BLOCK TURBO CODES FOR HIPERLAN/2 SYSTEMS: PERFORMANCE ANALYSIS

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ABSTRACT

In this paper, Block Turbo Codes (BTC), that is product codes obtained from the concatenation of either two extended or two expurgated BCH codes are evaluated for the HIPERLAN/2 system. Simulations show that only expurgated BTC outperforms the performance of the Convolutional Code (CC) specified in the standard. This result is surprising since expurgated and extended BTC have same performance on the theoretical Rayleigh channel. We will explain the performance degradation of the extended BTC. The specified HIPERLAN/2 interleaver will finally be modified for this extended BTC in order to obtain the same performances as for the expurgated BCH code.

I. 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 propagation. The selected channel coding scheme is the 64 states Convolutional Code (CC). To adapt the transmitted bit rate to the channel conditions, the user data rate can vary from 6 to 54 Mb/s by changing the CC code rate and the sub-carrier modulation.

The goal of this study is to improve the HIPERLAN/2 system performance with a more robust channel scheme than the CC 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 perform very well even for high code rates and they present good free distances even for small block sizes.

In section II, the iterative decoding of BCH product codes is described and in section III the HIPERLAN/2 physical layer is presented. In section IV, the performance of two iterative decoding algorithms of BCH extended and expurgated product codes are compared to the CC on the theoretical Rayleigh channel and on a multipath channel model defined during the HIPERLAN/2 standardisation process. From the simulation results, the expurgated BTC performs significantly better than the extended BTC and is the only one that outperforms the specified CC on the multipath HIPERLAN/2 channel model [4]. We argue in this paper, that the performance difference of the two BTC in the HIPERLAN/2 environment partly comes from the repartition of the correlation at the input of the turbo decoders and is due to the specified HIPERLAN/2 interleaver. Finally, the specified HIPERLAN/2 interleaver is modified in order to obtain the same repartition of the correlation at the input of the decoder for the two BTC and the performances are evaluated on the HIPERLAN/2 multipath channel and compared to the previous results.

II. ITERATIVE DECODING OF PRODUCT CODES

II.1. Product 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 length, the number of information bits 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 of n_2 rows and n_1 columns 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. 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.

II.2. Iterative decoding of product codes

Iterative decoding of product codes consists in decoding successively the rows and the columns of the matrix using a Soft-Input-Soft-Output (SISO) decoder 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 the rows or the columns, an extra information called extrinsic information is extracted and used to modify the soft input - the a priori information - of the next decoder. A suboptimal and an optimal Maximum Likelihood (ML) decoding algorithm of BCH constituent codes are evaluated in this paper.
The sub-optimal decoding algorithm was proposed by R. Pyndiah [3] and is based on the Chase algorithm to compute the approximated Log A Posteriori Probability ratios (LAPP). This sub-optimal algorithm offers a good trade off between performance and complexity.
The optimal decoding algorithm of the constituent block code was proposed by L.E. Nazarov [5] and minimises the symbol error probability. It provides Maximum A Posteriori (MAP) decoding with reduced complexity but is still rather complex. Its main interest is to quantify the sub-optimality of the sub-optimal elementary decoding algorithm mentioned above.

III. THE HIPERLAN/2 PHYSICAL LAYER

The HIPERLAN/2 physical layer is based on OFDM to combat frequency selective fading while providing good spectral efficiency (Table 1). In the TDMA frame, the data payload has a fixed length of 54 bytes. Those payloads are first coded with a CC 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, whose value is defined by the sub-carrier 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 to 9/16 or 3/4. A uniform row/column interleaver of depth of one OFDM symbol is then used to prevent error bursts at the input of the convolutional decoder in the receiver. The interleaved data is mapped to data symbols according to the chosen sub-carrier modulation. 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 (GI) with duration longer than the maximum excess delay of the radio channel is added to eliminate Inter-Symbol Interference (ISI). The PHY burst is formed by adding to the modulated data payload a training sequence of four OFDM symbols.
The OFDM receiver basically performs the reverse operations of the transmitter, together with time and frequency synchronisation and channel correction using the training sequence inserted at the beginning of each data payload.

IV. PERFORMANCE IN THE HIPERLAN/2 ENVIRONMENT

IV.1 Performance with the specified HIPERLAN/2 interleaver

The Packet Error Rate (PER) performance is evaluated with QPSK modulation for the extended BTC(1024,676) and the expurgated BTC(961,625) with the optimal and the sub-optimal BCH decoding algorithms and compared to the specified CC with equivalent code rate (*R*=2/3) on the theoretical Rayleigh and in the HIPERLAN/2 environment (Fig.1). The block turbo decoding is performed with 4 iterations. The channel corresponds to a Non Line Of Sight closed office environment [6]. The interleaver is the specified uniform row/column interleaver with a depth of one OFDM symbol (i.e. 96 bits for QPSK modulation). No BTC 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 data payload. For simulations the channel varies for each coded data payload (i.e. 1056 bits corresponding to 11 OFDM symbols for QPSK modulation).

With the specified row/column interleaver, the BTC(961,625,16) obtained from the concatenation of two expurgated BCH (31,25,4) codes and decoded with the optimal algorithm gives the best performance on the HIPERLAN/2 channel and outperforms the CC by 1 dB for a PER of 10^{-3}. In the contrary to the performance obtained on the theoretical Rayleigh channels, the other schemes have worse performance than the CC in this HIPERLAN/2 environment. The extended BTC(1024,676,16) obtained from the concatenation of two extended BCH (32,26,4) codes and decoded with the optimal algorithm is more than 4 dB away from the CC at a PER of 10^{-3}. With the elementary decoding sub-optimal algorithm, the performances of the two BTC are worse (by about 2.5 dB at a PER of 10^{-3}) than with the optimal elementary decoding algorithm and the expurgated BTC(961,625) is still much better than the extended BTC(1024,676), but performs close to the specified CC.

Table 1: Parameters of the HIPERLAN/2 physical layer

FFT size	64
Number of used sub-carriers	52, (48 subcarriers used for data and 4 pilots)
Channel spacing / Sampling rate	20 MHz / 20 Msamples/s
Useful symbol duration	3.2µs (64 samples)
Guard interval	0.8 µs (16 samples)
OFDM symbol duration	4µs (3.2µs+0.8 µs)
Sub-carrier modulation / demodulation	BPSK, QPSK, 16QAM and optional 64QAM / coherent
Mandatory channel coding	convolutional code with constraint lenght *K*=7 and code rate *R*=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, 12, 18, 27, 36 and optional 54 Mb/s
Interleaving	Row/column interleaver, depth of one OFDM symbol.

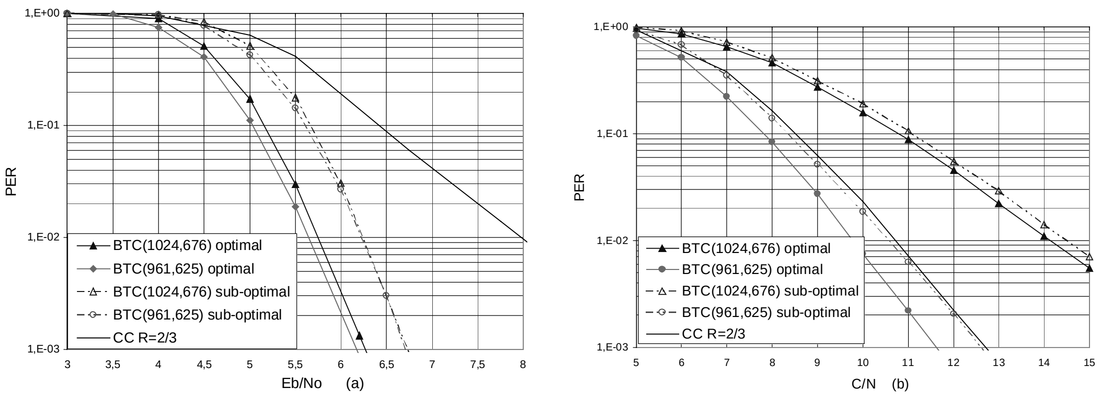

Fig.1: Performance comparison of the 2 BTC schemes (optimal and sub-optimal algorithms) with the convolutional code (*R*=2/3) with QPSK on the theoretical Rayleigh channel (a) and in the HIPERLAN/2 environment (b).

The codes have the same free distance, thus at high Signal to Noise Ratio (SNR), the performance difference is not due to the code structure but to the decoding process. More precisely, considering the two BTC, which are decoded with the same algorithm, the performance difference can only be explained by the sensitivity of the turbo decoder to the correlation of the input samples that influence the propagation of the extrinsic information in the iterative decoding process. This is a known fact for classical parallel convolutional turbo codes [7].

In order to explain this behaviour in the HIPERLAN/2 environment, the correlation between the input samples of the decoder for the expurgated BTC(961,625) and the extended BTC(1024,676) was analysed. Fig.2 gives an example of the correlation between the first input sample and the input product matrix samples. It appears that the metrics at the input of the decoder for the extended BTC(1024,676) are mainly correlated along the columns of the product code, hence the associated SISO decoder fails to bring decoding diversity and the iterative decoding process does not work correctly. However, for the expurgated BTC(961,625), the correlated metrics at the input of the decoder are spread uniformly along the lines and the columns of the product code, burst errors are randomised and the turbo decoder manages to correct the errors.

IV.2 Improved performance with the modified interleaver

In the HIPERLAN/2 environment, if the repartition of the correlated metrics is the same for the extended and the expurgated BTC at the input of the turbo decoder, we can expect that the performances are the same at least at high SNR. The specified HIPERLAN/2 interleaver was modified for the extended BTC(1024,676) in order to obtain the same repartition of the correlation as for the expurgated BTC(961,625). The performance of the extended BTC(1024,676) with the modified interleaver and the expurgated BTC(961,625) with the specified interleaver were evaluated in the HIPERLAN/2 environment and compared with the CC (Fig.3).

With the modified interleaver, the performances provided by the BTC(1024,676) with the optimal and the sub-optimal elementary decoding algorithms are similar to the ones of the BTC(961,625). This confirms that the particularly bad performances of the BTC(1024,676) is due to the repartition of the correlation along the columns at the input of the turbo decoder and thus to the specified HIPERLAN/2 row/column interleaver. Nevertheless, when considering the BTC code properties, the performances of BTC in the HIPERLAN/2 environment are still disappointing compared to CC performance. It seems that BTC turbo decoding is more sensitive to the HIPERLAN/2 channel than CC ML decoding.

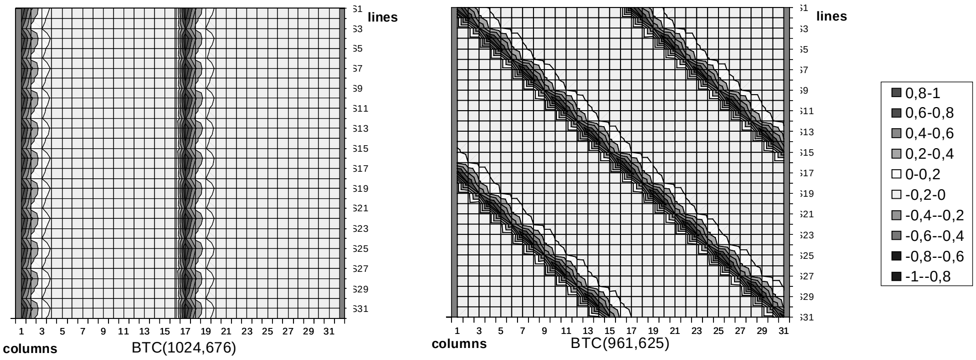

Fig.2: Repartition of the correlation of the BTC(1024,676) and the BTC(961,625) at the input of the turbo decoder.

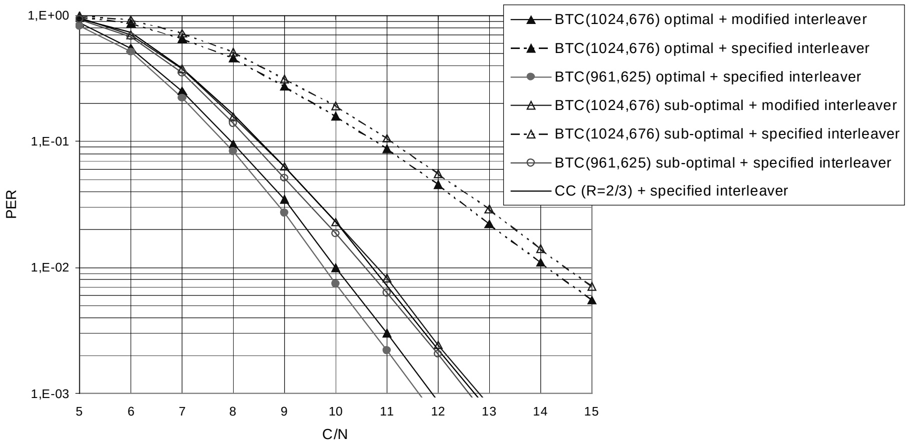

Fig.3: Performance of the 2 BTC (optimal and sub-optimal algorithms) with the modified interleaver.

V. CONCLUSION

BTC have been evaluated on the HIPERLAN/2 OFDM system. Simulations show that only the expurgated BTC(961,625) outperforms the specified CC (R=2/3) and that the extended BTC(1024,676) gives surprisingly bad performance. It is shown that the bad performance of the extended BTC(1024,676) comes from a critical repartition of the correlation at the input of the turbo decoder. By modifying the specified HIPERLAN/2 interleaver for the extended BTC(1024,676) in order to obtain the same repartition of the correlation as for the expurgated BTC(961,625), the performances of the two BTC stick together which is consistent with the results on the theoretical Rayeigh channel. However, considering only code properties, they should outperform much more the CC, this shows that BTC are still sub-optimal on the HIPERLAN/2 multipath channel. For BTC to give good performance, the correlation at the input of the turbo decoder should be spread uniformly along the lines and the columns of the product matrix.

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