Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	**Convolutional Turbo Codes for 802.16**
Date Submitted	**2002-07-02**
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Re:	
Abstract	Demonstrates that current optional coding scheme does not provide material benefit and proposes additional optional coding scheme.
Purpose	Provide background for comments submitted.
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Optional Coding Schemes for 802.16

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In addition to the text below that was part of the C802.16a-02/59 contribution made in Calgary, please see the BRAN contribution BRAN29d050.

Optional Coding

Richard Van Nee, et al., *OFDM for Wireless Multimedia Communications*, pages 62-63.

> "For frequency selective channels […] the Euclidean distance should be spread over as many symbols as possible, such that a few lost symbols have the smallest possible impact on the probability of a decoding error. As a consequence, in fading channels it is preferable to use high-order QAM constellations in combination with low-rate coding schemes."

This contribution demonstrates that the optional channel coding in the draft 802.16 standard provides little (between 0.6 and 0.8 dB) improvement over the mandatory forward error correction schemes. In light of poor performance it is proposed to add another optional channel coding be added to enable more material coding gain improvements.

The new optional channel coding scheme is compatible with all modes currently specified in the draft standard. It is also worth noting that this second optional forward error correction scheme was present in earlier versions of the draft standard (at late as meeting 17), so the current proposal is not attempting to bring in new material at this late time.

The proposal also adds virtually no additional complexity to the MAC layer, and in fact is much simpler from a messaging standpoint than the additional messages used for TPC coding. Additionally, the proposal leverages the DVB-T/RCT roots of the OFDMA mode by using similar channel coding.

Since some may still wish to implement the current optional channel coding for the small performance gains it offers we do not propose that it be removed or replaced. However, we do submit the more powerful forward error correction should be made available as part of the standard.

In the first part of this contribution the AWGN performance of the mandatory and optional schemes are compared. Additionally, performance results for the second optional coding scheme are also provided. In the second part of this contribution, the performance of the convolutional Turbo Codes is compared with the performance of the mandatory channel coding in selected fading channel models.

It should be noted that the performance improvement realized in fading channels from the use of Convolutional Turbo Codes is on the order of 6dB (or more) providing significant overall system performance improvement.

For simplicity the mandatory coding scheme is simulated as a convolutional code only of identical overall rate, rather than the concatenated code. For bit error rates between 1.0E-4 to 1.0E-6 the performance of the two codes is virtually identical.

New text to be added to the standard has been submitted in a separate comment.

Performance of the current FEC Schemes

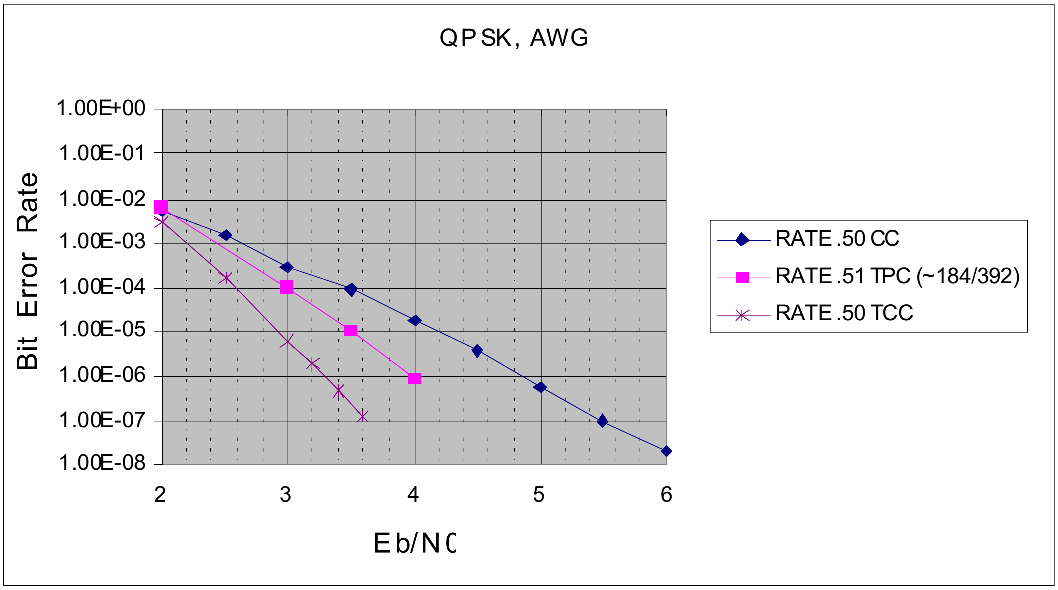

Figure 1. QPSK Rate _ OFDM Mode in AWGN

The current optional QPSK rate _ channel coding only provides 0.8 dB improvement at a BER of 1e-6. A new TCC channel coding would provide 1.5 dB additional coding gain, almost twice the improvement of TPC.

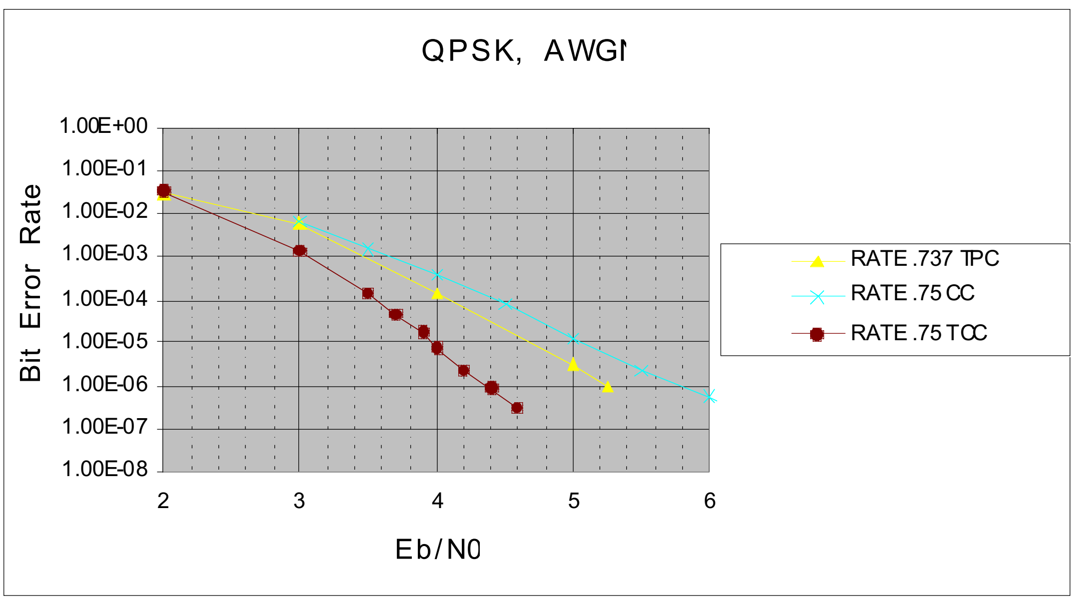

Figure 2. QPSK Rate3/4 OFDM Mode in AWGN

The optional QPSK rate 3/4 channel coding only provides 0.6 dB improvement over the mandatory mode at a BER of 1e-6. A new TCC option would provide a more material 1.4 dB improvement.

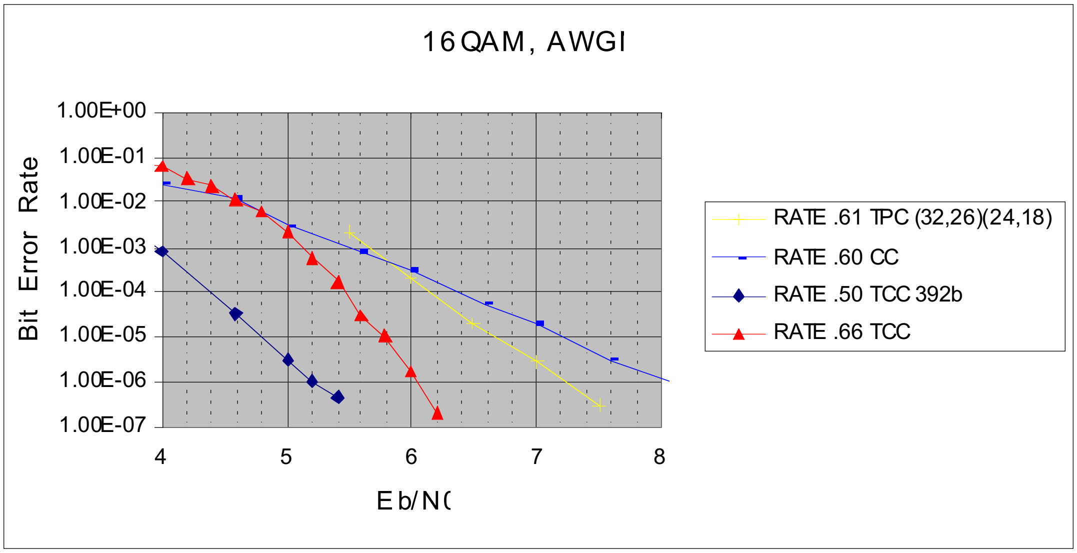

Figure 3. QPSK Rate3/4 OFDM Mode in AWGN

The current optional 16QAM rate 3/5 channel coding only provides 0.8 dB improvement at a BER of 1e-6. A new TCC rate 2/3 provides 2.0 dB coding gain (150% increase) over the mandatory channel coding, and an additional 10% increase in throughput over the optional channel coding. Alternatively, a new rate 1/2 Turbo Code would provide 2.0 dB additional coding gain over the optional rate 3/5 channel coding mode.

These results are just for the OFDM mode. The performance of the optional channel coding is even worse for OFDMA mode as the frame sizes are smaller.

Fading Channel Results

The following fading simulations were performed using ideal channel state information. The results show that the combination of OFDM modulation and Turbo Code channel coding provides 6 dB (or more) additional coding gain over the mandatory channel. Thus, Turbo-OFDM forms a powerful communication solution for non-line-of-sight communications.

The simulation results for the mandatory scheme are consistent with simulation results presented in [1]. For simplicity the mandatory coding scheme is simulated as just a convolutional code of identical overall rate, rather than the concatenated code. For bit error rates between 1e-4 to 1e-6 the performance of the two codes is virtually identical.

We welcome confirmation or correction of these results, as well as supplemental information including TPC and concatenated coding results. To facilitate comparison between results no power control was used during the simulation.

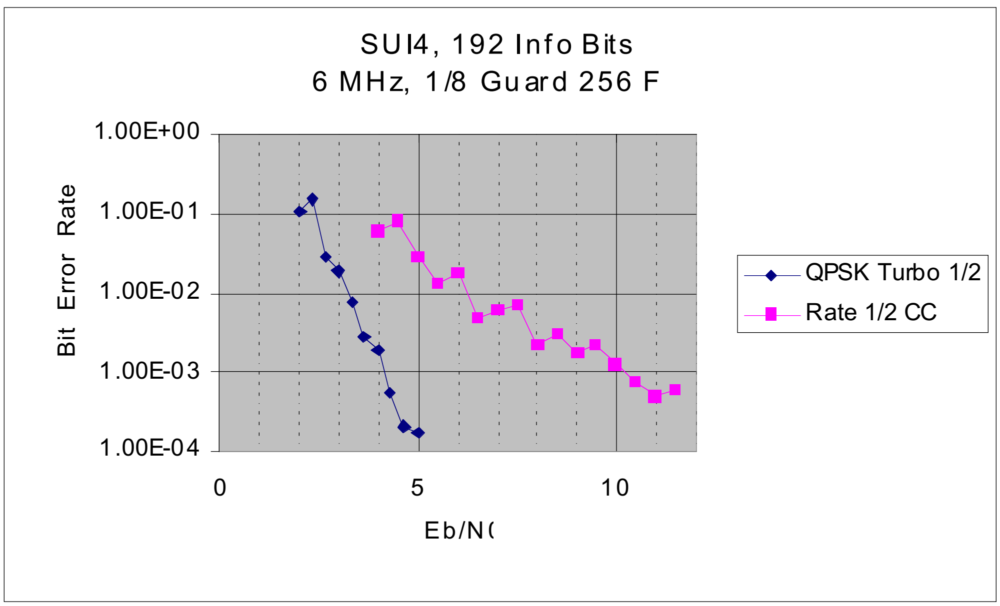

Figure 4. Fading Channel OFDM QPSK 1/2

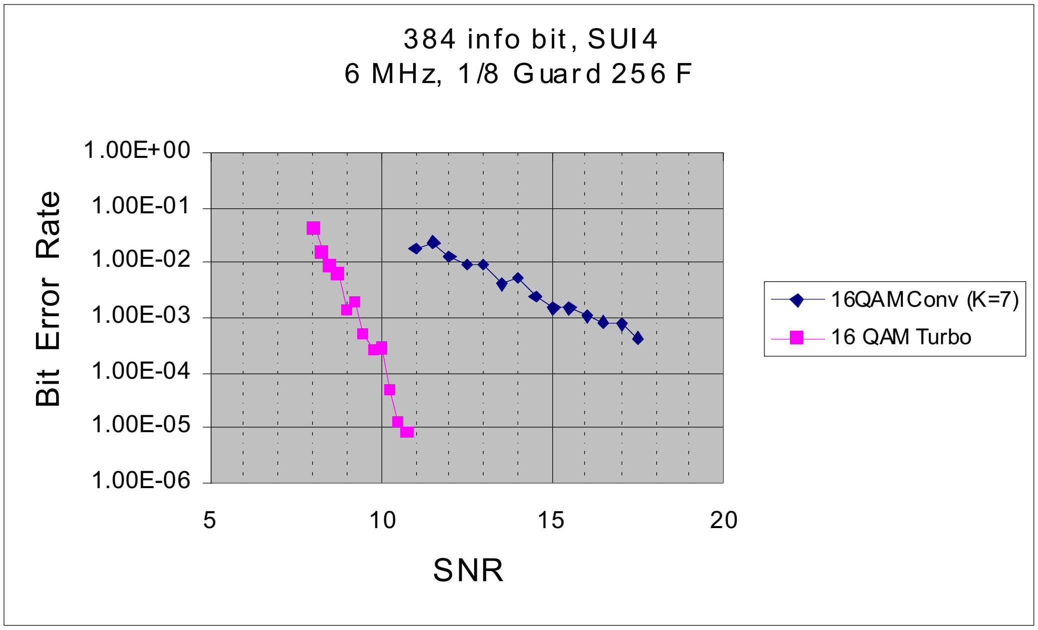

Figure 5. Fading Channel OFDM 16QAM Rate _ SUI4

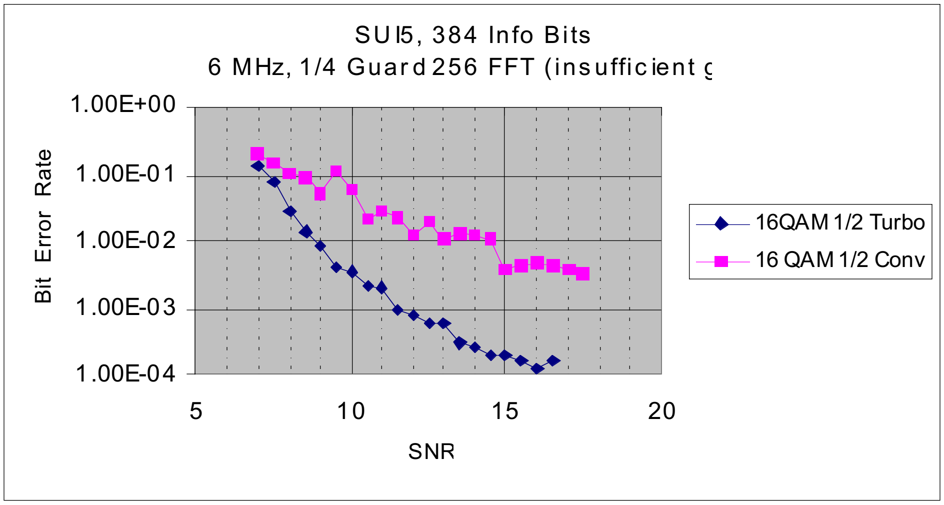

Figure 4. Fading Channel OFDM 16QAM _ SUI5

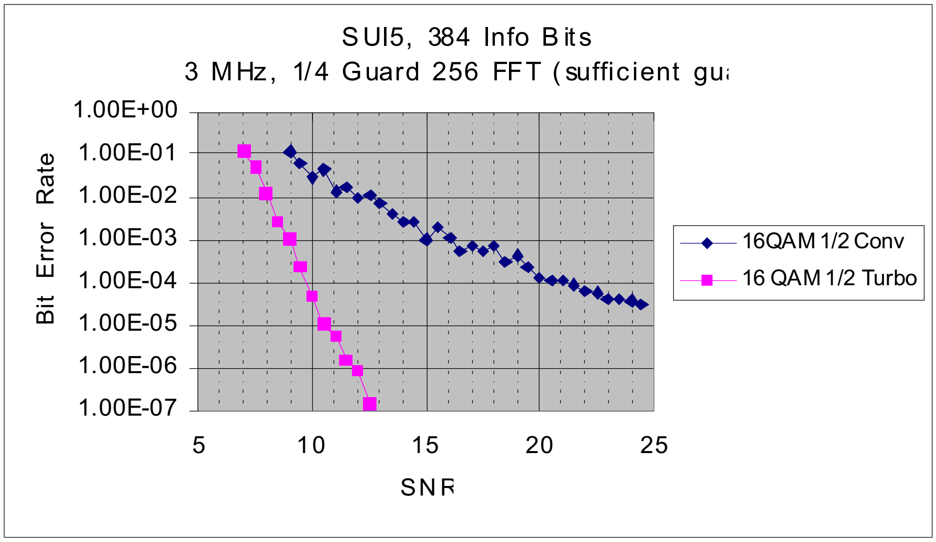

Figure 4. Fading Channel OFDM 16QAM _ SUI5 (2)

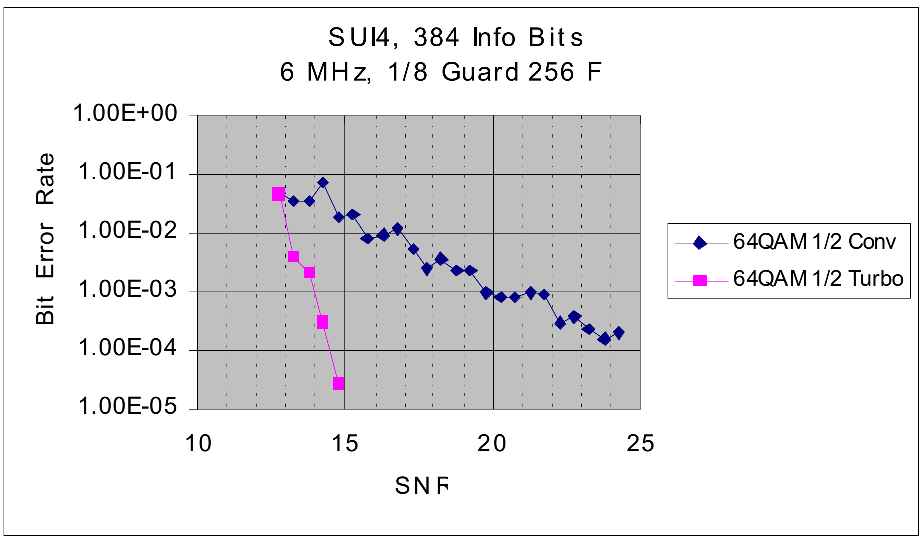

Figure 4. Fading Channel OFDM 64QAM Rate _ SUI4

Conclusion

Convolutional based Turbo Codes provide a more powerful channel coding option for 802.16. The improvements provided are particularly significant in the anticipated non line-of-sight channel environments for which the 802.16 wireless standard was designed.

Convolutional Turbo Codes improve the performance of all the modes currently specified including single carrier, OFDM, OFDMA and OFDMA2.

A second optional channel coding is particularly necessary in this case because of the minimal performance improvements supplied by the current optional channel coding.

Adding another optional channel coding scheme to 802.16 provides minimal additional complexity at the MAC and other layers as the information frame sizes are identical to those of the mandatory coding scheme (unlike TPC which creates new frame sizes).

References

[1] Richard Van Nee, et al., *OFDM for Wireless Multimedia Communications*, 2000, pp 68-69.

Appendix B additions:

B.1.3

The Turbo Code encoder is depicted in Figure 1. It uses a double binary Circular Recursive Systematic Convolutional (CRSC) code. The MSB of the first bit in the encoded frame is assigned to A, the next to B and so on for the rest of the encoded frame.

The encoder is fed by blocks of k bits or N couples (k = 2*N bits). For all the frame sizes k is a multiple of 8 and N is a multiple of 4.

The polynomials defining the connections are described in octal and symbol notations as follows:

- for the feedback branch: 015 (hex), equivalently $1+D+D^3$ (in symbolic notation)
- for the Y parity bit: 13, equivalently $1+D^2+D^3$

The input A bit is connect to tap 1 of the shift register and the input B is connected to the taps “1”, D and D^2.

First, the encoder (after initialization by the circulation state S_{c1}, see below) is fed the sequence in the natural order (position 1) with the incremental address i = 0 .. N-1. This first encoding is called C_1 encoding. Then the encoder (after initialization by the circulation state S_{c2}, see below) is fed by the interleaved sequence (switch in position 2) with incremental address j = 0, … N-1. This second encoding is called C_2 encoding. The function pi(j) that gives the natural address of i of the consider coupled when reading it at a place j for the second encoding is given below.

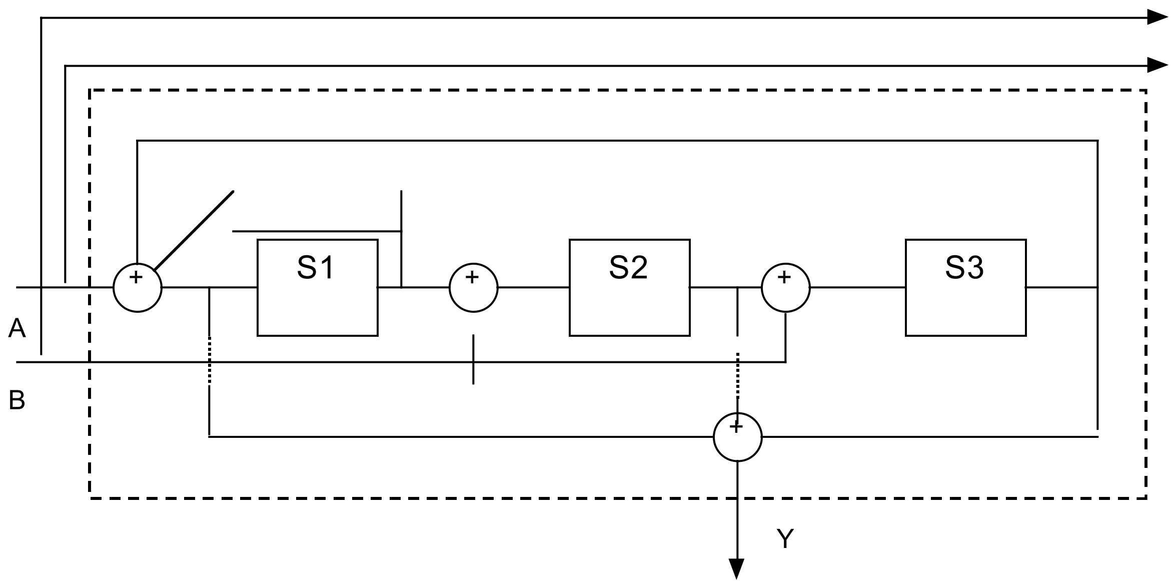

Figure 1. Constituent Encoder

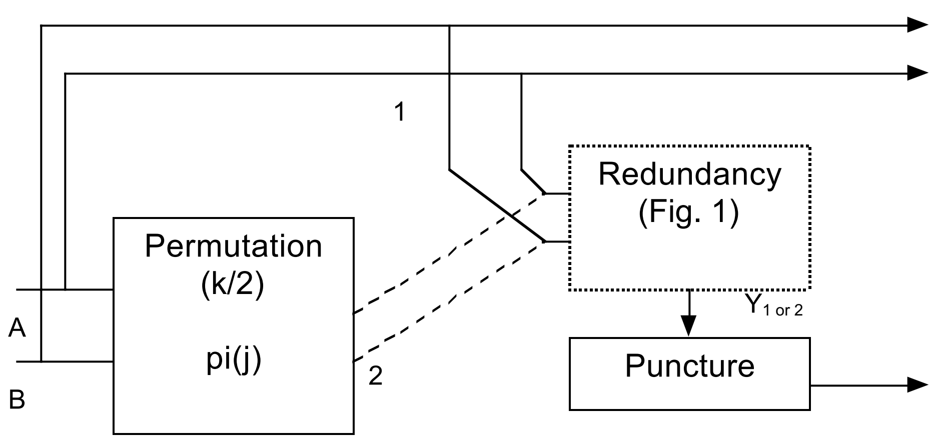

Figure 2. Turbo Code Encoder

B.1.3.1

The permutation is done on two levels; the first one inside the couples (level 1), the second one between couples (level 2).

Set the permutation parameters P_0, P_1, P_2 and P_3.

j = 0 .. N-1

level 1

if j mod. 2 = 0 let (A,B) = (B,A) (invert the couple)

level 2

- if j mod. 4 = 0 then P = 0;
- if j mod. 4 = 1 then P = N/2 + P_1;
- if j mod. 4 = 2 then P = P_2;
- if j mod. 4 = 3 then P = N/2 + P_3.

i = P_0*j+P+1 mod. N.

Interleaver Parameter table

Table 1: Turbo code permutation parameters

Frame size in couples	P_0	$\{P_1, P_2, P_3\}$	Mode
N = 96 (24 bytes)	7	{48,24,72}	OFDM
N = 144 (36 bytes)	17	{74, 72, 2}	OFDM
N = 192 (48 bytes)	11	{96,48,144}	OFDM
N = 288 (72 bytes)	13	{144,72,216}	OFDM
N = 384 (96 bytes)	17	{192,96,288}	OFDM
N = 432 (108 bytes)	17	{216,108,324}	OFDM
N = 72 (18 bytes)	11	{6, 0, 6}	OFDMA
N = 108 (27 bytes)	11	{54, 56, 2}	OFDMA
N = 144 (36 bytes)	17	{74, 72, 2}	OFDMA*
N = 216 (54 bytes)	31	{2, 4, 10}	OFDMA
N = 288 (72 bytes)	13	{144,72,216}	OFDMA*
N = 324 (81 bytes)	11	{172, 164, 16}	OFDMA
N = 256 (64 bytes)	13	{128,64,192}	SC2
N = 512 (128 bytes)	17	{256,128,384}	SC2
N = (integer number of bytes)/2 between 64 and 339 bytes	13	{N/2,N/4,3N/4}	SC2
N = (integer number of bytes)/2 between 338 and 512 bytes	17	{N/2,N/4,3N/4}	SC2

B.1.3.2 Determination of the circulation states

The state of the encoder is denoted S (0 <= S == 7) with S = $4s_1 + 2s_2 + s_3$ (See Figure 1). The circulation states Sc_1 and Sc_2 are determined by the following operations:

1) initialize the encoder with state 0. Encode the sequence in the natural order for the determination of Sc_1 or in the interleaved order for determination of Sc_2. In both cases the final state of the encoder is $S0_{N-1}$;
2) according to the length N of the sequence, use the following correspondence to find Sc_1 or Sc_2.

$S0_{N-1}$ -> N mod. 7	0	1	2	3	4	5	6	7
1	Sc = 0	6	4	2	7	1	3	5
2	0	3	7	4	5	6	2	1
3	0	5	3	6	2	7	1	4
4	0	4	1	5	6	2	7	3
5	0	2	5	7	1	3	4	6
6	0	7	6	1	3	4	5	2

Table 1. Circulation State Table

B.1.3.3 Rates and puncturing map

Four codes rates are defined for the convolutional Turbo Code mode: R =1/2, 2/3,3/4. This is achieved through selectively deleting the parity bits (puncturing). The puncturing patterns are identical for both codes C_1 and C_2.

Y/ Rate	0	1	2	3	4	5	6	7
_	1	1						
2/3	1	0	1	0				
_	1	0	0	1	0	0		

Table 1. Puncture Map

B.1.3.4 Order of output

The order in which the encoded bit are fed into the interleaver is:

A_0, B_0 .. A_{N-1}, B_{N-1}, $Y1_0$, $Y1_1$ .. $Y1_M$, $Y2_0$, $Y2_1$ .. $Y2_M$, where M is the number of parity bits.

{END OF APPENDIX B ADDITIONS.}

MODIFICATIONS TO THE DRAFT STANDARD

The following table should be added as section 8.3.5.5.4.2.3:

8.3.5.5.4.2.3

Table X. Optional Turbo Code Channel Coding per Modulation

Modulation	Data Block Size (Bytes)	Coded Block Size (Bytes)	Overall Rate
QPSK	24	48	1/2
QPSK	36	48	3/4
16QAM	48	96	1/2
16QAM	72	96	3/4
64QAM	96	144	2/3
64QAM	108	144	3/4

The following table should be added as section 8.3.5.6.4.2.3:

8.3.5.6.4.2.3

Table X. Optional Turbo Code Channel Coding per Modulation

Modulation	Data Block Size (Bytes)	Coded Block Size (Bytes)	Overall Rate
QPSK	18	36	1/2
QPSK	27	36	3/4
16QAM	36	72	1/2
16QAM	54	72	3/4
64QAM	72	108	2/3
64QAM	81	108	3/4

Table 234 in the fourth column, forth row (OFDM, OFDMA, OFDMA2) the following should be added:

14- TCC QPSK 2/3
15- TCC QPSK 3/4
16- TCC 16QAM 1/2
17- TCC 16QAM 3/4
18- TCC 64QAM 2/3
19- TCC 64QAM 2/3

Table 236 in the fourth column, forth row (OFDM, OFDMA, OFDMA2) the following should be added:

14- TCC QPSK 2/3
15- TCC QPSK 3/4
16- TCC 16QAM 1/2
17- TCC 16QAM 3/4
18- TCC 64QAM 2/3
19- TCC 64QAM 2/3

SINGLE CARRIER AMENDMENTS

a) specify gray mapping
    a. gray mapping figures
    b. f. 171 gray mapping for BPSK, QPSK, and 16QAM
    c. 174 gray mapping for 64
    d. 176 gray mapping for 256 QAM.
    e.
b) code rate are _, 2/3, and _ (5/6, 7/8).
c) all interleave sizes specified – DONE
d) note that everything is in bytes
e) append zero bits to create an even number of modulation symbols
f) MAC message issues – TLV's
    a. Add CTC to acronyms
        i. Line 23, page 21, clause 4, add "CTC convolutional Turbo Code"
    b. Single Carrier Section
        Line 19, page 131, Section 8.3.2.1.4.1.3.2 replace "CTC and CC specific parameters"
        Line 65, page 131, Section 8.3.2.1.4.1.3.4 replace "CTC and CC specific parameters"
        Line 8, Page 134,Section 8.3.2.1.4.2.1.2 replace … with "CRC and CC specific parameters"
        Line 60, page 237, Section 11.4.1.2.5.1 add "bit 5: CTC" {demodulation}
        Line 48, page 240, Section 11.4.1.2.6.1 add "bit 5: CTC" {modulation}

    c. Table 258 UCDBurst Profile encodings
        i. Add entry #5, line 22, page 224, Section 11.1.1.2
            1. 5 = CTC
            2. Table 258, line 24, page 226 amend to read CTC and "CC-specific parameters"

    d. Table DCDBurst Profile encodings
        i. Table 260, Add entry #5, line 19, page 229, Section 11.1.2.2
            1. 5 = CTC
            2. Table 260, line 60, page 231 amend to read "CTC and CC-specific parameters"