Project	**IEEE 802.16 Broadband Wireless Access Working Group** <http://ieee802.org/16>
Title	**Better TBCC for FCH in 802.16m**
Date Submitted	**2007-11-06**
Source(s)	T. Jason Chen and S. Shawn Tsai Ericsson Inc. SE-164 80 Stockholm, Sweden Voice: +46 8 4046214 (Jason) +46 8 4044213 (Shawn) E-mail: jason.t.chen@ericsson.com shawn.tsai@ericsson.com
Re:	IEEE 802.16m-07/040 - Call for Contributions on Project 802.16m System Description Document
Abstract	Better tail-biting convolutional codes (TBCC) for the frame control header (FCH) is proposed for 802.16m. The performance gains (over the WirelessMAN OFDMA reference system TBCC) by using better generator polynomials for length-24 and length-12 TBCC are about 1dB and 0.5dB, respectively, at the high SNR region over the AWGN channel. Also, the performance gains (over the reference system TBCC) by using better generator polynomials over multipath Rayleigh fading channels range from 1dB to 2.5dB.
Purpose	Inclusion of a section on new TBCC for FCH in a Physical Layer chapter of the 802.16m SDD.
Notice	
Release	
Patent Policy	

Better TBCC for FCH in 802.16m

T. Jason Chen and S. Shawn Tsai

Ericsson AB

Summary

The requirements [1] for the IEEE 802.16m project include better coverage than that currently supported by the WirelessMAN OFDMA Reference System [2][3]. The use of more efficient channel codes for the reference system frame control header (FCH) will certainly achieve better coverage. This document proposes better tail-biting convolutional codes (TBCC) to improve the FCH performances. The performance gains (over the reference system FCH TBCC) by using better generator polynomials for length-24 and length-12 TBCC are about 1dB and 0.5dB, respectively, at the high SNR region over the AWGN channel. Also, the performance gains over multipath Rayleigh fading channels range from 1dB to 2.5dB.

The legacy requirement is addressed by using the improved TBCC for FCH for the part of 802.16m system that is operated outside the band supporting legacy MS's.

Proposed SDD Text

[Section] Cell Coverage

[Subsection] Improved Tail-Biting Convolutional Code for Frame Control Header

Tail-Biting Convolutional Code (TBCC) used for Frame Control Header (FCH) shall be improved for 802.16m-only sub-system by using generator polynomials optimized for the given information payload size.

Rate ¼ TBCC with generator polynomials (474,534,664,744) and rate-1/2 with generator polynomials (414,730) are recommended, respectively, for FCH payload size of 24 and 12 for memory length 6, where rate ¼ TBCC with polynomials (472,556,726,762) is recommended for FCH with payload 24 for memory length 7. If rate ½ TBCC is required for FCH payload size of 24, TBCC with generator polynomials (334,464) with memory 6 is recommended.

Discussion of Proposed TBCC for 802.16m FCH

Introduction

The requirements for the IEEE 802.16m project include better coverage than that currently supported by the WirelessMAN OFDMA Reference System. The use of more efficient channel codes for frame control header (FCH) will certainly achieve better coverage. In this document, link-level performance of the reference system FCH with tail-biting convolutional codes (TBCC) has been studied. For TBCC, the weight spectrum and the performances of the codes depend on the payload sizes, and optimum generator polynomials need to be searched for TBCC with different payload sizes. In the reference system, a rate ½ TBCC with the overall constraint length 6, which has the best d_{min} (minimum distance) and n_{dmin} (number of codewords with weight d_{min}) for payload ≥ 33 bits, is used as the mother code for data channels with payload sizes 48 bits or more. Since the same TBCC is used for the FCH with shorter payload sizes 12 and 24 bits, suboptimum results can be expected. In this document, we study various options of using TBCC with better generator polynomials for the FCH. The performance gains (over the reference system FCH TBCC) by using better generator polynomials for length-24 and length-12 TBCC are about 1dB and 0.5dB, respectively, at the high SNR region over the AWGN channel. Also, the performance gains over multipath Rayleigh fading channels range from 1dB to 2.5dB. For the reference FCH TBCC, repetitions are employed to provide diversity and energy gains. It is shown that, over various fading channels, the diversity gains are about 1.5dB for the 2-time repetition and the extra gains from the 2-time repetition to the 4-time repetition are about 1dB or very limited.

FCH Structure and Decoding Scheme

The transmitter and receiver block diagrams for FCH are shown in Figure 1, where the blocks in yellow correspond to proposals made in this document. The payload sizes of the FCH are 24 bits (for FFT sizes 2048, 1024 and 512), and 12 bits (for FFT size 128). The payload bits in FCH are first repeated 2 times (or 4 times for FFT size 128) to generate 48 bits, and these 48 bits are encoded by the length-48 rate ½ TBCC [2][3], resulting in 96 coded bits. The 96 coded bits are then bit-interleaved, repeated 4 times (or no repetition for FFT size 128), and modulated by QPSK to generate 192 modulation symbols (or 48 modulation symbols for FFT size 128). These 192 (or 48 for FFT size 128) modulation symbols are used to modulate 192 (or 48 for FFT size 128) tones in DL-PUSC (partial usage of subchannels) [2][3].

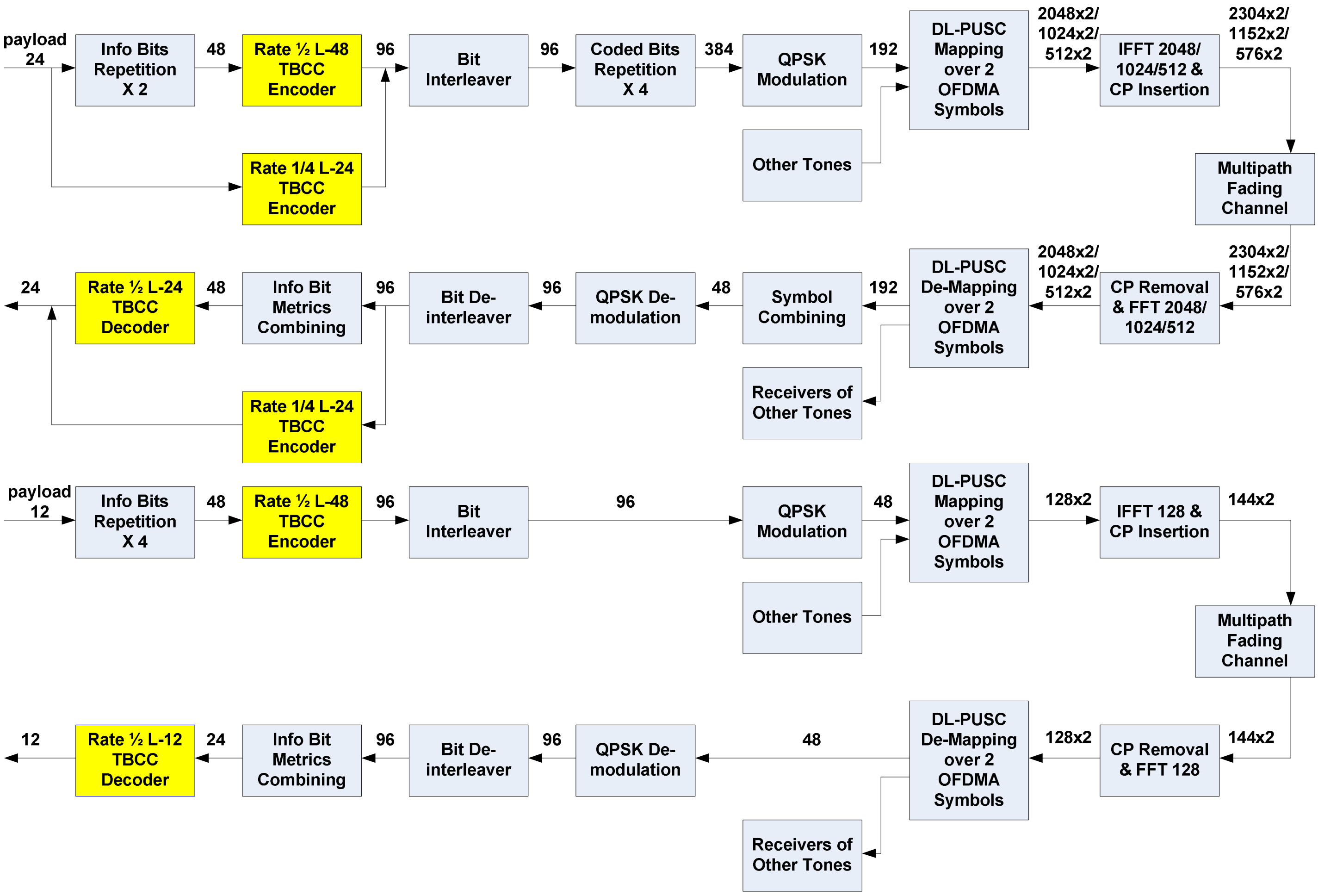

Figure 1: Transmitter and receiver block diagrams of FCH. The upper part is for length-24 FCH with FFT sizes 2048, 1024 or 512. The lower part is for length-12 FCH with FFT size 128. The rate ¼ TBCC in the upper part is an improvement of

FCH proposed in this report. Proposals made in this report are within the blocks in yellow.

At the receiver, the 4 repetitions of the 192 received symbols (or 48 symbols for FFT size 128), if needed, are first combined to generate 48 symbols. The 48 QPSK symbols are then demodulated to generate 96 interleaved soft bit values. After de-interleaving, the two (or four) repetitions of the 96 de-interleaved soft bit values are further combined to generate 48 (or 24 for FFT size 128) soft bit values. Finally, the 48 (or 24 for FFT size 128) soft bit values are decoded by the length-24 (or length-12 for FFT size 128) rate ½ TBCC decoder. Note that in the encoding process, the length-24 rate ½ TBCC encoder followed by a 2-time repetition (or length-12 rate ½ TBCC encoder followed by a 4-time repetition for FFT size 128) can be used instead of the the length-48 rate ½ TBCC. Therefore, the length-24 (or length-12 for FFT size 128) TBCC can be used for both the encoding and decoding processes.

The generator polynomials for the rate ½ reference system TBCC are given by g_1=(1 1 1 1 0 0 1) and g_2=(1 0 1 1 0 1 1) in binary notation, or g_1=744 and g_2=554 in octal notation. Here we follow the octal notation used in [6][14], where 0's are appended on the right of the binary notation to make the total number of digits a multiple of 3. According to [6][14], the generator polynomials used in the reference system TBCC have the best d_{min} (minimum distance) and n_{dmin} (number of nearest neighbors) for payload ≥ 33 bits and for some payload between 25 and 33 bits, assuming that the overall constraint length is 6 and the code rate is 1/2. As discussed later, the generator polynomials used by the reference system TBCC are not the optimum ones for FCH with payload sizes 24 and 12.

Simulation Results over the AWGN Channel

In this section, link-level results are provided for the single-carrier system over the AWGN channel. The 4-time repetition after the bit interleaving (for FFT sizes 2048, 1024 and 512) is not considered for the AWGN channel, because the results will be the same for both repetition and non-repetition cases if the curves are plotted over the combined Es/N0. For the best performance-complexity tradeoff, WAVA (wrap-around Viterbi algorithm) [5] is used for decoding TBCC, and we use the simple termination condition [5] as the stopping criterion for WAVA throughout this document.

In the following subsections, we compare the performances of the reference system TBCC and improved TBCC generator polynomials over the AWGN channel. The generator polynomials considered in this document are summarized in Table 1.

Results of Length-24 Reference System TBCC (FCH with Payload 24 Bits) and Length-24 TBCC with Better Generator Polynomials

As mentioned in the Introduction Section, the generator polynomials used by the reference system TBCC are not optimal for FCH with payload sizes 24. We consider other generator polynomials and compare their performances with the reference system TBCC in Figure 2, Figure 3 and Figure 4 (with 2000000 simulation trials per SNR point). The results of rate ¼ generator polynomials are discussed in the following, while the results of rate ½ generator polynomials are discussed in Appendix 1.

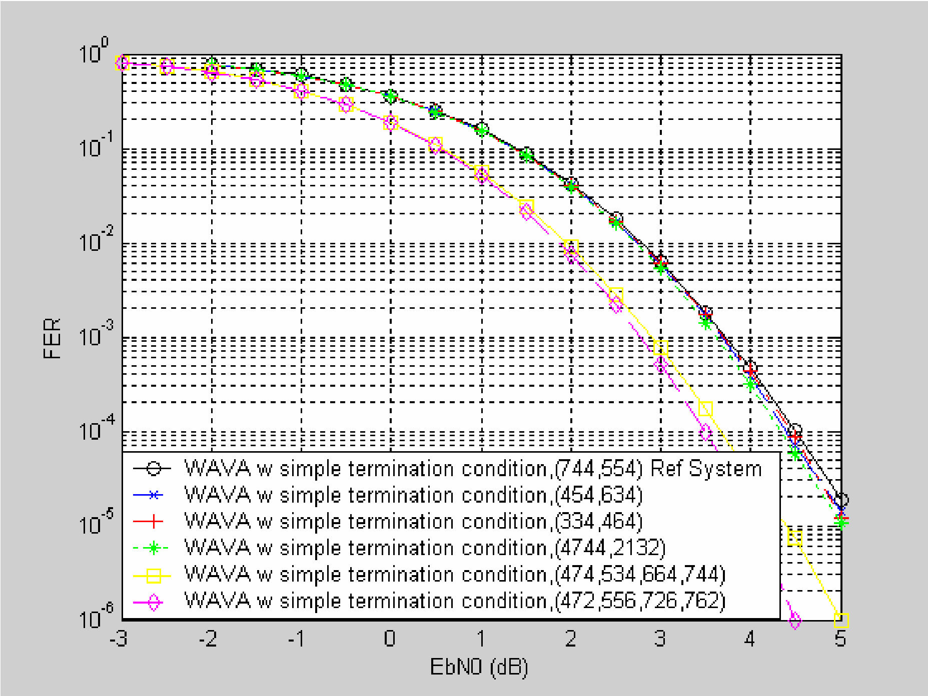

Figure 2: FER comparison of length-24 TBCC with reference system generator polynomials and other better generator polynomials.

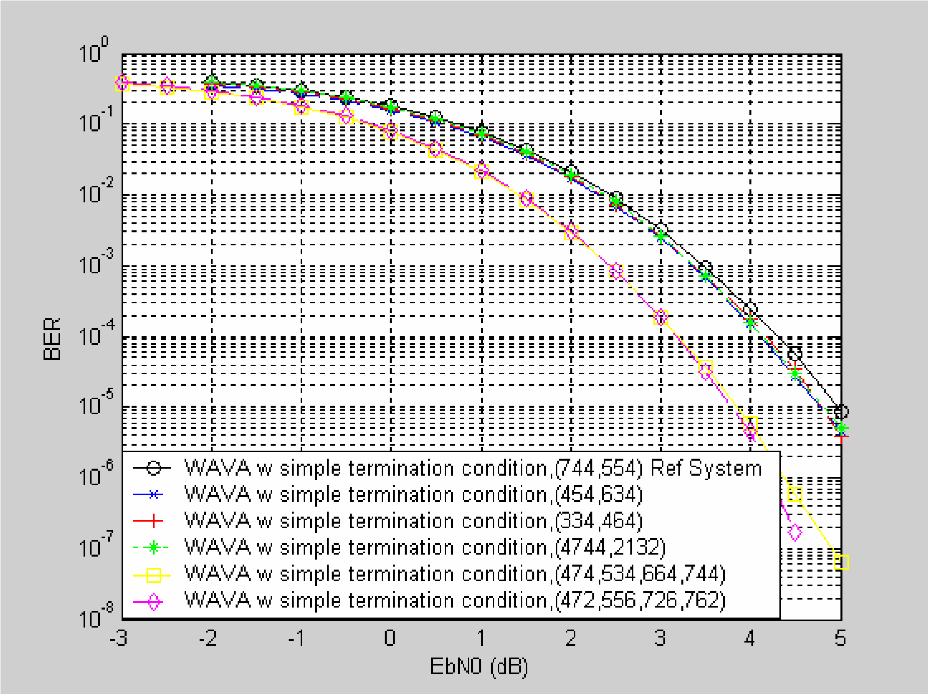

Figure 3: BER comparison of length-24 TBCC with reference system generator polynomials and other better generator polynomials.

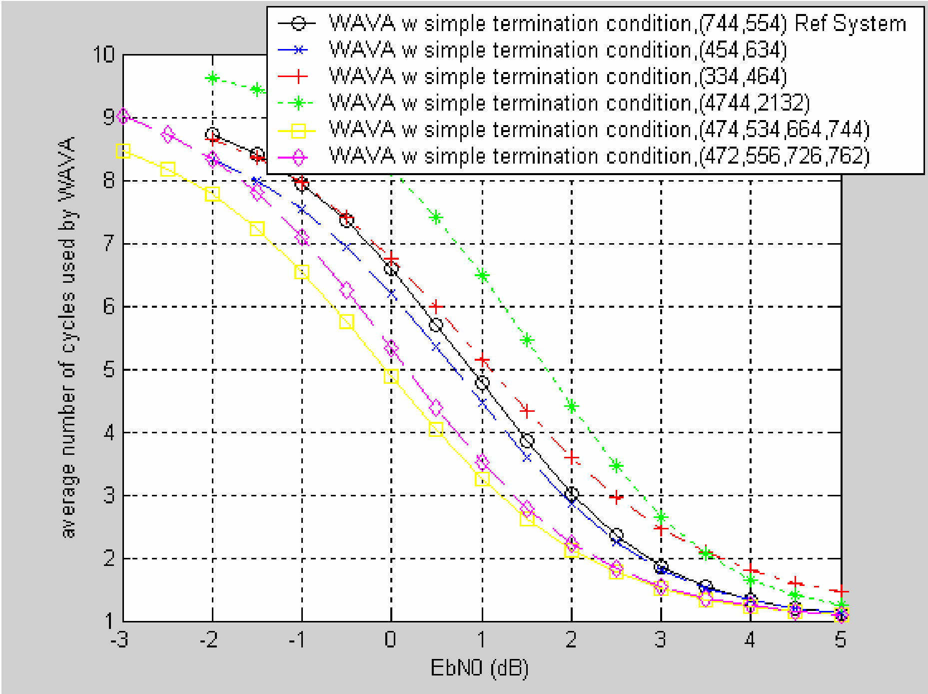

Figure 4: Decoding cycles comparison of length-24 TBCC with reference system generator polynomials and other generator polynomials.

- If there is no restriction on the code rate, a rate ¼ length-24 TBCC may be considered and in this case there will be no information bits repetition needed as the code rate has been changed from ½ to ¼. The rate ¼ TBCC with g_1=474, g_2=534, g_3=664 and g_4=744 has an overall constraint length of 6 and d_{min} of 20. The performance gain over the length-24 reference system TBCC is about 0.8dB in both FER and BER at the high SNR region. From Figure 4, the complexity reduction in the average number of cycles needed by WAVA is up to 32% of that for the length-24 reference system TBCC. Note that in this case, our search result for the optimum distance spectrum TBCC agrees with the best ZTCC (zero-tail convolutional code) from [10][11].

- If there is no restriction on the overall constraint length and the code rate, a rate ¼ length-24 TBCC with an overall constraint length of 7 may be considered and in this case there will be no information bits repetition needed as the code rate has been changed from ½ to ¼. The rate ¼ TBCC with g_1=472, g_2=556, g_3=726 and g_4=762 has an overall constraint length of 7 and d_{min} of 22 [6][14]. The performance gain over the length-24 reference system TBCC is about 1dB in both FER and BER at the high SNR region. From Figure 4, the complexity reduction in the average number of cycles needed by WAVA is up to 28% of that for the length-24 TBCC used in the reference system.

Results of Length-12 Reference System TBCC (FCH with Payload 12 Bits) and Length-12 TBCC with Optimum Generator Polynomials

As mentioned in the Introduction Section, the generator polynomials used in the reference system TBCC are not optimal for a payload size of 12. The optimum generator polynomials for length-12 TBCC with the overall constraint length 6 are given by g_1=414 and g_2=730 [6][14], and the results with the new generator polynomials are compared with the TBCC of the reference system in Figure 5, Figure 6 and Figure 7. We see that the length-12 TBCC with optimum generator polynomials are better than the length-12 TBCC in the reference system by about 0.5dB in both FER and BER at the high SNR region. In fact, the length-12 TBCC with the optimum generator polynomials for the overall constraint length 6 is equivalent to the well-known extended Golay code [6], which is the linear block code with the best minimum distance over all (n,k)=(24,12) block codes. Since the weight spectrum is available for the extended Golay code [15], an upper bound [13][15] on the FER can be computed for the length-12 TBCC with the optimum generator polynomials and is shown in Figure 5, which matches well with the simulated FER over the high SNR region. The results from maximum-likelihood decoding (denoted by ML) are also provided for reference. From Figure 7, the complexity reduction in the average number of cycles needed by WAVA is up to 15% of that for length-12 reference system TBCC.

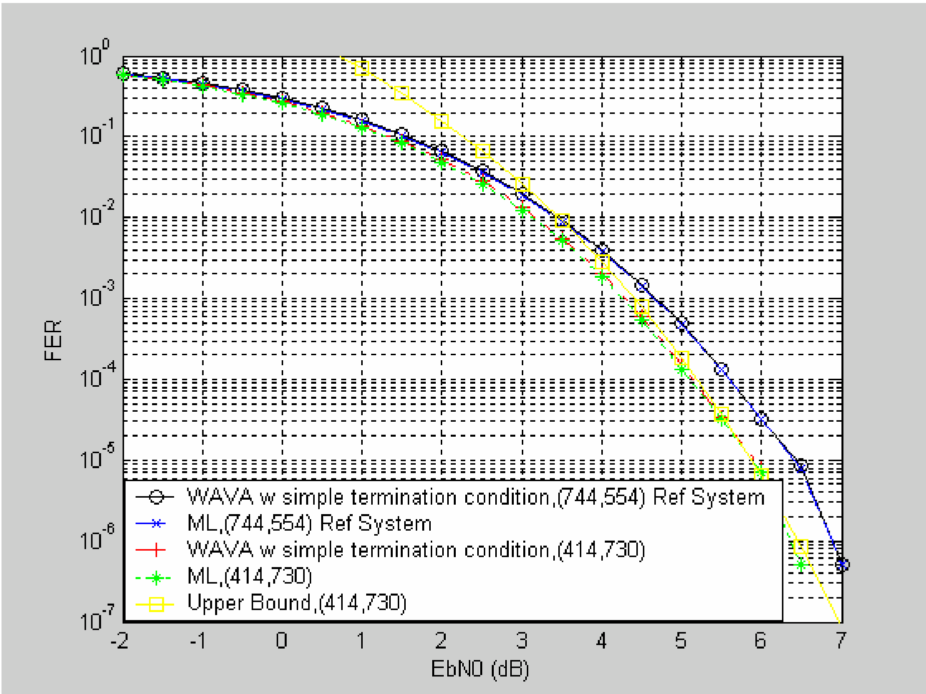

Figure 5: FER comparison of length-12 TBCC with reference system generator polynomials and optimum generator polynomials. The TBCC with optimum generator polynomial here is equivalent to the extended Golay code.

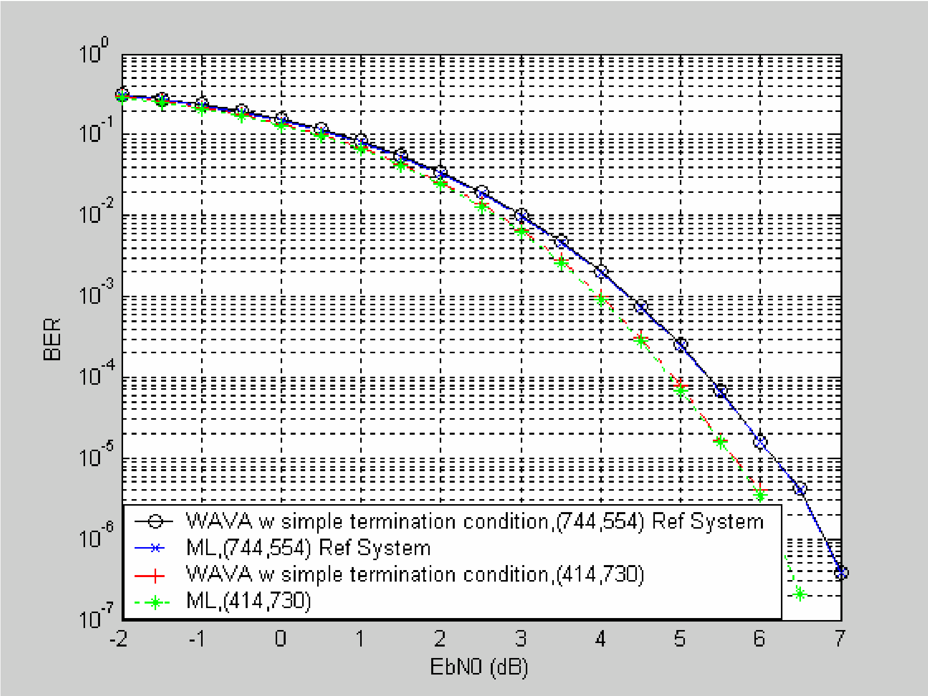

Figure 6: BER comparison of length-12 TBCC with reference system generator polynomials and optimum generator polynomials. The TBCC with optimum generator polynomials here is equivalent to the extended Golay code.

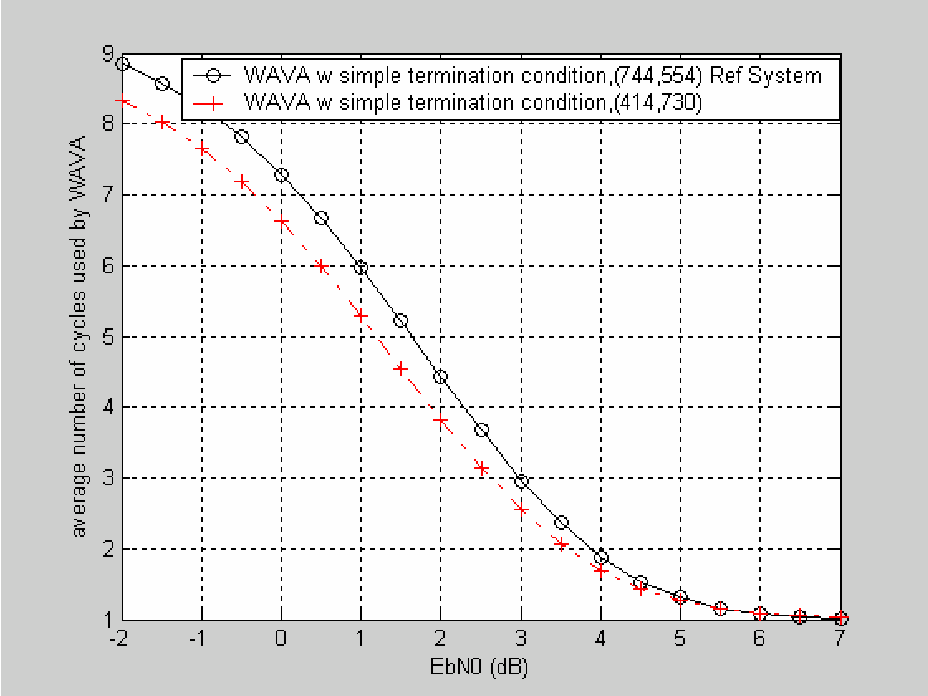

Figure 7: Decoding cycles comparison of length-12 TBCC with reference system generator polynomials and optimum generator polynomials.

Simulation Results over Fading Channels

In this section, link-level simulation results of FCH are discussed for the WirelessMAN OFDMA reference system with DL-PUSC over the fading channels. The simulations are performed according to Figure 1. The simulation methodology and link-level curves are provided in Appendix 2. For FFT sizes 512 and 1024, in addition to the 4-time repetition (denoted by "coded bits rep=4") after the bit interleaving, we also consider 2-time repetition (denoted by "coded bits rep=2") and no repetition (denoted by "coded bits rep=1") to study the diversity gains from repetition. For FFT size 128, there is no repetition after the bit interleaving. The performance of a TBCC with better generator polynomials over fading channels is compared with those of the TBCC in the reference system. For FFT sizes 512 and 1024, we consider the TBCC in the reference system and the rate ¼ TBCC with generator polynomials (472,556,726,762). For FFT size 128, we consider the TBCC in the reference system and the rate 1/2 TBCC with generator polynomials (414,730). The simulation parameters are summarized in Table 2.

For both the TBCC in reference system and the TBCC with better generator polynomials, we observe that there is a diversity gain from repetition of 1.5dB or less for 2-time repetition, and the extra gains going from 2-time repetition to 4-time repetition are about 1dB or very limited. As expected, for Rician fading channel there is virtually no diversity gain from repetition. The performance comparisons between the reference system TBCC and TBCC with better generator polynomials are summarized as follows:

- For FFT sizes 512 and 1024, and for multipath Rayleigh fading channels, the gains of using better generator polynomials are between 1.5dB to 2dB if there is no repetition after the bit interleaving. The gains are about 1dB if the 4-time repetition is used after the bit interleaving.

- For FFT sizes 512 and 1024, and for the Rician fading channel, the gains of using better generator polynomials are about 1dB, which agrees with the comparisons made for the AWGN channel.

- For FFT size 128 and for multipath Rayleigh fading channels, there is no repetition after the bit interleaving and the gains of using better generator polynomials are between 1dB and 2.5dB.

- For FFT size 128 and for the Rician fading channel, the gains of using better generator polynomials are about 0.6dB, which agrees with the comparisons made for the AWGN channel.

Conclusions

From the simulation results in this document, we conclude that better TBCC with the same or slightly higher complexities can be used to improve the FCH performances. The recommended solutions are:

Length-24 TBCC (FCH with payload 24 bits)

- The rate ¼ TBCC with generator polynomials (474,534,664,744) can be used for FCH with payload 24 bits if rate ¼ code is preferred and the same encoder memory m=6 as reference system TBCC is to be kept. The gain is about 0.8dB for both FER and BER over the AWGN channel and the high SNR region.

- The rate ¼ TBCC with generator polynomials (472,556,726,762) can be used for FCH with payload 24 bits if rate ¼ code is preferred and larger encoder memory m=7 than reference system TBCC is allowed. The gain is about 1dB for both FER and BER over the AWGN channel and the high SNR region.

- The rate 1/2 TBCC with generator polynomials (334,464) can be used for FCH with payload 24 bits if rate 1/2 code is preferred and the same encoder memory m=6 as reference system TBCC is to be kept.

Length-12 TBCC (FCH with payload 12 bits)

- The rate 1/2 TBCC with generator polynomials (414,730) can be used for FCH with payload 12 bits, and this TBCC is equivalent to the extended Golay code. The gain is about 0.5dB for both FER and BER over the AWGN channel and the high SNR region.

References

[1] IEEE 802.16m System Requirements IEEE 802.16m-07/002r4

[2] IEEE Std 802.16-2004: Part 16: IEEE Standard for Local and metropolitan area networks: Air Interface for Fixed Broadband Wireless Access Systems, June 2004

[3] IEEE Std 802.16e-2005 and IEEE Std 802.16-2004/Cor1-2005 (Amendment and Corrigendum to IEEE Std 802.16-2004), "IEEE Standard for local and metropolitan area networks, Part 16: Air Interface for Fixed and Mobile Broadband Wireless Access Systems, Amendment 2: Physical and Medium Access Control Layers for Combined Fixed and Mobile Operation in License Bands," Feb 28, 2006

[4] H. H. Ma and J. K. Wolf, "On tail biting convolutional codes," IEEE Trans. Commun., vol. 34, pp. 104-111, Feb. 1986.

[5] R. Y. Shao, S. Lin and M. P. C. Fossorier, "Two decoding algorithms for tail-biting codes," IEEE Trans. Commun., vol. 51, no. 10, pp. 1658-1665, Oct. 2003.

[6] P. Ståhl, J. B. Anderson and R. Johannesson, "Optimal and near-optimal encoders for short and moderate-length tail-biting trellises," IEEE Trans. Inform. Theory, vol. 45, pp. 2562-2571, Nov. 1999.

[7] I. E. Bocharova, R. Johannesson, B. D. Kudryashov and P. Ståhl, "Tailbiting codes: bounds and search results," IEEE Trans. Inform. Theory, vol. 48, pp. 137-148, Jan. 2002.

[8] P. Ståhl, J. B. Anderson and R. Johannesson, "A note on tailbiting codes and their feedback encoders," IEEE Trans. Inform. Theory, vol. 48, pp. 529-534, Feb. 2002.

[9] K. J. Larsen, "Short convolutional codes with maximal free distance for rate 1/2, 1/3, and 1/4," IEEE Trans. Inform. Theory, vol. 19, pp. 371-372, May 1973.

[10] J.-J. Chang, D.-J. Hwang and M.-C. Lin, "Some extended results on the search for good convolutional codes," IEEE Trans. Inform. Theory, vol. 43, pp. 1682-1697, Sep. 1997.

[11] P. Frenger, P. Orten and T. Ottosson, "Convolutional codes with optimum distance spectrum," IEEE Commun. Letters, vol. 3, no. 11, Nov. 1999.

[12] Y. Ould-Cheikh-Mouhamedou, S. Crozier and P. Kabal, "Distance measurement method for double binary turbo codes and a new interleaver design for DVB-RCS," IEEE Globecom 04, pp. 172-178.

[13] S. Lin and D. J. Costello, Jr, Error control coding. Upper Saddle River, New Jersey: Pearson, 2004.

[14] R. Johannesson and K. S. Zigangirov, Fundamentals of convolutional coding. Piscataway, New Jersey: IEEE Press, 1999.

[15] J. G. Proakis, Digital communications. New York, New York: McGraw-Hill, 2001.

Table 1: Summary of generator polynomials used in this document for TBCC. Rate=coding rate. K=information packet (payload) length. m=encoder memory. d_{min}=minimum distance. n_{dmin}=number of codewords with weight d_{min}. b_{dmin}= total number of nonzero information bits associated with codewords with weight d_{min}. LB and UB are lower bound and upper bound for d_{min} for given coding rate and K. R=recursive (feedback) encoder and the first polynomial is the feedback polynomial. Feedback encoders are listed only when they provide better BER than their corresponding feedforward encoders.

Rate	K	m	d_{min} (LB-UB)	n_{dmin}	b_{dmin}	Generator Polynomials	Reference and Note
1/2	24	6	8 (12-12)	24	432	(554,744)	Reference system [2][3]
1/2	24	6	8 (12-12)	24	96	(554,744) R	Feedback encoder with better BER
1/2	24	6	9 (12-12)	96	672	(454,634)	[6] 0.1dB/0.25dB gain in FER/BER over AWGN
1/2	24	6	9 (12-12)	96	432	(634,454) R	Feedback encoder with better BER
1/2	**24**	**6**	**9 (12-12)**	**96**	**240**	**(334,464)**	**New search results; recommended for length-24 FCH for rate ½ code**
1/2	24	10	10 (12-12)	252	3048	(4744,2132)	[6] 0.2dB gain in both FER/BER over AWGN
1/4	**24**	**6**	**20 (28-35)**	**48**	**72**	**(474,534,664,744)**	**[10][11] and new search results; 0.8dB gain in both FER/BER over AWGN; recommended for length-24 FCH for rate ¼ code with m=6**
1/4	**24**	**7**	**22 (28-35)**	**24**	**48**	**(472,556,726,762)**	**[6] 1dB gain in both FER/BER over AWGN; recommended for length-24 FCH for rate ¼ code with m=7**
1/2	12	6	6 (8-8)	64	384	(554,744)	Reference system [2][3]
1/2	12	6	6 (8-8)	64	192	(554,744) R	Feedback encoder with better BER
1/2	**12**	**6**	**8 (8-8)**	**759**	**4572**	**(414,730)**	**[6] 0.5dB gain in both FER/BER over AWGN; recommended for length-12 FCH**
1/2	12	6	8 (8-8)	759	3036	(414,730) R, (730,414) R	Feedback encoder with better BER

Table 2: Simulation parameters of FCH over fading channels.

Simulation Parameters	Values
FEC	tail-biting convolutional code (TBCC) with payload size, code rate, generator polynomials, and information bits repetition given by ▪ payload size 24: rate ½ (554,744) from reference system [2][3], repeated 2 times ▪ payload size 24: rate ¼ (472,556,726,762) [6], no repetition ▪ payload size 12: rate ½ (554,744) from reference system [2][3], repeated 4 times ▪ payload size 12: rate ½ (414,730) [6], repeated 4 times
Modulation	QPSK
Channel	▪ Ped-B 6-path 3Km/hr ▪ Veh-B 6-path 10Km/hr ▪ Veh-A 6-path 120Km/hr ▪ Veh-A 6-path 30Km/hr ▪ Rician 1-path fD=1.5Hz K=10dB
Channel Estimation	Perfect
OFDMA	DL-PUSC (over 2 OFDMA symbols)
Circular State Estimation and Decoding Algorithm	wrap-around Viterbi algorithm (WAVA) with simple termination condition
Maximum Number of Cycles for Circular State Estimation by WAVA	▪ 4 for FFT sizes 1024 and 512 ▪ 10 for FFT size 128
FFT Size, Carrier Frequency (GHz), Bandwidth (MHz)	▪ (128, 2.3GHz, 1.25MHz) ▪ (512, 2.3GHz, 3.5MHz) ▪ (1024, 3.5GHz, 7MHz)
Repetition Factor after Interleaver	▪ FFT sizes 1024 and 512: 4 (for FCH), 2, 1 ▪ FFT size 128: 1 (no repetition)
Cyclic Prefix	1/8
Number of Trials	▪ 2000000*2 OFDMA symbols for FFT size 128 (411.4286 sec) ▪ 100000*2 OFDMA symbols for FFT size 512: (28.8578 sec) and FFT size 1024 (28.8288 sec)
Number of Coding Blocks per 2 OFDMA Symbols	▪ FFT size 128: 3 for repetition factor 1 (FCH) ▪ FFT size 512: 3, 6,15 for repetition factor 4 (for FCH), 2, 1 ▪ FFT size 1024: 6, 15,30 for repetition factor 4 (for FCH), 2, 1
Error Statistics	long-term curves

Appendix 1

In this Appendix, we consider better rate ½ length-24 TBCC and compare their performances with the reference system TBCC in Figure 2, Figure 3 and Figure 4 (with 2000000 simulation trials per SNR point). If rate ½ TBCC needs to be used for length-24 FCH, TBCC with generator polynomials g_1=334 and g_2=464 is recommended.

- The optimum (by the criterion of best (d_{min},n_{dmin}) pair) generator polynomials for length-24 TBCC with the overall constraint length 6 are given by g_1=454 and g_2=634 [6][14]. The performance gain over the length-24 TBCC used in the reference system is about 0.1dB (or 0.25dB) in FER (or BER) at the high SNR region. Figure 4 shows that the complexity reduction in the average number of cycles needed by WAVA is up to 5% over the length-24 TBCC used in reference system.

- Our search for the optimum distance spectrum TBCC in terms of lowest BER yields the length-24 TBCC with the overall constraint length 6 given by g_1=334 and g_2=464. This TBCC has lower BER than the TBCC with g_1=454 and g_2=634 at the high SNR region. Figure 4 shows a slight increase of complexity in terms of the average number of cycles needed by WAVA when compared with the length-24 TBCC used in reference system at the high SNR region.

- Removal of the restriction on the overall constraint length provides even better generator polynomials [6][14] that can be used to further improve the performance. The length-24 TBCC with g_1=4744 and g_2=2132 has an overall constraint length of 10 and d_{min} of 10. The performance gain over the length-24 reference system TBCC is about 0.2dB in both FER and BER at the high SNR region. Figure 4 shows an increase of complexity in the average number of cycles needed by WAVA when compared with the length-24 TBCC used for the reference system.

Appendix 2

In this Appendix, the link-level performance results over fading channels for FCH with various TBCC's are provided. The FER results for the 5 different fading channels are shown in Figure 8 to Figure 12 for FFT size 512. The FER/BER results for FFT sizes 1024 and 128, and BER results for FFT size 512 are not shown here. Note that in these Figures, the "Long-term Es/N0" refers to the combined Es/N0 values after combining repetitions; that is, they are the long-term combined Es/N0 values seen by the demodulator. In DL-PUSC, the used tones are divided into 3 parts for 3 sectors. For FFT sizes 2048, 1024 and 512, one FCH is transmitted by each sector with 4 subchannels (192 tones), and for FFT size 128, one FCH is transmitted by each sector with 1 subchannel (48 tones). For simulation purpose, we try to fill in as many FCH as possible within the used tones for each sector to improve the simulation efficiency and the unfilled tones within each sector are modulated by random symbols. This simulation scheme is indicated by the blocks "Other Tones" and "Receivers of Other Tones" in Figure 1. For example, there are 10 subchannels available for each sector (30 for 3 sectors) when FFT size 1024 is considered. In this case, we simulate 2 FCH transmissions (8 subchannels) and modulate the unfilled tones (2 subchannels) by random symbols within each sector. Therefore there are 6 FCH transmissions and receptions in total per 2 OFDMA symbols over 3 sectors. The number of FCH transmissions is called the number of coding blocks and simulation parameters are summarized in Table 2.

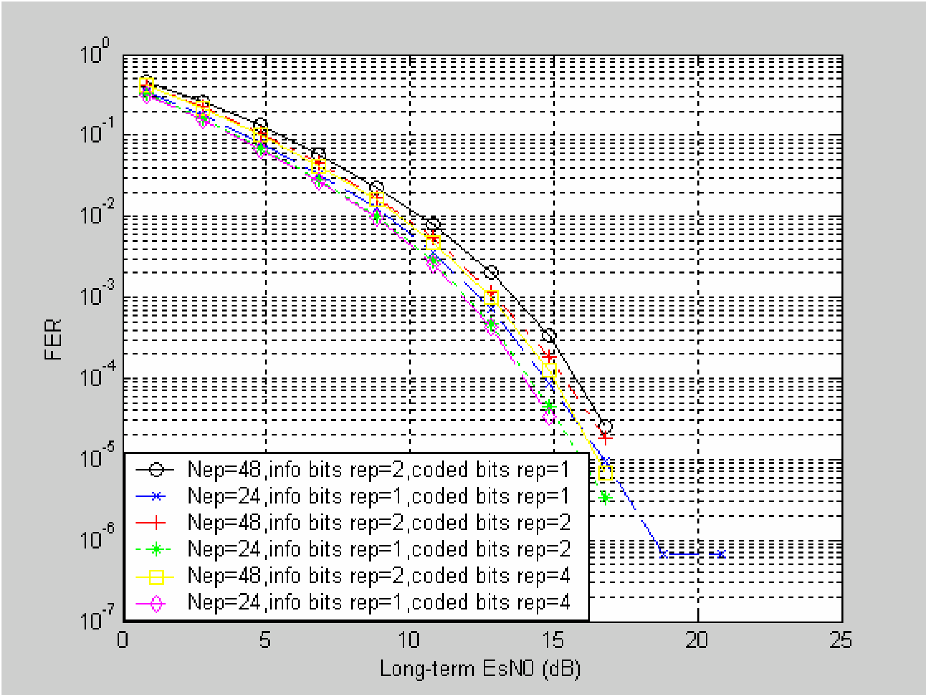

Figure 8: FER results over Ped-B (6-path 3Km/hr) channel. FFT size 512, carrier frequency 2.3GHz, bandwidth 3.5MHz. “coded bits rep=4” corresponds to FCH results. “Nep=48,info bits rep=2” is reference system TBCC, and “Nep=24,info bits rep=1” is rate ¼ TBCC.

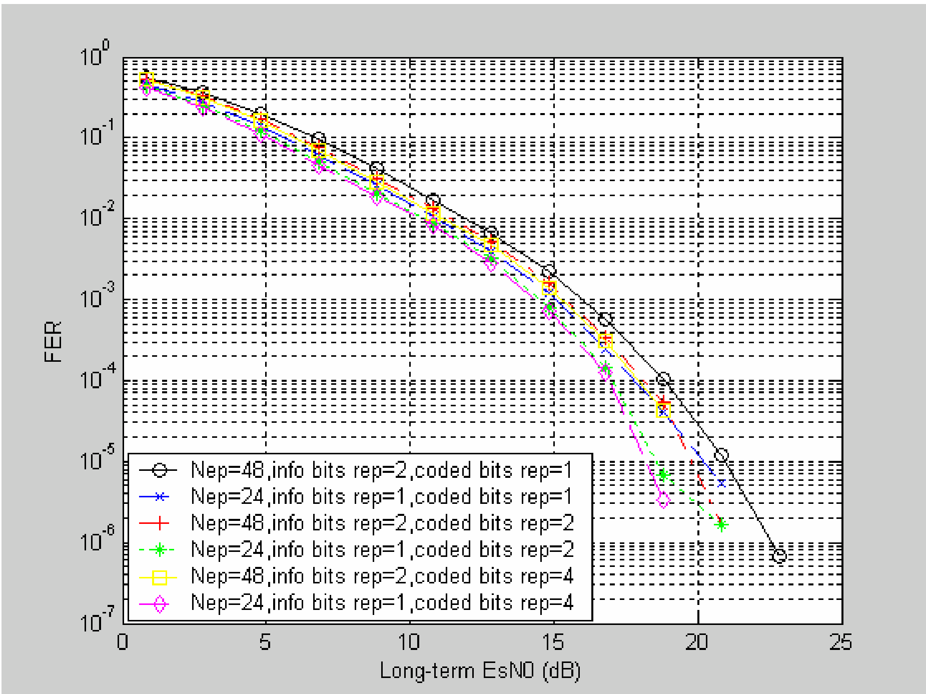

Figure 9: FER results over Veh-B (6-path 10Km/hr) channel. FFT size 512, carrier frequency 2.3GHz, bandwidth 3.5MHz. “coded bits rep=4” corresponds to FCH results. “Nep=48,info bits rep=2” is reference system TBCC, and “Nep=24,info bits rep=1” is rate ¼ TBCC.

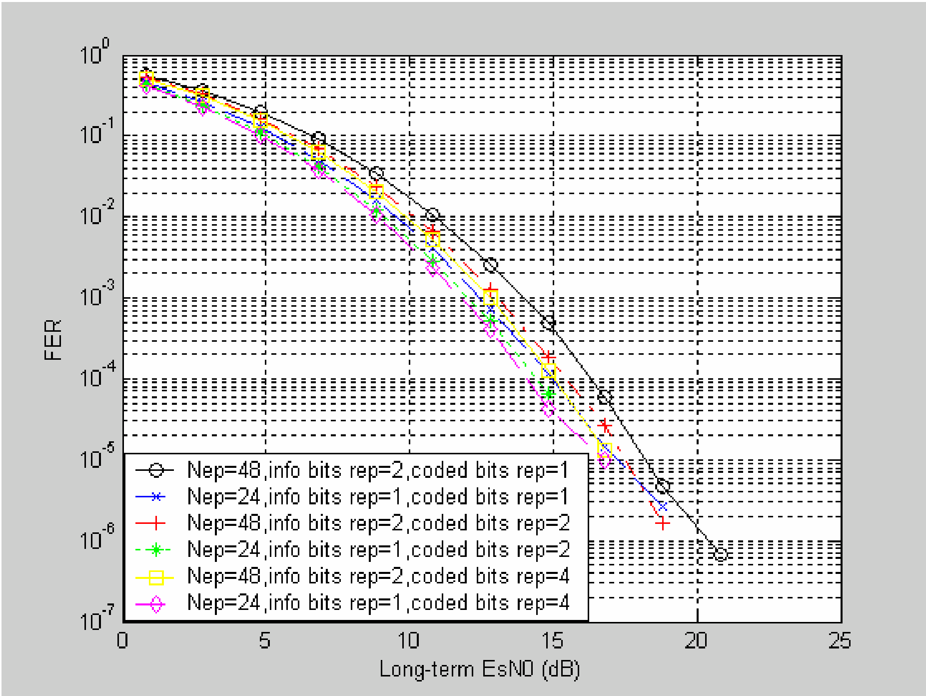

Figure 10: FER results over Veh-A (6-path 120Km/hr) channel. FFT size 512, carrier frequency 2.3GHz, bandwidth 3.5MHz. “coded bits rep=4” corresponds to FCH results. “Nep=48,info bits rep=2” is reference system TBCC, and “Nep=24,info bits rep=1” is rate ¼ TBCC.

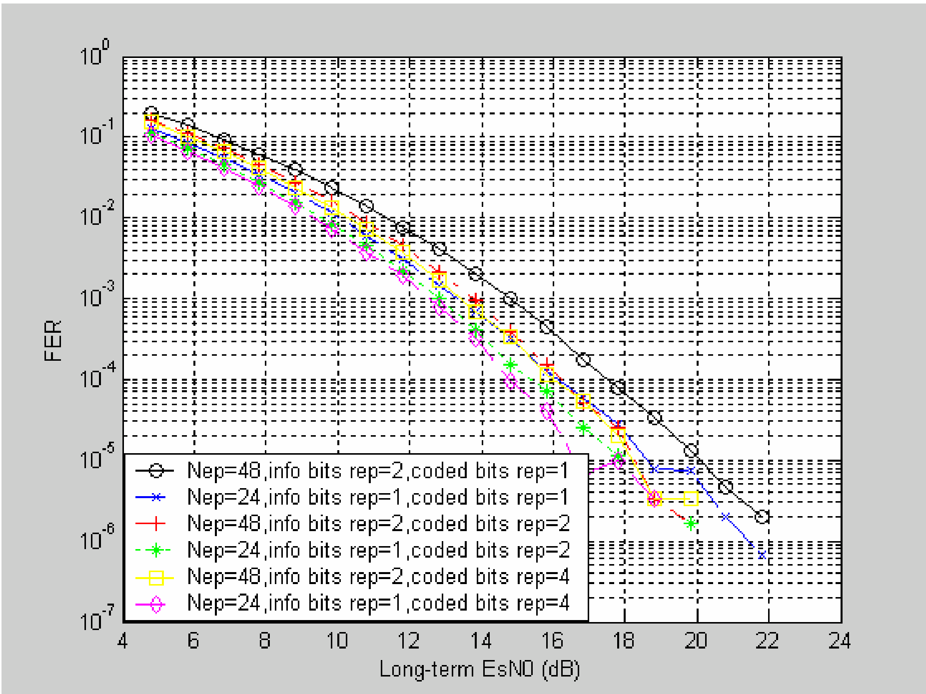

Figure 11: FER results over Veh-A (6-path 30Km/hr) channel. FFT size 512, carrier frequency 2.3GHz, bandwidth 3.5MHz. “coded bits rep=4” corresponds to FCH results. “Nep=48,info bits rep=2” is reference system TBCC, and “Nep=24,info bits rep=1” is rate ¼ TBCC.

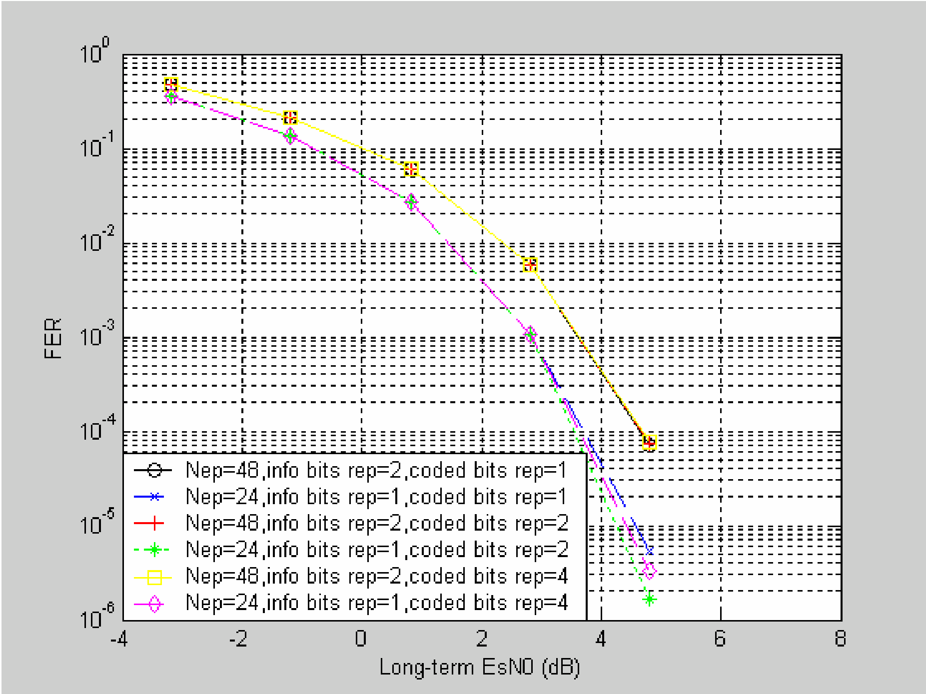

Figure 12: FER results over Rician channel. FFT size 512, carrier frequency 2.3GHz, bandwidth 3.5MHz. “coded bits rep=4” corresponds to FCH results. “Nep=48,info bits rep=2” is reference system TBCC, and “Nep=24,info bits rep=1” is rate ¼ TBCC.