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TITLE: G.gen: G.vdsl: G.dmt.bis: G.lite.bis: : Text to include a Turbo Encoder as mandatory in the transmitter for G.992.1.bis and G.992.2.bis following the proposal given in BA-020R1 and HC-073

ABSTRACT

In this contribution VOCAL Technologies Ltd. provides text and detailed information for the implementation of a Turbo Encoder as mandatory in the transmitter for G.992.1.bis and G.992.2.bis recommendations presented in BA-020R1 and HC-073.

1. Introduction

In this contribution, VoCAL Technologies Ltd. provides text to include the use of Turbo-Coding as a mandatory option in the transmitter for G.992.1.bis and G.992.2.bis recommendations presented in BA-020R1 and HC-073.

2. Text to include Turbo Code in the G.992.1.bis and G.992.2.bis Recommendation

In this point we include the text to include Turbo Coding in the recommendation G.992.1.bis mG.992.2.bis as mandatory in the transmitter.

Similar techniques are already in other standards such as the 3GPP recommendation (3G TS 25.212 v3.2.0), Consultative Committee for Space Data Systems (CCSDS) , Intelsat Digital Services, Inmarsat M4 and the ADSL's competitor, the Digital Video Broadcasting DVB-RCS (ETSI standard EN 301 790 up to 2 Mbps). In this standardization bodies Turbo Codes have been chosen as the preferred coding technique, and there are already commercial systems that use these techniques [20, 21, 22, 23, 24].

An independent I and Q mapping for a parallel concatenated scheme is proposed. The independent mapping has the advantage of reduced number of computations/memory required for each bit estimate from the received symbol at no significant penalty in performance. For example, for a 1024QAM constellation made of two independent unidimensional 32PAM signals, only 32 possible transmitted symbols are compared to estimate the bit probability for each bit in the 32PAM symbol. If no independent I and Q mapping is used, then all 1024 possible transmitted symbols have to be used to estimate each bit probability.

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Another advantage is the proposed mapping of the information bit in the most protected position of the QAM symbol. As confirmed in ([25], [26]) this mapping gains 0.5 dB when compared with mapping the parity bits into the most protected position, as proposed in [27].

The proposed turbo code is a 16-state code defined by (35o, 23o). This turbo code has a coding gain of 1.8 dB with respect to the 8-state code defined by (17o, 15o) which was proposed in [27] for a 64 QAM with a spectral efficiency of 4 bits.

" **X.X Constellation encoder (Turbo Code version)**

Block processing by a 16-state turbo code can be used to improve system performance. An algorithmic constellation encoder shall be used to construct constellations with a maximum number of bits equal to $N_{downmax}$, where $8 \le N_{downmax} \le 16$. The use of the turbo coding is a mandatory option in the transmitter.

X.X.1 Bit extraction

Data bytes from the data frame buffer shall be extracted according to a re-ordered bit allocation table b'_i , least significant bit first. The extraction is based upon individual values of b'_i, as in the non-coded case. Furthermore, due to the constellation expansion associated with coding, the bit allocation table, b'_i, specifies the number of coded bits per tone, which can be any integer from 2 to 16 in multiple of 2.

X.X.2 Turbo Encoder

The proposed turbo coding scheme is shown in Figure 1. The two systematic recursive codes (SRC) used are identical and are defined in Figure 2. The code is described by the generating polynomials 35o and 23o in octal.

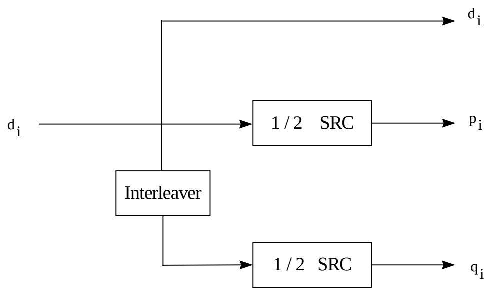

Figure 1

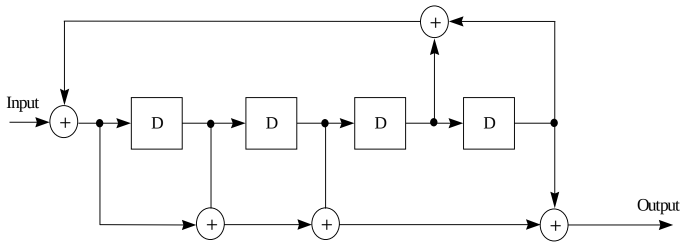

Figure 2

All the information bits are encoded.

All the information bits are sent to the first encoder and to the interleaver. The interleaver size is set to 14 DMT symbols, that permit an overall delay below 10 msec. After the interleaver, the interleaved bits are sent to the second encoder.

X.X.3 Turbo Code interleaver.

The Turbo code internal interleaver consists of bits-input to a rectangular matrix, intra-row and inter-row permutations of the rectangular matrix, and bits-output from the rectangular matrix with pruning. The bits input to the Turbo code internal interleaver are denoted by $x_1, x_2, x_3, \ldots, x_K$, where K is the integer number of the bits and takes one value of $40 \le K \le 32000$. The relation between the bits input to the Turbo code internal interleaver and the bits input to the channel coding is defined by $x_k = o_{irk}$ and $K = K_i$.

K	Number of bits input to Turbo code internal interleaver
R	Number of rows of rectangular matrix
C	Number of columns of rectangular matrix
p	Prime number
v	Primitive root
s(i)	Base sequence for intra-row permutation
qj	Minimum prime integers
rj	Permuted prime integers
T(j)	Inter-row permutation pattern
Uj(i)	Intra-row permutation pattern
i	Index of matrix
j	Index of matrix
k	Index of bit sequence

X.X.3.1 Bits-input to rectangular matrix

The bit sequence input to the Turbo code internal interleaver x_k is written into the rectangular matrix as follows.

(1) Determine the number of rows R of the rectangular matrix such that:

$$R = \begin{cases} 5, \text{if } (40 \le K \le 159) \\ 10, \text{if } ((160 \le K \le 200) \text{ or } (481 \le K \le 530)) \\ 20, \text{if } (K = \text{any other value}) \end{cases}$$

where the rows of rectangular matrix are numbered 0, 1, 2, …, R - 1 from top to bottom.

(2) Determine the number of columns C of rectangular matrix such that:

if (481 $\le K \le$ 530) then

$p = 53$ and $C = p$.

else

Find minimum prime p such that

$(p + 1) - K/R \ge 0$,

and determine C such that

if ($p - K/R \ge 0$) then

if ($p - 1 - K/R \ge 0$) then

$C = p - 1$.

else

$C = p$.

end if

else

$C = p + 1$

end if

end if

where the columns of rectangular matrix are numbered 0, 1, 2, …, C - 1 from left to right.

(3) Write the input bit sequence x_k into the $R\times C$ rectangular matrix row by row starting with bit x_1 in column
0 of row 0:

$$\begin{bmatrix} x_1 & x_2 & x_3 & \cdots x_C \\ x_{(C+1)} & x_{(C+2)} & x_{(C+3)} & \cdots x_{2C} \\ \vdots & \vdots & \vdots & \cdots \vdots \\ x_{((R-1)C+1)} & x_{((R-1)C+2)} & x_{((R-1)C+3)} & \cdots x_{RC} \end{bmatrix}$$

X.X.3.2 Intra-row and inter-row permutations

After the bits-input to the $R\times C$ rectangular matrix, the intra-row and inter-row permutations for the $R\times C$ rectangular matrix are performed by using the following algorithm.

(1) Select a primitive root v from table 2.

(2) Construct the base sequence $s(i)$ for intra-row permutation as:

$s(i) = [v \times s(i - 1)] \bmod p, i = 1, 2,\ldots, (p - 2).$, and $s(0) = 1$.

(3) Let $q_0 = 1$ be the first prime integer in $\{q_j\}$, and select the consecutive minimum prime integers $\{q_j\}$ (j =
1, 2, …, R - 1) such that:
g.c.d$\{q_j, p - 1\} = 1$, $q_j > 6$, and $q_j > q_{(j-1)}$,

where g.c.d. is greatest common divisor.

(4) Permute $\{q_j\}$ to make $\{r_j\}$ such that

$r_{T(j)} = q_j$, $j = 0, 1, \ldots, R - 1$,

where $T(j)$ (j = 0, 1, 2, …, R - 1) is the inter-row permutation pattern defined as the one of the following four kind of patterns: Pat_1, Pat_2, Pat_3 and Pat_4 depending on the number of input bits K.

$$\{T(0), T(1), T(2), ..., T(R-1)\} = \begin{cases} Pat_4 & \text{if } (40 \le K \le 159) \\ Pat_3 & \text{if } (160 \le K \le 200) \\ Pat_1 & \text{if } (201 \le K \le 480) \\ Pat_3 & \text{if } (481 \le K \le 530) \\ Pat_1 & \text{if } (531 \le K \le 2280) \\ Pat_2 & \text{if } (2281 \le K \le 2480) \\ Pat_1 & \text{if } (2481 \le K \le 3160) \\ Pat_2 & \text{if } (3161 \le K \le 3210) \\ Pat_1 & \text{if } (3211 \le K) \end{cases},$$

where Pat_1, Pat_2, Pat_3 and Pat_4 have the following patterns respectively.

Pat_1: {19, 9, 14, 4, 0, 2, 5, 7, 12, 18, 10, 8, 13, 17, 3, 1, 16, 6, 15, 11}
Pat_2: {19, 9, 14, 4, 0, 2, 5, 7, 12, 18, 16, 13, 17, 15, 3, 1, 6, 11, 8, 10}
Pat_3: {9, 8, 7, 6, 5, 4, 3, 2, 1, 0}
Pat_4: {4, 3, 2, 1, 0}

(5) Perform the j-th (j = 0, 1, 2, …, R - 1) intra-row permutation as:

if ($C = p$) then

$U_j(i) = s([i \times r_j] \bmod (p - 1))$, i = 0, 1, 2, …, (p - 2)., and $U_j(p - 1) = 0$,

where $U_j(i)$ is the input bit position of i-th output after the permutation of j-th row.

end if

if ($C = p + 1$) then

$U_j(i) = s([i \times r_j] \bmod (p - 1))$, i = 0, 1, 2, …, (p - 2)., $U_j(p - 1) = 0$, and $U_j(p) = p$,

where $U_j(i)$ is the input bit position of i-th output after the permutation of j-th row, and

if ($K = C \times R$) then

Exchange $U_{R-1}(p)$ with $U_{R-1}(0)$.

end if

end if

if ($C = p - 1$) then

$U_j(i) = s([i \times r_j] \bmod (p - 1)) - 1$, i = 0, 1, 2, …, (p - 2),

where $U_j(i)$ is the input bit position of i-th output after the permutation of j-th row.

end if

(6) Perform the inter-row permutation based on the pattern $T(j)$ (j = 0, 1, 2, …, R - 1), where $T(j)$ is the original row position of the j-th permuted row.

Table 2: Table of prime *p* and associated primitive root *v*

p	v	p	v	p	v	p	v	p	v
7	3	313	10	709	2	1129	11	1597	11
11	2	317	2	719	11	1151	17	1601	3
13	2	331	3	727	5	1153	5	1607	5
17	3	337	10	733	6	1163	5	1609	7
19	2	347	2	739	3	1171	2	1613	3
23	5	349	2	743	5	1181	7	1619	2
29	2	353	3	751	3	1187	2	1621	2
31	3	359	7	757	2	1193	3	1627	3
37	2	367	6	761	6	1201	11	1637	2
41	6	373	2	769	11	1213	2	1657	11
43	3	379	2	773	2	1217	3	1663	3
47	5	383	5	787	2	1223	5	1667	2
53	2	389	2	797	2	1229	2	1669	2
59	2	397	5	809	3	1231	3	1693	2
61	2	401	3	811	3	1237	2	1697	3
67	2	409	21	821	2	1249	7	1699	3
71	7	419	2	823	3	1259	2	1709	3
73	5	421	2	827	2	1277	2	1721	3
79	3	431	7	829	2	1279	3	1723	3
83	2	433	5	839	11	1283	2	1733	2
89	3	439	15	853	2	1289	6	1741	2
97	5	443	2	857	3	1291	2	1747	2
101	2	449	3	859	2	1297	10	1753	7
103	5	457	13	863	5	1301	2	1759	6
107	2	461	2	877	2	1303	6	1777	5
109	6	463	3	881	3	1307	2	1783	10
113	3	467	2	883	2	1319	13	1787	2
127	3	479	13	887	5	1321	13	1789	6
131	2	487	3	907	2	1327	3	1801	11
137	3	491	2	911	17	1361	3	1811	6
139	2	499	7	919	7	1367	5	1823	5
149	2	503	5	929	3	1373	2	1831	3
151	6	509	2	937	5	1381	2	1847	5
157	5	521	3	941	2	1399	13	1861	2
163	2	523	2	947	2	1409	3	1867	2
167	5	541	2	953	3	1423	3	1871	14
173	2	547	2	967	5	1427	2	1873	10
179	2	557	2	971	6	1429	6	1877	2
181	2	563	2	977	3	1433	3	1879	6
191	19	569	3	983	5	1439	7	1889	3
193	5	571	3	991	6	1447	3	1901	2
197	2	577	5	997	7	1451	2	1907	2
199	3	587	2	1009	11	1453	2	1913	3
211	2	593	3	1013	3	1459	3	1931	2
223	3	599	7	1019	2	1471	6	1933	5
227	2	601	7	1021	10	1481	3	1949	2
229	6	607	3	1031	14	1483	2	1951	3
233	3	613	2	1033	5	1487	5	1973	2
239	7	617	3	1039	3	1489	14	1979	2
241	7	619	2	1049	3	1493	2	1987	2
251	6	631	3	1051	7	1499	2	1993	5
257	3	641	3	1061	2	1511	11	1997	2
263	5	643	11	1063	3	1523	2	1999	3
269	2	647	5	1069	6	1531	2		
271	6	653	2	1087	3	1543	5		
277	5	659	2	1091	2	1549	2		
281	3	661	2	1093	5	1553	3		

p	v	p	v	p	v	p	v	p	v
283	3	673	5	1097	3	1559	19		
293	2	677	2	1103	5	1567	3		
307	5	683	5	1109	2	1571	2		
311	17	691	3	1117	2	1579	3		

X.X.3.3 Bits-output from rectangular matrix with pruning

After intra-row and inter-row permutations, the bits of the permuted rectangular matrix are denoted by y'_k:

$$\begin{bmatrix} y'_1 & y'_{(R+1)} & y'_{(2R+1)} & \cdots y'_{((C-1)R+1)} \\ y'_2 & y'_{(R+2)} & y'_{(2R+2)} & \cdots y'_{((C-1)R+2)} \\ \vdots & \vdots & \vdots & \cdots & \vdots \\ y'_R & y'_{2R} & y'_{3R} & \cdots & y'_{CR} \end{bmatrix}$$

The output of the Turbo code internal interleaver is the bit sequence read out column by column from the intra-row and inter-row permuted $R \times C$ matrix starting with bit y'_1 in row 0 of column 0 and ending with bit y'_{CR} in row R - 1 of column C - 1. The output is pruned by deleting bits that were not present in the input bit sequence, i.e. bits y'_k that corresponds to bits x_k with $k > K$ are removed from the output. The bits output from Turbo code internal interleaver are denoted by x'_1, x'_2, …, x'_K, where x'_1 corresponds to the bit y'_k with smallest index k after pruning, x'_2 to the bit y'_k with second smallest index k after pruning, and so on. The number of bits output from Turbo code internal interleaver is K and the total number of pruned bits is: $R \times C – K$.

X.X.4 Constellation encoder

For a given tone, the encoder shall select the number of bits that this tone can transport. This number must be always a multiple of 2, so that the constellations are always square (i.e. if the tone can transport up to 13 bits, the constellation must be of 14 bits).

For a given tone, the encoder shall select a point *(X, Y)* from the square-grid constellation based on the *b* bits of $\{v_{b-1}, v_{b-2}, ..., v_1, v_0\}$. NOTE - v_0 is the first bit extracted from the buffer.

X.X.4.1 Even values of b, b>1

For even values of *b*, b>1, the integer values *X* and *Y* of the constellation point *(X, Y)* shall be determined from the *b* bits $\{v_{b-1}, v_{b-2}, ..., v_1, v_0\}$.

X.X.4.1.1 Even values of b, b=2

The puncturing pattern is given in Table 1.

Table 1. Puncturing and Mapping for b = 2.

Information bit (d)	d_1	d_2
Parity bit (p)	p_1	-
Parity bit (q)	-	q_2
2AM symbol (I)	$(u_1) = (d_1)$	$(u_1) = (d_2)$
2AM symbol (Q)	$(u_2) = (p_1)$	$(u_2) = (q_2)$
4QAM symbol (I , Q)	$(I,Q) = (u_1, u_2) = (d_1, p_1)$	$(I,Q) = (u_1, u_2) = (d_2, q_2)$

X.X.4.1.2 Even values of b, b=4

The puncturing pattern is given in Table 2.

Table 2. Puncturing and Mapping for b = 4

Information bit (d)	d_1	d_2	d_3	d_4	d_5	d_6
parity bit (p)	-	p_2	-	-	-	-
parity bit (q)	-	-	-	-	q_5	-
4AM symbol (I)	(d_1, d_2)			(d_4, d_5)		
4AM symbol (Q)	(d_3, p_2)			(d_6, p_5)		
16 QAM symbol (I ,Q)	$(I, Q) = (d_1, d_2, d_3, p_2)$			$(I, Q) = (d_4, d_5, d_6, q_5)$		

X.X.4.1.3 Even values of b, b=6

The puncturing pattern is given in Table 3.

Table 3. Puncturing and Mapping for b = 6

Information bit (d)	d_1	d_2	d_3	d_4
parity bit (p)	p_1	-	-	-
parity bit (q)	-	-	q_3	-
8AM symbol (I)	(d_1, d_2, p_1)			
8AM symbol (Q)	(d_3, d_4, q_3)			
64 QAM symbol (I , Q)	$(I, Q)=(d_1, d_2, p_1, d_3, d_4, q_3)$			

X.X.4.1.4 Even values of b, b=8

The puncturing pattern is given in Table 4.

Table 4. Puncturing and Mapping for b = 8.

Information bit (d)	d_1	d_2	d_3	d_4	d_5	d_6	d_7	d_8	d_9	d_{10}
parity bit (p)	p_1	-	-	-	p_5	-	-	p_8	-	-
parity bit (q)	-	-	q_3	-		q_6	-	-	-	q_{10}
16AM symbol (I)	(d_1, d_2, d_3, p_1)					(d_6, d_7, d_8, q_6)				
16AM symbol (Q)	(d_4, d_5, q_3, p_5)					$(d_9, d_{10}, p_8, q_{10})$				
256 QAM symbol (I , Q)	$(d_1, d_2, d_3, p_1, d_4, d_5, q_3, p_5)$					$(d_6, d_7, d_8, q_6, d_9, d_{10}, p_8, q_{10})$				

X.X.4.1.5 Even values of b, b=10

The puncturing pattern is given in Table 5.

Table 5. Puncturing and Mapping for b = 10

Information bit (d)	d_1	d_2	d_3	d_4	d_5	d_6	d_7	d_8	d_9	d_{10}	d_{11}	d_{12}	d_{13}	d_{14}
parity bit (p)	p_1	-	-	-	-	p_6	-	-	-	-	p_{11}	-	-	-
parity bit (q)	-	-	q_3	-	-	-	-	q_8	-	-	-	-	q_{13}	-
32AM symbol (I)	$(d_1, d_2, d_3, p_1, q_3)$							$(d_8, d_9, d_{10}, d_{11}, q_8)$						
32AM symbol (Q)	$(d_4, d_5, d_6, d_7, p_6)$							$(d_{12}, d_{13}, d_{14}, p_{11}, q_{13})$						
1024QAM symbol	$(d_1, d_2, d_3, p_1, q_3, d_4, d_5, d_6, d_7, p_6)$							$(d_8, d_9, d_{10}, d_{11}, q_8, d_{12}, d_{13}, d_{14}, p_{11}, q_{13})$						

X.X.4.1.6 Even values of b, b=12

The puncturing pattern is given in Table 6.

Table 6. Puncturing and Mapping for b = 12

Information bit (d)	d_1	d_2	d_3	d_4	d_5	d_6	d_7	d_8	d_9	d_{10}
parity bit (p)	p_1	-	-	-	-	-	-	-	-	-
parity bit (q)	-	-	-	-	-	q_6	-	-	-	-
64 AM symbol (I)	$(d_1, d_2 , d_3, d_4 d_5, p_1)$									
64 AM symbol (Q)	$(d_6, d_7, d_8 ,d_9 , d_{10}, q_6)$									
4096 QAM symbol (I , Q)	$(d_1, d_2 , d_3, d_4 d_5, p_1, d_6, d_7, d_8 ,d_9 , d_{10}, q_6)$									

X.X.4.1.7 Even values of b, b=14

The puncturing pattern is given in Table 7.

Table 7. Puncturing and Mapping for b = 14

Information bit (d)	d_1	d_2	d_3	d_4	d_5	d_6	d_7	d_8	d_9	d_{10}	d_{11}	d_{12}
parity bit (p)	p_1	-	-	-	-	-	-	-	-	-	-	-
parity bit (q)	-	-	-	-	-	-	q_7	-	-	-	-	-
128AM symbol (I)	$(d_1, d_2 , d_3, d_4 d_5, d_6 , p_1)$											
128AM symbol (Q)	$(d_7, d_8, d_9 ,d_{10} , d_{11}, d_{12}, q_7)$											
16384 QAM symbol (I , Q)	$(d_1, d_2 , d_3, d_4 d_5, d_6 , p_1, d_7, d_8, d_9 ,d_{10} , d_{11}, d_{12}, q_7)$											

X.X.4.1.8 Even values of b, b=16

The puncturing pattern is given in Table 8.

Table 8. Puncturing and Mapping for b = 16

Information bit (d)	d_1	d_2	d_3	d_4	d_5	d_6	d_7	d_8	d_9	d_{10}	d_{11}	d_{12}	d_{13}	d_{14}
parity bit (p)	p_1	-	-	-	-	-	-	-	-	-	-	-	-	-
parity bit (q)	-	-	-	-	-	-	-	q_8	-	-	-	-	-	-
256AM symbol (I)	$(d_1, d_2 , d_3, d_4 d_5, d_6 , d_7 , p_1)$													
256AM symbol (Q)	$(d_8, d_9 ,d_{10} , d_{11}, d_{12}, d_{13} , d_{14} , q_8)$													
65536 QAM symbol (I , Q)	$(d_1, d_2 , d_3, d_4 d_5, d_6 , d_7 , p_1, d_8, d_9 ,d_{10} , d_{11}, d_{12}, d_{13} , d_{14} , q_8)$													

X.X.4.2 Od d values of b.

For odd values of b, a non-square constellation is formed from two square separable constituent independent I&Q constellations. The following steps are used to form the square separable constellations:

1. Start with a square constellation that has double the number of points, i.e. 2^{b+1} points, than the non-square constellation to be used, i.e. 2^n points (For example, for a 32 QAM, start with a 64 QAM constellation) with independent I&Q and Gray mapping.

2. Delete every other point in each dimension such that each row keeps half of the points and each column keeps half of the points. The constellation points that remain must have the same distance between them.

3. Assign to each remaining point, a number formed from the bits of the I value and bits of the Q value of the original constellation mapping, where the least significant bit of the I value has been removed.

The resulting non-square constellation can be decoded with independent probabilities. When one bit in a dimension is removed, the resulting bits have independent I and Q.

For each of the constituent square constellations, proceed according to section X.X.4.1.

X.X.5 Case A and case B constellations.

In the case of b = 2, the first tone that can use b = 2 use case A constellation, that is defined as the first mapping, (I,Q) = (u_1,u_2) = (d_1, p_1). The next tone that can use b = 2, uses case B constellations, that is defined as the second mapping, (I,Q) = (u_1, u_2) = (d_2, q_2). The next tone that use b = 2 uses again case A constellations etc.

This is extendible to more than one DMT symbol, if the last tone with b = 2 in the DMT symbol k is constellation case A, the first tone with b=2 in the k+1 DMT symbol will use constellation case B.

The same procedure is applicable to b = 4, b = 8 and b = 10.

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3. Conclusion

We propose text for G.992.1.bis and G.992.2.bis recommendations, for the use of Turbo Codes as a mandatory option in the transmitter and allow the receiver to select the option in G.hs. We also propose the use of sized constellations with independent I & Q decoding. The reason to include in the standard is to allow manufacturer interoperability, and provide improvements over Trellis Codification Modulation.

4. Summary

We recommend that G.992.1.bis, G.992.2.bis and G.vdsl use Turbo Codes to reach longer loops or increase the throughput of the system.

1. Agenda Item: G.992.1.bis issue 4.2, G.992.2.bis issue 1.4 and G.vdsl issue 11.17.
2. Expectations: The committee accepts the baseline text described in this paper.

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