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

Digital sections and digital line system – Metallic access networks

Self-FEXT cancellation (vectoring) for use with VDSL2 transceivers

Recommendation ITU-T G.993.5

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Recommendation ITU-T G.993.5

Self-FEXT cancellation (vectoring) for use with VDSL2 transceivers

Summary

Vectoring is a transmission method that employs the coordination of line signals for reduction of crosstalk levels and improvement of performance. The degree of improvement depends on the channel characteristics. Vectoring may be for a single user or for multiple users' benefit.

Recommendation ITU-T G.993.5 is specifically limited to the self-far-end crosstalk (self-FEXT) cancellation in the downstream and upstream directions. It defines a single method of self-FEXT cancellation, in which FEXT generated by a group of near-end transceivers and interfering with the far-end transceivers of that same group is cancelled. This cancellation takes place between very high-bit-rate digital subscriber line 2 (VDSL2) transceivers, not necessarily of the same profile. This Recommendation is intended to be implemented in conjunction with Recommendation ITU-T G.993.2.

This version of this Recommendation integrates all of the previous amendments and corrigenda with the 2015 version 2.0 of Recommendation ITU-T G.993.5.

This version of Recommendation ITU-T G.993.5 corrects or adds the following functionality:

– Typographical correction in clause 8.2 (Corrigendum 1)
– Generalization of the segmentation of SOC messages in clause 10.4.2.2 for vectoring of profile 35b (Corrigendum 1)
– Transceiver O-DEACTIVATING state (Amendment 1)
– Annex A: Mitigating strong FEXT (Amendment 2)
– Annex B: Vectored Long Reach VDSL2 (Amendment 2)
– Encoding of R-P-VECTOR-2 in LR mode with long loop operation (Annex B) (Corrigendum 2)
– Long reach VDSL2 corrigendum related to MAXNOMATP (new).

History

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Crosstalk Cancellation, Long Reach, VDSL2, Vectoring.

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FOREWORD

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

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

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Recommendation ITU-T G.993.5

Self-FEXT cancellation (vectoring) for use with VDSL2 transceivers

1 Scope

Vectoring is a transmission method that employs the coordination of line signals for reduction of crosstalk levels and improvement of performance. The degree of improvement depends on the channel characteristics. Vectoring may be for a single user or for multiple users' benefit.

This Recommendation is specifically limited to the self-far-end crosstalk (self-FEXT) cancellation in the downstream and upstream directions. This Recommendation defines a single method of self-FEXT cancellation, in which far-end crosstalk (FEXT) generated by a group of near-end transceivers and interfering with the far-end transceivers of that same group is cancelled. This cancellation takes place between very high-bit-rate digital subscriber line 2 (VDSL2) transceivers, not necessarily of the same profile. This Recommendation is intended to be implemented in conjunction with [ITU-T G.993.2]. Multi-pair digital subscriber line (DSL) bonding ([b-ITU-T G.998.1], [b-ITU-T G.998.2] and [b-ITU-T G.998.3]) may be implemented in conjunction with vectoring.

The techniques described in this Recommendation provide means of reducing self-FEXT generated by the transceivers in a multi-pair cable or cable binder. Self-FEXT cancellation techniques are particularly beneficial with short cable lengths (< 1 km) and limited near-end crosstalk (NEXT), background noise, and FEXT from systems which are not a part of the vectored group (alien noise). The level of non-self-FEXT noise sources relative to that of self-FEXT sources determines the degree to which self-FEXT reduction can improve performance. Another significant factor is the degree to which the self-FEXT cancelling system has access to the disturbing pairs of the cable. Maximum gains are achieved when the self-FEXT cancelling system has access to all of the pairs of a cable carrying broadband signals. For multi-binder cables, significant gains are possible when the self-FEXT cancelling system has access to all of the pairs of the binder group(s) in which it is deployed and has the ability to cancel at least the majority of dominant self-FEXT disturbers within the binder. When multiple self-FEXT cancelling systems are deployed in a multi-binder cable without binder management, gains may be significantly reduced.

2 References

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

[ITU-T G.993.2] Recommendation ITU-T G.993.2 (2019), *Very high speed digital subscriber line transceivers 2 (VDSL2)*.

[ITU-T G.994.1] Recommendation ITU-T G.994.1 (2018), *Handshake procedures for digital subscriber line transceivers*.

[ITU-T G.997.1] Recommendation ITU-T G.997.1 (2019), *Physical layer management for digital subscriber line transceivers*.

[ITU-T G.998.4] Recommendation ITU-T G.998.4 (2018), *Improved impulse noise protection for digital subscriber line (DSL) transceivers*.

[IEEE 802.3] IEEE 802.3-2018, *IEEE Standard for Information technology – Telecommunications and information exchange between systems – Local and metropolitan area networks – Specific requirements Part 3: Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications*.

3 Definitions

3.1 Terms defined elsewhere

This Recommendation adopts the definitions of [ITU-T G.993.2].

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 backchannel: The channel through which the VTU-R sends clipped error samples to the vectoring control entity (VCE). The backchannel may be implemented as part of the eoc or as part of the Ethernet data stream from the VTU-R to the VTU-O.

3.2.2 ceiling: Rounding to the nearest higher integer, denoted as $\lceil x \rceil$.

3.2.3 channel matrix: For a particular line in a group of lines, the channel matrix characterizes the FEXT couplings on each subcarrier frequency between the line and all other lines in the group.

3.2.4 clipped error sample: A (B_max+1)-bit 2's complement representation of a normalized error sample through multiplying each component by 2^{N_max-1}, flooring and clipping to the $[-2^{B\_max}, 2^{B\_max}-1]$ interval (with N_max a fixed value, and B_max a value controlled by the VCE).

3.2.5 expected throughput (ETR): see clause 3.2 of [ITU-T G.998.4].

3.2.6 flag tones: All subcarriers of a sync symbol with indices equal to 10n+1 or 10n+7, with n an integer value. Flag tones are used to signal OLR transitions during Showtime.

3.2.7 flooring: Rounding to the nearest lower integer, denoted as $\lfloor x \rfloor$.

3.2.8 normalized error sample: The complex error measured by the VTU-R, being the distance between the received signal vector and the decision constellation point referred to the input of the constellation descrambler, expressed in units equal to half the distance between two adjacent constellation points.

3.2.9 pilot sequence: A binary sequence set by the VCE. When the pilot sequence is transmitted during initialization and in Showtime, each bit of the pilot sequence determines whether the VTU-O (downstream pilot sequence) or the VTU-R (upstream pilot sequence), respectively, modulates ZEROs on all probe tones or ONEs on all probe tones of a particular sync symbol.

3.2.10 probe tones: All subcarriers of a sync symbol with indices equal to 10n, 10n+2, 10n+3, 10n+4, 10n+5, 10n+6, 10n+8, or 10n+9, with n an integer value. Probe tones are used for transmission of pilot sequences.

3.2.11 Syncflag: A sync symbol in which the sync frame bits modulated on the flag tones are inverted relative to the sync frame modulated by the most recently transmitted sync symbol (i.e., if the previous sync frame was all ZEROs modulated on the flag tones, the Syncflag would correspond to a sync frame of all ONEs modulated on the flag tones, and vice versa). The Syncflag is used to signal online reconfiguration transitions.

3.2.12 vectored group: The set of lines over which transmission from the access node (AN) is eligible to be coordinated by pre-compensation (downstream vectoring), or over which reception at the AN is eligible to be coordinated by post-compensation (upstream vectoring), or both.

Depending on the configuration of the vectored group, downstream vectoring, upstream vectoring, both or none may be enabled.

3.2.13 vectoring: The coordinated transmission and/or coordinated reception of signals of multiple DSL transceivers using techniques to mitigate the adverse effects of crosstalk to improve performance.

4 Abbreviations and acronyms

This Recommendation adopts the abbreviations defined in [ITU-T G.993.2]. In addition, this Recommendation uses the following abbreviations:

ACTATP	Actual Aggregate Transmit Power
AFE	Analogue Front End
AN	Access Node
ATP	Aggregate Transmit Power
BDR	Backchannel Data Rate
CO	Central Office
CO-MIB	Central Office-Management Information Base
CO-side	End of the line nearer to the Central Office
CP	Customer Premises
CP-side	End of the line nearer to the Customer Premises
DMT	Discrete Multi-Tone
DSE	Disorderly Shutdown Event
DSL	Digital Subscriber Line
EC	Echo Canceller
eoc	Embedded Operation Channel
ERB	Error Report Block
ETR	Expected Throughput
FEXT	Far-end crosstalk
HDLC	High-Level Data Link Control
IDFT	Inverse Discrete Fourier Transform
L2+	Ethernet Layer 2 and above
ME	Management Entity (or Mean Error)
MIMO	Multiple Input Multiple Output
NEXT	Near-end crosstalk
NDR	Net Data Rate
NMS	Network Management System
NOMATPds	Nominal Aggregate Transmit Power in downstream
NOMATPus	Nominal Aggregate Transmit Power in upstream
NT	Network Termination

PCB	Power Cut-Back
PDF	Probability Density Function
PDM	Physical Medium Dependent
PSD	Power Spectral Density
QAM	Quadrature Amplitude Modulation
OLR	On-Line Reconfiguration
ONU	Optical Network Unit
QLN	Quiet Line Noise
RT	Remote Terminal
RTX	Retransmission
SC	Segment Code
SNR	Signal-to-Noise Ratio
SOC	Special Operations Channel
SOS	Save Our Showtime
SRA	Seamless Rate Adaptation
SSC	Sync Symbol Counter
TA	Timing Advance
TEQ	Time Domain Equalizers
TID	TIGAV identification number
TIGAV	Transmitter Initiated Gain Adjustment for VDSL2
UPBO	Upstream Power Back Off
VBB	Vectored Band Block
VCE	Vectoring Control Entity
VDSL2	Very high-bit-rate Digital Subscriber Line 2
VDSL2-LR	Long Reach mode for Vectored VDSL2
VME	VDSL2 Management Entity
VTU	Very high-speed digital subscriber line Transceiver Unit
VTU-O	VTU at the ONU (or central office, exchange, cabinet, etc., i.e., operator end of the loop)
VTU-R	VTU at the Remote site (i.e., subscriber end of the loop)
XTU-C	X digital subscriber line Transceiver Unit at the Central office
XTU-R	X digital subscriber line Transceiver Unit at the Remote end

5 Reference models

5.1 General

A reference model for a vectored system is illustrated in Figure 5-1. In a vectored system, the access node (AN), located at a central office (CO) or remote terminal (RT) or other location, transmits to and receives from a number of network terminations (NTs). The common element of all forms of vectoring is coordinated transmission (downstream vectoring) or coordinated reception (upstream vectoring) of signals from lines in the vectored group at the AN. Thus, the signals may be represented as a vector where each component is the signal on one of the lines. This coordination is made possible through an interface between a very high-speed digital subscriber line transceiver unit (VTU) at the ONU (VTU-O) (here called VTU-O-1) and all other VTU-Os (here called VTU-O-*n*, *n*=2…*N*, where *N* denotes the number of lines in the vectored group), which is here called ε-1-*n* to indicate that the coordination takes place between line 1 and line *n*.

Coordinated management of the lines is performed by the network management system (NMS), passing management information to the management entity (ME) through the Q-interface (see clause 11). Both the NMS and the ME are defined in [ITU-T G.997.1]. Inside the AN, the ME further conveys the management information for a particular line (over an interface here called ε-m) to the vectoring control entities (VCEs) of the vectoring group that line belongs to. Each VCE controls a single vectored group, and controls VTU-O-*n* (connected to line *n* in the vectored group) over an interface here called ε-c-*n*. Pre-coder data are exchanged between VTU-O-*n*1 and VTU-O-*n*2 over an interface here called ε-*n*1-*n*2.

Figure 5-1 shows the reference model for a vectored system (only line 1 out of a vectored group of *N* lines is shown). The PHY blocks represent the physical layer of the AN interface towards the network and of the NT interface towards the customer premises (CP). These blocks are shown for completeness of the data flow but are out of scope of this Recommendation. The Ethernet layer 2 and above (L2+) blocks represent the Ethernet Layer 2 and above functionalities contained in the AN and NT. These blocks are shown for completeness of the data flow but are out of scope of this Recommendation, except for the encapsulation (at NT) and decapsulation (at AN) of the backchannel (see clause 7.4.1).

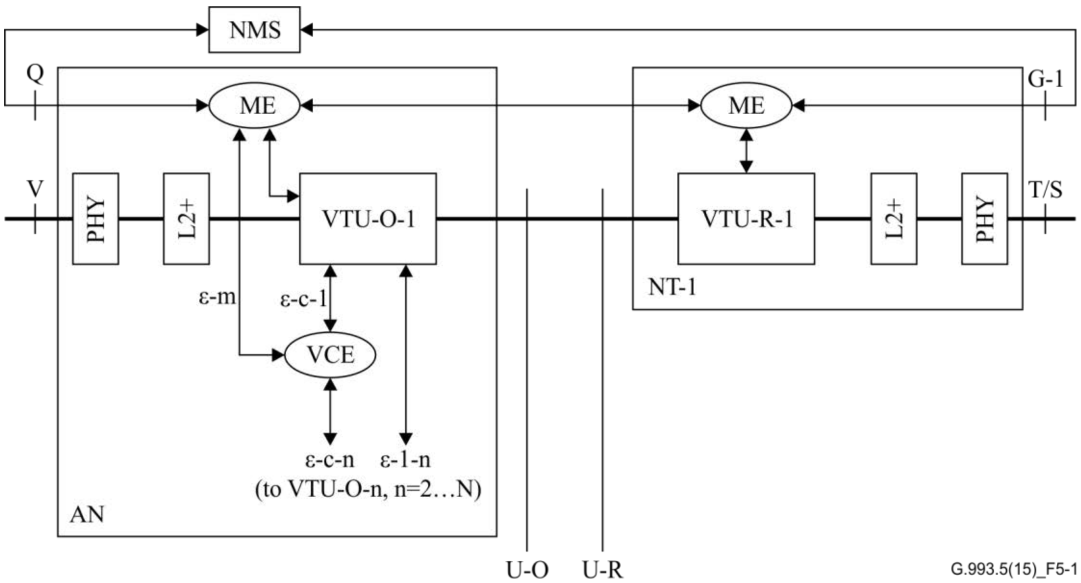

Figure 5-1 – Reference model for a vectored system (shown for line 1 in a vectored group of *N* lines)

Using [b-ITU-T G.998.1], [b-ITU-T G.998.2] and [b-ITU-T G.998.3], data rates can be increased by deploying multiple lines to the same customer premises – a technique known as bonding.

NOTE – Vectoring is not another name for bonding; bonding may be used with or without vectoring. The use of vectoring over bonded lines is often defined as bonded vectoring or as multiple input multiple output (MIMO) DSL.

The focus of this Recommendation is the use of vectoring over lines that are not bonded, although it does not preclude the use of vectoring over bonded lines.

A vectored VDSL2 system improves its performance from the use of joint signal processing in the downstream direction (coordinated transmission), or from the use of joint signal processing in the upstream direction (coordinated reception) which allows cancelling of self-FEXT (i.e., FEXT generated by the lines of the vectored group). The noise sources which are external to the group of vectored pairs in the vectored system (for example, alien crosstalk from lines operated by another service provider, interference from AM broadcast channels or interference from amateur radio ("HAM") transmitters above the AM broadcast band) reduce the benefits of FEXT cancellation and reduce the performance enhancement provided by a vectored system.

5.2 Downstream vectoring

For relatively short lines and high-bandwidth systems such as VDSL, self-FEXT is the limiting factor for downstream data rates. This Recommendation defines multi-line pre-coding at the AN to mitigate FEXT in the downstream direction, based on "pre-subtraction" or "pre-compensation" of the FEXT, while meeting transmitted power constraints. To accommodate for such pre-coding, the [ITU-T G.993.2] physical medium dependent (PMD) layer is modified as shown in Figure 5-2 (adapted from Figure 10-1 of [ITU-T G.993.2], with differences shown shaded). Figure 5-2 shows the VTU-O functional model for line 1 out of a vectored group of *N* lines. For each line in the vectored group, the PMD sublayer includes an *N*×1 pre-coder. Over the vectored group, the *N* pre-coders for each of the *N* lines constitute the FEXT cancellation pre-coder shown in Figure 6-1.

NOTE – The pre-coder may or may not be implemented in the same physical device as the other functional blocks shown in Figure 5-2.

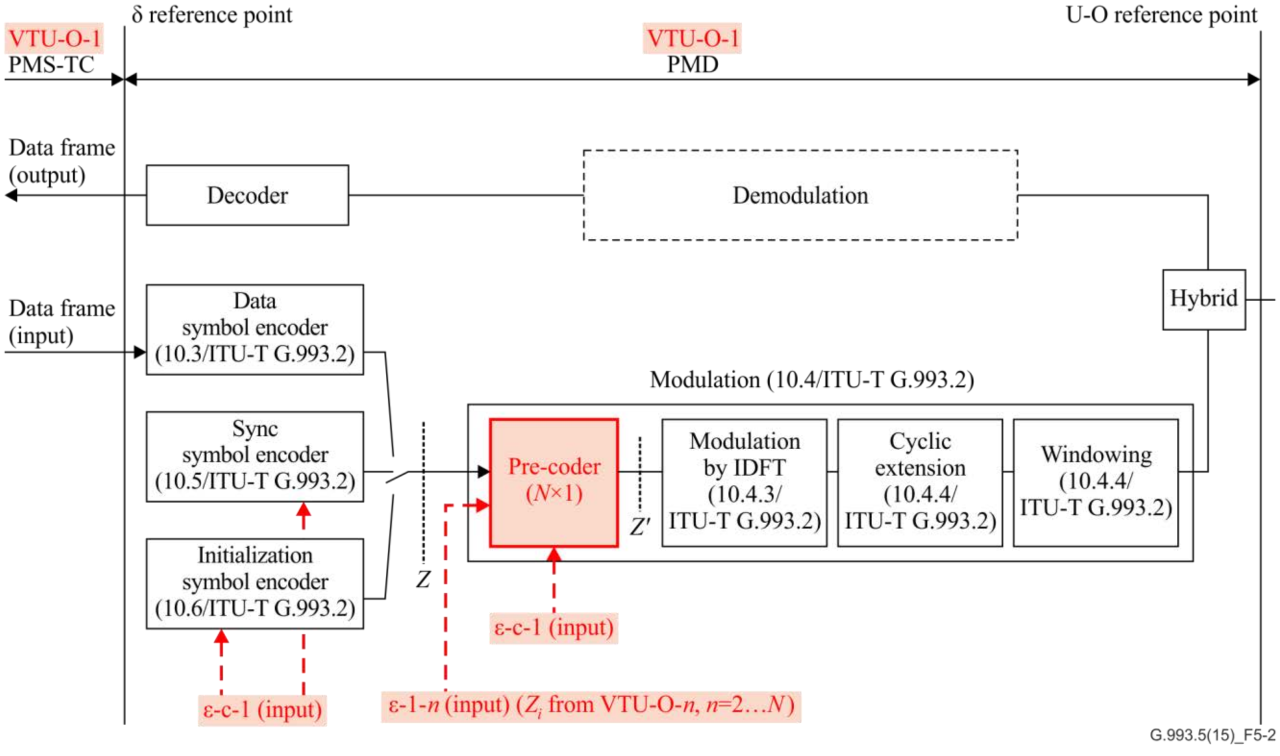

Figure 5-2 – VTU-O functional model of PMD sub-layer using *N*×1 pre-coder for downstream vectoring (shown for line 1 in vectored group of *N* lines)

The VTU at the remote site (VTU-R) functional model of PMD sublayers is as shown in Figure 10-1 of [ITU-T G.993.2], with an addition of vectoring-related control signals applied to the sync symbol encoder and initialization symbol encoder to provide pilot sequence modulation on sync symbols, similar to those shown in Figure 5-2 (see clauses 10.3 and 10.4).

5.3 Upstream vectoring

Upstream vectoring is mainly a receiver function at the end of the line nearer to the central office (CO-side), and therefore its implementation is vendor discretionary. This Recommendation only defines the VTU-R transmitter requirements to facilitate upstream FEXT cancellation at the CO-side (e.g., transmission of upstream pilot sequence with timing and content under VCE control).

6 CO-side requirements in a vectored group

This clause describes the CO-side steady-state behaviour to support operation of an *N*-pair vectored group.

6.1 General

Figure 6-1 shows the functional model for the inclusion of downstream FEXT cancellation pre-coding at the AN for all lines in the vectored group, as a generalization of Figure 5-2 from a signal processing perspective. The model shows only the portion of an array of the downstream symbol encoders (which represent the data, sync or initialization symbol encoders shown in Figure 5-2) and the modulation by the inverse discrete Fourier transform (IDFT) functional blocks of the VTU-Os, with the FEXT cancellation pre-coder inserted between the symbol encoders and the modulation by the IDFT blocks.

The VCE of the vectored group learns and manages the channel matrix per vectored subcarrier, which reflects the channel characteristics of the managed group of lines. In the functional model in Figure 6-1, the channel matrix for each vectored subcarrier is of size $N \times N$ where N is the number of lines in the vectored group.

From the channel matrix, a FEXT pre-coder matrix may be derived and used to compensate the FEXT from each line in the vectored group. In the functional model in Figure 6-1, this is shown by a matrix of FEXT cancellation pre-coders per vectored subcarrier of size $N \times N$. This FEXT cancellation pre-coding matrix may be "sparse" (see Note). Knowing the transmit symbols on each disturbing channel, the pre-coder pre-compensates the actual transmit symbol such that at the far-end receiver input, the crosstalk is significantly reduced.

NOTE – In typical cases, several of the pre-coder coefficients may be set to 0 for implementation reasons, or because the crosstalk coefficients are negligibly small.

The channel matrix and the resulting FEXT cancellation pre-coder matrix are assumed to be entirely managed inside the AN. An information exchange between the VTU-O and VTU-R is required in each vectored line to learn, track, and maintain the channel matrix and associated FEXT cancellation pre-coder matrix (see backchannel definition in clause 7 and initialization in clause 10). The actual algorithms for processing this information to obtain the channel matrix and to generate the FEXT cancellation pre-coder are vendor discretionary. Depending on the implementation, it may be possible for the VCE to directly determine the FEXT cancellation pre-coder matrix and only have an implicit learning of the channel matrix.

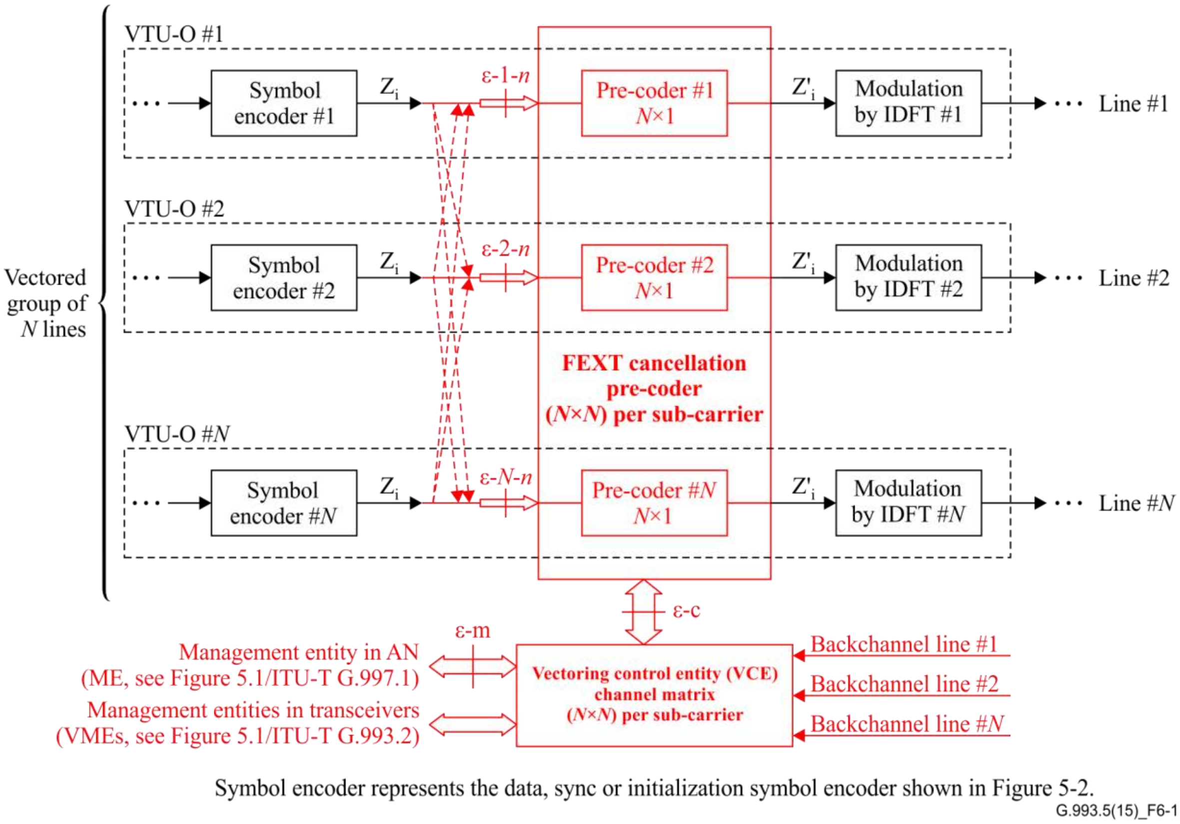

Figure 6-1 – Vectored group functional model of PMD sub-layer using *N*×*N* pre-coder for downstream vectoring

The VTU-O shall support downstream vectoring (see clause 6.2) and may support upstream vectoring (see clause 6.3).

The VTU-O shall support seamless rate adaptation ((SRA), on-line reconfiguration (OLR) Type 3) in the downstream and upstream direction, including mandatory support within SRA of:

– dynamic interleaver reconfiguration (change of D_p);
– framing reconfiguration (change of T_p, G_p and B_{p0})

as defined in clause 13.1 of [ITU-T G.993.2].

If [ITU-T G.998.4] is enabled in a particular direction, the VTU-O shall also support seamless rate adaptation (SRA, OLR Type 5) in this same direction, including mandatory support within SRA of all configurations specified in clause C.3.2 of [ITU-T G.998.4].

6.2 Downstream vectoring requirements for the VTU-O

The VTU-O shall comply with [ITU-T G.993.2], with the exceptions and additional requirements contained in this Recommendation.

In order to enable the VCE to fulfil the tasks described in clause 6.1, the VTU-O shall support the requirements in this clause and the following clauses.

6.2.1 Synchronous mode

Under VCE control, all VTU-Os in the vectored group shall use the same subcarrier spacing and symbol rate, and shall start transmission of discrete multi-tone (DMT) symbols at the same time on all of the lines in the vectored group. The transmit symbol clocks shall be phase-synchronous at all VTU-Os in the vectored group with a 1 µs maximum phase error tolerance at the U-O2 reference point (defined in Figure 5-4 of [ITU-T G.993.2]).

6.2.2 Sync symbol position

The VTU-O shall have the capability to transmit sync symbols as defined in clause 10.2 of [ITU-T G.993.2]. The downstream sync symbol time positions are determined by the VCE. The VCE may configure all VTU-Os in the vectored group to transmit downstream sync symbols at the same time positions or use different time positions for one or more VTU-Os in the vectored group.

The VTU-O shall keep a downstream sync symbol counter (SSC) (MODULO N_SSC), counting continuously during Showtime. The value *N_SSC* shall be selected by the VCE and transmitted during initialization to the VTU-R in O-SIGNATURE (see clause 10.3.2.1). The counter value of the first downstream sync symbol transmitted after entering Showtime shall be set by the VCE and transmitted to VTU-R in the field First SSC of the Error Feedback command (see Table 8-3).

NOTE – This setting at the start of Showtime synchronizes the downstream sync symbol counter with the VTU-R (see clause 7.3.3).

6.2.3 Modulation of a pilot sequence

The VTU-O shall have the capability to modulate a VCE-specified downstream pilot sequence on all probe tones of the downstream sync symbols during initialization (see e.g., clause 10.3.3.1) and on all probe tones (see clause 3.2.10) of the downstream sync symbols during Showtime. The downstream pilot sequence is vendor discretionary, determined by the VCE, and is a binary string of length *Npilot_ds* (with bits indexed from 0 to *Npilot_ds – 1*, and the bit with index 0 transmitted first). If the "pilot sequence length multiple of 4" is enabled (see clause 10.2), then valid values of *Npilot_ds* are all multiples of 4 in the range from 8 to 512. Otherwise, the valid values of *Npilot_ds* shall be all powers of 2 in the range from 8 to 512. The pilot sequence shall be cyclically repeated after *Npilot_ds* bits, except the case where the downstream pilot sequence is changed by the VCE. The downstream pilot sequence bits may be changed by the VCE at any time without notification to the VTU-R, while maintaining the length of the pilot sequence. During initialization, the VTU-O may modulate on all flag tones of the downstream sync symbols either the downstream pilot sequence (the same as modulated on the probe tones), or an all ONEs sequence.

In Showtime, the first downstream sync symbol position shall be as defined in clause 10.6. Each sync symbol shall modulate a pilot sequence, which may be frequency independent or frequency dependent.

The modulation of a frequency independent pilot sequence on the probe tones of sync symbols is defined as whether the sync frame bits modulated onto the probe tones are set to all ZEROs (if the pilot sequence bit is ZERO) or set to all ONEs (if the pilot sequence bit is ONE) (i.e., a 1-bit control per sync symbol).

The modulation of a frequency dependent pilot sequence on a probe tone of sync symbols is defined as whether the sync frame bits modulated onto the probe tone shall be set to either 00 (if the pilot sequence bit for that probe tone is ZERO) or set to 11 (if the pilot sequence bit for that probe tone is ONE). Over the tones of a particular sync symbol, the pilot sequence bit shall have a periodicity of 10 tones (considering both probe and flag tones).

The sync frame bits modulated on the flag tones (see clause 3.2.6) shall be used for the transmission of a Syncflag as defined in clause 10.5.3 of [ITU-T G.993.2]. The sync frame shall be modulated onto a sync symbol as defined in clause 10.5 of [ITU-T G.993.2] (including the quadrant scrambling of all MEDLEY subcarriers, regardless of being a flag or probe tone).

6.2.4 Pre-coding

A VTU-O, when enabled for downstream vectoring, shall support FEXT cancellation pre-coding, as shown in Figure 5-2 and Figure 6-1. The pre-coding coefficients for each individual VTU-O (see clause 6.1) shall be under VCE control.

6.2.5 Transceiver states and transceiver state diagram (replaces clause 12.1.2 of [ITU-T G.993.2])

NOTE 1 – This clause replaces clause 12.1.2 of [ITU-T G.993.2] as applicable to the VTU-O. Transceiver states and transceiver state diagram requirements as applicable to the VTU-R are unchanged.

State diagrams are given in Figure 6-2 for the VTU-O and in Figure 12-3 of [ITU-T G.993.2] for the VTU-R. States are indicated by ovals, with the name of the state given within the oval. The states are defined in Table 6-1 for the VTU-O and in Table 12-2 of [ITU-T G.993.2] for the VTU-R. Transitions between states are indicated by arrows, with the event causing the transition listed next to the arrow. All states are mandatory.

A variety of "host controller" commands (events preceded by "c:_" and "r:_") are shown in either state diagram to provide example events and transitions between states. The way in which these events are implemented is left to the vendor.

In the state diagram for the VTU-O, an O-IDLE state is intended to establish a quiet mode, that is necessary to allow to discontinue service or to perform certain tests (e.g., as defined in [ITU-T G.996.2]).

In the state diagram for the VTU-R, a self-test function is desirable, but it may be a vendor/customer option to define when self-test occurs (e.g., always at power-up or only under VTU-O control), and which transition to take after successfully completing self-test (e.g., enter R-IDLE, or enter R-SILENT).

IDLE is the state where the VTU is provisioned through a management interface for the service desired by the operator. In this state, the VTU does not transmit any signal. A VTU that receives a higher layer signal to activate (c:_L0_request for VTU-O or r:_L0_request for VTU-R) shall use the initialization procedure defined in clause 12.3 to transition the link from the L3 to the L0 state. A VTU that detects the signals of the initialization procedure at the U reference point, if enabled, shall respond by using the initialization procedure. If disabled, the VTU shall remain in the IDLE state.

The link transitions to the L0 state once the initialization procedure has completed successfully and both VTUs are in the SHOWTIME state. A VTU-O shall return to the O-SILENT state upon a guided power management (c:_L3_request, see clause 11.2.3.9), or upon a re-initialization triggered by Re-Initialization Policy (see clause 12.1.4). A VTU-R shall return to the R-SILENT state upon a guided power management (r:_L3_request, see clause 11.2.3.9), or upon a re-initialization triggered by Re-Initialization Policy (see clause 12.1.4). With the former, a VTU-R shall set AUTO_init=OFF to disable autonomous proceeding to the R-INIT/HS state. With the latter, a VTU-R shall set AUTO_init=ON to enable autonomous proceeding to the R-INIT/HS state.

The receiving VTU shall transition from the SHOWTIME state upon Persistent LOS and/or LOF failure (see clause 12.1.4). This implies that if no high_BER-hs or high_BER-fs events cause the receiving VTU to transition state earlier, then the persistency of the LOS and/or LOF failure allows the transmitting VTU to detect the LOS or LOF failure condition through the indicator bits, before the receiving VTU transitions state.

NOTE 2 – High_BER-fs event relates to fast start-up, which is for further study (see clause 12.5).

The receiving VTU shall also transition state upon a high_BER event (see clause 12.1.4). This event relates to near-end and/or far-end performance primitives and performance counters for which thresholds may be configured through the CO-MIB as to declare a high_BER event upon threshold crossing.

A VTU-O shall either enter the O-SILENT state via the O-DEACTIVATING state, upon a guided power management (c:_L3_request), or upon a re-initialization triggered by Re-Initialization Policy.

NOTE 3 – Setting the duration of O-DEACTIVATING (vendor discretionary) to zero implements an immediate transition from O-SHOWTIME to O-SILENT.

When the VTU-O transitions from the O-SHOWTIME state to the O-DEACTIVATING state followed by transition to the O-SILENT state, the VTU-R detects a Persistent LOS Failure. Upon detection, the VTU-R shall transition to the R-SILENT state followed by the R-INIT/HS state and shall start transmitting R-TONES-REQ within a maximum of 6 s after the VTU-O transitioning to the O-SILENT state.

When the VTU-O transitions from the O-INIT/TRAIN state to the O-DEACTIVATING state followed by transition to the O-SILENT state, , the VTU-R detects a failure in the training. Upon detecting a failure in the training, the FTU-R shall transition to the R-SILENT state followed by transition to the R-INIT/HS state.

NOTE 4 – The direct transition from the O-INIT/TRAIN state to the O-SILENT state is shown in Figure 6-2 as a transition via the O-DEACTIVATING state, the duration of which is vendor discretionary and may be zero DMT symbols.

When the VTU-R transitions from the R-SHOWTIME state to the R-SILENT state, the VTU-O detects a Persistent LOS Failure. Upon detection, the VTU-O shall transition to the O-DEACTIVATING state followed by transition to the O-SILENT state, either followed by waiting to receive R-TONES-REQ (VTU-R initiated HS) or followed by the O-INIT/HS state (VTU-O initiated HS).

NOTE 5 – While the VTU-O is in the O-DEACTIVATING state, the VCE may update the FEXT cancellation coefficients among the showtime lines.

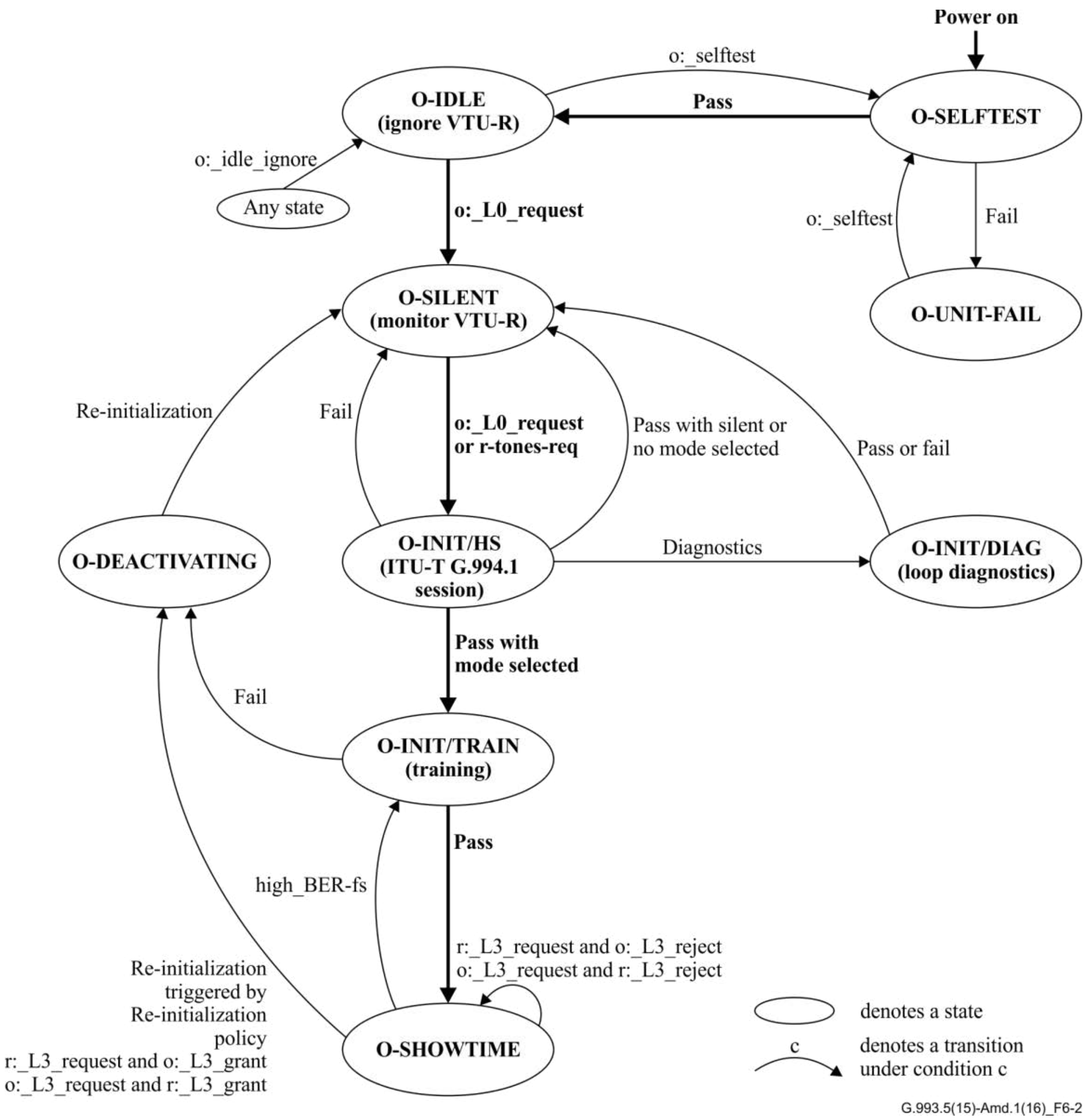

Figure 6-2 – State diagram for the VTU-O

Table 6-1 – VTU-O state definitions

State name	Description
O-SELFTEST (mandatory)	• Temporary state entered after power-up in which the VTU performs a self-test; • Transmitter off (QUIET at U-O interface); • Receiver off (no response to R-TONES-REQ signal); • No response to host control channel; • If self-test pass then transition to O-IDLE; • If self-test fail then transition to O-UNIT-FAIL.
O-UNIT-FAIL (mandatory)	• Steady state entered after an unsuccessful VTU self-test; • Transmitter off (QUIET at U-O interface); • Receiver off (no response to R-TONES-REQ signal); • Monitor host control channel if possible (allows the host controller to retrieve self-test results).
O-IDLE (mandatory)	• Steady state entered after successful self-test; • Transmitter off (QUIET at U-O interface); • Receiver off (no response to R-TONES-REQ signal); • Monitor host control channel.
O-SILENT (mandatory)	• Steady state defined in [ITU-T G.994.1], entered upon host controller command; • Transmitter off (QUIET at U-O interface); • Receiver on (monitor for R-TONES-REQ signal, if detected, transition to O-INIT/HS state); • Monitor host control channel.
O-INIT/HS (mandatory)	• Temporary state entered to perform ITU-T G.994.1 phase of initialization; • Transmitter on (start with transmitting C-TONES signal); • Receiver on (start with monitoring for R-SILENT0 signal); • Monitor host control channel; • If silent period or no mode selected then transition to O-SILENT1; • If loop diagnostics mode then transition to O-INIT/DIAG; • If operating mode selected then transition to O-INIT/TRAIN.
O-INIT/TRAIN (mandatory)	• Temporary state entered to perform other phases of initialization; • Transmitter on (start with O-P-QUIET1); • Receiver on (start with monitoring for R-P-QUIET1); • If init pass then transition to O-SHOWTIME; • If init fail then transition to O-DEACTIVATING; • Monitor host control channel.
O-INIT/DIAG (mandatory)	• Temporary state entered to perform other phases of initialization in loop diagnostics mode; • Transmitter on (start with O-P-QUIET1); • Receiver on (start with monitoring for R-P-QUIET1); • Transition to O-SILENT; • Monitor host control channel.

Table 6-1 – VTU-O state definitions

State name	Description
O-SHOWTIME (mandatory)	• Steady state in which one or more bearer channels are active; • On-line reconfigurations occur within this state; • Upon conditions satisfying the Re-Initialization Policy ($RIpolicy_n$) then transition to O-DEACTIVATING; • If link transition to L3 state is granted, then transition to O-DEACTIVATING; • Monitor host control channel.
O-DEACTIVATING (mandatory)	• Temporary state entered upon line transition to L3 state. The duration of this state is vendor discretionary and may be zero; • Transmitter is on: VTU-O shall not transmit the direct signal (i.e, Zi=0 for all sub-carriers) while it may transmit the pre-compensation signal Zi' in downstream; • Receiver may be on: VTU-O may receive signals in upstream to support upstream FEXT cancellation; • VCE may update the downstream and upstream FEXT cancellation coefficients; • Controlled by the VCE, the VTU-O transitions to the O-SILENT state.

6.3 Upstream vectoring requirements for the VTU-O

The implementation at the CO-side is vendor discretionary, apart from the required ability to convey sync symbol timing and upstream vectoring control parameters from the VCE to the end of the line nearer to the customer premises (CP-side). These requirements are defined in clause 10 and apply to each VTU-O member of a vectored group.

The VTU-O shall comply with [ITU-T G.993.2], with the exceptions and additional requirements contained in this Recommendation.

During initialization, each VTU-O in a vectored group shall have the capability to transmit a time marker to the VTU-R to indicate which symbols are at a time position that coincides with Showtime sync symbols on active lines. The modulation method of such time marker on such symbols is defined in clause 10.3.3.5.

The VTU-O shall have the capability to convey the control parameters of the upstream vectored group defined in clause 7 and clause 10 from the VCE to the CP-side.

If upstream vectoring is enabled, the VTU-O shall support operation also in the case when not all probe tones of the upstream sync symbol have the same sign, but the sign pattern over the tones of the sync symbol has a periodicity of 10 tones (considering both probe and flag tones).

6.4 Requirements for the VCE

The VCE shall support downstream vectoring.

The VCE shall include the capability to be controlled by the ME over the ε-m interface (shown in Figure 5-1) to use *B_min*=0 (see Table 7-1 for the definition and Table 7-2 for valid values of *B_min*).

7 CP-side requirements in a vectored group

This clause describes the CP-side steady-state behaviour as part of an N-pair vectored group.

7.1 General

The VTU-R shall send clipped error samples (defined in clause 7.2.1) to the VCE of the vectored group, through the backchannel (defined in clauses 7.2.2 through 7.2.4). The VTU-R shall support Layer 2 Ethernet encapsulation (defined in clause 7.4.1) and shall support embedded operation channel (eoc) encapsulation (defined in clause 7.4.2) of the backchannel information. The VCE shall select the encapsulation method to be used, and communicate this setting to the VTU-R during initialization (see clause 10.5.2.1). The set encapsulation method shall be kept unchanged during Showtime.

Figure 7-1 shows the reference model for the Layer 2 encapsulated backchannel information flow. Within the NT, the clipped error samples are first sent from the VTU-R to the L2+ functional block (streamBC.indicate primitive), where they are encapsulated into the Layer 2 transport protocol (defined in clause 7.4.1) and further multiplexed into one of the upstream Ethernet (or Ethernet over ATM) data streams (stream(*n*).confirm, see Annex K of [ITU-T G.993.2]). At the AN, the Layer 2 encapsulation is terminated in the L2+ functional block and the clipped error samples are delivered to the VCE (streamBC.indicate primitive).

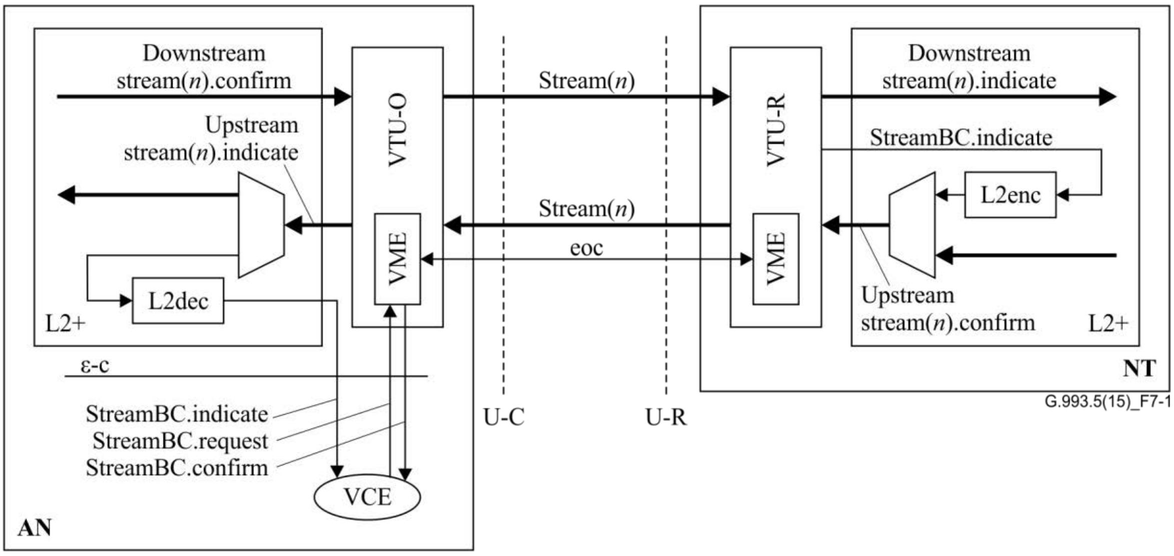

Figure 7-1 – Reference model for the Layer 2 encapsulated backchannel information flow

Figure 7-2 shows the reference model for the eoc encapsulated backchannel information flow. Within the VTU-R, the clipped error samples are sent to the VDSL2 management entity (VME), where they are encapsulated into an eoc message, as defined in clause 8.1. At the VDSL2 management entity (VME, see clause 11.2 of [ITU-T G.993.2]) of the VTU-O, the eoc encapsulation is terminated and the clipped error samples are delivered to the VCE (streamBC.indicate primitive).

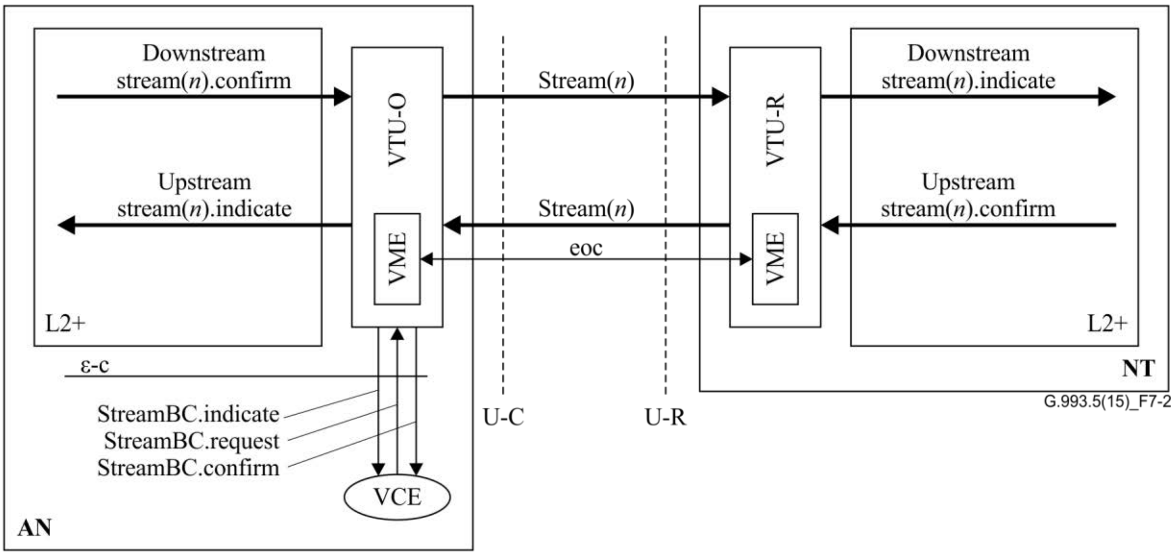

Figure 7-2 – Reference model for the eoc encapsulated backchannel information flow

Regardless of the backchannel encapsulation method, the VCE communicates with the VTU-O VME to set the backchannel control parameters (defined in Table 7-1), e.g., for which subcarriers the VTU-R shall send clipped error samples through the backchannel (streamBC.request primitive). The VTU-O VME uses eoc commands (defined in clause 8.1) to communicate these backchannel control parameters to the VTU-R VME and delivers the information received from VTU-R VME eoc responses back to the VCE (streamBC.confirm primitive).

The VTU-R shall support seamless rate adaptation (SRA, OLR Type 3) in the downstream and upstream direction, including mandatory support within SRA of:

– dynamic interleaver reconfiguration (change of D_p);

– framing reconfiguration (change of T_p, G_p and B_{p0}).

as defined in clause 13.1 of [ITU-T G.993.2], titled "Types of on-line reconfiguration".

If [ITU-T G.998.4] is enabled in a particular direction, the VTU-R shall also support seamless rate adaptation (SRA, OLR Type 5) in this same direction, including mandatory support within SRA of all configurations specified in clause C.3.2 of [ITU-T G.998.4].

7.2 Downstream vectoring requirements for the VTU-R

The VTU-R shall comply with [ITU-T G.993.2], with the exceptions and additional requirements contained in this Recommendation.

This Recommendation defines that all probe tones of a sync symbol, both during initialization and during Showtime, may have the same sign (i.e., if a frequency independent pilot sequence is modulated, see clause 6.2.3) or may not have the same sign (i.e., if frequency dependent pilot sequence is modulated, see clause 6.2.3). The VTU-R shall support reception and all related functionalities required for computing error signals also in case when not all probe tones of the sync symbol have the same sign, but the sign pattern over the tones of the downstream sync symbol has a periodicity of 10 tones (considering both probe and flag tones).

7.2.1 Definition of normalized error sample

The VTU-R converts the received time domain signal into frequency domain samples, resulting in a complex value Z for each of the received subcarriers. The subsequent constellation de-mapper associates each of these complex values Z with a constellation point, represented by a value $\hat{C}$. Figure 7-3 shows the computation of a normalized error sample E for a particular subcarrier in a particular sync symbol. The normalized error sample represents the error between the received complex data sample Z normalized to the 4-quadrature amplitude modulation (QAM) constellation point and the corresponding decision constellation point $\hat{C}$ associated with the received sync symbol in a VTU-R and referred to the input of the constellation descrambler. For illustration, in Figure 7-3, the received normalized complex data sample Z is shown to occur within the constellation boundary of the decision constellation point $\hat{C}$ = (+1, +1).

For each of the subcarriers, the complex normalized error sample E is defined as $E = Z - \hat{C}$, where E is the complex error defined as $E = e\_x + j \times e\_y$ with real component e_x and imaginary component e_y, and Z is the received normalized data sample defined as $Z = z\_x + j \times z\_y$ with real component z_x and imaginary component z_y, and $\hat{C}$ is the decision constellation point associated with the received data sample *Z,* defined as $\hat{C} = \hat{c}\_x + j \times \hat{c}\_y$ with real component $\hat{c}\_x$ and imaginary component $\hat{c}\_y$ (with $\hat{c}\_x = \pm 1$ and $\hat{c}\_y = \pm 1$).

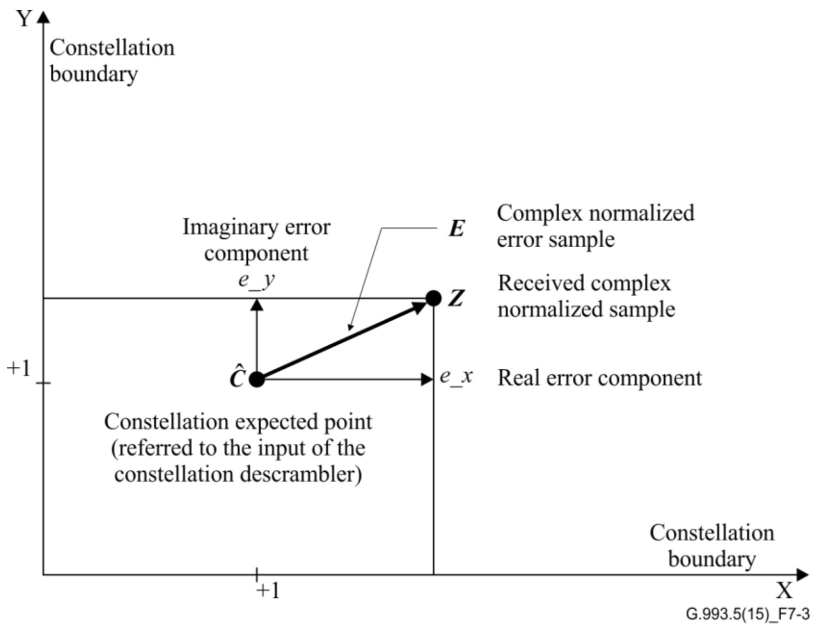

Figure 7-3 – Definition of the normalized error sample *E*

The real and imaginary components of each normalized error sample E are clipped and quantized to integer values for the clipped error sample components q_x and q_y respectively, as follows:

$$q\_x = \max\left(-2^{B\_\max}, \min\left(\left\lfloor e\_x \times 2^{N\_\max - 1} \right\rfloor, 2^{B\_\max} - 1\right)\right)$$
$$q\_y = \max\left(-2^{B\_\max}, \min\left(\left\lfloor e\_y \times 2^{N\_\max - 1} \right\rfloor, 2^{B\_\max} - 1\right)\right)$$

where $Q = q\_x + j \times q\_y$ represents the clipped error sample and *N_max* represents the VTU-R's maximum quantization depth of normalized error samples and shall be set to 12, and *B_max* represents the upper bound of the bit index for reporting clipped error sample components q_x and q_y (*B_max* < *N_max*, with *B_max* configured by the VCE, see Tables 7-1 and 7-2).

The values of both clipped error sample components q_x and q_y shall be represented using the two's-complement representation of *B_max*+1 bits. The format of the clipped error sample for reporting over the backchannel is defined in clause 7.2.2. The particular subcarriers on which clipped error samples shall be reported during initialization and Showtime shall be configured as described in clauses 10.4.2.1, and in clause 8.1, respectively.

7.2.2 Reporting of clipped error samples

The VTU-R shall send clipped error samples (defined in clause 7.2.1) to the VTU-O through the backchannel established between the VTU-O and the VTU-R in each line of the vectored group, as defined in clause 7.4.1 (Layer 2 backchannel) or in clause 8.1 (eoc backchannel) or in clause 10 (special operations channel (SOC) backchannel). The VTU-O conveys the received clipped error samples to the VCE of the vectored group.

7.2.2.1 Control parameters for clipped error sample reporting

The VCE communicates to the VTU-O a set of control parameters for clipped error sample reporting defined in Table 7-1.

Table 7-1 – Control parameters of clipped error samples

Parameter name	Definition
Vectored bands	The downstream frequency bands for which the VTU-R shall send clipped error samples for the subcarriers through the backchannel. The vectored downstream bands shall be defined by indices of the lowest frequency and the highest frequency subcarriers. *N_band* denotes the number of vectored bands configured. No more than eight bands shall be configured (i.e., *N_band* ≤ 8). The configured bands shall be identified by their numbers: *vb* = 0, 1, 2, 3, 4, 5, 6, 7 assigned in the ascending order of subcarrier indices associated with the band. *N_carrier*(*vb*) denotes the number of subcarriers in frequency band number *vb*, i.e., the index of the last subcarrier minus the index of the first subcarrier plus one. The index of the first (lowest frequency) subcarrier of each vectored downstream band shall be an even value. Each of the vectored downstream bands shall be assigned within the boundaries of a single ITU-T G.993.2 standard downstream band (as exchanged during the ITU-T G.994.1 phase) and possibly having more than one vectored band per such standard downstream band. The vectored bands shall not overlap one another.
F_sub	The sub-sampling factor to be applied to the vectored bands. For every vectored downstream band, the clipped error sample of the subcarrier with the smallest index shall be transmitted first, followed by the clipped error sample of every F_sub^{th} subcarrier within the vectored band. Configured by the VCE for each vectored downstream band separately.
F_block	The block size (number of subcarriers) for grouping of clipped error samples. Configured by the VCE. The same block size configuration shall be used for all vectored downstream bands (see Table 8-4).
B_min	Lower bound of the bit index for reporting of a clipped error sample component (see clause 7.2.2.2). Configured by the VCE for each vectored downstream band separately.
B_max	Upper bound of the bit index for reporting of a clipped error sample component (see clause 7.2.1). Configured by the VCE for each vectored downstream band separately.

Table 7-1 – Control parameters of clipped error samples

Parameter name	Definition
L_w	Maximum number of bits for reporting of a clipped error sample component. Configured by the VCE for each vectored downstream band separately. If *L_w* is set to 0 for a particular vectored downstream band, then that band shall not be reported. *L_w* shall be set to a non-zero value for at least one vectored downstream band.
padding	Indicates whether or not the VTU-R shall pad clipped error samples through sign extension or zero padding to maintain using *L_w* bits for reporting of a clipped error sample component if $S < L\_w - 1$ (see clause 7.2.2.2). Configured by the VCE. The same padding configuration shall be used in all vectored downstream bands. If padding is enabled, then *B_min* shall be set to 0.

Table 7-2 defines the optional and mandatory values for the clipped error samples control parameters. In particular, it defines the valid values for the VCE to configure and the mandatory values for the VTU-R to support. The VTU-O shall support all valid values for VCE to configure. The VTU-R shall indicate during initialization its capabilities to support optional values, and the VCE shall select the values accordingly (see clause 10).

Table 7-2 – Values of backchannel control parameters

Parameter	Valid values for VCE	Mandatory values for VTU-R to support
F_sub	1, 2, 4, 8, 16, 32 and 64	2, 4, 8, 16, 32 and 64
F_block	1, 32, and $\left\lceil \frac{N\_carrier}{F\_sub} \right\rceil$	1 and $\left\lceil \frac{N\_carrier}{F\_sub} \right\rceil$
B_min	0, … , 11	All valid values
B_max	*B_min*, … , 11	All valid values
L_w	0, 1, … , min(8, *B_max* – *B_min* + 1)	0, 1, … , 8
padding	1 (enable); 0 (disable) with *F_block* = 32; 0 (disable) with *F_block* = $\left\lceil \frac{N\_carrier}{F\_sub} \right\rceil$	1 (enable); 0 (disable) with *F_block* = $\left\lceil \frac{N\_carrier}{F\_sub} \right\rceil$

For each vectored downstream band assigned by the VTU-O for clipped error sample reporting, the VTU-R shall report the clipped error samples for all subcarriers with indices $X = X\_L + n \times F\_sub$, where n gets all integer values 0, 1, 2, … for which $X\_L \leq X \leq X\_H$ and with *X_L* and *X_H* respectively, the indices of the lowest frequency and the highest frequency subcarriers of the vectored downstream band. Clipped error samples of other subcarriers shall not be reported.

On the subcarriers that are not used for transmission ($b_i = 0$, and $g_i = 0$) but assigned for clipped error sample reporting, the VTU-R shall report a dummy error sample. The value of this dummy error sample is vendor discretionary, but shall comply with error sample control parameters and shall not impact reports on other subcarriers.

NOTE – It is the responsibility of the VTU-O and/or the VCE to identify and drop clipped error samples for subcarriers that are not intended for channel estimation.

7.2.2.2 Grouping of clipped error samples

The VTU-R shall group clipped error samples into blocks. Valid block sizes for the parameter *F_block* are defined in Table 7-2. For each block, the VTU-R shall calculate parameters *B_M* and *B_L*. The parameters *B_M* and *B_L* represent the highest and the lowest bit indices of the reported clipped error sample, with the assumption that bit index is counted from the LSB to the MSB, starting from 0.

Figure 7-4 depicts the example of *F_block*=1, *B_min*=2, *B_max*=10, *L_w*=4, and *padding*=0. Two registers each (*B_max*+*L_w*) bits wide contain a clipped error sample component in the bits labelled from *B_max* (clipped error sample MSB) down to 0 (clipped error sample LSB), while the *L_w* – 1 = 3 remaining bits of each register are set to 0 and labelled with a negative bit index –1 down to 1 – *L_w* = –3. For each component in the block, only the *B_M* – *B_L* + 1 bits with indices from *B_M* down to *B_L* inclusive are included in the error report block (ERB) format defined in clause 7.2.3.1. Parameters *B_M* and *B_L* shall be computed for each block as described below. The VTU-R shall examine all clipped error sample components in each block and determine for each component *ec* (*ec* = 1 to 2×*F_block*) a data-dependent scale parameter s_{ec}, defined to be the sign bit index of the shortest 2's complement representation of the component.

For example, as depicted in Figure 7-4, the first clipped error sample component, having the 11-bit 2's complement representation 11110010101, has shortest representation 10010101 and hence its scale is $s_1 = 7$. Likewise, the second component 00000010010 has shortest representation 010010 and hence its scale is $s_2 = 5$.

The VTU-R then computes for each block a data-dependent block scale parameter $S = \max_{ec}(s_{ec})$, where the maximization index *ec* runs over all 2×*F_block* clipped error sample components in the block.

For example, as depicted in Figure 7-4, *F_block* = 1 and the block scale parameter *S* is the maximum of s_1 and s_2, hence *S* = 7.

If *padding* = 0, then for each block in the given vectored band, the VTU-R shall set

$$B\_M = \max(S, B\_\min), \quad B\_L = \max(B\_M - L\_w + 1, B\_\min) \tag{7-1}$$

If *padding* = 1, then for each block in all the vectored bands, the VTU-R shall set

either *B_M* = max(*S, L_w*-1) (sign extension) or *B_M* = *S* (zero padding);

and

$$B\_L = B\_M - L\_w + 1 \text{ (with bits set to 0 for bit indices < 0).} \tag{7-2}$$

The parameters *B_M* and *B_L* shall always satisfy the relations *B_L* ≤ *B_M* and 0 ≤ *B_M* ≤ *B_max*.

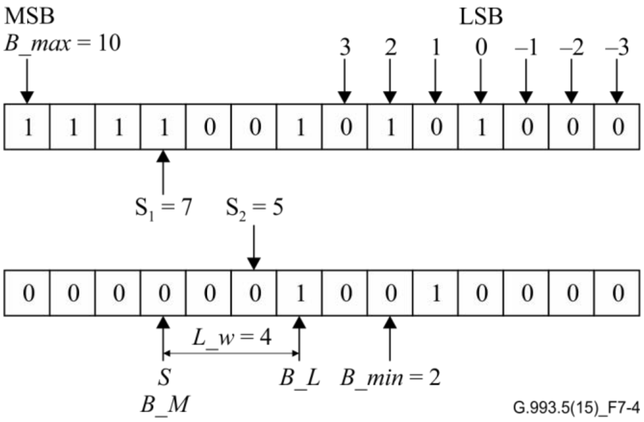

Figure 7-4 – Example of two registers, each representing a clipped error sample component

Figure 7-5 depicts an example of the reported bits (shown shaded) for a block of clipped error samples for different padding types, with *F_block*=1, *B_min*=1, *B_max*=7, *L_w*=5.

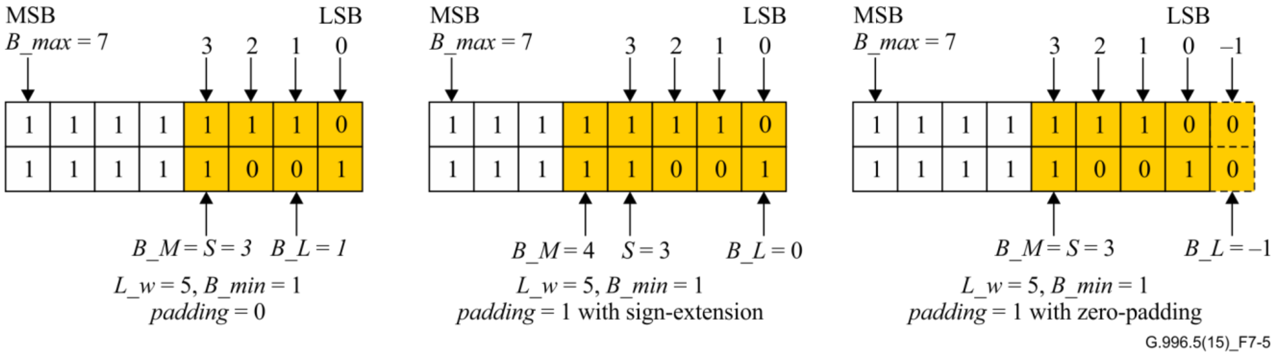

Figure 7-5 – Example of reported bits for a block of clipped error samples for different padding types

For the assigned value of *F_block*, the block consists of clipped error samples reported for *F_block* subsequent subcarriers from those assigned for reporting in the vectored downstream band. The subcarriers shall be assigned to blocks starting from the lowest frequency subcarrier of the vectored band, subsequently, in ascending order, *F_block* subcarriers in each block. The number of blocks in the vectored band *vb* can be computed as:

$$N\_block(vb) = \left\lceil \frac{\left\lfloor \frac{N\_carrier(vb)}{F\_sub(vb)} \right\rfloor}{F\_block} \right\rceil$$

The blocks shall be identified by their numbers: $eb = 0$ to $N\_block(vb) - 1$, assigned in the ascending order of subcarrier indices associated with the block. The last components of the last block that do not belong to the subcarriers of the vectored downstream band (if any) shall be set to dummy values that represent the value of zero.

7.2.3 Backchannel format

For each sync symbol, an integer number of octets shall be sent through the backchannel.

The number of bytes per symbol needed to report the clipped error samples depends on the values configured by the VCE for the backchannel control parameters (see clause 7.2.2). Blocks of clipped error samples (error blocks) of the vectored downstream bands are mapped into the ERB.

Each ERB is associated with a particular symbol of the O-P-VECTOR 2-1 signal (see clause 10.4.3.7). The ERB has a single format that is further encapsulated into:

– Ethernet format (for an L2-based backchannel); or

– eoc format (for an eoc-based backchannel); or

– SOC format (for an SOC-based backchannel).

The sync symbol associated with the ERB is identified by the value of its sync symbol counter (for an L2 or an eoc backchannel during Showtime) or by the timing of the report (for an SOC backchannel during initialization).

7.2.3.1 Format of the ERB

The format of the ERB is presented in Figure 7-6. The ERB starts from an 8-bit ERB_ID field, followed by up to eight vectored band blocks (VBBs) fields. The VTU-R may set the MSB of the

ERB_ID field to '1' to indicate that the clipped error samples in the ERB are potentially corrupted (e.g., due to impulse noise, or RFI). Otherwise, the VTU-R shall set the MSB of the ERB_ID field to '0'. The seven LSB of the ERB_ID field shall be set to 0 and are reserved for ITU-T. The number of bytes in the ERB (*N_ERB*) is the sum of the number of bytes in each of the VBBs, plus one byte for the ERB_ID field. The concatenation of VBBs in an ERB shall be in the ascending order of the vectored band numbers, i.e., starting from the vectored band associated with lowest subcarrier indices. Some vectored bands may not be reported on request of the VCE (i.e., the ERB shall not contain a VBB for the vectored bands for which VCE configures *L_w*=0).

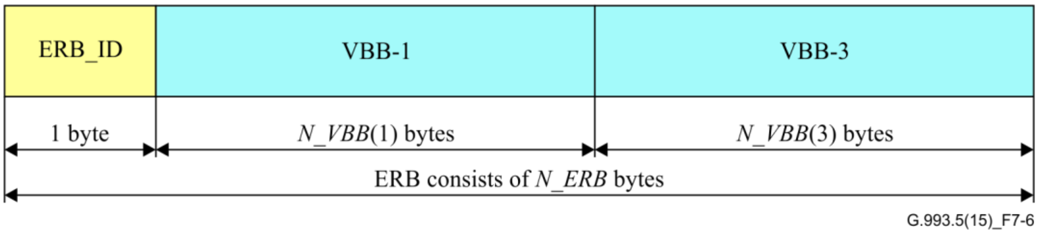

Figure 7-6 – ERB format (in case only vectored bands 1 and 3 are requested by the VCE)

The format of the VBB is presented in Figure 7-7. Each VBB starts from an 8-bit VBB_ID field, followed by a VBB_Aux field, followed by concatenated error blocks, and ends with a pad of 0, 2, 4 or 6 bits to fit the length of the VBB to an integer number of bytes (odd number of padding bits is not applicable). The three MSBs of the VBB_ID field shall include the number of the vectored band (000 for VBB-0, 001 for VBB-1, … up to 111 for VBB-7). The five LSBs of the VBB_ID field shall be set to '0' and be reserved for ITU-T. The error blocks shall be concatenated in a VBB in ascending order: the first block inside the vectored band is the one that contains clipped error samples for subcarriers with lowest indices and shall be transmitted first.

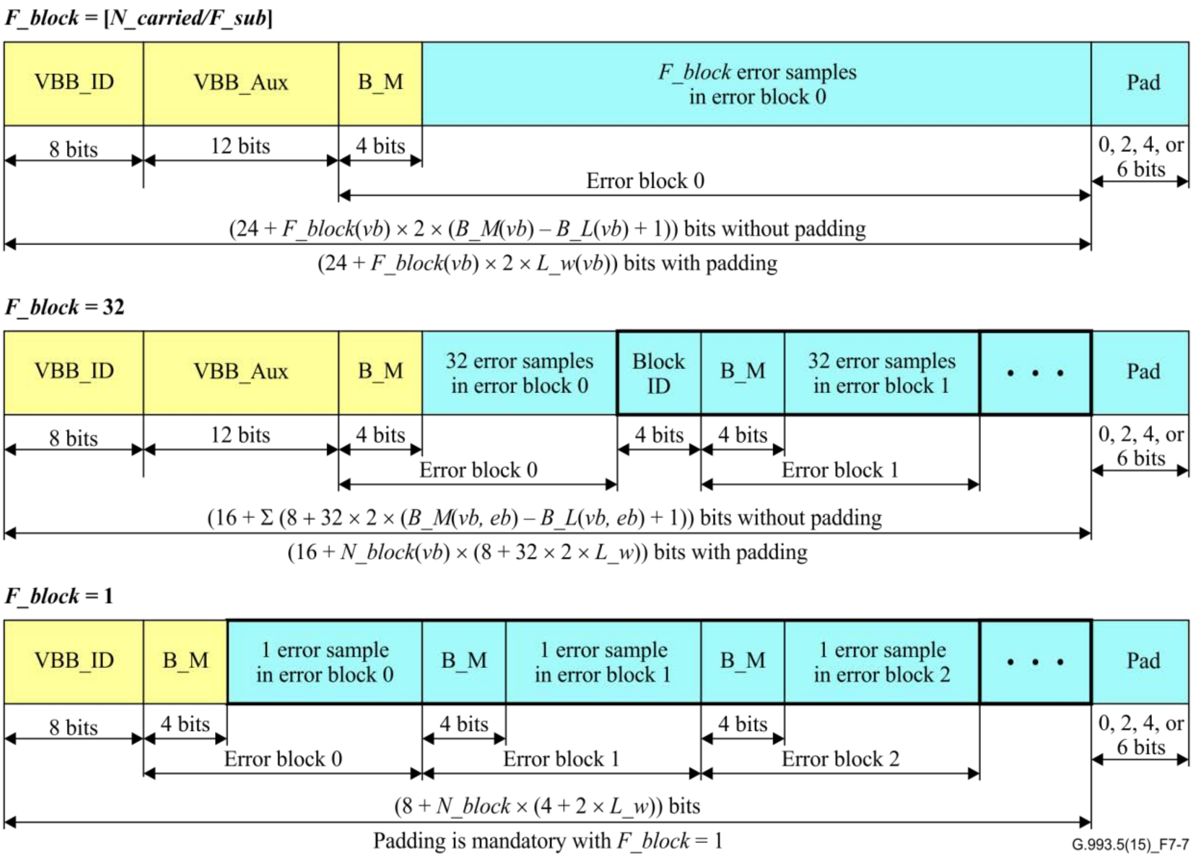

Figure 7-7 – VBB format depending on *F_block*

The format of the error block is defined in clause 7.2.3.2.

In case *F_block* = 32, a Block_ID shall be pre-pended to each error block, starting with error block number 1. A Block_ID shall not be inserted just before error block 0. The Block_ID shall be 4 bits long, and shall represent modulo 16 the number of the error block it precedes as an unsigned integer, with the assumption that the first block in the vectored band has the number 0.

In case *F_block* = 1 or $\left|\frac{N\_carrier}{F\_sub}\right|$, a Block_ID shall not be inserted.

NOTE 1 – The VCE can identify VBB in the received ERB by its VBB_ID and then compute the number of error blocks, *N_block(vb)*, in the VBB-*vb* as described in clause 7.2.2.2, since all the backchannel control parameters are known at the CO-side. The length of the error block is computed using the parameters (*B_M*, *B_L*) of the clipped error sample and the block size *F_block*. The first reported sample of the first error block in the vectored band is for the subcarrier with index *X_L* (which is always even).

NOTE 2 – With *F_block* = 32, the end of each error block is byte aligned. No padding bits are added at the end of the VBB.

The VBB_Aux field shall be used to communicate the mean error value using the format defined in Table 7-3. The mean error (*ME*) for vectored band *vb* shall be computed as:

$$ME(vb) = \sum_{n=0}^{\left\lceil \frac{N\_carrier(vb)}{F\_sub(vb)} \right\rceil - 1} \left(\left| e\_x\left(X\_L(vb) + n \times F\_sub(vb)\right) \right| + \left| e\_y\left(X\_L(vb) + n \times F\_sub(vb)\right) \right| \right)$$

where *e_x*(*sc*) and *e_y(sc*) are real and imaginary components of the normalized error estimated on subcarrier *sc* (see Figure 7-3).

The clipped and quantized value of *ME(vb)* shall be represented as:

$$MEq(vb) = \min\left(\left\lfloor ME(vb) \times 2^{ME\_N\_\max - 1} \right\rfloor,\ 2^{ME\_B\_\max} - 1 \right)$$

where *ME_N_max* = 12 and *ME_ B_max* = 22.

The value of the *ME*q shall be reported using a 4-bit exponent and an 8-bit mantissa, in the similar way as for the clipped error sample components. The VTU-R shall compute the scale *ME_S* as the index of the most significant bit of the *MEq* that is not a sign extension bit. The mantissa shall consist of the 8 bits with indices *ME_B_M* down to *ME_B_L*. The values of *ME_B_M* and *ME_B_L* shall be computed at the VTU-R as:

ME_B_M = max(*ME_S*, 7), and

ME_B_L = *ME_B_M* – 7

Table 7-3 – Format of the VBB_Aux field

Parameter	Bit numbers	Description
ME_EXP	[11:8]	4-bit value of *ME_B_L*
ME_MANT	[7:0]	8-bit mantissa of the *MEq*

7.2.3.2 Format of the error block

The representation for an error block containing *F_block* clipped error samples (2×*F_block* clipped error sample components of *F_block* subcarriers) shall include a *B_M* field (4 bits), and an error field (variable length), see Figure 7-8. The error field includes *F_block* sub-fields, each carrying a complex clipped error sample of a subcarrier which is assigned for reporting during the backchannel configuration (see clause 7.2.2).

For each clipped error sample component, the compressed representation, as defined in clause 7.2.2.2, includes only those bits of the clipped error sample component with indices *B_L* through *B_M*, using the convention that the MSB of the compressed representation of the component has index *B_max* and the least significant bit (LSB) of the compressed representation of the component has index *B_min*. Accordingly, the total number of bits in the error field of a block of clipped error samples in compressed representation shall be $2 \times F\_block \times (B\_M - B\_L + 1)$.

The *B_M* fields shall include parameter *B_M* represented as a 4-bit unsigned integer, in the range from 0 to 15.

NOTE – The parameter *B_L* is not reported as it can be calculated by the VCE from the clipped error sample control parameters (see equations 7-1 and 7-2) and the value of the reported *B_M* parameter.

The format of the error block is presented in Figure 7-8. All parameters and clipped error samples shall be mapped with the MSB at the left side so that the MSB is transmitted first (i.e., the first transmitted bit is the MSB of the *B_M* field).

Clipped error samples in the error field shall be mapped in ascending order of subcarrier index from left to right. For each clipped error sample, the *q_x* (real) component shall be mapped left from the *q_y* (imaginary) component.

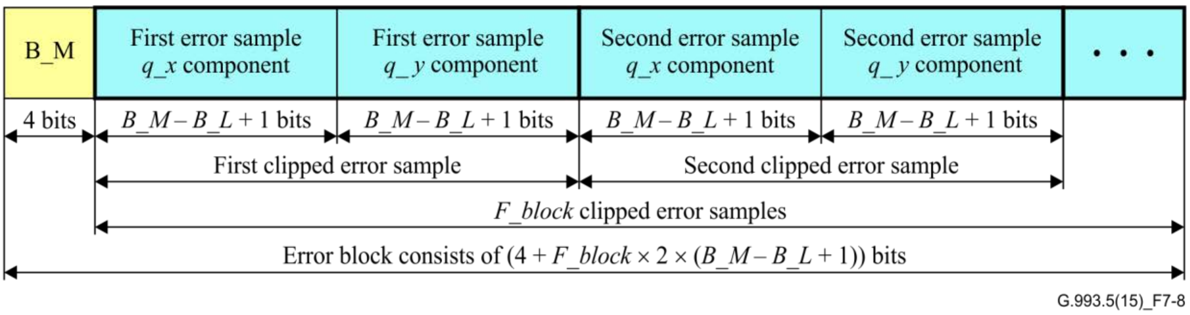

Figure 7-8 – Format of an error block

7.2.3.3 Backchannel data rate (informative)

In case $F\_block = \left\lfloor \frac{N\_carrier}{F\_sub} \right\rfloor$, the number of bytes in the VBB-*vb*, following from Figures 7-6, 7-7 and 7-8 is:

$$N\_VBB(vb) = \left\lceil \frac{24 + F\_block(vb) \times 2 \times (B\_M(vb) - B\_L(vb) + 1)}{8} \right\rceil$$

where *B_M(vb)* represents the *B_M* parameter for the vectored band number *vb*, and *B_L(vb)* represents the *B_L* parameter for the vectored band *vb*.

Note that in general this value is not fixed, but may be different from one error report to the next, depending on the exact values of the clipped error samples. If padding (see Table 7-1) is used, on the other hand, the number of bytes in the VBB-*vb* only depends on the clipped error sample control parameters and not on the values of the clipped error sample values:

$$N\_VBB(vb) = \left\lceil \frac{24 + F\_block(vb) \times 2 \times L\_w(vb)}{8} \right\rceil$$

In case *F_block* = 32, the number of bytes in the VBB-*vb*, following from Figures 7-6 and 7-8 is:

$$N\_VBB(vb) = 2 + \sum_{eb=0}^{N\_block(vb)-1} \left(1 + 8 \times (B\_M(vb,eb) - B\_L(vb,eb) + 1)\right)$$

where *B_M(vb,eb)* represents the *B_M* parameter for the error block number *eb* of vectored band number *vb*, *B_L(vb,eb)* represents the *B_L* parameter for the error block number *eb* of vectored band *vb*.

Note that in general this value is not fixed, but may be different from one error report to the next, depending on the exact values of the clipped error samples. If padding (see Table 7-1) is used, the number of bytes in the VBB-*vb* only depends on the clipped error sample control parameters and not on the values of the clipped error sample values:

$$N\_VBB(vb) = 2 + N\_block(vb) \times (1 + 8 \times L\_w(vb))$$

In case *F_block* = 1, padding is used and the number of bytes in the VBB-*vb* only depends on the clipped error sample control parameters and not on the values of the clipped error sample values:

$$N\_VBB(vb) = \left\lceil \frac{8 + N\_block(vb) \times (4 + 2 \times L\_w(vb))}{8} \right\rceil$$

The *N_ERB* can be calculated as:

$$N\_ERB = 1 + \sum_{vb=0}^{N\_band-1} report(vb) \times N\_VBB(vb)$$

where *report(vb)* =1 if the VBB-*vb* is included in the ERB (i.e., *L_w* > 0 for band number *vb*), and *report(vb)* = 0 if the VBB-*vb* is not included in the ERB (i.e., *L_w* = 0 for band number *vb*).

The backchannel data rate (BDR) for transmission of the error report block for each sync symbol is:

$$BDR = 8 \times N\_ERB \times (f_{DMT} / 257)$$

where f_{DMT} is the symbol rate (in symbols/s) defined in clause 10.4.4 of [ITU-T G.993.2].

The BDR is not defined when padding is not used. In that case, *N_ERB* varies from error report to error report.

7.2.4 Identification of the ERB during Showtime

At each of the sync symbol counts indicated by the VTU-O, the VTU-R shall transmit a single ERB. With each ERB, the VTU-R shall also transmit the downstream sync symbol count (as defined in clause 7.3.2) as identification of the downstream sync symbol the ERB corresponds to. The VTU-O shall indicate such sync symbol counts using the following time identification control parameters:

– the error sample update period (*m*);

– the error sample shift period (*z*).

The error sample update period gets value of *m* if the error sample has to be reported on every *m*-th sync symbol, i.e., on the sync symbol positions with sync symbol counts *SSC* = *m*×*P*+*k*, where *P* is any integer in the range from 0 to $\lfloor (N\_SSC - 1 - k)/m \rfloor$, and *k* is the offset, which is an integer in the range from 0 to *m*–1. which is an integer in the range from 0 to *m*–1. After the SSC counter wraps around at the value of *N_SSC*-1, the next sync symbol count at which ERB shall be reported is SSC = *k* (this count is obtained by setting *P*=0).

The VTU-R shall set *k*=0 for the first report after the VTU-O's Error Feedback request. This report shall be sent for the first available sync symbol with SSC count that is a multiple of *m* after reception of the ERB request (see clause 8.1). If *z* > 0, the VTU-R shall increase *k* by 1 after each error sample shift period of *z* reports, wrapping around *k* at *m*-1.

If $m = 1$, the VTU-R shall report on each sync symbol. The error sample update period value of $m = 0$ is special and shall be used to indicate that the VTU-R shall stop error sample reporting. The non-zero error sample shift period z is valid only for $m > 1$. The error sample shift period value of $z = 0$ shall be used if no error sample shift is to be done and if m=1.

NOTE 1 – The parameters m and z should be selected such that the error samples are reported at least once for all the bits of the pilot sequence after a certain time.

NOTE 2 – For example, with $N\_SSC = 1024$, $m = 3$, and the first report sent at SSC = 6, the reports are on the following sync symbol counts:

$m = 3$ and $z = 0$ then $SSC = 6, 9, \ldots, 1020, 1023, 0, 3, 6, 9, \ldots$

$m = 3$ and $z = 128$ then $SSC = 6, 9, \ldots, 128\times3, 129\times3, 130\times3+1, 131\times3+1, \ldots\ 257\times3+1, 258\times3+2, 259\times3+2, \ldots.\ 340\times3+2, 2, 5, \ldots.44\times3+2, 45\times3, 46\times3, 47\times3, \ldots$

The values for the time identification control parameters are defined in Table 7-4.

Table 7-4 – Values of time identification control parameters

Parameter	Valid values for VCE	Mandatory values for VTU-R to support
m	0, 1, 2, …, 63, 64	All valid values
z	If $m > 1$: 0, 2, …, 254, 255, 256 If $m \leq 1$: 0	All valid values

7.3 Upstream vectoring requirements for the VTU-R

The VTU-R shall comply with [ITU-T G.993.2], with the exceptions and additional requirements contained in this Recommendation.

In order to enable the VCE to fulfil the tasks described in clause 6.1, the VTU-R shall support the requirements in the following clauses.

7.3.1 Symbol alignment

Under VCE control, all VTU-Rs in the vectored group shall use the same subcarrier spacing and symbol rate.

NOTE – The VCE may control the alignment of symbols from different lines of the vectored group at the U-O2 reference point (defined in Figure 5-4 of [ITU-T G.993.2]) by adjusting the timing advance (TA) of these lines during initialization (see clause 10).

7.3.2 Sync symbol position

The VTU-R shall have the capability to transmit sync symbols as defined in clause 10.2 of [ITU-T G.993.2]. The VTU-R shall transmit sync symbols at time positions assigned by the VCE and communicated to the VTU-R during initialization. The time position of upstream sync symbols is defined by an offset between upstream and downstream sync symbol positions.

The offset between the upstream and downstream sync symbol time positions is set by the VCE and sent to the VTU-R in the O-SIGNATURE message.

The VCE may configure all VTU-Rs in the vectored group to transmit upstream sync symbols at the same time positions or at different time positions for one or more VTU-Rs in the vectored group.

The VTU-R shall keep a downstream sync symbol counter (MODULO N_SSC), counting continuously over Showtime. The counter value of the first downstream sync symbol transmitted in Showtime shall be set by the VTU-R to the value of the field First SSC of the first received Error Feedback command (see Table 8-3). Before receiving the first Error Feedback command, the value of the downstream sync symbol counter for the first downstream sync symbol transmitted in Showtime is vendor discretionary.

NOTE – This setting at the start of Showtime synchronizes the downstream sync symbol counter with the VTU-O/VCE (see clause 6.2.2).

7.3.3 Modulation of pilot sequence

The VTU-R shall have the capability to modulate a VCE-specified upstream pilot sequence on all subcarriers of the upstream sync symbols during initialization (see clause 10.3.4.1) and on the probe tones (see clause 3.2.10) of the upstream sync symbols during Showtime. The upstream pilot sequence is vendor discretionary, determined by the VCE, with length *Npilot_u*s and sent to the VTU-R at initialization in the O-SIGNATURE message. Pilot sequence bits are indexed from 0 to *Npilot_us* – 1. The bit with index 0 shall be transmitted first, followed by the bit with index 1, up to bit with index *Npilot_us* – 1. If the "pilot sequence length multiple of 4" is enabled (see clause 10.2), then valid values of *Npilot_us* are all multiples of 4 in the range from 8 to 512. Otherwise, the valid values of *Npilot_us* shall be all powers of 2 in the range from 8 to 512. The pilot sequence shall be cyclically repeated after *Npilot_u*s bits, except for the case where the upstream pilot sequence is changed by the VCE through the procedure defined in clause 8.2.

The time position of the upstream pilot sequence is determined by the VCE and communicated to VTU-R during the initialization by special markers (see clause 10.3.3.5). Subcarriers of upstream sync symbols shall be modulated by the upstream pilot sequence bits corresponding to the time position of the upstream pilot sequence.

In Showtime, the first upstream sync symbol position shall be as defined in clause 10.6.

The modulation of a pilot sequence on the probe tones (see clause 3.2.10) of sync symbols is defined as whether the sync frame bits modulated onto the probe tones are set to either 00 (if the pilot sequence bit is ZERO) or set to 11 (if the pilot sequence bit is ONE). Over the tones of a particular sync symbol, the pilot sequence bit shall have a periodicity of 10 tones (considering both probe and flag tones).

If upstream frequency dependent pilot sequence (upstream FDPS) is enabled through ITU-T G.994.1, then eight pilot sequences with indices from 0 to 7 are defined. The pilot sequences #(0,1,2,3,4,5,6,7) shall be modulated onto tone indices $10n$+(0,2,3,4,5,6,8,9) respectively. All eight pilot sequences shall have the same length *Npilot_us*. All pilot sequences shall start at the same sync symbol position.

The sync frame bits modulated on the flag tones (see clause 3.2.6) shall be used for the transmission of a Syncflag as defined in clause 10.5.3 of [ITU-T G.993.2]. The sync frame shall be modulated onto a sync symbol as defined in clause 10.5 of [ITU-T G.993.2] (including the quadrant scrambling of all MEDLEY subcarriers, regardless of it being a flag or a probe tone).

7.4 Requirements for the NT system

The NT (see Figure 5-1) shall support downstream vectoring.

7.4.1 Layer 2 Ethernet encapsulation of the backchannel data

If the VCE selects to use this encapsulation type, the backchannel data shall be encapsulated as defined in this clause.

Within the NT, the clipped error samples are first sent from the VTU-R to the L2+ functional block, where they are encapsulated into the Layer 2 transport protocol and multiplexed into one of the upstream Ethernet (or Ethernet over ATM) data streams.

Ethernet encapsulation is based on [IEEE 802.3] and shall be as described in this clause.

The Layer 2 Ethernet frame encapsulation shall consist of the following fields:

– Destination MAC address shall be MAC address of the VCE;

– Source MAC address shall be the MAC address of the VTU-R;

– Length field (as per the IEEE 802.3 MAC frame format [IEEE 802.3]);
– LLC PDU header coding for SNAP protocol (3 bytes, AA-AA-03);
– SNAP PDU header containing a 3-octet ITU OUI 00-19-A7 + 2-octet Protocol ID of ITU subtype 00-03 for a PRIVATE protocol;
– Protocol payload data (Line_ID, Sync Symbol Count, Segment Code and Backchannel Data);
– Padding (only for the last segment and as per the IEEE 802.3 MAC frame format [IEEE 802.3]);
– Standard Ethernet 4-byte FCS (as per the IEEE 802.3 Ethernet frame FCS [IEEE 802.3]).

The VCE MAC Address field shall contain the VCE MAC Address as configured by the VCE through O-PMS, see clause 10.5.2.1. The protocol payload data shall contain the Line_ID (as configured by the VCE through O-PMS, see clause 10.5.2.1), the Sync Symbol Count (as defined in clause 7.2.4), the Segment Code (as defined in [ITU-T G.993.2]) and the backchannel data ERB (as defined in clause 7.2.3). The Length field shall equal the length of the protocol payload data, increased with the 8-byte LLC SNAP header length, and shall not exceed 1024+8=1032. If the protocol payload data exceeds 1024 bytes, the backchannel data ERB shall be segmented as defined in clause 11.2.3.1 of [ITU-T G.993.2]. For protocol payload data lengths shorter than or equal to 1024 bytes, the backchannel data ERB may also be segmented. If segmented, each segment of the backchannel data ERB shall be Layer 2 Ethernet encapsulated as shown in Figure 7-9, with the number of segments per backchannel data ERB not exceeding 16.

The format of the Ethernet encapsulated backchannel data ERB is shown in Figure 7-9.

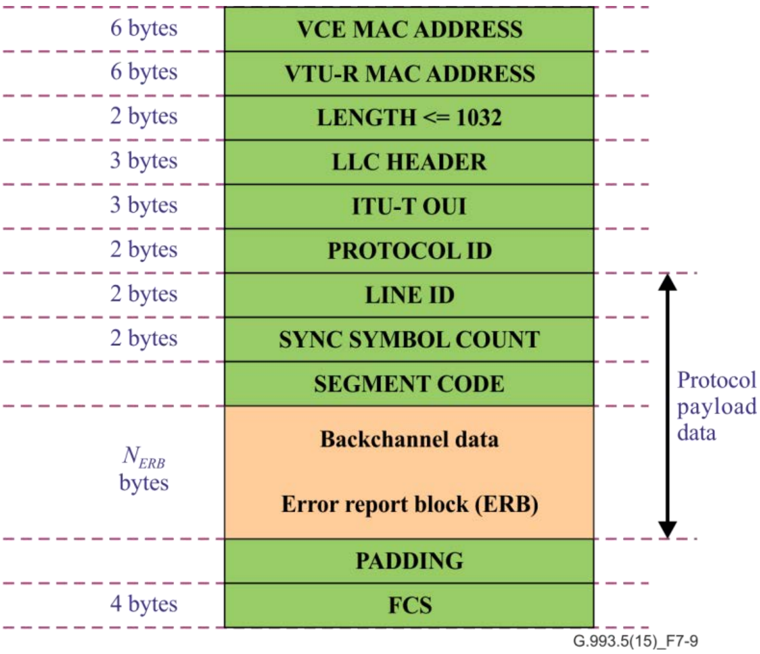

Figure 7-9 – Format of the Ethernet encapsulation of backchannel data message

7.4.2 eoc encapsulation of the backchannel data

If the VCE selects to use this encapsulation type, the backchannel data shall be communicated using the eoc protocol described in clause 8.1.

8 Vectoring-specific eoc messages

The VTU-O and VTU-R VME shall use the eoc commands and responses defined in this clause to support vectoring. For vectoring-related eoc commands and responses, both the VTU-O and VTU-R shall use the standard eoc protocol for message communication defined in clause 11.2.2 of [ITU-T G.993.2] and the protocol for commands and responses defined in clause 11.2.3 of [ITU-T G.993.2], except for the protocol for the Error Feedback command and responses, which shall be as defined in clause 8.1.

The list of additional eoc commands to facilitate operation of vectored lines is presented in Table 8-1 (high priority) and Table 8-2 (normal priority).

Table 8-1 – High priority commands and responses

Command type and assigned value	Direction of command	Command content	Response content
Error Feedback 0001 1000_2	From VTU-O to VTU-R	Request for error samples for the given vectored band and with the given format	eoc encapsulated error samples and associated parameters, ACK or NACK

Table 8-2 – Normal priority commands and responses

Command type and assigned value	Direction of command	Command content	Response content
Pilot sequence update 0001 0001_2	From VTU-O to VTU-R	Request to update upstream pilot sequence	Acknowledgement

8.1 eoc messages for backchannel configuration

The VTU-O VME shall use the Error Feedback command and responses for obtaining clipped error samples from the VTU-R VME and for updates of backchannel control parameters. The command (request for clipped error samples) may be initiated only by the VTU-O and shall use the format shown in Table 8-3; the VTU-R shall respond with clipped error samples for the requested subcarriers in the requested format, or with ACK (if error samples are communicated over L2-based backchannel), or with NACK. The NACK provides a rejection code describing the reason of the request denial. Prior to sending the NACK, the VTU-R VME shall suspend sending clipped error samples until it receives a new Error Feedback command with a valid set of backchannel and error report control parameters. The VTU-R shall use the format of the response message as described in Table 8-6 or Table 8-7. The rejection codes shall be as described in Table 8-8.

The first octet of the command and the response shall be the assigned value of the Error Feedback command type, as shown in Table 8-1. The second and subsequent octets shall be as shown in Table 8-3 for the command and in Table 8-6 or Table 8-7 for responses. The communicated data octets shall be mapped using the generic format described in clause 11.2.3.1 of [ITU-T G.993.2].

The VTU-O sends an Error Feedback command to request the VTU-R to start sending clipped error samples with particular parameters. The command indicates:

– the error sample update period (m);

– the error sample shift period (z);

– the range of subcarrier indices to be covered in the report (defined by vectored downstream bands);

– the error report control parameters (*F_sub*, *F_block*, *B_min*, *B_max*, *L_w*, etc.).

Upon reception of the command, the VTU-R shall either start sending clipped error samples (Error Feedback data messages as defined in Table 8-6 for the eoc backchannel, and in Table 8-7 for the L2 backchannel) or respond with a NACK (as defined in Table 8-8). The first Error Feedback data message is an ACK that the Error Feedback command was admitted. More Error Feedback data messages may be transmitted if necessary (either as subsequent eoc messages or as L2 Ethernet packets). Transmissions of Error Feedback data messages shall be triggered by every error sample update sync symbol counts requested in the Error Feedback command (update period and shift period). If the update period is more than 1, the VTU-R shall update error samples at the exact sync symbol counts indicated by the VTU-O.

Error Feedback data messages shall not be acknowledged. If the Error Feedback data message exceeds 1024 bytes, it shall be segmented as defined in clause 11.2.3.1 of [ITU-T G.993.2] with the maximum number of segments not to exceed 16; segments shall be sent without waiting for IACK. The VTU-R shall not retransmit Error Feedback data messages or their segments. If the VTU-O does not receive the response (ACK), it may send another Error Feedback command, possibly with different control parameters. The VTU-R shall continue sending Error Feedback data messages while waiting for Syncflag after an OLR command. If in the time period allocated to send a particular Error Feedback data message the eoc channel is busy with another high-priority message (e.g., OLR command), the VTU-R shall drop this Error Feedback data message and continue with the next Error Feedback data message.

At the start of Showtime, the VTU-R shall not send clipped error samples until it receives an Error Feedback command with a valid set of backchannel and error report control parameters. To start communication of clipped error samples, the VTU-O shall send a backchannel configuration eoc command within the first second of Showtime. To stop communication of clipped error samples, the VTU-O shall send an Error Feedback command that carries a special backchannel configuration (i.e., error sample update period m=0, see Table 8-3). Upon reception of the command, the VTU-R shall first stop sending Error Feedback data messages and subsequently respond with NACK.

Table 8-3 – Error Feedback command transmitted by the VTU-O

Name	Length (octets)	Octet number	Content
Error Feedback request	$9 + 5 \times N\_band$ ($N\_band \leq 8$)	2	01_{16} (Note 1)
		3 to 4	First SSC (see clause 6.2.2, clause 7.3.2 and Note 6)
		5	Error sample update period (m) (see clause 7.2.4 and Note 2)
		6 to 7	Error sample shift period (z) (see clause 7.2.4 and Note 3)
		8 to $8 + 3 \times N\_band$	Vectored bands descriptor (see Table 12-18 of [ITU-T G.993.2], Note 4)
		$9 + 3 \times N\_band$ to $9 + 5 \times N\_band$	Error report configuration descriptor (Note 5)

NOTE 1 – All other values are reserved by ITU-T.

NOTE 2 – The error sample update period (m) shall be represented as an unsigned integer.

NOTE 3 – The error sample shift period (z) shall be represented as an unsigned integer.

NOTE 4 – The value of *N_band* is defined as octet 1 of the ITU-T G.993.2 band descriptor

NOTE 5 – This descriptor defines *N_band* sets of clipped error sample reporting parameters defined in clause 7.2.2 for each downstream vectored band (2 octets per band). It shall use the format defined in Table 8-4.

NOTE 6 – The value of the First SSC shall be the same for all error feedback commands after entering Showtime.

Table 8-4 – Error report configuration descriptor

Parameter	Bit	Octet number	Description
N_band	[7:4]	0	The number of configured vectored bands in the range from 1 to 8 represented as an unsigned integer
padding	3		As defined in clause 7.2.2.
Reserved by ITU-T	2		Shall be set to 0_2.
F_block	[1:0]		Block size, encoded as (see Note): 00_2 – $F\_block = \left\lvert \frac{N\_carrier}{F\_sub} \right\rvert$ 01_2 – *F_block* = 1 10_2 – *F_block* = 32 11_2 – Reserved for use by ITU-T
Parameters for vectored band 1		1-2	See Table 8-5
. . . . . .		…..	
Parameters for vectored band *N_band*		2 × *N_band* – 1 to 2 × *N_band*	See Table 8-5
NOTE – If encoded 01_2 or 10_2, then *F_block* has the same value for all vectored bands. If encoded 00_2, then *F_block* may have a different value for each vectored band depending on the number of subcarriers *(N_carrier)* and subsampling *(F_sub)*.			

Table 8-5 – Vectored band control parameters

Parameter	Bits	Octet number	Description
F_sub	[7:4]	0	Sub-sampling rate *F_sub* as defined in clause 7.2.2, with $\log_2$(*F_sub*) represented as unsigned integer.
L_w	[3:0]		Length of the clipped error sample in compressed representation as defined in clause 7.2.2, with *L_w* represented as an unsigned integer.
B_min	[7:4]	1	Parameter *B_min* as defined in clause 7.2.2, with *B_min* represented as an unsigned integer.
B_max	[3:0]		Parameter *B_max* as defined in clause 7.2.2, with *B_max* represented as an unsigned integer.

Table 8-6 – Error Feedback response transmitted by the VTU-R for eoc backchannel

Name	Length (Octets)	Octet number	Content
Error Feedback data/ACK	5 + N_{ERB}	2	80_{16} (see Note 1)
		3-4	Sync symbol count (SSC) represented as unsigned integer in the range as defined in clause 7.3.2 (see Note 2).
		5	Segment code (SC), represented as defined in clause 11.2.3.3 of [ITU-T G.993.2].
		6 to 5 + N_{ERB}	Backchannel data, represented with N_{ERB} octets as defined in clause 7.2.3 (see Note 3).
NACK	3	2	81_{16} (see Note 1)
		3	1 octet for reason code (see Table 8-8)
NOTE 1 – All other values for this octet are reserved by ITU-T. NOTE 2 – This field identifies the downstream sync symbol for which clipped error samples are reported. NOTE 3 – This field shall carry the ERB using the format described in clause 7.2.3.			

Table 8-7 – Error Feedback response transmitted by the VTU-R for L2 backchannel

Name	Length (Octets)	Octet number	Content
ACK	6	2	80_{16} (see Note 1)
		3-4	Both octet shall be set to 00_{16}
		5	Octet shall be set to 11000000_2 (see Note 2)
		6	Octet shall be set to 00_{16} (see Note 3).
NACK	3	2	81_{16} (see Note 1)
		3	1 octet for reason code (see Table 8-8)
NOTE 1 – All other values for this octet are reserved by ITU-T. NOTE 2 – This value corresponds with the segment code of a non-segmented eoc message as defined in clause 11.2.3.3 of [ITU-T G.993.2]. NOTE 3 – This field shall serve as ACK indicating that the backchannel configuration required by Error Feedback command was accepted.			

Table 8-8 – NACK reason codes

Value	Definition
01_{16}	Invalid set of error sample parameters or clipped error sample report format.
02_{16}	VTU-R stops sending error reports on the VCE's request.
NOTE – All other reason codes are reserved by ITU-T.	

8.2 Pilot sequence update command and response

The VTU-O VME shall use the pilot sequence update command and response to force an update of the upstream pilot sequence(s) and communicate the updated pilot sequence(s) for the vectored line (see clause 7.3.3) to the VTU-R VME. Separate commands are defined for updating a single pilot sequence (in case upstream FDPS is disabled through ITU-T G.994.1) and for updating eight upstream pilot sequences (in case upstream FDPS is enabled through ITU-T G.994.1). These commands are shown in Table 8-9, and may be initiated only by the VTU-O; the VTU-R shall respond with the ACK, using the format shown in Table 8-10.

The first octet of the command shall be the assigned value of the pilot sequence update command type, as shown in Table 8-2. The second and subsequent octets shall be as shown in Tables 8-9 for commands and in Table 8-10 for responses. The data octets shall be mapped using the format described in clause 11.2.3.1 of [ITU-T G.993.2].

Using the pilot sequence update message, the VCE may update the upstream pilot sequence(s).

The command message length depends on the length of the upstream pilot sequence (*Npilot_us* bits, see clause 7.3.3). Only the upstream pilot sequence bits may be changed during Showtime. The newly assigned upstream pilot sequence length shall be the same as the length of the upstream pilot sequence that was set at initialization.

The command message bytes shall be defined as shown in Table 8-9.

Table 8-9 – Pilot sequence update commands transmitted by the VTU-O

Name	Length (Octets)	Octet number	Content
Pilot sequence configuration (FDPS disabled through ITU-T G.994.1)	$3 + Npilot\_us/8$	2	01_{16} for change of upstream pilot sequence with upstream FDPS disabled through ITU-T G.994.1 (see Note)
		3	01_{16} if interruption of current upstream pilot sequence is not allowed; 02_{16} if interruption of current upstream pilot sequence is allowed (see Note)
		4 to $3 + \lceil Npilot\_us/8 \rceil$	Upstream pilot sequence bits, coded as defined for field #4 in Table 10-7.
Pilot sequence configuration (FDPS enabled through ITU-T G.994.1)	$11 + (Naips + 1) \times \lceil Npilot\_us/8 \rceil$	2	02_{16} for change of upstream pilot sequences with upstream FDPS enabled through ITU-T G.994.1 (see Note)
		3	01_{16} if interruption of current upstream pilot sequence is not allowed; 02_{16} if interruption of current upstream pilot sequence is allowed (see Note)
		4 to $3 + \lceil Npilot\_us/8 \rceil$	Upstream pilot sequence bits, coded as defined for field #4 in Table 10-7.
		$4 + \lceil Npilot\_us/8 \rceil$ to $11 + (Naips + 1) \times \lceil Npilot\_us/8 \rceil$	The upstream FDPS descriptor as defined in Table 10-9.
NOTE – All other values for this octet are reserved by ITU-T.			

The third octet of the pilot sequence update command defines the time at which the upstream pilot sequence change shall occur:

– If interruption of the current upstream pilot sequence is not allowed (value 01_{16}), the upstream pilot sequence change shall be applied starting from the next sync symbol position after the end of the current upstream pilot sequence, i.e., after the sync symbol that modulates the last bit of the old upstream pilot sequence, the next sync symbol shall modulate the first bit of the new upstream pilot sequence.

– If interruption of the current upstream pilot sequence is allowed (value 02_{16}), the upstream pilot sequence change may occur at any sync symbol position, i.e., after the sync symbol that modulates bit i of old upstream pilot sequence, the next sync symbol shall modulate bit i+1 of the new upstream pilot sequence.

The only allowed response from the VTU-R is to acknowledge the correct reception of the command, as shown in Table 8-10.

Table 8-10 – Pilot sequence update response transmitted by the VTU-R

Name	Length (Octets)	Octet number	Content
ACK	2	2	80_{16} (see Note)
NACK	3	2	81_{16} (see Note)
		3	1 octet for reason code (see Table 8-11)
NOTE – All other values for this octet are reserved by ITU-T.			

Table 8-11 – NACK reason codes

Value	Definition
01_{16}	Invalid set of parameters.
NOTE – All other reason codes are reserved by ITU-T.	

If the pilot sequence update command updates the upstream pilot sequence(s), the VTU-R shall apply the change only after sending the ACK message. If interruption of the current pilot sequence(s) is allowed, the update should occur as soon as possible, and shall occur within 200 ms after sending the ACK message.

The timing diagram of the pilot sequence eoc command and response is shown in Figure 8-1.

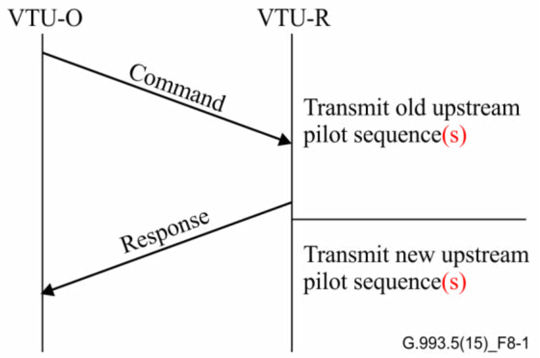

Figure 8-1 – Timing diagram of the pilot sequence update command and response

8.3 Power management commands and responses

The same power management commands and responses shall be used as defined in clause 11.2.3.9 of [ITU-T G.993.2]. The orderly shutdown procedures described in clauses 11.2.3.9.1 and 11.2.3.9.2 of [ITU-T G.993.2] shall be modified as defined in this clause.

8.3.1 L3 Request by VTU-R (replaces clause 11.2.3.9.1 of [ITU-T G.993.2])

Upon receipt of the L3 Request command, the responding VTU-O shall send either the Grant or Reject response. The proposed link state shall be formatted as 03_{16} for the L3 link state. If any other link state is received, the Reject response shall be sent with the reason code 02_{16}.

The VTU-O may reject a request to move to link state L3 using reason code 01_{16} because it is temporarily busy, or reject it using code 03_{16} because it has local knowledge that the L3 state is not desired at this time.

When the VTU-R receives the Grant response, the VTU-R shall transition from the R-SHOWTIME state to R-SILENT (see Figure 12-3). Upon entering the R-SILENT state, the VTU-R shall not yet change the input impedance as seen from the line at the U-R2 reference point.

When the VTU-O detects that the VTU-R has stopped transmission (because the VTU-R transitioned to the R-SILENT state), the VTU-O shall transition from the O-SHOWTIME state to the O-DEACTIVATING state.

Controlled by the VCE, the VTU-O shall transition from the O-DEACTIVATING state to the O-SILENT state.

When the VTU-R detects that the VTU-O has stopped transmission (because the VTU-O transitioned to the O-DEACTIVATING state or the O-SILENT state), the VTU-R may change the characteristics of the transmission path. However, for the sake of vectoring stability of the vectored group, the VTU-R should maintain approximately the input impedance as seen from the line at the U-R2 reference point.

8.3.2 L3 Request by VTU-O (replaces clause 11.2.3.9.2 of [ITU-T G.993.2])

Upon receipt of the L3 Request command, the responding VTU-R shall send either the Grant or Reject response. The proposed link state shall be formatted as 03_{16} for the L3 link state. If any other link state is received, the Reject response shall be sent with the reason code 02_{16}.

The VTU-R may reject a request to move to link state L3 using reason code 01_{16} because it is temporarily too busy, or reject it using code 03_{16} because it has local knowledge that the L3 state is not desired at this time.

When the VTU-O receives the Grant response, the VTU-O shall transition from the O-SHOWTIME state to the O-DEACTIVATING state. In the O-DEACTIVATING state, the VTU-O shall not yet change the input impedance as seen from the line at the U-O2 reference point.

Controlled by the VCE, the VTU-O shall transition from the O-DEACTIVATING state to the O-SILENT state. Upon entering the O-SILENT state, the VTU-O shall still not change the input impedance as seen from the line at the U-O2 reference point.

When the VTU-R detects that the VTU-O has stopped transmission (because the VTU-O transitioned to the O-DEACTIVATING state or the O-SILENT state), the VTU-R shall transition from the R-SHOWTIME state to the R-SILENT state.

When the VTU-O detects that the VTU-R has stopped transmission (because the VTU-R transitioned to the R-SILENT state), the VTU-O may change the characteristics of the transmission path. However, for the sake of vectoring stability of the vectored group, the VTU-O should maintain approximately the input impedance as seen from the line at the U-O2 reference point.

9 Activation and deactivation of pairs in a vectored group

The activation of a line in a vectored group is achieved through the initialization procedure defined in clause 10.

The deactivation of a line from the vectored system also requires an orderly procedure. If the line to be deactivated is used in upstream or downstream FEXT cancellation, then the performance of the vectoring system may suffer from an abrupt disconnection. The procedures for an "Orderly shutdown event" and for a "Disorderly shutdown event" are described in this clause.

9.1 Orderly shutdown event

The orderly shutdown event shall consist of a power management transition to line state L3. The related power management commands and responses are defined in clause 8.3.

9.2 Disorderly shutdown event

Upon detection of a near-end *los* defect, (see clause 11.3.1.3 of [ITU-T G.993.2]), the VTU-O shall transition from the O-SHOWTIME state to the O-DEACTIVATING state.

Controlled by the VCE, the VTU-O shall transition from the O-DEACTIVATING state to the O-SILENT state.

NOTE – If errors on the other lines in the vectored group are acceptable, an additional and/or alternative technique to the switching-off of the transmit signal, is fast update of the coefficients. This may be effectuated as follows. When a disorderly shutdown event (DSE) or other disorderly event is detected on a line, the VTU-Os of the other lines should send error feedback requests preferably using robust eoc channel to their VTU-Rs. The VTU-Rs should then provide the requested error samples to the respective VTU-Os in the vectoring feedback channel. Upon receiving the error samples, it is sufficient that the VCE estimates only the changed channel coefficients, i.e., the channel coefficients associated with the line subject to DSE, in order to update an estimate of the full channel. This can be performed using error samples corresponding to a few sync symbols only. Then, the VCE uses the updated channel estimate comprising the estimated changed channel coefficients and the unchanged channel coefficients to update the pre-coder. The duration of the period of errors, before the pre-coder is updated using such a fast update mechanism, has an approximate length of a few superframes, and therefore may avoid the other lines to retrain due to the DSE.

10 Initialization of a vectored group

This clause defines the initialization of a vectored group.

10.1 Overview

The initialization procedure described in this clause is based on ITU-T G.993.2 initialization with addition of steps for FEXT channel estimation. The final mode of vectored operation (i.e., downstream and upstream vectoring, or downstream only vectoring) is determined during the ITU-T G.994.1 Phase of initialization.

Figure 10-1 provides an overview of the initialization procedure for both upstream and downstream directions. For this Recommendation, the ITU-T G.993.2 initialization phases are adopted with some modifications to the SOC messages and addition of initialization signals for FEXT channel estimation. The initialization signals added to the ITU-T G.993.2 Channel Discovery phase and Training phase are highlighted in Figure 10-1.

If several lines are initialized simultaneously, the initialization procedures of these lines have to be aligned in time, so that all lines pass the vectoring-related phases simultaneously (see clauses 10.3.3.6 and 10.4.3.9).

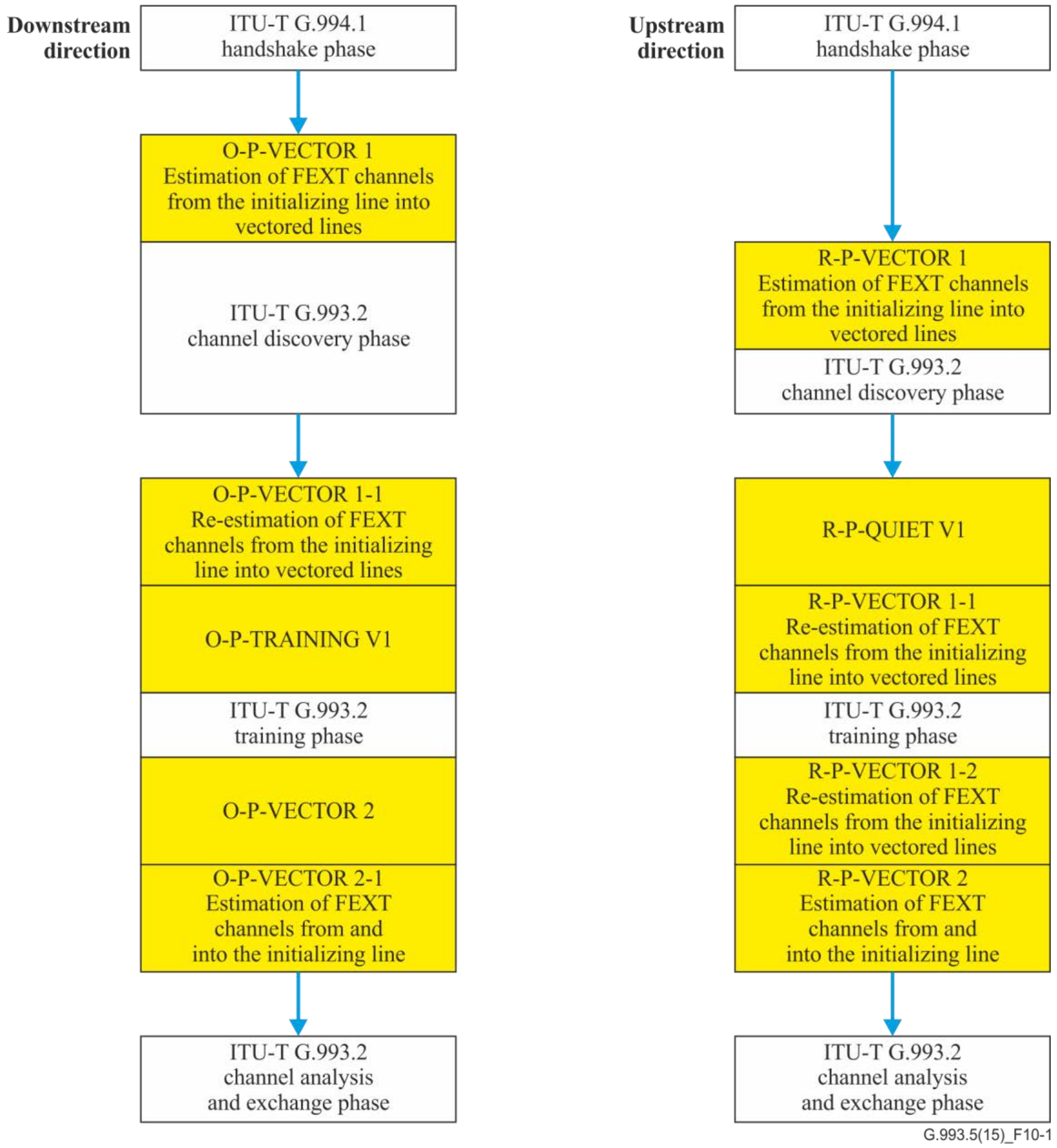

Figure 10-1 – ITU-T G.993.5 initialization overview

In the downstream direction, at the beginning of the Channel Discovery phase, the VTU-O of the initializing line transmits O-P-VECTOR 1 signal which comprises only sync symbols modulated by the pilot sequence and which is aligned with sync symbols of vectored lines, see Figure 10-2. The O-P-VECTOR 1 signal allows the VCE to estimate FEXT channels from the initializing lines into the vectored lines. The VCE estimates these FEXT channels based on the reported clipped error samples from the VTU-Rs of the vectored lines and enables the pre-coding in the VTU-Os of these vectored lines to cancel FEXT from the initializing lines into these vectored lines during the remainder of the initialization of the initializing lines.

At the beginning of the Training phase, the initializing VTU-O will transmit O-P-VECTOR 1-1 signal, which is the same as O-P-VECTOR 1 and allows the VCE to update the downstream FEXT channel estimates from the initializing lines into the vectored lines, prior to transitioning into the ITU-T G.993.2 Training phase.

After the ITU-T G.993.2 Training phase, the VTU-O transmits the O-P-VECTOR 2 signal, followed by the O-P-VECTOR 2-1 signal, which both comprise sync symbols modulated by the pilot sequence and regular symbols carrying the SOC, see Figure 10-3. During the transmission of O-P-VECTOR 2-1, the VCE estimates FEXT channels from all vectored lines into each initializing line and vice versa. Finally, at the end of the transmission of O-P-VECTOR 2-1, the whole FEXT channel matrix, including FEXT coefficients from the initializing line into the vectored lines and FEXT coefficients from the vectored lines into each initializing line, is estimated by the VCE. At this point the initialization process is complete and the initializing lines may be included in the pre-coding operation. After O-P-VECTOR 2-1 transmission is complete, the VTU-O of the initializing line enters the Channel Analysis and Exchange phase for estimation of the signal-to-noise ratio (SNR) and determination of the bit loading to be used during Showtime.

In the upstream direction, in order to avoid excessive FEXT into vectored lines, the VTU-R of an initializing line, after detection of the O-SIGNATURE message in the Channel Discovery phase, starts transmitting an R-P-VECTOR 1 signal, which has the same format as O-P-VECTOR 1, see Figure 10-2. During transmission of the R-P-VECTOR 1, the VCE estimates the FEXT channels from the initializing lines into all vectored lines, and enables the VTU-Os of the vectored lines to cancel FEXT from the initializing lines during the remainder of the initialization of the initializing lines. The time position of the upstream sync symbols and the upstream pilot sequence are assigned by the VCE and are indicated to the VTU-R in the O-SIGNATURE message and by special markers added to the O-P-CHANNEL DISCOVERY V1 signal.

Furthermore, other optional parameters may be added to the O-P-SIGNATURE message for upstream transmit power reduction during the initial upstream phase (R-P-VECTOR 1). The upstream transmit power reduction can be used to reduce the crosstalk of the R-P-VECTOR 1 signals into non-vectored lines operating in the same binder and provides a flat attenuation of the upstream transmit PSD of R-P-VECTOR 1 in addition to the standard upstream power back-off as defined in [ITU-T G.993.2].

NOTE 1 – Parameters *a, b* that determine the limiting upstream PSD mask (UPBOMASK, see clause 7.2.1.3.2.2 of [ITU-T G.993.2]) are provided by the operator via the CO-MIB as specified in [ITU-T G.997.1]. The operator may provision or allow for default values of a, b that are different from those geographic region specific values defined in [ITU-T G.993.2] (e.g., Annexes A.2.3, B.3, and C.2.1.4), and thus allow higher upstream PSDs, since upstream FEXT is reduced through crosstalk cancellation. After UPBO has been applied (during the initialization), the VTU-R may further adjust its transmit PSD (while it remains below the UPBOMASK) during the Showtime by request from the VTU-O, via SRA, as per clause 7.2.1.3.1 of [ITU-T G.993.2], to improve upstream performance (under control of the VCE). The operator may also adjust the applied parameters *a, b* via a new initialization.

At the beginning of the Training phase, the initializing VTU-R will transmit the R-P-VECTOR 1-1 signal, which is the same as R-P-VECTOR 1 and allows the VCE to update the upstream FEXT channel estimates from the initializing lines into the vectored lines, prior to transitioning into the ITU-T G.993.2 Training phase. The VTU-O transmits the O-P-TRAINING V1 signal as a time fill signal while the VTU-R transmits R-P-VECTOR 1-1.

The initial value of timing advance is assigned by the VTU-O and is communicated in O-SIGNATURE, based on the provisional knowledge on the length of the line. If the timing advance is further re-adjusted during the Training phase, then the FEXT channel estimate in the upstream direction will be updated at the end of the Training phase to account for any resulting change in the FEXT channel (signal R-P-VECTOR 1-2 in Figure 10-1). The VTU-O transmits the O-P-VECTOR 2 signal as a time fill signal while the VTU-R transmits R-P-VECTOR 1-2.

At the end of the Training phase, the VTU-R transmits R-P-VECTOR 2, which comprises sync symbols modulated by the pilot sequence and regular symbols carrying the SOC. During the transmission of R-P-VECTOR 2, the VCE estimates the FEXT channels from all vectored lines into the initializing lines and vice versa. Finally, at the end of the R-P-VECTOR 2 transmission, the whole FEXT channel matrix, including FEXT coefficients from the initializing lines into the vectored lines and FEXT coefficients from vectored lines into the initializing lines, are estimated by the VCE. At this point the initialization process is complete and the initializing lines become active members of the vectored group. After R-P-VECTOR 2 transmission is complete, the VTU-R enters the Channel Analysis and Exchange phase for estimation of the SNR and determination of the bit loading to be used during Showtime.

During the transmission of R-P-VECTOR 2, the SOC parameters may be set to provide higher speed SOC, necessary to convey clipped error samples from the VTU-R to the VTU-O. Since both VTU-O and VTU-R already passed the Training phase, the number of repetitions in the SOC may be reduced (similarly to [ITU-T G.993.2] during the Channel Analysis and Exchange phase). This will provide a fast backchannel which is necessary for quick estimation of FEXT channels from vectored lines into the initializing line.

Figures 10-2 and 10-3 show how positions of sync symbols modulated by pilot sequences are aligned during the initialization signals O-P-VECTOR and R-P-VECTOR; the downstream sync symbols of all lines are synchronized in time and upstream sync symbols of all lines are synchronized in time. A time shift between upstream and downstream sync symbols of one or more symbols is set during initialization (see clause 10.3.2.1).

NOTE 2 – In some implementations, the transmit path of an initializing VTU may change during the Channel Discovery phase. The update of the downstream and upstream FEXT channel allows to capture any related change of the FEXT generated into the vectored lines. Any changes in the transmit path of the analogue front end (AFE) prior to the transmission of O-P-VECTOR 1-1 or R-P-VECTOR 1-1 may increase FEXT generated by the initializing line into vectored lines from the moment of the change until the start of O-P-VECTOR 1-1 or R-P-VECTOR 1-1. Therefore, implementations should minimize the modifications in AFE during the Channel Discovery phase.

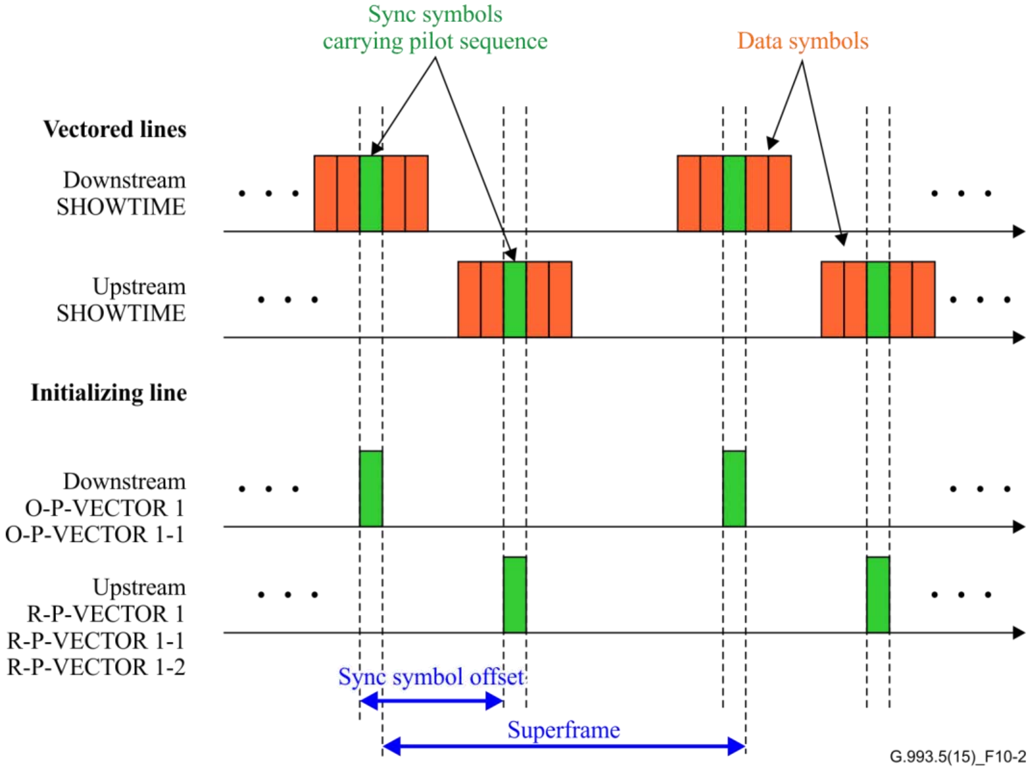

Figure 10-2 – Signal timing in the upstream and downstream directions (signals O-P-VECTOR 1 and R-P-VECTOR 1)

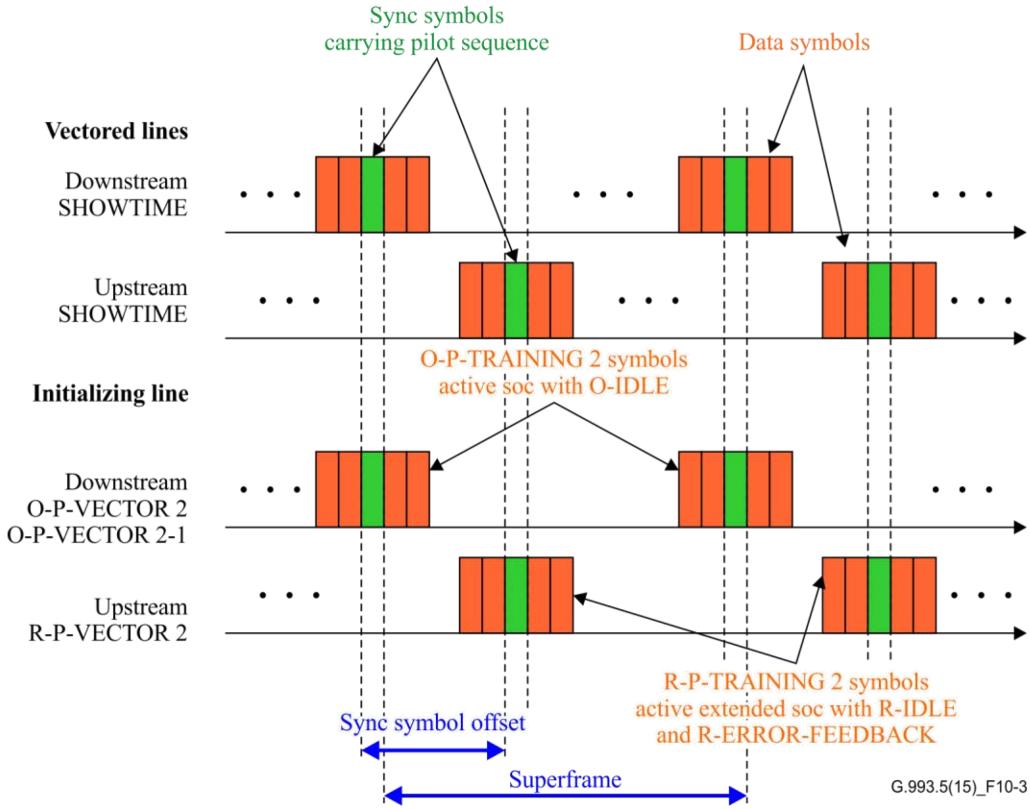

Figure 10-3 – Signal timing in the upstream and downstream directions (signals O-P-VECTOR 2 and R-P-VECTOR 2)

In the following, various phases of the initialization procedure are discussed in more detail.

10.2 ITU-T G.994.1 Handshake phase

The initialization procedure starts with the ITU-T G.994.1 Handshake phase. During this phase, the VTU-O and the VTU-R shall exchange their enabled vectoring capabilities in addition to the parameters communicated in a regular Handshake phase of [ITU-T G.993.2]. The VTU-O shall support downstream vectoring and may support upstream vectoring. The VTU-R shall support downstream vectoring and shall support upstream vectoring. Based on these capabilities, the final mode of vectored operation (i.e., downstream and upstream vectoring, or downstream only vectoring) is determined during the ITU-T G.994.1 phase of initialization (see Tables 11.68.0.1 and 11.68.10 of [ITU-T G.994.1] and Tables 7-a/b/c/d).

Before transmission of the MS message, the VTU-O shall verify whether all of the following conditions are TRUE (Note 1):

– the CO-MIB parameter VECTORMODE_ENABLE bit 0 is set to 0;
– the Annex X "ITU-T G 993.5-friendly ITU-T G.993.2 operation in the downstream direction" NPar(2) bit is set to ZERO in the CL message or in the CLR message;
– the Annex Y "Full ITU-T G.993.5-friendly ITU-T G.993.2 operation" NPar(2) bit is set to ZERO in the CL message or in the CLR message;
– the "ITU-T G.993.5" SPar(2) bit is set to ZERO in the CL message or in the CLR message.

If all of the above conditions are TRUE, then the VTU-O shall ensure that the "ITU-T G.993.2" SPar(1) bit is set to ZERO in the last transmitted MS message before the ITU-T G.994.1 cleardown procedure (Note 2). Otherwise, the operating mode shall be negotiated solely based on the VTU-O and VTU-R enabled capabilities indicated in the CL and CLR message respectively, as defined in Annex X of [ITU-T G.993.2], Annex Y of [ITU-T G.993.2], and in this clause.

NOTE 1 – The verification of these conditions is for the VTU-O to ensure that the line will not initialize in "ITU-T G.993.2 mode with neither Annex X nor Annex Y enabled" if this mode is not allowed in the CO-MIB.

NOTE 2 – This may require the use of the ITU-T G.994.1 extended transaction A:B as defined in Table 14 of [ITU-T G.994.1].

The VCE shall force the VTU-O to set the subcarrier spacing and symbol rate in the initializing line to the same value as used in the other vectored lines.

NOTE 3 – The same symbol rate between all lines of the vectored group is achieved by setting the same ratio between the IDFT size and CE length in samples for upstream and downstream.

NOTE 4 – During the Handshake phase, the VTU-O selects the value of CE based on the supported values indicated by the VTU-O and the VTU-R. Only the value CE=5×N/32 (where 2×N is the IDFT size) is mandatory. In the absence of other information about the CE capabilities of the VTU-R, this will be the only value that is guaranteed to be supported by a new initializing line.

Table 10-1 – VTU-O CL message SPar(2) and NPar(3) bit definitions

ITU-T G.994.1 SPar(2) Bit	Definition of SPar(2) bit
ITU-T G.993.5	This bit shall be set to ONE, if and only if the VTU-O supports ITU-T G.993.5 and ITU-T G.993.5 is allowed via the CO-MIB (i.e., VECTORMODE_ENABLE bit 3 set to 1, see clause 7.3.1.13.9 of [ITU-T G.997.1]).
ITU-T G.994.1 NPar(3) Bit	**Definition of NPar(3) bits**
Downstream vectoring	This bit shall be set to ONE, indicating the VTU-O supports downstream vectoring.
Upstream vectoring	If set to ONE, this bit indicates the VTU-O supports upstream vectoring. If set to ZERO, this bit indicates the VTU-O does not support upstream vectoring.
Pilot sequence length multiple of 4	If set to ONE, this bit indicates the VTU-O supports pilot sequence lengths that are a multiple of 4. If set to ZERO, this bit indicates the VTU-O only supports pilot sequence lengths that are a power of 2.
Upstream FDPS	If set to ONE, this bit indicates the VTU-O supports upstream FDPS. If set to ZERO, this bit indicates the VTU-O does not support upstream FDPS.
8192 superframes duration for O-P-VECTOR 1	If set to ONE, this bit indicates the VTU-O supports extending of O-P-VECTOR 1 duration to 8192 superframes. If set to ZERO, this bit indicates the VTU-O does not support extending of O-P-VECTOR 1 duration to 8192 superframes.
Use of O-P-VECTOR 1 flag tones only	If set to ONE, this bit indicates the VTU-O supports the use of O-P-VECTOR 1 flag tones only (see clause 10.3.3.1). If set to ZERO, this bit indicates that the VTU-O does not support use of O-P-VECTOR 1 flag tones only. If bit "8192 superframes duration for O-P-VECTOR 1" is set to ZERO, then bit "Use of O-P-VECTOR 1 flag tones" shall also be set to ZERO.

Table 10-2 – VTU-O MS message SPar(2) and NPar(3) bit definitions

ITU-T G.994.1 SPar(2) Bit	Definition of SPar(2) bits
ITU-T G.993.5	This bit shall be set to ONE if, and only if, it was set to ONE in both the last previous CL message and the last previous CLR message. If set to ONE, this bit indicates that both VTUs shall enter ITU-T G.993.5 initialization.
ITU-T G.994.1 NPar(3) Bit	**Definition of NPar(3) bits**
Downstream vectoring	This bit shall be set to ONE, indicating downstream vectoring.
Upstream vectoring	This bit shall be set to ONE if, and only if, it was set to ONE in both the last previous CL message and the last previous CLR message. If set to ONE, this bit indicates upstream vectoring is enabled. If set to ZERO, this bit indicates upstream vectoring is disabled.
Pilot sequence length multiple of 4	This bit shall be set to ONE if, and only if, it was set to ONE in both the last previous CL message and the last previous CLR message. If set to ONE, this bit indicates that "pilot sequence length multiple of 4" is enabled. If set to ZERO, this bit indicates only pilot sequence lengths that are a power of 2 are enabled.
Upstream FDPS	This bit shall be set to ONE if, and only if, it was set to ONE in both the last previous CL message and the last previous CLR message. If set to ONE, this bit indicates that upstream FDPS is enabled. If set to ZERO, this bit indicates that upstream FDPS is disabled.
8192 superframes duration for O-P-VECTOR 1	This bit shall be set to ONE if, and only if, it was set to ONE in both the last previous CL message and the last previous CLR message. If set to ONE, this bit indicates that "8192 superframes duration for O-P-VECTOR 1" is enabled. If set to ZERO, this bit indicates that "8192 superframes duration for O-P-VECTOR 1" is disabled.
Use of O-P-VECTOR 1 flag tones only	This bit shall be set to ONE if, and only if, it was set to ONE in both the last previous CL message and the last previous CLR message. If set to ONE, this bit indicates that "Use of O-P-VECTOR 1 flag tones only" is enabled. If set to ZERO, this bit indicates that "Use of O-P-VECTOR 1 flag tones only" is disabled.

Table 10-3 – VTU-R CLR message SPar(2) and NPar(3) bit definitions

ITU-T G.994.1 SPar(2) Bit	**Definition of SPar(2) bits**
ITU-T G.993.5	This bit shall be set to ONE, if and only if the VTU-R supports ITU-T G.993.5.
ITU-T G.994.1 NPar(3) Bit	**Definition of NPar(3) bits**
Downstream vectoring	This bit shall be set to ONE, indicating the VTU-R supports downstream vectoring.
Upstream vectoring	This bit shall be set to ONE, indicating the VTU-R supports upstream vectoring.
Pilot sequence length multiple of 4	If set to ONE, this bit indicates the VTU-R supports pilot sequence lengths that are a multiple of 4. If set to ZERO, this bit indicates the VTU-R only supports pilot sequence lengths that are a power of 2.
Upstream FDPS	If set to ONE, this bit indicates the VTU-R supports upstream FDPS. If set to ZERO, this bit indicates the VTU-R does not support upstream FDPS.
8192 superframes duration for O-P-VECTOR 1	If set to ONE, this bit indicates the VTU-R supports extending of O-P-VECTOR 1 duration to 8192 superframes. If set to ZERO, this bit indicates the VTU-R does not support extending of O-P-VECTOR 1 duration to 8 192 superframes.
Use of O-P-VECTOR 1 flag tones only	If set to ONE, this bit indicates the VTU-R supports the use of O-P-VECTOR 1 flag tones only (see clause 10.3.3.1). If set to ZERO, this bit indicates that the VTU-R does not support use of O-P-VECTOR 1 flag tones only. If bit "8192 superframes duration for O-P-VECTOR 1" is set to ZERO, then bit "Use of O-P-VECTOR 1 flag tones" shall also be set to ZERO.

Table 10-4 – VTU-R MS message SPar(2) and NPar(3) bit definitions

ITU-T G.994.1 SPar(2) Bit	Definition of SPar(2) bits
ITU-T G.993.5	This bit shall be set to ONE if, and only if, it was set to ONE in both the last previous CL message and the last previous CLR message. If set to ONE, this bit indicates that both VTUs shall enter ITU-T G.993.5 initialization.
ITU-T G.994.1 NPar(3) Bit	**Definition of NPar(3) bits**
Downstream vectoring	This bit shall be set to ONE, indicating downstream vectoring.
Upstream vectoring	This bit shall be set to ONE if, and only if, it was set to ONE in both the last previous CL message and the last previous CLR message. If set to ONE, this bit indicates upstream vectoring is enabled. If set to ZERO, this bit indicates upstream vectoring is disabled.
Pilot sequence length multiple of 4	This bit shall be set to ONE if, and only if, it was set to ONE in both the last previous CL message and the last previous CLR message. If set to ONE, this bit indicates that "pilot sequence length multiple of 4" is enabled. If set to ZERO, this bit indicates only pilot sequence lengths that are a power of 2 are enabled.
Upstream FDPS	This bit shall be set to ONE if, and only if, it was set to ONE in both the last previous CL message and the last previous CLR message. If set to ONE, this bit indicates that upstream FDPS is enabled. If set to ZERO, this bit indicates that upstream FDPS is disabled.
8192 superframes duration for O-P-VECTOR 1	This bit shall be set to ONE if, and only if, it was set to ONE in both the last previous CL message and the last previous CLR message. If set to ONE, this bit indicates that "8192 superframes duration for O-P-VECTOR 1" is enabled. If set to ZERO, this bit indicates that "8192 superframes duration for O-P-VECTOR 1" is disabled.
Use of O-P-VECTOR 1 flag tones only	This bit shall be set to ONE if, and only if, it was set to ONE in both the last previous CL message and the last previous CLR message. If set to ONE, this bit indicates that "Use of O-P-VECTOR 1 flag tones only" is enabled. If set to ZERO, this bit indicates that "Use of O-P-VECTOR 1 flag tones only" is disabled.

10.2.1 Avoidance of false initialization in crosstalk environment

The functionality defined in this clause prevents one VTU-O from establishing communication with two VTU-Rs. Such communication would lead to two VTU-Rs sending the same upstream pilot sequence, with potential negative impact on the VCE learning the upstream channel matrix.

Support of this functionality is optional for the VTU-O and is optional for the VTU-R. If supported, the functionality shall be implemented as defined in this clause.

In the ITU-T G.994.1 identification field, two parameters are defined for the exchange of transceiver IDs (see [ITU-T G.994.1] Table 9.14, Tables 9.14.1.x, and Tables 9.14.2.x):

– network side transceiver ID SPar(2) with associated 30-bit NPar(3) parameter;

– remote side transceiver ID SPar(2) with associated 30-bit NPar(3) parameter.

The network side transceiver ID is the VTU-O ID. The VTU-O ID shall be generated by the VTU-O.

The remote side transceiver ID is the VTU-R ID. The VTU-R ID shall be generated by the VTU-R.

The 30 bit VTU ID shall consist of two parts:

– a first part (the MSBs) derived from the serial number and vendor ID;

– a second part (the LSBs) using a random number generator.

The first part has length 16 bits and shall be calculated as the 16-bit high-level data link control (HDLC) frame check sequence (FCS), as specified in clause 6.4.3 of [ITU-T G.997.1], of the VTU vendor ID and the VTU serial number.

The FCS shall be calculated over all bits of the VTU vendor ID followed by the VTU serial number.

The FCS shall be calculated starting with bit 1 (LSB) of octet 1. The octets shall following each other in ascending numerical order. Within an octet, the bits shall follow each other in ascending numerical order.

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

The VTU vendor ID shall consist of the T.35 country code (2 octets) followed by the provider code (4 octets), as indicated in the Vendor ID information block during the ITU-T G.994.1 Handshake phase of initialization (see Table 7 of [ITU-T G.994.1]).

NOTE – This is excluding the "Vendor-specific information" of the Vendor ID information block.

The VTU-O serial number shall be the G.997.1 X digital subscriber line transceiver unit at the central office (XTU-C) serial number (see clause 7.4.7 of [ITU-T G.997.1]).

The VTU-R serial number shall be the equipment serial number that is part of the G.997.1 X digital subscriber line transceiver unit at the remote end (XTU-R) serial number (see clause 7.4.8 of [ITU-T G.997.1]).

NOTE – This is excluding the equipment model and the equipment firmware version that are also part of the G.997.1 XTU-R serial number.

The second part has length 14 bits and shall be generated by the VTU by means of a vendor discretionary random number generator. The randomly generated number shall change from one ITU-T G.994.1 session to the next.

If a transceiver sends any of the messages listed in Table 10-5, that message shall include the transceiver IDs as listed in Table 10-5. The "M" denotes "mandatory", the "CO" denotes "conditionally optional", and the "CM" denotes "conditionally mandatory", with the condition being that the far-end transceiver ID is included if and only if it has been received in a previous message during the same ITU-T G.994.1 session.

Table 10-5 – Transceiver IDs included in ITU-T G.994.1 and initialization messages

	VTU-O ID	VTU-R ID
CLR	–	M
CL	M	CO
MP	CM	M
MS from VTU-O	M	CM
MS from VTU-R	CM	M
O-SIGNATURE	–	CM

If the VTU-R receives a CL or MS message that contains a VTU-R ID different from the VTU-R ID sent in the CLR message, then the VTU-R shall respond with a NAK-CD message followed by the ITU-T G.994.1 session cleardown procedure specified in clause 11.3 of [ITU-T G.994.1].

If the VTU-O receives an MP or MS message that contains a VTU-O ID different from the VTU-O ID sent in the CL message, then the VTU-O shall respond with a NAK-CD message followed by the ITU-T G.994.1 session cleardown procedure specified in clause 11.3 of [ITU-T G.994.1].

If the VTU-R receives an O-SIGNATURE message that contains a VTU-R ID different from the VTU-R ID sent in the CLR message, then the VTU-R shall return to the R-SILENT state.

If the VTU-R receives an O-SIGNATURE message that contains a VTU-R ID equal to the VTU-R ID sent in the CLR message, then communication has been be established only among transceivers with acknowledged transceiver IDs, and initialization shall proceed as defined in clause 10.3.

NOTE 1 – The VTU-R transceiver ID is included in O-SIGNATURE to avoid false detection in the case a VTU-O decides to interrupt the communication during O-P-VECTOR-1.

NOTE 2 – Even if communication has been be established only among transceivers with acknowledged transceiver IDs, the resulting communication may be over a crosstalk path (i.e., not the direct path). If this should occur, the integrity of the upstream channel matrix is not compromised during the R-P-VECTOR 1 phase of channel discovery, since the VCE will see unique upstream pilot sequences on each initializing line.

The VTU-O shall ensure that the ITU-T G.994.1 message sequence allows both the VTU-O and the VTU-R to get acknowledgement of their transceiver ID during the ITU-T G.994.1 session. Table 10-6 lists examples of such ITU-T G.994.1 message sequences.

Table 10-6 – Examples of ITU-T G.994.1 transaction sequences

Example nr	ITU-T G.994.1 message sequence
1	Transaction C: CLR → CL → ACK(1); Transaction D: MP → MS → ACK(1).
2	Transaction C: CLR → CL → ACK(1); Extended transaction A:B: MS → REQ-MR → MR → MS → ACK(1).
3	Transaction C: CLR → CL (including the VTU-R ID) → ACK(1); Transaction A: MS → ACK(1).
4	Transaction C: CLR → CL (including the VTU-R ID) → ACK(1); Transaction B: MR → MS → ACK(1).

10.3 Channel Discovery phase

10.3.1 Overview

The Handshake phase shall be followed by the Channel Discovery phase. If both downstream and upstream vectoring are disabled after the ITU-T G.994.1 phase, then all vectoring-related parts of the initialization shall be skipped and the Channel Discovery phase shall be performed as defined in [ITU-T G.993.2].

If downstream vectoring or upstream vectoring is enabled, then the Channel Discovery phase is a modified version of the ITU-T G.993.2 Channel Discovery phase. Figures 10-4 and 10-5 highlight the signals added and the signals/messages modified in the ITU-T G.993.2 Channel Discovery phase for ITU-T G.993.5 transceivers. Non-highlighted signals and messages shall be as defined in [ITU-T G.993.2].

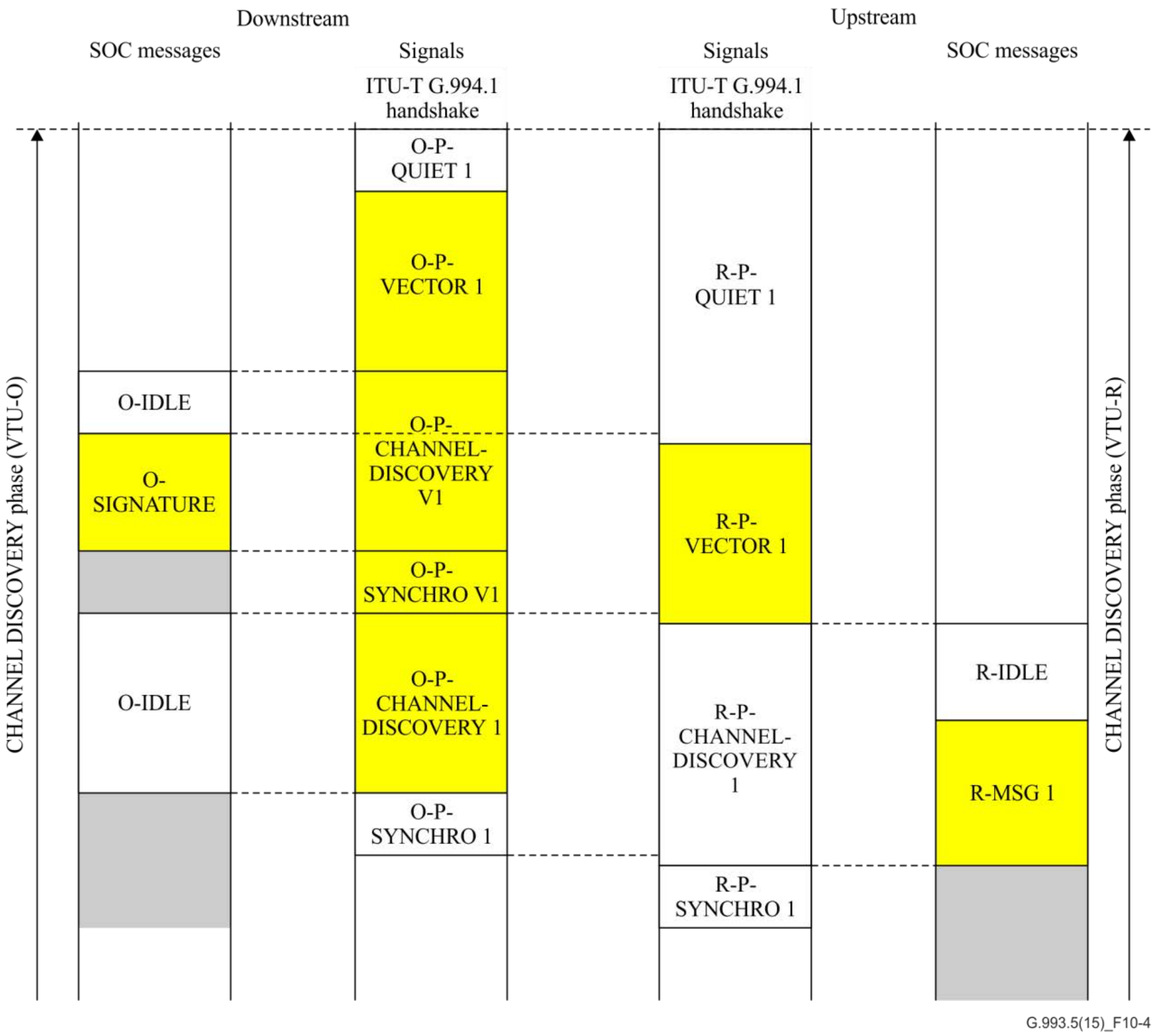

Figure 10-4 – Early stages of the Channel Discovery phase

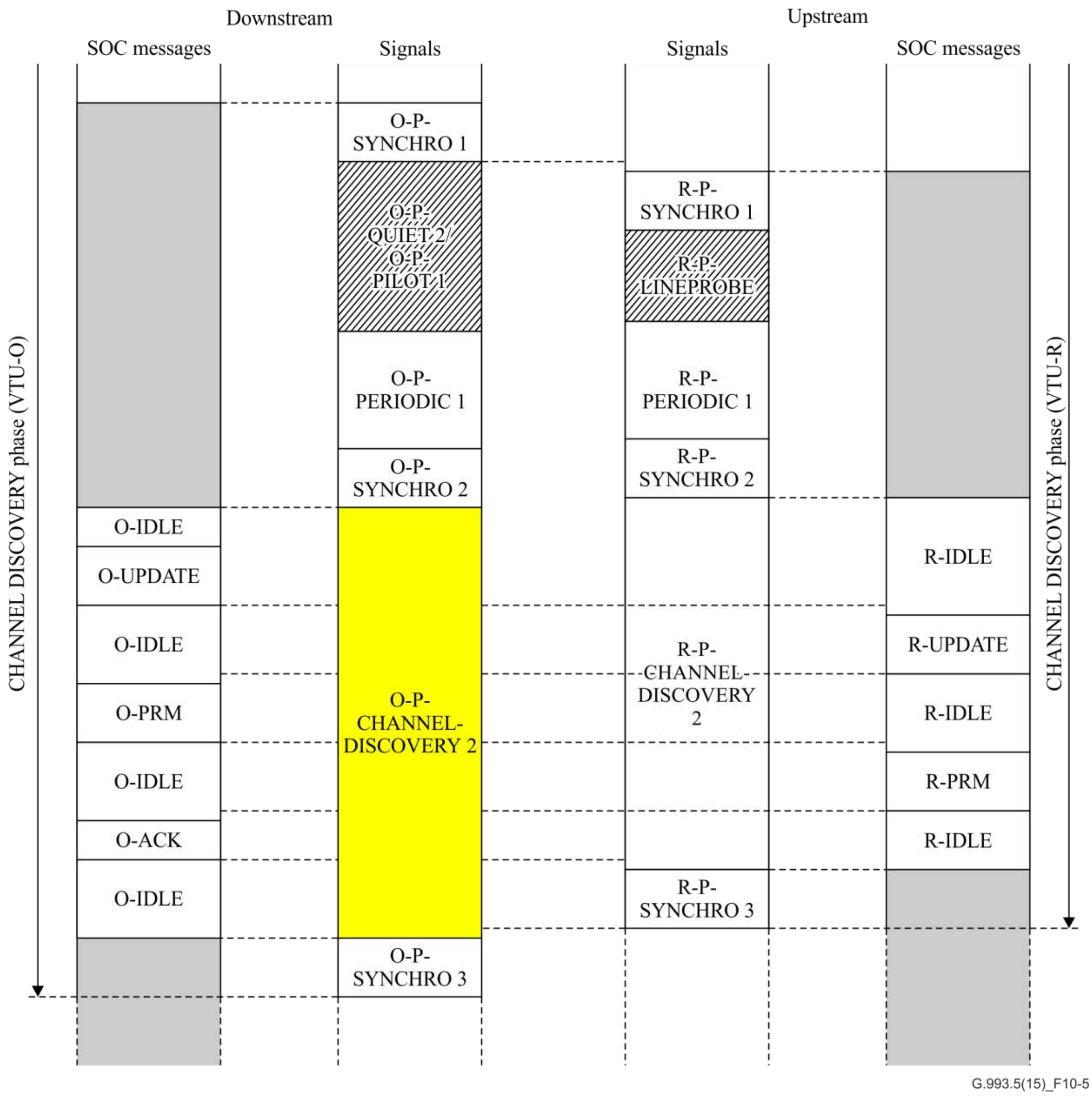

Figure 10-5 – Last stages of the Channel Discovery phase

10.3.2 Modified SOC messages sent during Channel Discovery phase

10.3.2.1 O-SIGNATURE

The O-SIGNATURE message which is transmitted during O-P-CHANNEL DISCOVERY V1 and O-P-CHANNEL DISCOVERY 1 contains an ITU-T G.993.5 parameter field A and an ITU-T G.993.5 parameter field B. The ITU-T G.993.5 parameter field A is of variable length and contains several parameters needed for the FEXT cancellation operation, as shown in Table 10-7. The ITU-T G.993.5 parameter field B includes parameters needed to define the upstream FDPS, as shown in Table 10-9.