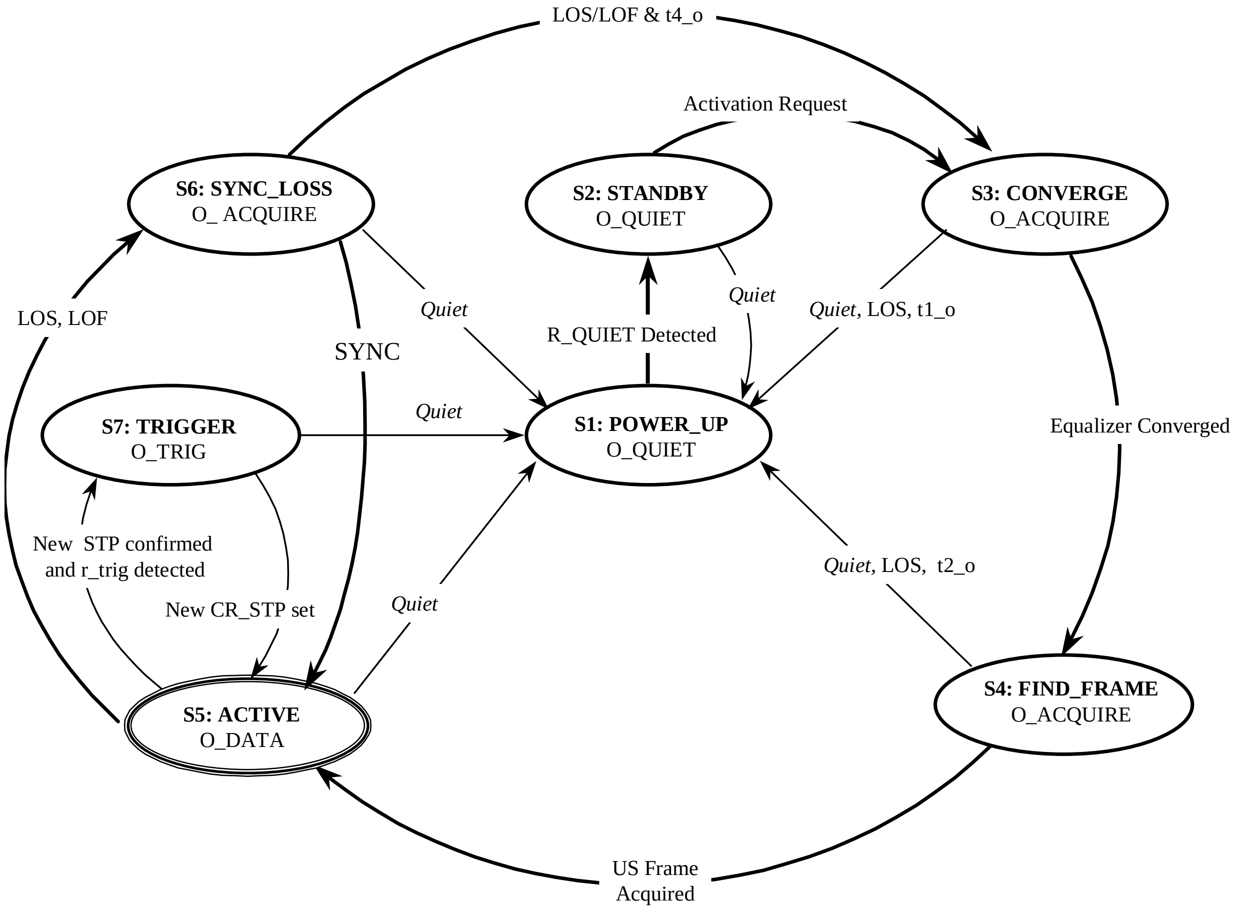


Figure 59: VTU-O Activation/De-activation State Machine

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 synchronized 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 6.5.1.5). The VTU-O shall transit to state *S5* as soon as the frame acquisition occurs. 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 should 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 US_LOS or US_LOF 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

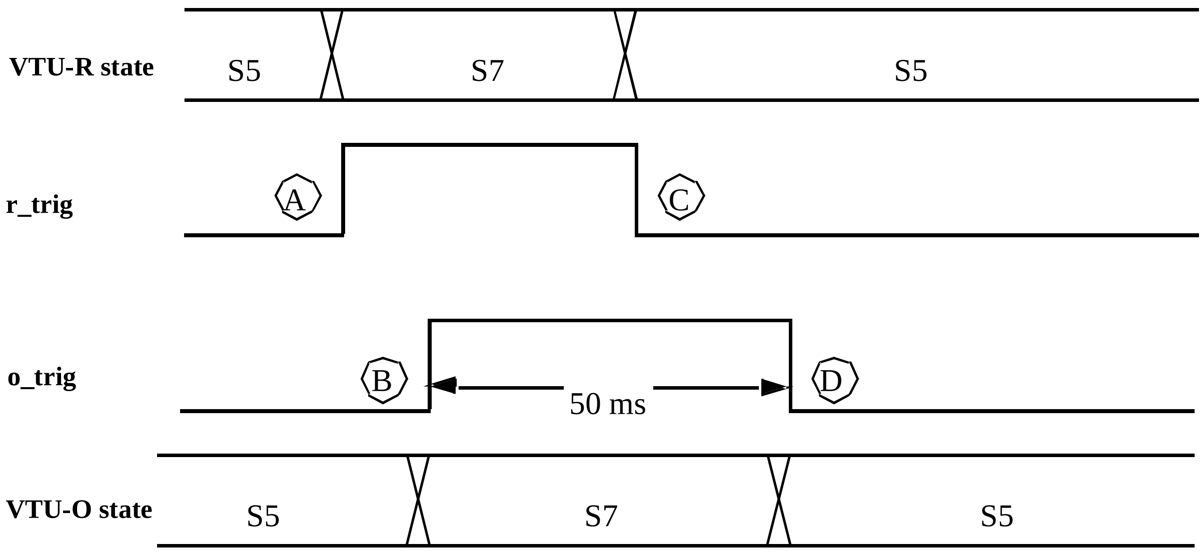
In this state the VTU-O attempts to recover the lost transmission frame synchronization. After the synchronization is recovered the VTU-O shall return to state *S5*. If synchronization is not recovered during the time-out interval of $t_{4\text{-}O}$ ms, the VTU-O shall move to state *S3* to initiate 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 synchronization loss by setting o_pmd_rai = 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 its 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 synchronize 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 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 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 the absence of a received downstream signal (the VTU-O transmits O_QUIET) is detected for more than in t_{P_R} ms.

NOTE 1: The definition for *los* given in 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 synchronization process.

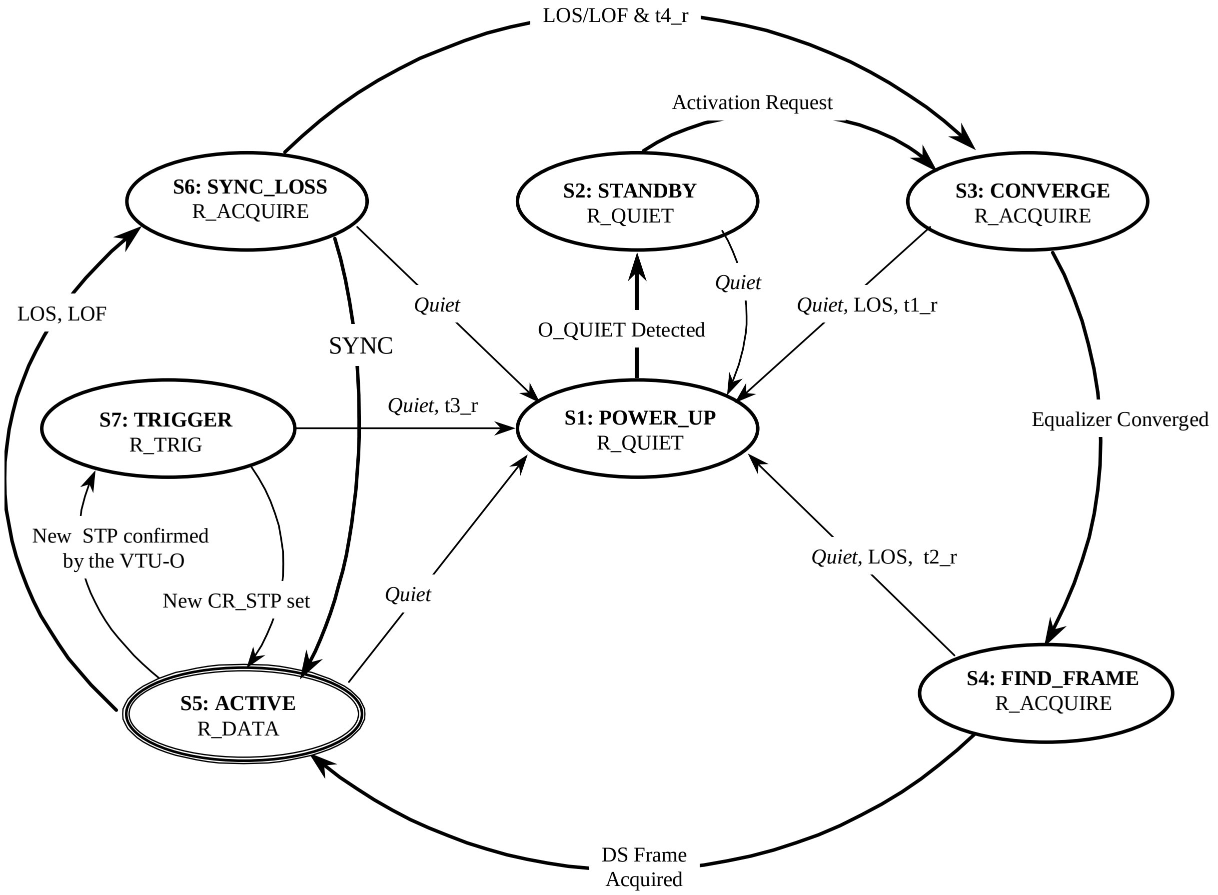


Figure 61: VTU-R Activation/Deactivation State Machine

S3: R_CONVERGE

In state *S3* the VTU-R shall transmit the R_ACQUIRE signal while attempting to converge the downstream equalizer(s). The r_pmd_rai bit shall be set 1 to indicate that the downstream direction is not synchronized. This state is entered from state *S2* following an activation request, or from state *S6* following a non recovered synchronization 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 should converge its downstream equalizer(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 equalizer 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.

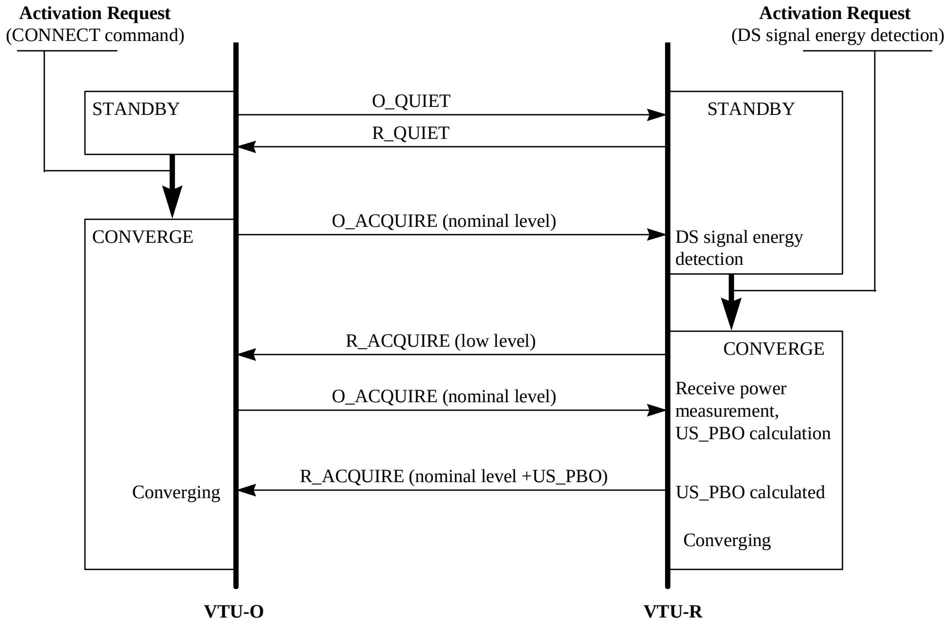


Figure 62: Activation From the VTU-O

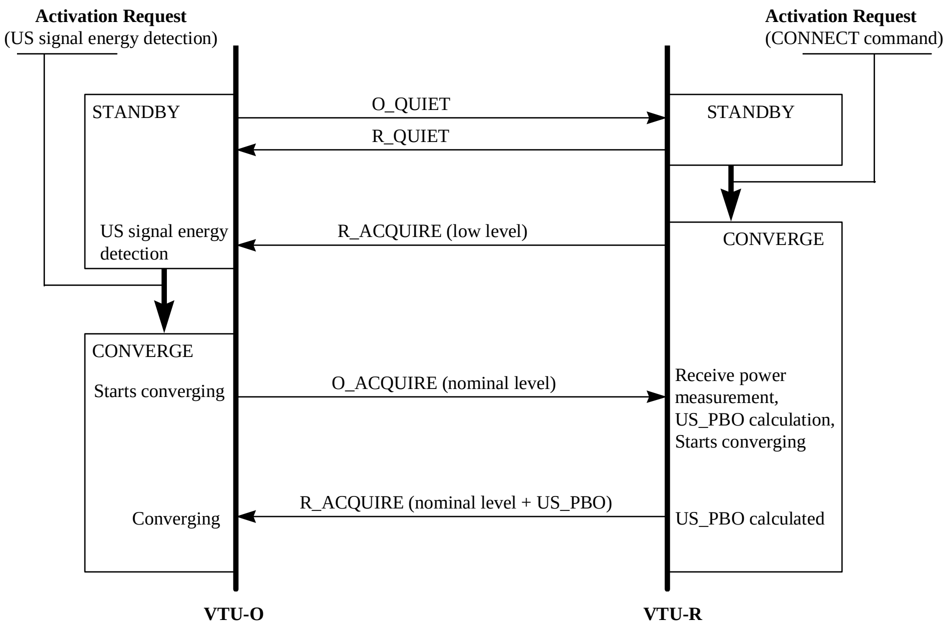


Figure 63: Activation From the VTU-R

S4: R_FINDFRAME

While in state *S4* the VTU-R shall transmit R_ ACQUIRE and r_pmd_rai bit shall be set 1 to indicate that the downstream direction is not synchronized 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 6.5.1.5). The VTU-R shall transit to state *S5* as soon as the frame acquisition occurs. If frame acquisition is not complete before t_R reaches $t_{2\text{-}R}$ 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 DS_LOS or DS_LOF 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 synchronization. After the synchronization is recovered the VTU-R shall return back to state *S5*. If synchronization 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 synchronization loss by setting r_pmd_rai = 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*.

9 Service Splitters and Electrical Characteristics

The requirements are specified in TS 101 270-1 [1].

10 Performance

For transceivers designed to conform to this issue of the specifications, the requirements given in Part 1 shall be met when the transceiver is operating at payload rates A1, A2, A3 and S1, S2, S3. For payload rates S4, S5 and A4 the transceiver performance will not fully meet the requirements specified in Part 1 due to the upper frequency constraint of 12 MHz.

The results of simulations that estimate the theoretical reach of the transceiver can be found in annex G.

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.

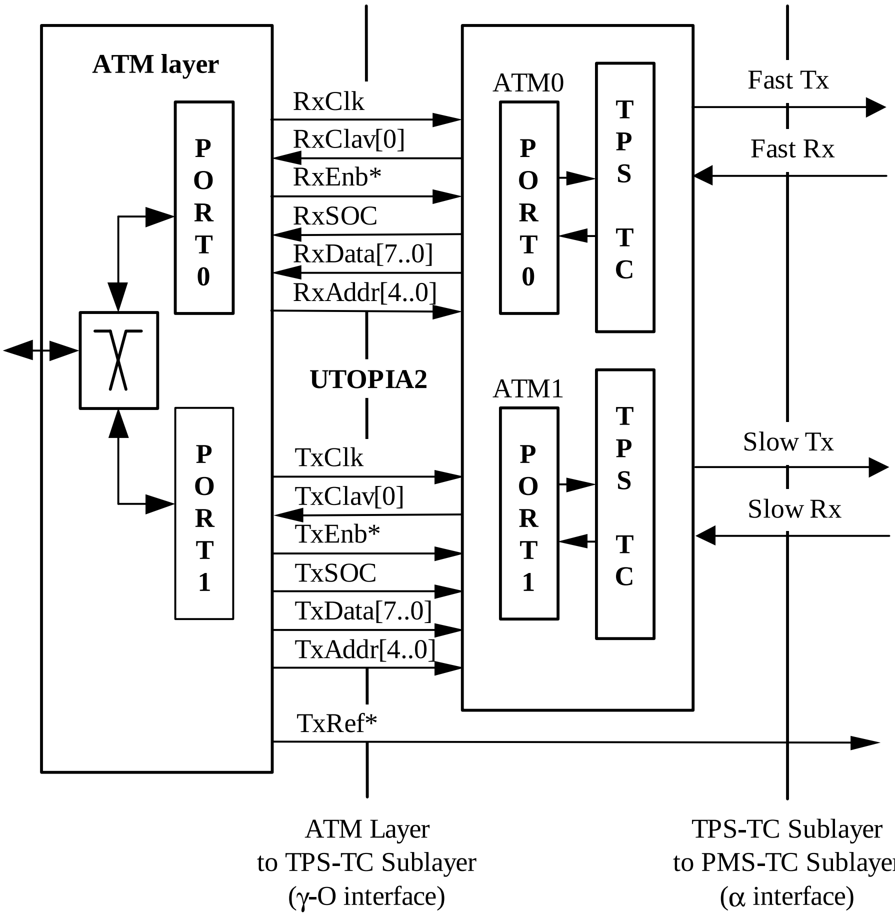


Figure A.1: Interfaces to ATM TPS-TC Sublayer, internal to ATM VTU-O

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 A1 and A2 and shown in figure A1. 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): Single carrier shaping filter impulse response

B.1 Impulse response of shaping filters

The in-phase and quadrature impulse responses of the BSS filter are shown in figure B.1. The in-phase and quadrature impulse responses of the PSS shaping filters are shown in figure B.2.

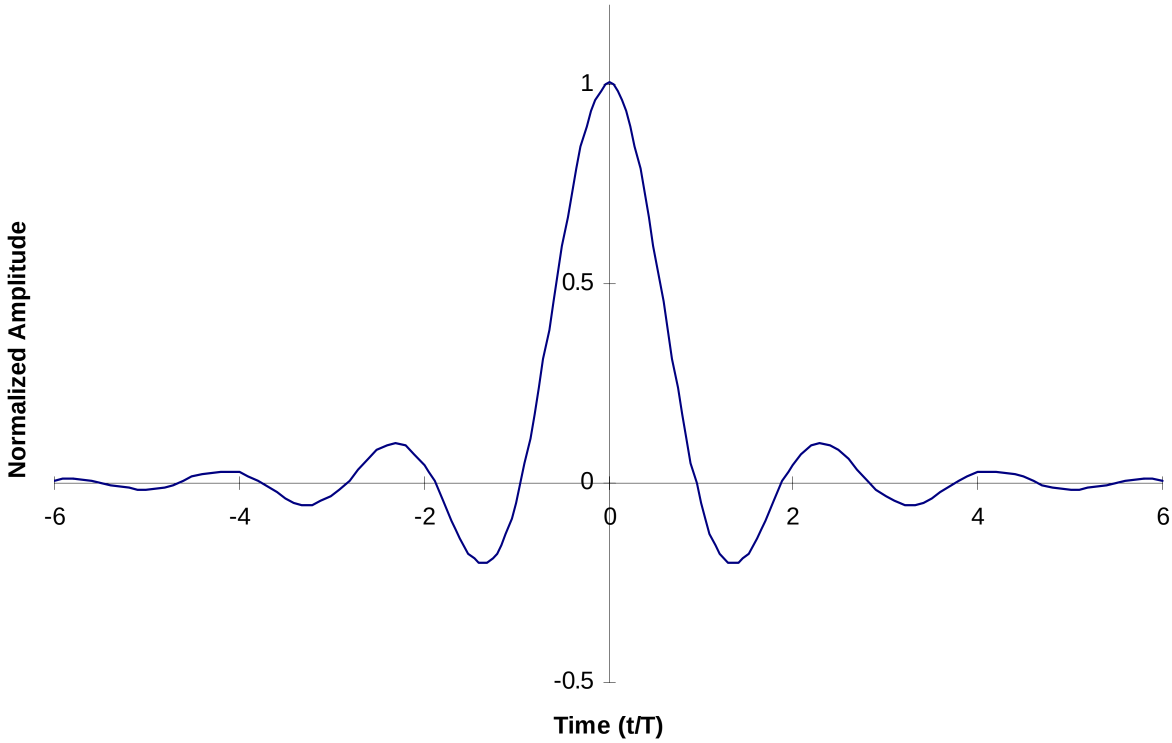


Figure B.1: Impulse Response of a Square-root Raised Cosine BSS Filter

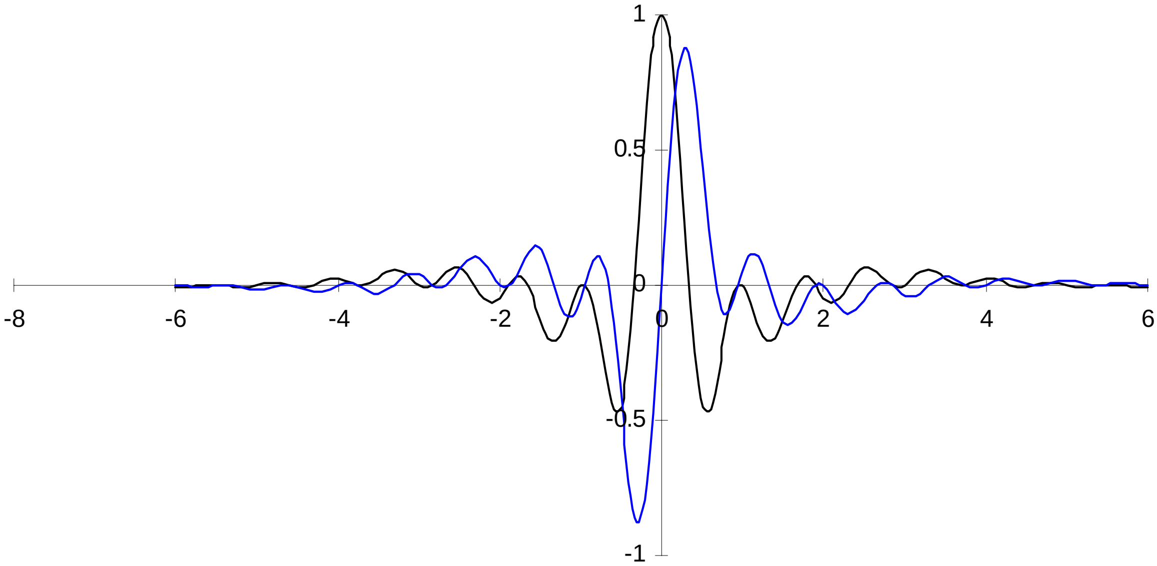


Figure B.2: Impulse Responses of an In-Phase and Quadrature PSS Filters

B.2 Transmit signal equations

The BSS transmit signal can be written as:

$$S_{QAM}(t) = \left[\sum_n I_n g(t - nT)\right]\cos(2\pi f_c t) - \left[\sum_n Q_n g(t - nT)\right]\sin(2\pi f_c t),$$

where I_n and Q_n take values ±1, ±3, ±5, … independently from each other.

The PSS transmit signal shall be defined as:

$$S(t) = \sum_n [I_n \bullet f(t - nT) - Q_n \bullet f'(t - nT)]$$

where I_n and Q_n take values ±1, ±3, ±5, … independently from each other.

Annex C (informative): TC example algorithms

C.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 C.1.

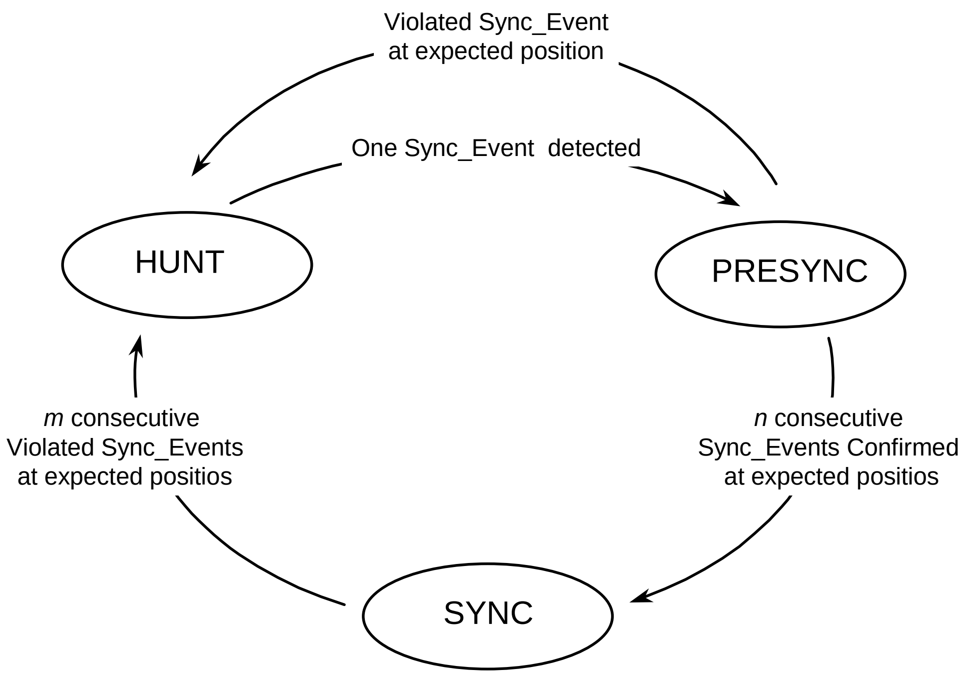


Figure C.1: Frame Delineation State Machine

In HUNT state the frame synchronization is lost and the state machine attempts to acquire frame synchronization 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.

C.2 Convolutional interleaver

C.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: $M*j$.

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* * (*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.

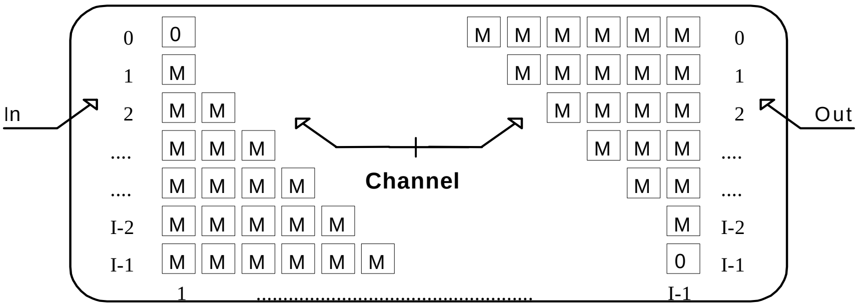


Figure C.2: Interleaver/De-interleaver Implementation example

Figure C2 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.

C.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 C.1.

Table C.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 µsec of erasure correction	M, octets	2	4	8	16	32	64
	Delay, msec	5,9					
500 µsec of erasure correction	M, octets	4	8	16	32	64	128
	Delay, msec	11,8					

Annex D (informative):
Theoretical reach simulation results

This annex contains the results from extensive simulation of the two frequency plans. The following limits and assumptions were made.

- Shannon gap 9,8 dB
- Coding gain 3,8 dB
- SNR margin 6 dB
- Noise model FSAN
- Additional noise AWGN (-140 dBm/Hz)
- Maximum SNR 45 dB
- FEXT 20 VDSL
- Efficiency 10%
- Transmit power < 11,5 dBm
- Number of bands ≤ 2 in each direction
- PSD mask notched mask M1 (Pcab.D.M1 and Pex.D1.M1)
- Type of cable VDSL loop 1 (0,5 mm)

D.1 Standard band plan with 0% guard band

This band plan has band edges at 138, 3 000, 5 100, 7 050 and 12 000 kHz. The table below shows the reach in metres expected when using no guard bands.

Table D.2: Standard band plan with 0% guard bands

Service	Noise A	Noise B	Noise C	Noise D	Noise E	Noise F
S1: 6,40/6,40	1350	1350	970	1160	1240	900
S2: 8,57/8,57	1220	1220	910	1060	1130	840
S3: 14,46/14,46	990	990	680	860	920	710
S4: 23,16/23,16	440	530	220	350	530	430
A1: 6,40/2,04	1740	1740	1020	1460	1560	1080
A2: 8,57/2,04	1740	1740	930	1460	1560	1060
A3: 14,46/3,07	1280	1310	680	1120	1370	830
A4: 23,16/4,09	440	530	220	350	610	430

D.2 Standard band plan with 15% guard band

This band plan has band edges at 138, 3 000, 5 100, 7 050 and 12 000 kHz. The table below shows the reach in metres expected when allowing for 15% guard bands.

Table D.3: Standard band plan with 15% guard bands

Service	Noise A	Noise B	Noise C	Noise D	Noise E	Noise F
S1: 6,40/6,40	1190	1190	910	1030	1110	840
S2: 8,57/8,57	1090	1090	820	940	1010	780
S3: 14,46/14,46	830	830	400	710	770	610
S4: 23,16/23,16	190	220	0	130	250	170
A1: 6,40/2,04	1640	1640	940	1390	1490	1020
A2: 8,57/2,04	1640	1640	820	1390	1490	1010
A3: 14,46/3,07	1010	1110	400	750	1210	700
A4: 23,16/4,09	190	220	0	130	250	170

D.3 Regional-specific optional band plan with 0% guard band

This band plan has band edges at 138, 3 750, 5 200, 8 500 and 12 000 kHz. The table below shows the reach in metres expected when using no guard bands.

Table D.4: Regional-specific optional band plan with 0% guard bands

Service	Noise A	Noise B	Noise C	Noise D	Noise E	Noise F
S1: 6,40/6,40	1120	1120	870	990	1050	810
S2: 8,57/8,57	1000	1000	800	880	930	740
S3: 14,46/14,46	610	610	540	570	590	510
S4: 23,16/23,16	150	150	140	140	140	140
A1: 6,40/2,04	1580	1580	1070	1410	1490	1010
A2: 8,57/2,04	1580	1580	1000	1410	1490	1010
A3: 14,46/3,07	1400	1430	850	1260	1390	910
A4: 23,16/4,09	1020	1060	570	880	1080	690

D.4 Regional-specific optional band plan with 15% guard band

This band plan has band edges at 138, 3 750, 5 200, 8 500 and 12 000 kHz. The table below shows the reach in metres expected when allowing for 15% guard bands.

Table D.5: Regional-specific optional band plan with 15% guard bands

Service	Noise A	Noise B	Noise C	Noise D	Noise E	Noise F
S1: 6,40/6,40	910	910	750	800	850	700
S2: 8,57/8,57	750	750	640	660	700	600
S3: 14,46/14,46	260	260	210	220	230	210
S4: 23,16/23,16	0	0	0	0	0	0
A1: 6,40/2,04	1410	1410	990	1260	1330	920
A2: 8,57/2,04	1410	1410	970	1260	1330	920
A3: 14,46/3,07	1180	1180	780	1060	1120	850
A4: 23,16/4,09	720	810	380	580	890	570

Annex E (informative): Provisional handshake parameters

Table E.6: 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 E.7: Mandatory carrier sets

xDSL Recommendation(s)	Carrier set designation
G.992.1 – Annex A, G.992.2 – Annex A/B	A43
G.992.1 – Annex B	B43
G.992.1 – Annex C, G.992.2 – Annex C, G.992.1 – Annex H	C43
ETSI MCM VDSL	D43

Table E.8: 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 E.9: 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 F (informative): Bibliography

- T1E1.4/2000-009: "Very-high-speed Digital Subscriber Line (VDSL) Metallic Interface, Part 1: Functional Requirements and Common Specification".
- T1E1.4/2000-011: "Interface Between Networks and Customer Installations - Very-high Speed Digital Subscriber Lines (VDSL) Metallic Interface. Part 2: Technical Specification of a Single-carrier Modulation (SCM) Transceiver - Part 2 of VDSL draft for trial use".
- T1E1.4/2000-013: "Very-high-speed Digital Subscriber Lines (VDSL) Interface, Part 3: Technical Specification of a Multi-Carrier Modulation transceiver".
- ATM Forum Specification at-phy-0040.000: "Physical interface specification for 26.5 Mb/s over Twisted Pair Cable".
- 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", clause 7.

History

Document history		
V1.1.1	February 2001	Publication