PERFORMANCE OF BLOCK TURBO CODES IN A HIPERLAN/2 OFFICE ENVIRONMENT

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ABSTRACT

In this paper, the iterative decoding of BCH product codes also called Block Turbo Codes (BTC) is evaluated for the HIPERLAN/2 OFDM system. Simulations show that expurgated BCH codes should be chosen as constituent codes in order to outperform the performance of the specified convolutional code. We also show that the frequency interleaver has a big impact on the behaviour of the turbo decoding process and that increasing its size lead to good performance when compared to the convolutional code.

1. INTRODUCTION

HIgh PErformance Radio Local Access Networks type 2 (HIPERLAN/2) [1] will provide high-speed wireless communications between mobile terminals and various broadband infrastructures in the 5 GHz band. This centralized Time Division Duplex/ Time Division Multiple Access (TDD/TDMA) cellular network will mainly operate in an indoor environment (i.e. coverage range of 50 m) with restricted user mobility (i.e. 3m/s). The Orthogonal Frequency Division Multiplexing (OFDM) has been chosen as the physical layer modulation scheme for its good spectral efficiency and its robustness towards multipath transmission. The selected channel coding scheme is the 64 states convolutional code. To improve the link capability, the user data rate can vary from 6 to 54 Mb/s by changing the convolutional code rate and the sub-carriers modulation.

The goal of this study is to improve the HIPERLAN/2 system performance with a more robust channel scheme than the convolution code specified. In this view, Turbo codes [2], well known for their performance approaching Shannon's theoretical limit seem particularly attractive. This paper focuses on BCH product codes also called Block Turbo codes BTC [3] because they are very efficient for high code rate and they present good free distance even for small block sizes.

The aim of this paper is first to evaluate the performances of two iterative decoding algorithms of BCH product codes on a multipath channel model defined during the HIPERLAN/2 standardisation process and to compare them to the specified convolutional code. Secondly, we will propose a way to improve the turbo decoding process in the HIPERLAN/2 context by modifying the specified interleaver.

In section 2, the two iterative decoding algorithms of BCH product codes are described and in section 3 the HIPERLAN/2 physical layer is presented. The performance of BTC is compared to the convolution code in the multipath HIPERLAN/2 environment in section 4. In section 5, the specified interleaver is modified in order to improve the performance of BTC. At last, some conclusions are given.

2. ITERATIVE DECODING OF PRODUCT CODES

2.1. The products codes

Let P be the product code resulting from the serial concatenation of two linear block codes $C_1(n_1,k_1,d_1)$ and $C_2(n_2,k_2,d_2)$, where n_i, k_i and d_i are respectively the code word length, the number of information bits per code word and the Hamming distance of code C_i, i=1,2. The product code $P=C_1 \otimes C_2$ is represented by a matrix obtained by encoding the k_2 rows of k_1 information bits by code C_1, then encoding the n_1 resulting columns of the matrix by code C_2. By construction, all the n_2 rows of the matrix are code words of code C_1 and all the n_1 columns are code words of code C_2. The product code parameters are the product of the elementary code parameters: $n=n_1.n_2$, $k=k_1.k_2$, $d_{\min}=d_1.d_2$, and the code rate is given by $R=R_1.R_2$ where R_i is the code rate of code C_i, i=1,2.

2.2. Iterative decoding of product codes

Iterative decoding of product codes consists in decoding successively the rows and the columns of the matrix and iterating the procedure. To be efficient, the constituent code decoder has to work on soft inputs and deliver soft outputs that evaluate the reliability associated to the decision on each bit. From the soft outputs generated by the decoding of one dimension (the rows or the columns), an extra information called extrinsic information is extracted and used to modify the associated soft inputs -

the a priori informations - of the next decoder. A sub-optimal and an optimal ML decoding algorithm of BCH constituent codes are evaluated in this paper as the elementary SISO decoders of the turbo decoder. These two algorithms are presented below.

2.2.1. The sub-optimal algorithm

A SISO decoder was proposed by R. Pyndiah [3] that is based on the Chase algorithm to compute the approximated Log A Posteriori Probability ratios (LAPP). The Chase algorithm generates a subset of a given number of the nearest code words from the received word. In order to compute the soft output component in position j of the decoded word, the two nearest code words with opposite component in position j are searched in this subset. The nearest code word will be the approximated Maximum Likelihood (ML) decision D and the second is the competing code word C. In some cases there is no competing code word with opposite component in position j in the subset and the extrinsic information component is not calculated from the soft output component but estimated by a predefined value.

2.2.2. The optimal algorithm

The optimal decoding algorithm of the constituent block codes is a Maximum A Posteriori (MAP) algorithm that minimizes the symbol error probability and was proposed by L.E. Nazarov [4]. This algorithm uses Fast Hadamard Transform (FHT) for the calculation of the soft information with the dimension of the FHT basis being determined by the dimension of the dual code matrix. The decoding rule is exhaustive in the sense that every word in the constituent dual code is used in the decoding process.

3. THE HIPERLAN/2 PHYSICAL LAYER

The HIPERLAN/2 physical layer is based on OFDM to combat frequency selective fading while providing good spectral efficiency. In the TDMA frame, the data payload has a fixed length of 54 bytes. Those payloads are first coded with a convolutional code of generator polynomial (133,171) and constraint length K equal to 7. The coded payload is then mapped to an integer number of OFDM symbols, which value is defined by the sub-carriers modulation and the coding rate selected for transmission. The puncturing schemes are applied in order to increase the code rate of 1/2 of the convolutional mother code. A uniform row/column interleaver of depth of one OFDM symbol is then used to prevent error bursts at the input of the convolution decoder in the receiver. The interleaved data is mapped to data symbols according to the sub-carrier modulation chosen. The OFDM symbol is implemented by an Inverse Fast Fourier transform (IFFT) and is formed of 48 data symbols and 4 pilots to facilitate coherent reception. A guard interval with duration longer than the excess delay of the radio channel is added to eliminate Inter-Symbol Interference (ISI).

The OFDM receiver basically performs the reverse operations of the transmitter, together with additional training tasks.

The main parameters of the HIPERLAN/2 OFDM physical layer are summarized in Table 1.

IFFT size	64
Number of used sub-carriers	52, (48 subcarriers used for data and 4 are pilots)
Channel spacing	20 MHz
Sampling rate	20 Msamples/s
Useful symbol duration	3.2 µs (64 samples)
Guard interval	800 ns (16 samples)
OFDM symbol duration	4 µs (3.2 µs + 0.8 µs)
Sub-carrier modulation	BPSK, QPSK, 16 QAM and optional 64 QAM
Sub-carrier demodualtion	coherent
Mandatory channel coding	Convolution code with constraint length K=7 and code rate=1/2 as mother code. Code rates R=9/16 and 3/4 are obtained by puncturing the mother code
Supported data rates	6, 9,1 2, 18, 27, 36 and 54 Mb/s optional
interleaving	Row/column interleaver, depth of one OFDM symbol

Table 1: parameters of the HIPERLAN/2 physical layer.

4. PERFORMANCE OF BTC IN THE HIPERLAN/2 CLOSED OFFICE ENVIRONMENT

The Packet Error Rate (PER) performance is evaluated with QPSK modulation for the three BTC listed in Table 2 with the optimal and the sub-optimal BCH decoding algorithms and compared to the specified convolutional code with equivalent code rate (R=2/3). The channel is a Non Line Of Sight (NLOS) multipath (i.e. 18 paths) Rayleigh fading channel characterized by a delay spread of 150 ns which corresponds to a closed office environment [5]. The interleaver is the specified uniform row/column one with a depth of one OFDM symbol (i.e. 96 bits for QPSK modulation). No puncturing has been considered, thus the coded block are not exactly equal to the data payload length of 54 bytes and padding has to be introduced to obtain an integer number of OFDM symbols per coded block. The Block turbo decoding is performed with 4 iterations. For the simulations the channel varies for each coded blocks (i.e. coded payload of 54 bytes).

BTC(n,k,d_{min})	$R=R_1.R_2$	$C_1(n_1,k_1,d_1)$	$C_2(n_2,k_2,d_2)$
BTC(961,676,9)	0.7	(31,26,3) BCH code	(31,26,3) BCH code
BTC(961,625,16)	0.65	(31,25,4) expurgated BCH code	(31,25,4) expurgated BCH code
BTC(1024,676,16)	0.66	(32,26,4) extended BCH code	(32,26,4) extended BCH code

Table 2: BTC evaluated in the HIPERLAN/2 office environment.

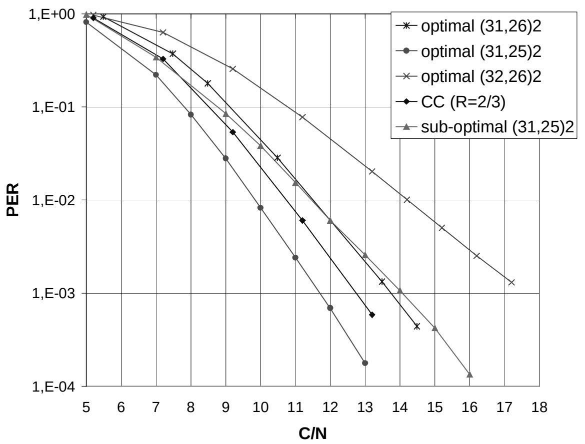

Figure 1: Performance comparison of the 3 BTC schemes with the convolution code (R=2/3) with QPSK in the HIPERLAN/2 office environment

With the specified row/column interleaver of depth of one OFDM symbol, the BTC obtained from the concatenation of two expurgated BCH (31,25,4) codes and decoded with the optimal algorithm gives the best performance and outperforms the convolutional code by 1 dB for a PER of 10^{-3}. In the contrary to the performance obtained on theoretical AWGN and Rayleigh channels, the other BTC schemes have worse performance than the convolutional code in this HIPERLAN/2 environment.

5. PERFORMANCES WITH DIFFERENT INTERLEAVERS

5.1 Interleavers of size of one coded block

The performance is evaluated for the BTC $(31,25,4)^2$ with the optimal and the sub-optimal BCH decoding algorithms and compared to the specified convolutional code with equivalent code rate (R=2/3) and QPSK modulation in the office environment.

For simulations (Figure 2), two types of interleavers are tested, a uniform row/column interleaver and a diagonal interleaver, both with a size of one coded block (i.e. 1056 bits (coded bits and padding bits) corresponding to 11 OFDM symbols for QPSK modulation). The channel is invariant on a coded block basis.

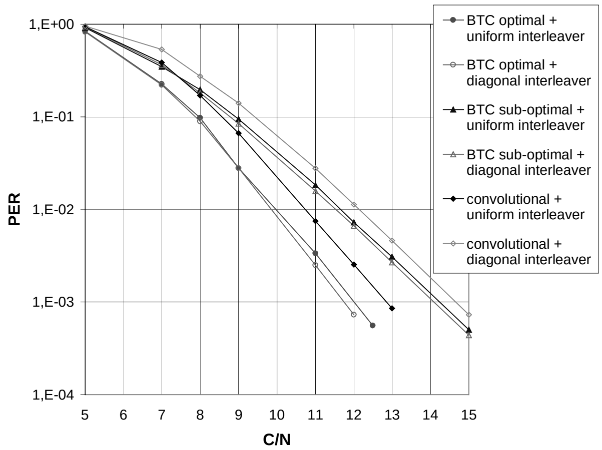

Figure 2: Comparison of the BTC(31,25,4)2 (optimal and sub-optimal algorithms) with the convolution code, when interleaved on a coded block with a uniform row/column interleaver and a diagonal interleaver.

Changing from a row/column to a diagonal interleaver leads to big performance degradation for the convolutional code, whereas it has small impact for the BTC. When the interleaver size is equal to one coded block, the turbo decoding with the optimal algorithm outperforms the convolutional code by 0.85 dB with the uniform interleaver and by 2.9 dB with the diagonal interleaver.

5.2 Interleavers of size of three coded blocks without time diversity

Simulations are done with the same assumptions as before but the size of the interleavers is increased to three coded blocks (i.e. 3168 bits for QPSK modulation). Note that increasing the depth if the interleaver from one to three coded blocks has an impact on the system performance since it increases the decoding delay by three.

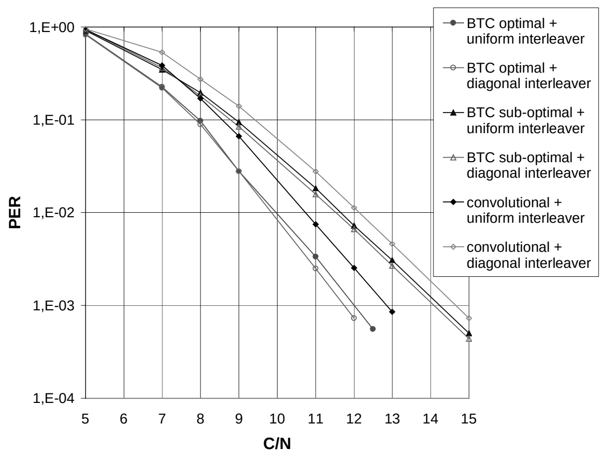

Figure 3: Comparison of the BTC(31,25,4)2 (optimal and sub-optimal algorithms) with the convolution code, when interleaved on 3 coded blocks with a uniform row/column interleaver and a diagonal interleaver without time diversity.

When the data is interleaved on three coded blocks without time diversity, the performance of BTC (31,25,4)2 is the same as when it is interleaved on one OFDM symbol or one coded block. For slowly varying multipath channels, increasing the interleaver size does not decorrelated the errors at the input of the decoder.

5.3 Interleavers of size of three coded blocks with time diversity

In those Simulations, the size of the interleavers is still equal to three coded blocks but each coded block is sent independently in the TDMA frame, thus making use of time diversity. The channel from one coded block to another is no longer the same and if deep fades occur on one coded block the non reliable bits will be spread among the three coded blocks.

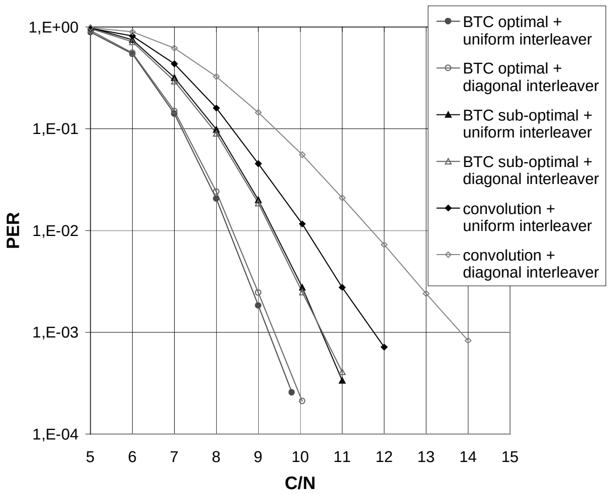

Figure 4: Comparison of the BTC(31,25,4)2 (optimal and sub-optimal algorithms) with the convolution code, when interleaved on 3 coded blocks with a uniform row/column interleaver and a diagonal interleaver with time diversity.

When the data is interleaved on three coded blocks with time diversity, the BTC $(31,25,4)^2$ always perform better than the convolutional code. With the row/column interleaver the gain provided by the BTC is 1.25 dB with the sub-optimal decoding algorithm and 2.5 dB with the optimal decoding algorithm when compared to the convolutional code at a PER of 10^{-3}. In this case the channel is different from one coded block to another and the packets of errors are spread over the three coded blocks before the decoding process. Using time diversity has a big impact on the decoding delay for the HIPERLAN/2 system and it can be applied to only non real-time applications. However those simulations show that for the BTC to work well, the inputs of the decoder must be decorrelated otherwise the extrinsic information generated at each iteration is not enough reliable and near-optimal performance is not obtained.

6. CONCLUSIONS

Block Turbo Codes have been evaluated on the HIPERLAN/2 OFDM system in an office area. Simulation results show that the product code should be constructed with expurgated BCH codes to be efficient. Furthermore, changing the frequency interleaver law from a row/column to a diagonal law leads to big performance degradation on the specified convolutional code whereas it has small impact for the BTC. When the interleaver size is increased from one OFDM symbol to one and three coded blocks, the performance remains the same. However, using time diversity with an interleaver depth of three coded blocks the errors at the input of the decoder are not as correlated. Thus, the turbo decoding process is more efficient and the BTC always outperforms the convolutional code, the gain is up to 2.5 dB at a PER of 10^{-3}.

REFERENCES

[1] DTS/BRAN030003, HIPERLAN Type 2 Functional Specification, ETSI BRAN, 1999.

[2] C. Berrou, A. Glavieux, P. Thitimajshima: "Near Shannon limit error-correction coding: Turbo codes", in Proc. IEEE ICC'93, Geneva, Switzerland, pp. 1064-1070, May 1993.

[3] R. Pyndiah, A.Glavieux,A. Picart and S.Jacq: "Near optimum decoding of product codes",in Proc. of IEEE GLOBECOM'94, San Franscico, USA, vol.1/3, pp. 339-343.

[4] L.E. Nazarov, V.M. Smolyaninov: "Use of Walsh-Hadamard transformation for optimal symbol-by-symbol binary block code decoding", Electronics Letters, vol. 34, n°3, pp.261-262, Feb. 1998.

[5] BRAN WG3 PHY Subgroup. Criteria for Comparison. ETSI/BRAN document no. 30701F, 1998.