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ITU-T

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G.993.5

Amendment 4

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

Digital sections and digital line system – Metallic access networks

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

Amendment 4

Recommendation ITU-T G.993.5 (2010) – Amendment 4

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Recommendation ITU-T G.993.5

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

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Summary

Amendment 4 to Recommendation ITU-T G.993.5 (2010) covers the following corrigendum and new functionality:

1. Pilot sequence update during Showtime (corrigendum)
2. Extended duration of O-P-VECTOR 1 (new functionality).

History

Edition	Recommendation	Approval	Study Group
1.0	ITU-T G.993.5	2010-04-22	15
1.1	ITU-T G.993.5 (2010) Cor. 1	2011-06-22	15
1.2	ITU-T G.993.5 (2010) Amd. 1	2011-12-16	15
1.3	ITU-T G.993.5 (2010) Cor. 2	2012-06-13	15
1.4	ITU-T G.993.5 (2010) Amd. 2	2012-10-29	15
1.5	ITU-T G.993.5 (2010) Amd. 3	2013-04-22	15
1.6	ITU-T G.993.5 (2010) Amd. 4	2013-08-29	15

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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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1) Pilot sequence update during Showtime (corrigendum)

Change Table 8-9 in clause 8.2 as follows:

8.2 Pilot sequence update command and response

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)	$3 + \lceil Npilot\_us/8 \rceil$	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 10-1.
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 10-1.
		$4 + \lceil Npilot\_us/8 \rceil$ to $11 + (Naips + 1) \times \lceil Npilot\_us/8 \rceil$	~~Field #5 of t~~The upstream FDPS descriptor as defined in Table 10-1b.
NOTE – All other values for this octet are reserved by ITU-T.			

2) Extended duration of O-P-VECTOR 1 (new functionality)

Add a row at end of Tables 7-a-b-c-d in clause 10.2 as follows:

10.2 ITU-T G.994.1 handshake phase

Table 7-a – VTU-O CL message NPar(3) bit definitions

…	
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 7-b – VTU-O MS message NPar(3) bit definitions

…	
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 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 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 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.

Table 7-b – VTU-O MS message NPar(3) bit definitions

ITU-T G.994.1 NPar(3) Bit	Definition of NPar(3) bits
8192 superframes duration for O-P-VECTOR 1	This bit shall be set to ONE if and only if set to ONE in both the last previous CL message and the last previous CLR message. If set to ONE, this bit indicates that "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 is 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 7-c – VTU-R CLR message NPar(3) bit definitions

…	
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 8192 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 7-d – VTU-R MS message NPar(3) bit definitions

…	
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 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 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 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 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 is 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.

Change clause 10.3.3.1 as follows:

10.3.3.1 O-P-VECTOR 1

The O-P-QUIET 1 signal shall be followed by the O-P-VECTOR 1 signal.

The O-P-VECTOR 1 signal shall consist of sync symbols and quiet symbols only. Sync symbols shall be transmitted at each downstream sync symbol position (as defined in clause 6.2.3). Quiet symbols shall be transmitted at all other symbol positions (see Figure 10-2).

The O-P-VECTOR 1 sync symbols shall be generated as described in clause 10.5 of [ITU-T G.993.2]. These sync symbols shall modulate a pilot sequence. The pilot sequence is a repetitive sequence, as defined in clause 6.2.3, assigned to the initializing line by the vectoring control entity (VCE). Each probe tone of a sync symbol from the SUPPORTEDCARRIERSds set with a pilot sequence bit equal to ZERO shall modulate a 00 constellation point, and with a pilot sequence bit equal to ONE shall modulate a 11 constellation point. The 00 and 11 constellation points shall be per the 4-QAM constellation defined in clause 10.3.3.2.1 of [ITU-T G.993.2]. The constellation points on sub-carriers shall then be rotated by the quadrant scrambler defined in clause 12.3.6.2 of [ITU-T G.993.2].

If the bit "8192 superframes duration for O-P-VECTOR 1" is disabled in the ITU-T G.994.1 phase (see clause 10.2), then ~~F~~for sync symbols, the transmit PSD of all sub-carriers shall be equal to CDPSDds.

If the bit "8192 superframes duration for O-P-VECTOR 1" is enabled and the bit "Use of O-P-VECTOR 1 flag tones only" is disabled in the ITU-T G.994.1 phase (see clause 10.2), then for sync symbols, the transmit PSD of all sub-carriers shall be equal to CDPSDds.

If both the bit "8192 superframes duration for O-P-VECTOR 1" and the bit "Use of O-P-VECTOR 1 flag tones only" are enabled in the ITU-T G.994.1 phase (see clause 10.2), then for sync symbols, the transmit PSD of all sub-carriers shall be equal to CDPSDds, except that for the first *N* sync symbols, the transmit power of all probe tones shall be 0 (with *N* a value determined by the VCE, in the range from 0 to 2048 sync symbols).

NOTE 1 – A way to identify the value of *N* is described in Appendix II.

The duration of O-P-VECTOR 1 is vendor discretionary, but shall be minimum 4×257 symbols and maximum *M*×1024×257 symbols. Valid values for *M* are 1 and 8. Support of *M* = 1 is mandatory for the VTU-O and the VTU-R. Support of *M* = 8 is optional for both the VTU-O and the VTU-R. If the bit "8192 superframes duration for O-P-VECTOR 1" is enabled in the ITU-T G.994.1 phase (see clause 10.2), then *M* = 8. Otherwise, *M* = 1.

NOTE ~~1~~2 – The O-P-VECTOR 1 signal should be shortened by the VCE to accelerate full system start-up.

NOTE 3 – Appendix II provides examples of VCE control of the initialization process in the activation of multiple lines in the vectored group. Clause II.2 describes such VCE control using the "8192 superframes duration for O-P-VECTOR 1" capability in handling two groups of lines. Clause II.3 describes such VCE control using handshake capabilities.

During transmission of the O-P-VECTOR 1 signal, the SOC is in its inactive state.

During transmission of the O-P-VECTOR 1 signal, the VCE estimates the downstream FEXT channels from the initializing lines into the vectored lines based on the reported clipped error samples from the VTU-Rs of the vectored lines. From this point on, FEXT cancellation matrices are established in the VTU-Os for all vectored lines in the downstream direction and FEXT from the initializing line into vectored lines is cancelled.

The O-P-VECTOR 1 signal shall be followed by the O-P-CHANNEL DISCOVERY V1 signal, which determines the actual duration of O-P-VECTOR 1. The start time of O-P-CHANNEL DISCOVERY V1 transmission is determined by the VCE.

3) New Appendix II

Replace Appendix II and wording "Blank" with the following text:

Appendix II

Examples of VCE control of initialization process in the activation of multiple lines in the vectored group

(This appendix does not form an integral part of this Recommendation.)

II.1 Introduction

Vectoring is designed for the FEXT cancellation across multiple VDSL2 lines. In clause 10, the initialization is described in detail mainly from the viewpoint of a single line. This appendix provides two examples of methods allowing the VCE to handle activation of multiple lines that attempt to join the vectored group in arbitrary order. If the bit "8192 superframes duration for O-P-VECTOR 1" is enabled in the ITU-T G.994.1 phase (see clause 10.2), the VCE may use the first method based on the handling lines that became late for the current initialization cycle in a

waiting group. Alternatively, the VCE may use the second method based on ITU-T G.994.1 handshake capabilities to control the time when line is ready for joining.

II.2 VCE handling two groups of initializing lines

In this method, the VCE maintains initializing lines in two groups after the vectored group is started. One group is called "joining group" and the other is called "waiting group". Both of the groups have two states: the open state and the closed state. When a line enters the Channel Discovery phase of the initialization, it will be added to one of the groups. Table II.1 shows the decision to which group the line is added.

Table II.1 – VCE decision to which group the line is added

Joining group state	Open	Closed	Closed	Open
Waiting group state	Closed	Open	Closed	Open
Decision by the VCE for new lines	Added to the joining group	Added to the waiting group	Will be added to the waiting group when it opens	Not valid

Note that the joining group and the waiting group are never in the open state at the same time. The full mechanism is described as follows:

1. The joining group is a group of lines which are controlled by the VCE for normal initialization. These lines are currently performing or about to perform a normal initialization process after the ITU-T G.994.1 phase. Initially, after the system power is on, the joining group is open and empty. Once the VCE starts FEXT channel coefficient estimation (VTU-O starts transmission O-P-VECTOR 1 signal), the joining group is closed. The joining group can be open again when the joining process is over (no lines remain in the joining group). When a line in the joining group drops during the initialization or reaches Showtime, it is removed from the joining group.
2. The waiting group is a group of lines which are controlled by the VCE to wait prior to beginning their normal initialization after the ITU-T G.994.1 phase, until lines in the joining group complete their initialization. Initially, after the system power is on, the waiting group is closed and empty. The VCE can add new lines that have completed ITU-T G.994.1 handshake to the waiting group as follows:
   - if a line is ready to join the waiting group at an instant when the waiting group is open, it joins the waiting group and the VTU-O starts transmitting on the joining line the O-P-VECTOR 1 signal with all tones active until the lines in the joining group complete the initialization.
   - if a line is ready to join the waiting group at an instant when the waiting group is closed, then the VTU-O proceeds as follows:
     - if the bit "Use of O-P-VECTOR 1 flag tones only" is enabled in the ITU-T G.994.1 phase, the line joins the waiting group and the VTU-O starts transmitting on the joining line the O-P-VECTOR 1 signal with only flag tones active, while other tones are masked. When the waiting group opens, the VTU-O continues transmitting the O-P-VECTOR 1 signal now with all tones active until the lines in the joining group complete the initialization;

- if the bit "Use of O-P-VECTOR 1 flag tones only" is disabled in the ITU-T G.994.1 phase, the line waits up to 512 symbols for the waiting group to open. If the waiting group opens within 512 symbols, the VTU-O starts transmitting O-P-VECTOR 1 with all tones active until the lines in the joining group complete the initialization. Otherwise, the VTU-O returns to the state O-SILENT.

The waiting group can only be open when the joining group is closed. When the VCE estimates the FEXT channel coefficients, the waiting group is kept closed to avoid introducing non-orthogonal crosstalk from new lines. After the estimation of FEXT channel coefficients is finished, the waiting group can be open again. If a line in the waiting group drops during the initialization, it is removed from the waiting group.

3. When the joining lines transmit the O-P-VECTOR 1-1 and O-P-VECTOR 2-1 signals, the VCE estimates the downstream FEXT coupling coefficients from the lines of the waiting group into the lines that are in Showtime and into the lines of the joining group. Thus, the FEXT from the waiting group lines can be cancelled such that the SNR of the joining group lines can be measured with no impact of downstream FEXT from the waiting lines.
4. When the lines in the joining group are in the Channel Analysis and Exchange phase of initialization, the waiting group should be kept closed to avoid any new lines being added to the waiting group until all the joining lines have completed the SNR measurements. New lines cannot therefore disturb measuring SNR in the joining group in the Channel Analysis and Exchange phase.
5. Once there are no lines remaining in the joining group, all lines of the waiting group are moved into the joining group, and the waiting group is closed. After that, if the joining group is not empty, the VCE can start the Channel Discovery phase of the new initialization process. Otherwise, the joining group is kept open for the new activating lines thereafter.

The above procedure is illustrated in Figure II.1.

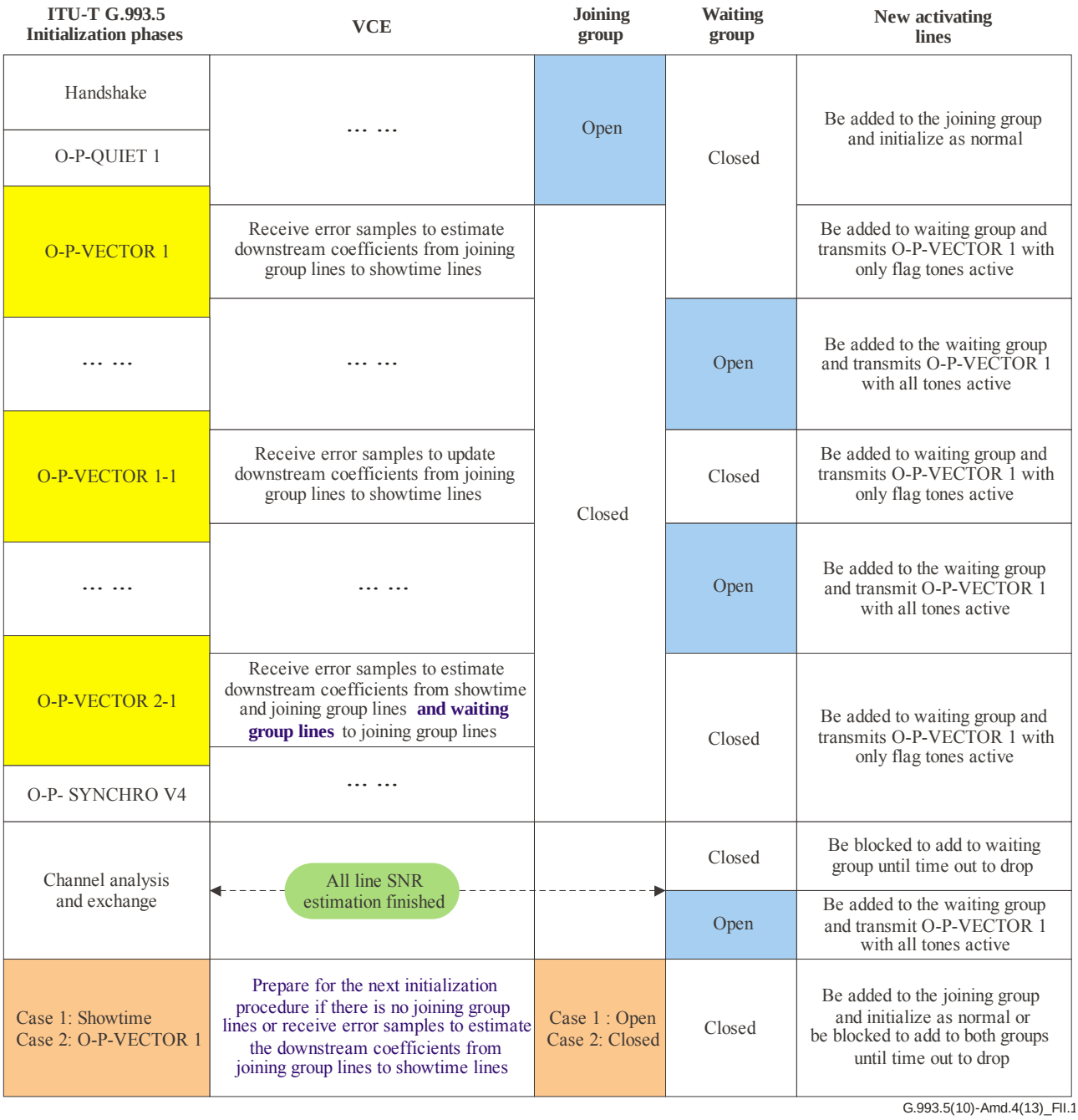

Figure II.1 – Status of joining and waiting groups, and the new activating lines during initialization (in the case where the bit "Use of O-P-VECTOR 1 flag tones only" is enabled in the ITU-T G.994.1 phase)

With this controlling mechanism by the VCE, at least the following three benefits can be achieved:

1. For the waiting group lines, they can start transmission of the O-P-VECTOR 1 signal even if they complete the ITU-T G.994.1 phase after other joining lines entered the Channel Discovery phase. Thus, the time of the ITU-T G.994.1 phase is saved. The O-P-VECTOR 1 time may be significantly shortened because VCE already estimated crosstalk from the majority of lines in the waiting group into active lines.
2. In the multiple lines initialization scenarios, the majority of lines that enter the Channel Discovery phase after the VCE starts to estimate the FEXT coupling channel coefficients will be added to the waiting group. Hence, they can start their initialization process in a synchronized step after the current initialization process handled by the VCE is completed.

All lines can go to Showtime in not more than two cycles of the vectoring initialization process (from Channel Discovery to Channel Analysis and Exchange). Thus, initialization time is substantially reduced compared to the current initialization process, in which lines that arrive after the beginning of initialization are dropped back to handshake and their initialization could last for multiple cycles of the vectoring initialization process.

3. If there are no new lines added to the waiting group after the SNR estimation during the Channel Analysis and Exchange phase, then the downstream FEXT channel coefficients from the lines of the waiting group into showtime lines are already handled by the VCE, and the O-P-VECTOR 1 stage can be passed straight forwardly by applying the minimum O-P-VECTOR 1 duration of 4 × 257 symbols. This further saves initialization time.

II.3 VCE using handshake capabilities

The activation of multiple lines in the vectored group may be managed by the VCE through the use of ITU-T G.994.1 handshake capabilities as follows:

1. When new lines in the vector group enter the ITU-T G.994.1 phase of initialization, the VTU-R may continually send R-TONES-REQ to initiate handshake as defined in [ITU-T G.994.1].
2. The VCE knows the state of all of the transceivers undergoing ITU-T G.993.5 initialization. When the VCE detects completion or near-completion of the ITU-T G.993.5 initialization cycle for the current group of joining lines, the VCE enables the VTU-Os that are detecting R-TONES-REQ to respond with C-TONES to progress with handshake for constructing the next group of joining lines.
3. The timeout of the VTU-Rs to the detection of O-SIGNATURE is vendor specific. It is observed that the duration of O-P-QUIET 1 is 1024 symbols maximum, that the duration of O-P-VECTOR 1 is 1024 × 257 symbols, and that the duration of O-IDLE is a maximum of 2000 symbols; this corresponds to a time period of approximately 66.5 seconds.

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