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TITLE: G.gen.bis: G.dmt.bis: G.lite.bis: Performance of full Turbo coding with variable interleaver with more protection to the information bits for G.992.1.bis and G.992.2.bis

ABSTRACT

This contribution presents simulation results of the performance of full turbo coding with a variable interleaver size and protecting more the information bits than the parity bits for G.992.1.bis and G.992.2.bis.

1. Introduction

This paper provides the evaluation of VOCAL's proposed Turbo codes for G.992.1.bis and G.992.2.bis as described in BA-020R1, according to the requirements requested in the Coding Ad Hoc report from the Antwerp meeting (BA-108R1). The same technique is proposed for G.vdsl.

This document introduces two differences with B-020R1. One is the inclusion of the 12 bit per tone patterns and the second is the modification of the interleaver proposed, that is the one defined by the 3GPP mobile group and proposed in part by document BA-088R1. Some parameters are included to allow the generation of the interleavers.

2. Description of the method for its implementation

2.1 Capacity Bounds

The minimum E_b/N_0 values to achieve the Shannon bound 64 QAM and 16384 QAM bounds for spectral efficiencies of 4 and 12 bits/s/Hz respectively are as in Table 1 for a BER=10^{-5}.

Table 1. Shannon bounds.

Spectral efficiency η [bit/s/Hz]	Shannon bound Eb/No [dB]
4	5.6
12	24.7

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The conversion from SNR to E_b / N_0 is performed using the following relation

$$E_b / N_0[dB] = SNR\ [dB] - 10 \log_{10}(\eta)\ [dB] \qquad (1)$$

where η is the number of information bits per symbol.

For a D-dimension modulation the following formulae are used:

$$SNR = \frac{E[|a_k^2|]}{E[|w_k^2|]} = \frac{E[|a_k^2|]}{D\sigma_N^2} = \frac{E_{av}}{D\sigma_N^2} \qquad (2)$$

$$SNR = \frac{E_s}{D\frac{N_0}{2}} = \frac{\eta E_b}{D\frac{N_0}{2}} \qquad (3)$$

where σ^2_N is the noise variance in each of the D dimension and η is the number of information bits per symbol. From the above relations:

$$\sigma_N^2 = E_{av}\left(\frac{2\eta E_b}{N_0}\right)^{-1} \qquad (4)$$

2.2 Coding

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

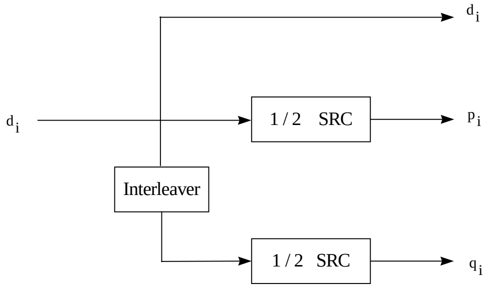

Figure 1

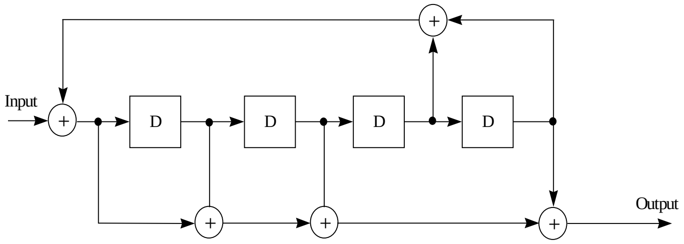

Figure 2

2.3 Turbo code internal interleaver.

It is recommended to use the interleaver defined in HC-073 from the 3GPP.

2.4. Coding And Modulation For 4 Bit/S/Hz Spectral Efficiency.

2.4.1 Puncturing

In order to obtain a rate 4/6 code, the puncturing pattern used is shown in Table 3.

Table 3. Puncturing and Mapping for Rate 4/6 64 QAM

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)	$(I, Q)=(d_1, d_2, p_1, d_3, d_4, q_3)$			

2.4.2 Modulation

Gray mapping was used in each dimension. Four information bits are required to be sent using a 64 QAM constellation. For a rate 4/6 code and 64 QAM, the noise variance in each dimension is

$$E_{av} = (8(49+25+9+1+25+49+49+9+49+1+25+9+25+1+9+1))\, A^2 / 64 = 42\, A^2 \qquad (10)$$

$$\sigma_N^2 = E_{av}\left(\frac{2\eta E_b}{N_0}\right)^{-1} = 42\, A^2\left(\frac{2 \times 4 \times E_b}{N_0}\right)^{-1} = 5.25\, A^2\left(\frac{E_b}{N_0}\right)^{-1} \qquad (11)$$

The puncturing and mapping scheme is shown in Table 6 for 4 consecutive information bits that are encoded into 6 coded bits, therefore one 64 QAM symbol. The turbo encoder with the puncturing presented in Table 6 is a rate 4/6 turbo code which in conjunction with 64 QAM gives a spectral efficiency of 4 bits/s/Hz. Considering two independent Gaussian noises with identical variance σ^2_N, the LLR can be determined independently for each I and Q. It is assumed that at time k u_1^k, u_2^k and u_3^k modulate the I component and u_4^k, u_5^k and u_6^k modulate the Q component of the 64 QAM scheme. At the receiver, the I and Q signals are treated independently in order to take advantage of the simpler formulae for the LLR values.

2.4.3 Bit Probabilities

The 8AM symbol is defined as $u^k = (u_1^k, u_2^k, u_3^k)$, where u_1^k is the most significant bit and u_3^k is the least significant bit . The following set can be defined.

bit-1-is-1 = $\{ A_4, A_5, A_6, A_7 \}$; bit-2-is-1 = $\{A_0, A_1, A_6, A_7\}$; bit-3-is-1 = $\{A_1, A_2, A_5, A_6\}$

From each received symbol, the bit probabilities are computed as follows:

$$LLR(u_n^k) = \log\left(\frac{\sum_{i=1}^{4} \exp[-\frac{1}{2\sigma_N^2}\left(I^k - a_{1,i,n}^k\right)^2]}{\sum_{i=1}^{4} \exp[-\frac{1}{2\sigma_N^2}\left(I^k - a_{0,i,n}^k\right)^2]}\right) \qquad (12)$$

For I dimension. An identical computation effort is required for the Q dimension, the I^k being replaced with the Q^k demodulated value in order to evaluate LLR(u_4^k), LLR(u_5^k) and LLR(u_6^k).

2.4.4 Simulation Results

Figure 3 shows the simulation results for 10,400 information bits with interleaver option 1. A BER of 10^{-7} can be achieved after 8 iterations at E_b/N_0 = 8.3 dB.

2.5 Coding And Modulation For 12 Bit/S/Hz Spectral Efficiency.

This section investigated a rate 12/14 coding scheme with 16384 QAM.

2.5.1 Puncturing

In order to obtain a rate 12/14 code, the puncturing pattern used is shown in Table 4.

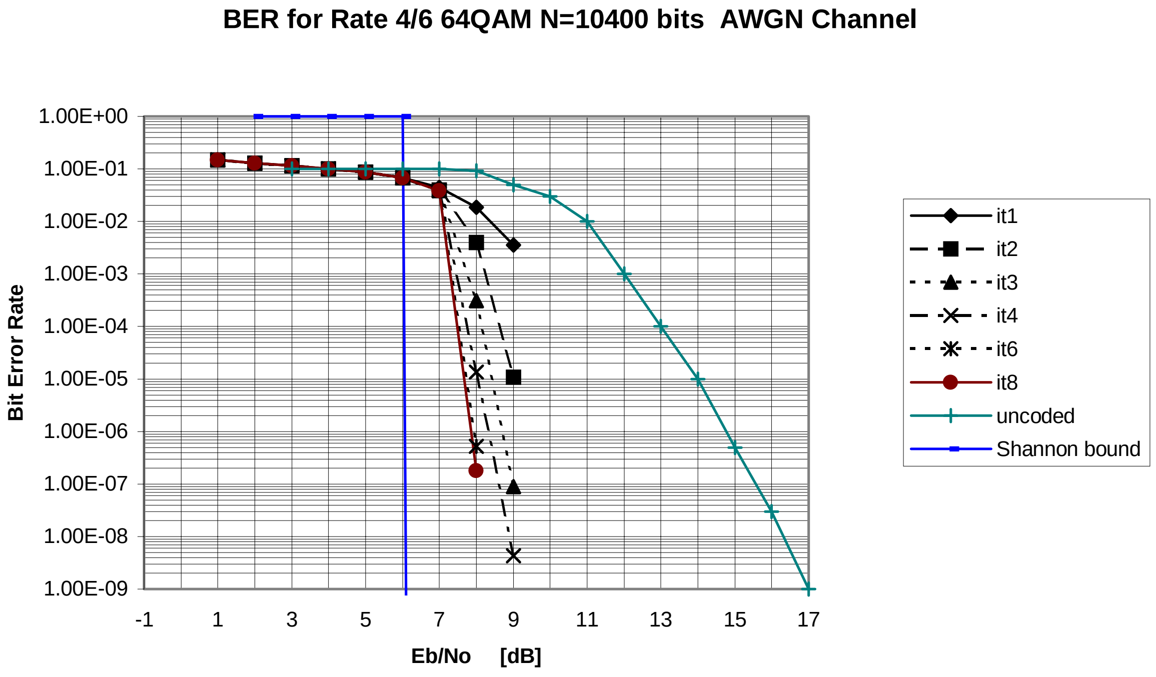

Figure 3.

Table 4. Puncturing and Mapping for Rate 12/14 16384 QAM

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)	$(d_1, d_2, d_3, d_4 d_5, d_6, p_1, d_7, d_8, d_9, d_{10}, d_{11}, d_{12}, q_7)$											

2.5.2 Modulation

For a 16384 QAM constellation with points at –127A, -125A, -123A, -121A, -119A, -117A, -115A, -113A, -111A, -109A, -107A, -105A, -103A, -101A, -99A, -97A, -95A, -93A, -91A, -89A, -87A, -85A, -83A, -81A, -79A, -77A, -75A, -73A, -71A, -69A, -67A, -65A, -63A, -61A, -59A, -57A, -55A, -53A, -51A, -49A, -47A, -45A, -43A, -41A, -39A, -37A, -35A, -33A, -31A, -29A, -27A, -25A, -23A, -21A, -19A, -17A, –15A, -13A, -11A, -9A, -7A, -5A, -3A, -A, A, 3A, 5A, 7A, 9A, 11A, 13A, 15A, 17A, 19A, 21A, 23A, 25A, 27A, 29A, 31A, 33A, 35A, 37A, 39A, 41A, 43A, 45A, 47A, 49A, 51A, 53A, 55A, 57A, 59A, 61A, 63A, 65A, 67A, 69A, 71A, 73A, 75A, 77A, 79A, 81A, 83A, 95A, 87A, 89A, 91A, 93A, 95A, 97A, 99A, 101A, 103A, 105A, 107A, 109A, 111A, 113A, 115A, 117A, 119A, 121A, 123A, 125A, 127A. E_{av} is:

$$E_{av} = 5461 A^2 \tag{13}$$

It is assumed that at time k the symbol $u^k = (u_1^k, u_2^k, u_3^k, u_4^k, u_5^k, u_6^k, u_7^k, u_8^k, u_9^k, u_{10}^k, u_{11}^k, u_{12}^k, u_{13}^k, u_{14}^k)$ is sent though the channel. It is assumed that at time k the symbol u_1^k, u_2^k, u_3^k, u_4^k, u_5^k, u_6^k and u_7^k modulate the I component and u_8^k, u_9^k, u_{10}^k u_{11}^k, u_{12}^k, u_{13}^k and u_{14}^k modulate the Q component of a 16384 QAM scheme.

For a rate 12/14 code and 16384 QAM, the noise variance is:

$$\sigma_N^2 = E_{av}\left(\frac{2\eta E_b}{N_0}\right)^{-1} = 5461 A^2\left(\frac{2 \text{ x } 6 \text{ x } E_b}{N_0}\right)^{-1} = 455.08 A^2\left(\frac{E_b}{N_0}\right)^{-1} \tag{14}$$

In order to study the performance of this scheme, a rate 6/7 turbo code and a 128AM is used. The 16384 QAM scheme will achieve a similar performance in terms of bit error rate (BER) at twice the spectral efficiency, assuming an ideal demodulator. The puncturing and mapping scheme shown in Table 8 is for 12 consecutive information bits that are coded into 14 encoded bits, therefore, one 16384 QAM symbol. The turbo encoder is a rate 12/14 turbo code, which in conjunction with 16384 QAM, gives a spectral efficiency of 12 bits/s/Hz.

2.5.3 Bit Probabilities

The 128AM symbol is defined as $u^k = (u_1^k, u_2^k, u_3^k, u_4^k, u_5^k, u_6^k, u_7^k)$, where u_1^k is the most significant bit and u_7^k is the least significant bit . The following set can be defined.

1. bit-1-is-1 = $\{A_{64},A_{65},A_{66}, A_{67}, A_{68}, A_{69}, A_{70}, A_{71}, A_{72}, A_{73}, A_{74}, A_{75}, A_{76}, A_{77}, A_{78}, A_{79}$
   $A_{80}, A_{81}, A_{82}, A_{83}, A_{84}, A_{85}, A_{86}, A_{87}, A_{88}, A_{89}, A_{90}, A_{91}, A_{92}, A_{93}, A_{94}, A_{95}$
   $A_{96}, A_{97}, A_{98}, A_{99}, A_{100}, A_{101}, A_{102}, A_{103}, A_{104}, A_{105}, A_{106}, A_{107}, A_{108}, A_{109}, A_{110}, A_{111}$
   $A_{112}, A_{113}, A_{114}, A_{115}, A_{116}, A_{117}, A_{118}, A_{119}, A_{120}, A_{121}, A_{122}, A_{123}, A_{124}, A_{125}, A_{126}, A_{127}\}$
2. bit-2-is-1 = $\{A_{32}, A_{33}, A_{34}, A_{35}, A_{36}, A_{37}, A_{38}, A_{39}, A_{40}, A_{41}, A_{42}, A_{43}, A_{44}, A_{45}, A_{46}, A_{47}$
   $A_{48}, A_{49}, A_{50}, A_{51}, A_{52}, A_{53}, A_{54}, A_{55}, A_{56}, A_{57}, A_{58}, A_{59}, A_{60}, A_{61}, A_{62}, A_{63}$
   $A_{64}, A_{65}, A_{66}, A_{67}, A_{68}, A_{69}, A_{70}, A_{71}, A_{72}, A_{73}, A_{74}, A_{75}, A_{76}, A_{77}, A_{78}, A_{79}$
   $A_{80}, A_{81}, A_{82}, A_{83}, A_{84}, A_{85}, A_{86}, A_{87}, A_{88}, A_{89}, A_{90}, A_{91}, A_{92}, A_{93}, A_{94}, A_{95}\}$
3. bit-3-is-1 = $\{A_{16}, A_{17}, A_{18}, A_{19}, A_{20}, A_{21}, A_{22}, A_{23}, A_{24}, A_{25}, A_{26}, A_{27}, A_{28}, A_{29}, A_{30}, A_{31}$
   $A_{32}, A_{33}, A_{34}, A_{35}, A_{36}, A_{37}, A_{38}, A_{39}, A_{40}, A_{41}, A_{42}, A_{43}, A_{44}, A_{45}, A_{46}, A_{47}$
   $A_{80}, A_{81}, A_{82}, A_{83}, A_{84}, A_{85}, A_{86}, A_{87}, A_{88}, A_{89}, A_{90}, A_{91}, A_{92}, A_{93}, A_{94}, A_{95}$
   $A_{96}, A_{97}, A_{98}, A_{99}, A_{100}, A_{101}, A_{102}, A_{103}, A_{104}, A_{105}, A_{106}, A_{107}, A_{108}, A_{109}, A_{110}, A_{111}$
   $\}$
4. bit-4-is-1 = $\{A_8, A_9, A_{10}, A_{11}, A_{12}, A_{13}, A_{14}, A_{15}, A_{16}, A_{17}, A_{18}, A_{19}, A_{20}, A_{21}, A_{22}, A_{23},$
   $A_{40}, A_{41}, A_{42}, A_{43}, A_{44}, A_{45}, A_{46}, A_{47}, A_{48}, A_{49}, A_{50}, A_{51}, A_{52}, A_{53}, A_{54}, A_{55},$
   $A_{72}, A_{73}, A_{74}, A_{75}, A_{76}, A_{77}, A_{78}, A_{79}, A_{80}, A_{81}, A_{82}, A_{83}, A_{84}, A_{85}, A_{86}, A_{87},$
   $A_{104}, A_{105}, A_{106}, A_{107}, A_{108}, A_{109}, A_{110}, A_{111}, A_{112}, A_{113}, A_{114}, A_{115}, A_{116}, A_{117}, A_{118}, A_{119},$
   $\}$
5. bit-5-is-1 = $\{A_4, A_5, A_6, A_7, A_8, A_9, A_{10}, A_{11}, A_{20}, A_{21}, A_{22}, A_{23}, A_{24}, A_{25}, A_{26}, A_{27}$
   $A_{36}, A_{37}, A_{38}, A_{39}, A_{40}, A_{41}, A_{42}, A_{43}, A_{52}, A_{53}, A_{54}, A_{55}, A_{56}, A_{57}, A_{58}, A_{59}$
   $A_{68}, A_{69}, A_{70}, A_{71}, A_{72}, A_{73}, A_{74}, A_{75}, A_{84}, A_{85}, A_{86}, A_{87}, A_{88}, A_{89}, A_{90}, A_{91},$
   $A_{100}, A_{101}, A_{102}, A_{103}, A_{104}, A_{105}, A_{106}, A_{107} A_{116}, A_{117}, A_{118}, A_{119}, A_{120}, A_{121}, A_{122}, A_{123}, \}$
6. bit-6-is-1 = $\{A_0, A_1\ A_6, A_7, A_8, A_9, A_{14}, A_{15}, A_{16}, A_{17}\ A_{22}, A_{23}, A_{24}, A_{25}, A_{30}, A_{31}$
   $A_{32}, A_{33}\ A_{38}, A_{39}, A_{40}, A_{41}\ A_{46}, A_{47}, A_{48}, A_{49}\ A_{54}, A_{55}, A_{56}, A_{57}\ A_{62}, A_{63}$
   $A_{64}, A_{65}, A_{70}, A_{71}, A_{72}, A_{73}, A_{78}, A_{79}, A_{80}, A_{81}, A_{86}, A_{87}, A_{88}, A_{89}, A_{94}, A_{95}$
   $A_{96}, A_{97}, A_{102}, A_{103}, A_{104}, A_{105}, A_{110}, A_{111}\ A_{112}, A_{113}, , A_{118}, A_{119}, A_{120}, A_{121}, A_{126}, A_{127}\}$
7. bit-7-is-1 = $\{A_1, A_2, A_5, A_6, A_9, A_{10}, A_{13}, A_{14}, A_{17}, A_{18}, A_{21}, A_{22}, A_{25}, A_{26}, A_{29}, A_{30},$
   $A_{33}, A_{34}, A_{37}, A_{38}, A_{41}, A_{42}, A_{45}, A_{46}, A_{49}, A_{50}, A_{53}, A_{54}, A_{57}, A_{58}, A_{61}, A_{62}$
   $A_{65}, A_{66}, A_{69}, A_{70}, A_{73}, A_{74}, A_{77}, A_{78}, A_{81}, A_{82}, A_{85}, A_{86}, A_{89}, A_{90}, A_{93}, A_{94}, A_{97},$
   $A_{98}, A_{101}, A_{102}, A_{105}, A_{106}, A_{109}, A_{110}, A_{113}, A_{114}, A_{117}, A_{118}, A_{121}, A_{122}, A_{125}, A_{126}\}$

From each received symbol, R^k , the bit probabilities are computed as follows:

$$LLR(u_n^k) = \log\left(\frac{\displaystyle\sum_{A_i \in bit\text{-}n\text{-}is\text{-}1} \exp\left(-\frac{1}{2\sigma_N^2} \left\| R^k - A_i \right\| \right)}{\displaystyle\sum_{A_j \in bit\text{-}n\text{-}is\text{-}0} \exp\left(-\frac{1}{2\sigma_N^2} \left\| R^k - A_j \right\| \right)} \right) \qquad (17)$$

2.5.4 Simulation Results

Figure 4 shows the simulation results for 31200 information bits with interleaver option 1. A BER of 10^{-7} can be achieved after 8 iterations at E_b/N_0 = 28.5 dB.

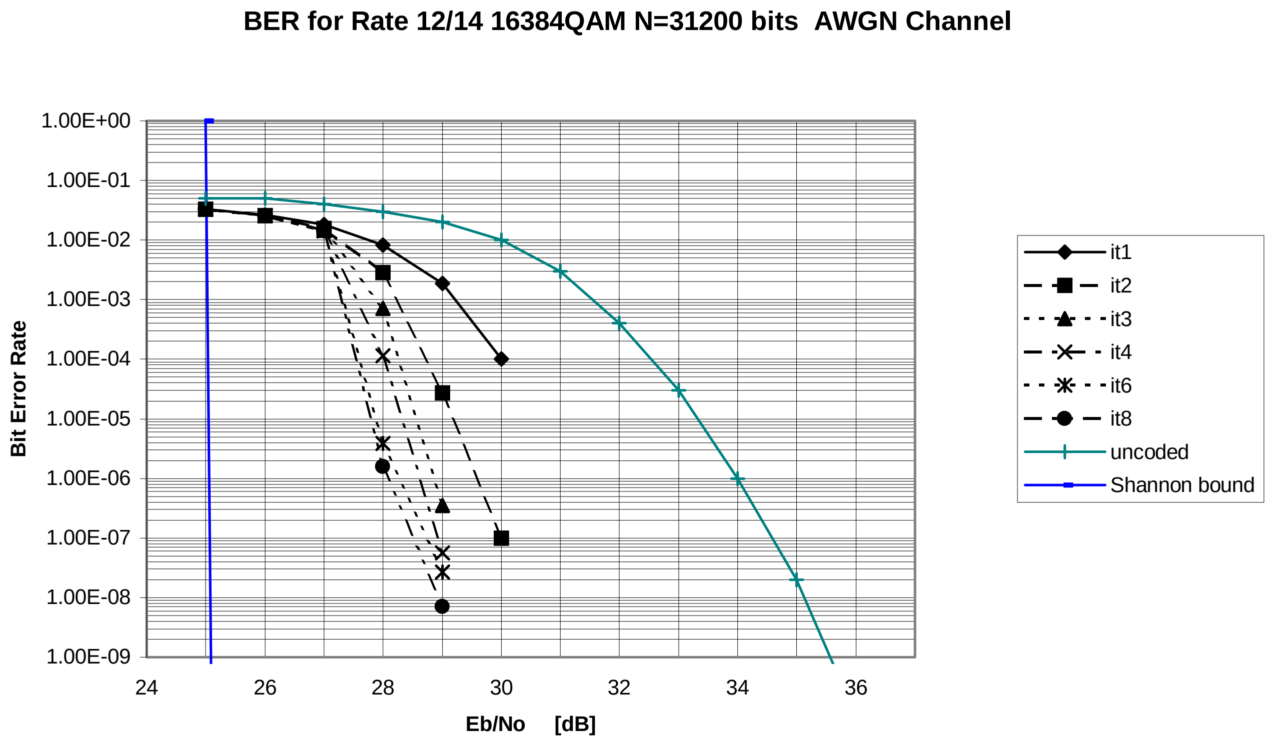

Figure 4

3. Results.

3.1 Without Reed-Solomon

3.1.1 Net Coding Gain.

Table 5. Net Coding Gain

Bit/Tone	Tones	Interleaver Size	# of DMT symbols	Latency (Tx+Rx) ms <	10^{-3}	10^{-7}	10^{-9} exp
4	100	5,200	13	10.0	**4.60**	**7.42**	**7.94**
		800	2	1.5	3.70	4.92	4.84
		400	1	0	3.30	3.62	3.84
	200	10,400	13	10.0	**4.60**	**7.52**	**8.14**
		1,600	2	1.5	4.10	6.42	6.64
		800	1	0	3.70	4.92	4.84
12	100	15,600	13	10.0	**4.10**	**5.91**	**6.03**
		2,400	2	1.5	3.60	5.51	5.63
		1,200	1	0	3.00	3.91	4.03
	200	31,200	13	10.0	4.10	5.81	6.53
		4,800	2	1.5	3.60	5.91	6.43
		2,400	1	0	3.60	5.51	5.63
4	100	TCM	1	0.5	**1.38**	**3.30**	**3.65**
4	200	TCM	1	0.5	**1.45**	**3.38**	**3.75**
12	100	TCM	1	0.5	**1.38**	**3.4**	**3.83**

3.1.2 Errors due to Impulse noise.

The impulse noise is defined as 2 consecutive DMT symbols with an increase AWGN respect to the reference noise level of a carrier-to-noise ratio of 21.5 dB (for 4 bit/tone) and 45.5 dB (for 12 bit/tone).

Table 6. Error due to Impulse Noise

Bit/ Tone	Tones	Interleaver Size	RL + 2.5 dB	RL + 5 dB	RL + 7.5 dB	RL + 10 dB	RL + 12.5 dB	RL + 15 dB	RL + 17.5 dB	RL + 20 dB
4	100	5,200	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**4**
		800	0	0	39	65	104	140	188	243
		400	0	0	10	50	89	127	161	214
	200	10,400	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**7**
		1,600	0	0	0	127	189	267	363	448
		800	0	0	40	116	187	252	346	440
12	100	15,600	**0**	**0**	**0**	**0**	**10**	**58**	**130**	**207**
		2,400	0	0	40	78	121	171	216	295
		1,200	0	0	43	98	129	188	255	329
	200	31,200	0	0	0	0	90	175	313	482
		4,800	0	0	75	177	254	341	462	608
		2,400	0	0	80	166	244	345	457	598
4	100	TCM	**0**	**0**	**65**	**125**	**175**	**250**	**313**	**375**
4	100	TCM	**0**	**0**	**140**	**250**	**370**	**500**	**630**	**760**
12	200	TCM	**0**	**0**	**100**	**175**	**275**	**340**	**405**	**470**

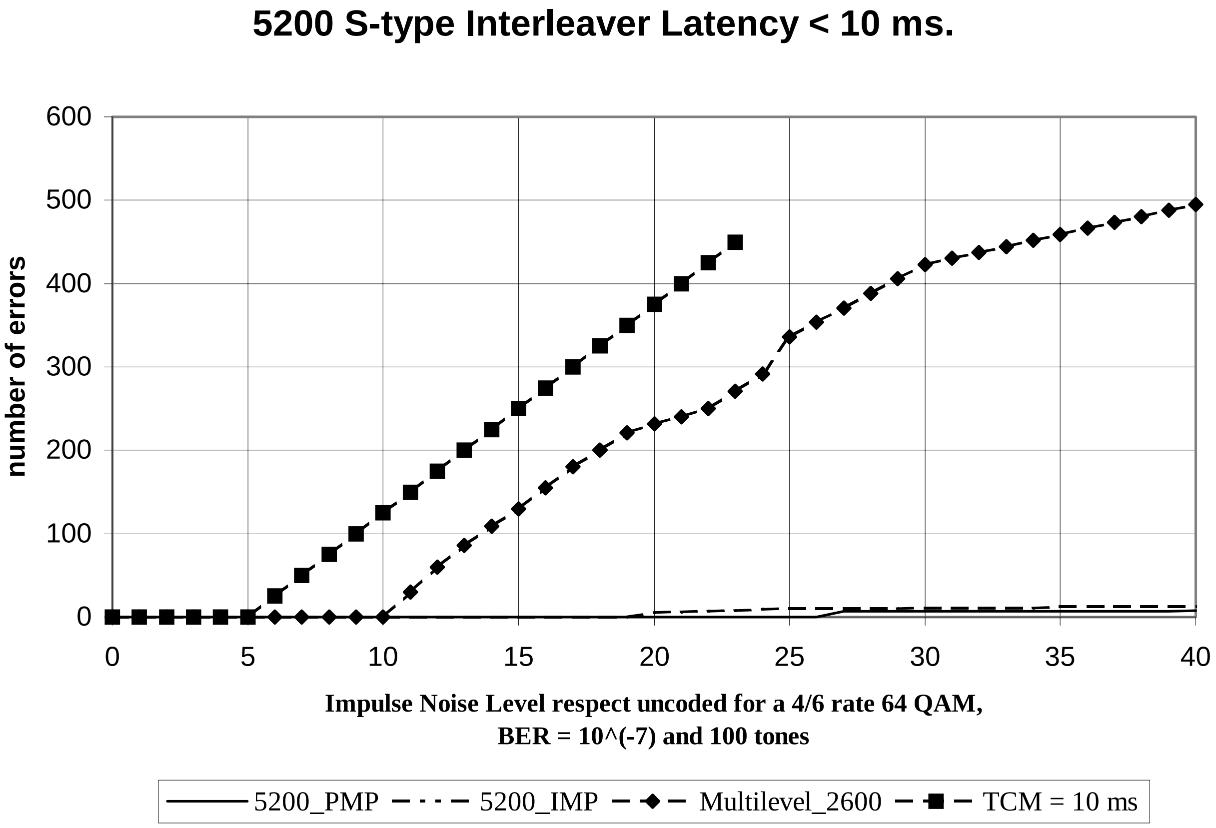

Figure 5. Errors due to Impulse Noise for a rate 4/6 64 QAM and 100 tones

3.1.3 Error Statistics.

3.1.3.1 For AWGN

Table 7. Error Statistics for AWGN

Bit/Tone	Tones	Interleaver Size	1 consec. error	2 consec errors	3 consec errors	4 consec errors	5 consec errors	6 consec errors
4	100	5,200	87.30%	10.81%	1.47%	0.29%	0.03%	0.10%
		800	94.35%	5.64%	0.00%	0.00%	0.00%	0.00%
		400	90.28%	9.72%	0.01%	0.00%	0.00%	0.00%
	200	10,400	89.90%	8.63%	1.21%	0.20%	0.06%	0.00%
		1,600	97.94%	2.06%	0.00%	0.00%	0.00%	0.00%
		800	90.28%	9.72%	0.01%	0.00%	0.00%	0.00%
12	100	15,600	99.79%	0.21%	0.00%	0.00%	0.00%	0.00%
		2,400	98.72%	1.28%	0.00%	0.00%	0.00%	0.00%
		1,200	97.94%	2.06%	0.00%	0.00%	0.00%	0.00%
	200	31,200	99.86%	0.14%	0.00%	0.00%	0.00%	0.00%
		4,800	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%
		2,400	98.72%	1.28%	0.00%	0.00%	0.00%	0.00%

3.1.3.2 Impulse Noise

Table 8. Error Statistics for Impulse noise

Bit/Tone	Tones	Interleaver Size	1 consec. error	2 consec errors	3 consec errors	4 consec errors	5 consec errors	6 consec errors
4	100	5,200	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%
		800	75.97%	18.99%	18.99%	3.36%	0.84%	0.84%
		400	79.89%	17.24%	1.72%	1.15%	0.00%	0.00%
	200	10,400	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%
		1,600	80.24%	13.05%	4.47%	1.68%	0.47%	0.00%
		800	79.03%	17.50%	2.46%	0.46%	0.46%	0.00%
12	100	15,600	95.19%	4.81%	0.00%	0.00%	0.00%	0.00%
		2,400	94.61%	5.28%	0.11%	0.00%	0.00%	0.00%
		1,200	93.63%	5.95%	93.63%	0.00%	0.00%	0.00%
	200	31,200	93.25%	6.65%	0.00%	0.00%	0.00%	0.00%
		4,800	94.89%	4.95%	0.16%	0.00%	0.00%	0.00%
		2,400	94.59%	5.36%	0.06%	0.00%	0.00%	0.00%

It is interesting that for the large turbo decoders the impulse errors still tends to stay within the 2 DMT symbols. This implies a moderately large turbo coder of 5 ms follow by a convolutional interleaver/Reed Solomon of 10 ms should create both robust performance and good impulse resistance.

3.2 With Reed-Solomon

3.2.1 Net Coding Gain.

Table 9. Coding Gain

Bit/Tone	Tones	Interleaver Size	# of DMT symbols	Latency (Tx+Rx) ms <	10^{-3}	10^{-7}	10^{-9} extrap.
4	100	5,200	13	10.0	**5.00**	**8.62**	**9.64**
		800	2	1.5	3.50	7.12	8.44
		400	1	0.7	3.50	6.42	7.44
	200	10,400	13	10.0	**5.30**	**8.82**	**9.84**
		1,600	2	1.5	4.60	7.72	8.74
		800	1	0.7	3.50	7.12	8.44
12	100	15,600	13	10.0	**4.40**	**7.71**	**8.53**
		2,400	2	1.5	4.60	7.41	8.33
		1,200	1	0.7	4.10	6.81	7.63
	200	31,200	13	10.0	4.40	7.71	8.53
		4,800	2	1.5	4.40	7.21	8.13
		2,400	1	0.7	4.60	7.41	8.33

Table 10. Net Coding Gain

Bit/Tone	Tones	Interleaver Size	# of DMT symbols	Latency (Tx+Rx) ms <	10^{-3}	10^{-7}	10^{-9} extrap.
4	100	5,200	13	10.0	**3.42**	**7.04**	**8.06**
		800	2	1.5	1.78	5.40	6.72
		400	1	0.7	1.94	4.86	5.88
	200	10,400	13	10.0	**3.72**	**7.24**	**8.26**
		1,600	2	1.5	2.88	6.00	7.02
		800	1	0.7	1.94	5.56	6.88
12	100	15,600	13	10.0	**0.20**	**3.51**	**4.33**
		2,400	2	1.5	0.02	2.83	3.75
		1,200	1	0.7	-0.24	2.47	3.29
	200	31,200	13	10.0	1.06	3.57	4.39
		4,800	2	1.5	0.76	3.57	4.49
		2,400	1	0.7	0.26	3.07	3.99
4	100	TCM	1	10	**1.33**	**5.01**	**6.12**
4	200	TCM	1	10	**1.37**	**5.15**	**6.27**
12	100	TCM	1	10	**0.87**	**4.29**	**5.22**

3.2.2 Errors due to Impulse noise.

The impulse noise is defined as 2 consecutive DMT symbols with an increase AWGN respect to the reference noise level of a carrier-to-noise ratio of 21.5 dB (for 4 bit/tone) and 45.5 dB (for 12 bit/tone).

Table 11. Error due to Impulse Noise

Bit/ Tone	Tones	Interleaver Size	RL + 2.5 dB	RL + 5 dB	RL + 7.5 dB	RL + 10 dB	RL + 12.5 dB	RL + 15 dB	RL + 17.5 dB	RL + 20 dB
4	100	5,200	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
		800	0	0	0	0	0	0	0	0
		400	0	0	0	0	0	0	0	0
	200	10,400	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
		1,600	0	0	0	0	0	0	0	0
		800	0	0	0	0	0	0	0	0
12	100	15,600	**0**	**0**	**0**	**0**	**10**	**58**	**130**	**207**
		2,400	0	0	0	0	0	0	0	0
		1,200	0	0	0	0	0	0	0	0
	200	31,200	0	0	0	0	90	175	313	482
		4,800	0	0	0	0	0	10	11	65
		2,400	0	0	0	0	9	10	24	115
4	100	TCM	**0**	**0**	**65**	**125**	**175**	**250**	**313**	**375**
4	100	TCM	**0**	**0**	**140**	**250**	**370**	**500**	**630**	**760**
12	200	TCM	**0**	**0**	**100**	**175**	**275**	**340**	**405**	**470**

3.2.3 Error Statistics.

The statistics results obtained are practically the same than for the non Reed-Solomon case

4. Summary:

This paper provides the evaluation of VOCAL’s proposed Turbo codes for G.992.1.bis and G.992.2.bis as described in BA-020R1, according to the requirements requested in the Coding Ad Hoc report from the Antwerp meeting (BA-108R1). The same technique is proposed for G.vdsl.

The performance for non-flat SNR channel is implementation dependent. With the same procedure used in CF-062, the performance results are equivalent.

The present paper relates to a technique for implementation of Turbo Code for DSL modems. Taken into account the benefits of Turbo Codes for DSL modems it is recommend to include Turbo Codes in the next DSL’s ITU Recommendations.

1. Agenda Item: G.992.1.bis issue 4.6 and G.992.2.bis issue 10.14.
2. Expectations: The committee accepts the inclusion of Turbo codes for G.992.1.bis, G.992.2.bis