

COMBINED-CODING EFFECTS OVER MULTIPLE ACCESS TRANSMISSIONS

Ioana MARCU¹, Carmen VOICU², Simona HALUNGA³

Coding/decoding techniques represent important error correction methods in multiple access transmissions which ensure reliable communications. This paper aims to evaluate the results obtained by combining of two relevant techniques (convolutional and LDPC), analyzing their joint effects based on the BER performances. Multiple access transmission is achieved with different types of signature sequences and based on their correlation degrees the performances of the transmissions are highlighted.

The signals are affected by AWGN and the efficiency of combined coding/decoding techniques is reflected in improved BER as SNR increases. Based on the achieved results multiple conclusions are outlined in the final chapter.

Keywords: combined effect, convolutional, LDPC technique, BER

1. Introduction

The error-correction coding is an important signal processing technique used to improve the reliability of digital communication systems [1]. Convolutional coding/decoding technique represents one of the most popular error correction techniques used for wireless communication systems. Due to its iterative Viterbi decoding algorithm the performances are improved, the price paid being the increased computational complexity. Its efficiency has been illustrated in a large number of researches. In [2] the performances of the Code Division Multiple Access (CDMA) cooperative schemes with two and eight users, employing systematic convolutional code (CC) are presented and is shown that the use of CC significantly decrease the bit error rate (BER) values achieved in all cases. In [3] has been shown that the use of CC improves the performances achieved by each user in a CDMA system affected by jamming. Thus, up to 4 dB decrease of the BER can be achieved if CC is used in processing the data transmitted by each user, this improvement depending on the decoding schemes. Convolutional encoder and Viterbi decoder using System on Programming Chip (SOPC) for variable constraint length are designed in [4]. Using 1/2 and 1/3 code

¹ Dept.of Telecommunication, University POLITEHNICA of Bucharest, Romania

² Dept.of Telecommunication, University POLITEHNICA of Bucharest, Romania

³ Dept.of Telecommunication, University POLITEHNICA of Bucharest, Romania, e-mail: shalunga@elcom.pub.ro

rates with constraint length of 7, 8 and 9 bits, it has been deduced that the Viterbi decoding algorithm achieves lower error rate for 1/2 code rates than 1/3, therefore increasing constraint leads to an increase in efficiency and better utilization of resources as bandwidth and power.

Low-density parity check (LDPC) coding/decoding technique has already proved to have excellent performances for high speed data transmission because of their low complexity. The iterative decoding approach gives better results for LDPC structure. Their performances are comparable with the ones achieved by turbocodes in a DS-CDMA system [5] but their contribution to BER decrease is influenced by the type of spreading codes used for signature, the modulation type, the multiuser detector use for signals' recovery. In non-ideal environment LDPC codes proved to be efficient for Multiple Input Multiple Output (MIMO) systems operating in block-fading and fast Rayleigh fading channels [6]. In [7] it have been studied the effects of LDPC technique in a multiuser system, when either conventional or Minimum Mean Square Error (MMSE) detectors are used at the receiver, the channel is affected by different type of fading and Walsh-Hadamard codes are used. The results have shown that the LDPC encoding – decoding technique reduces BER for all users and for all analyzed detectors, the improvement being more important for uncorrelated or less-correlated users.

In this paper we present a novel approach of a joint method that consists in combining convolutional and LDPC techniques and we aim to exemplify its effects over BER values (as the performances of the system are illustrated in graphics for BERs versus Signal to Noise Ratios (SNRs)).

2. Construction of multiple access transmission

A multiple access transmission is simulated using signature sequences to separate the signals for all users. There are four users (N users) transmitting 5000 bits length data (randomly generated) with equal powers (amplitude $A=3V$). The general configuration of the system is illustrated in Fig. 1.

For each user two stages of encoding are used. In the first one the data are convolutional encoded using generator polynomials defined as

$$\begin{aligned} g_1(D) &= 1 + D^3 + D^4 + D^5 + D^6 \\ g_2(D) &= 1 + D^2 + D^3 + D^5 + D^6 \end{aligned} \quad (1), (2)$$

and each individual sequence at the output of the convolutional encoder is achieved by using convolution and multiplexing operations. Implementing the convolutional encoder of rate $1/2$ thus that to each bit of data corresponds 2 bits of encoded data therefore the length of the output data stream is 4×10^4 bits.

Then the LDPC encoding stage is applied. Defining a certain parity-check matrix \mathbf{H} , the usual way to encode LDPC codes is to multiply the data words from

the output of convolutional encoder by a code generator matrix \mathbf{G} (determined based on \mathbf{H}).

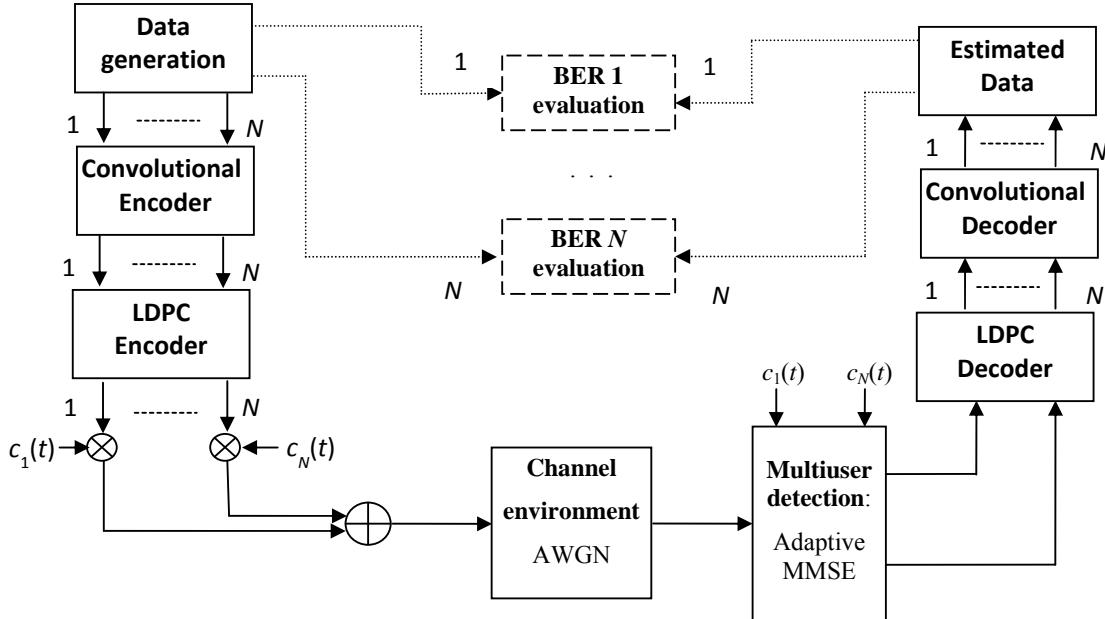


Fig.1. Overall configuration of combined-coding system

Though the parity-check matrix \mathbf{H} for LDPC codes is sparse, the associated generator matrix \mathbf{G} is not [8]. LDPC codes can be constructed by various methods, which generally involve some random selection of where to put 1s in the parity check matrix.

Considering an LDPC encoder of rate $1/2$, each bit of double encoded data, is represented by a signature sequence $s_k(t)$. The cross-correlation of the signature sequences is given by

$$\rho_{ij} = \int_{nT_b}^{(n+1)T_b} s_i(t) s_j(t) dt, \quad \rho_{ii} = 1 \quad (\forall i = 1, N) \quad (3)$$

where T_b is the bit period and $N = T_b / T_c$ is the spreading factor (T_c is the code period). Therefore the correlation matrix of all users is

$$\mathbf{R} = \begin{bmatrix} \rho_{11} & \dots & \rho_{1N} \\ \dots & \dots & \dots \\ \rho_{N1} & \dots & \rho_{NN} \end{bmatrix} \quad (4)$$

a symmetric, non-negative, Toeplitz matrix [9], with ones on the main diagonal.

In this paper three types of sequences are used, namely Walsh-Hadamard, PN and Gold. The Walsh-Hadamard sequences (*Long WH1*) are perfectly correlated signature sequences and, within the simulations, we used sequences of length 32 and indexes 5, 9, 13, 22. The corresponding correlation matrix is

$$R_{Long\ WH1} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (5)$$

Long shifted Walsh-Hadamard (WH2) sequence are obtained from the previous ones by cyclic-shifting with couple of bits the sequences, in order to model the de-synchronization effect that may appear at the receiver due to communication channel effects. The first sequence has been thus left un-shifted, the second one has been shifted with 10 bits, the third with 14 bits and the fourth has been shifted with 23 bits respectively. The correlation matrix is, then,

$$R_{Long\ WH2} = \begin{bmatrix} 1 & 0 & 0.1875 & 0 \\ 0 & 1 & -0.6875 & 0 \\ 0.1875 & -0.6875 & 1 & 0.0625 \\ 0 & 0 & 0.0625 & 1 \end{bmatrix} \quad (6)$$

Pseudo-noise (PN) sequences are periodic binary codes which are random in nature generated by the use of shift registers, but achieved with generator polynomials [10]. In this paper the generator polynomial used is

$$g(D) = 1 + D^3 + D^5 \quad (7)$$

Assuming synchronous reception, each user data is spread with the same PN code but different initial conditions. The correlation matrix is

$$R_{PN} = \begin{bmatrix} 1 & -0.0323 & -0.0323 & -0.0323 \\ -0.0323 & 1 & -0.0323 & -0.0323 \\ -0.0323 & -0.0323 & 1 & -0.0323 \\ -0.0323 & -0.0323 & -0.0323 & 1 \end{bmatrix} \quad (8)$$

The *Gold* sequences are achieved from the previous PN sequence using a decimating factor by 3 and adding the original sequence with the repeated decimated one. The correlation matrix is

$$R_{Gold} = \begin{bmatrix} 1 & 0.2258 & -0.0323 & -0.0323 \\ 0.2258 & 1 & 0.2258 & -0.0323 \\ -0.0323 & 0.2258 & 1 & 0.2258 \\ -0.0323 & -0.0323 & 0.2258 & 1 \end{bmatrix} \quad (9)$$

Assuming the baseband model, on the communication channel the received signal is added with Additive White Gaussian Noise (AWGN) with zero mean and variance σ^2 , leading to a SNR range from 0dB up to 20dB.

At the receiver this signal is passed through an adaptive MMSE multiuser detector. The main attraction of the adaptive MMSE detection lies in the natural link between adaptive filtering and MMSE estimation, which translates into practical implementation of MMSE detectors using adaptive filtering algorithms, which are well understood [11]. The adaptive MMSE equalizer as a classic approach has been widely used in communications [12]. The adaptive detectors with training sequence were proposed in [13] and [14]. After the training phase, the detectors can continue to adapt in a decision-directed mode [15].

In [16] Verdu has establish the conditions that the spreading sequences, the adaptive part and the impulse response of linear transformation of the observations should fulfill in order for the adaptive MMSE detector to produce reliable estimators of the double-encoded transmitted bits.

In order to achieve the estimated of the transmitted bits LDPC decoding is performed. Based on the log-likelihood algorithm [17], Min-sum decoding is achieved using as input data the received symbol vector, base of parity check matrix \mathbf{H} transpose, convolutional code period, noise variance and number of iteration [18]. The output matrix of LDPC decoder has 4×10^4 bits length.

Convolutional decoding of received symbols from the LDPC decoder implies the use of Viterbi algorithm [19] to obtain the estimated transmitted sequences with 4×5000 bits length. Viterbi algorithm searches within trellis structure the best estimated of the path followed by bits in the encoder. Using $g_1(D)$ and $g_2(D)$ as generated polynomials (identical with the polynomials used in the convolutional encoder) the trellis structure can be generated considering the constrain length of 7 bits. Based on the trellis structure the binary decoded sequence can be achieved taking into considerations the trace-back depth and the operation mode of the decoder.

3. Performance evaluation

The performances of the implemented system with two combined coding/decoding techniques are illustrated as average BER vs SNR values. Within graphical representations the abbreviations are: Co= convolutional technique; LDPC= LDPC technique and CC=combined coding/decoding technique.

Fig.2 illustrates the BER results as a function of SNR, achieved in case of Long WH1 codes use for spreading the transmitted data.

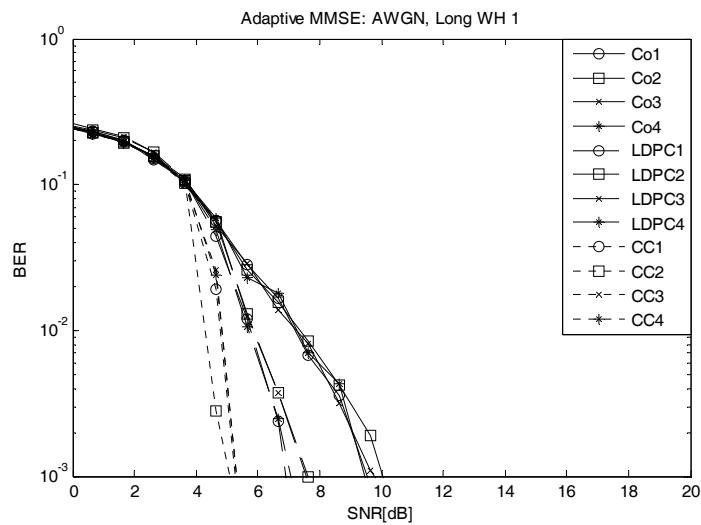


Fig.2. BER vs SNR: Co/LDPC/CC (Long WH1)

The combined effect of CC techniques leads to fast decrease of BER values as SNRs increase. While using only convolutional coding/decoding technique BER reaches 10^{-3} for $\text{SNR} \approx 10\text{dB}$, for CC the same BER is obtained for $\text{SNR} \approx 5\text{dB}$. Therefore the coding gain is 5dB and comparing LDPC technique with CC it can be noticed that a coding gain of 3dB is achieved. Thus the implemented technique is efficient especially for high SNR environment and the implementation complexity is rather modest.

Besides for small SNRs (around 0dB) all described techniques lead to similar performances meaning that the double coding is no longer justified at low power signals. Therefore these techniques are very efficient in transmissions with SNR roughly larger than 5 dB.

Fig. 3 illustrates the results achieved for BERs considering that the signature sequences are Long WH2. There can be notice that different behaviors occur in such conditions depending on the degree of the correlation factor between users' signals. The values for BER are widely spread depending on the

correlation degree between users' signals (Fig.3). The more correlated the signals are, as, for instance $\rho_{23}=0.6875$ in Eq. (4), the higher BER are achieved, as shown in Fig.3. Regardless the coding/decoding techniques the performances are far from those achieved for very small correlation degree, as $\rho_{43}=0.0625$.

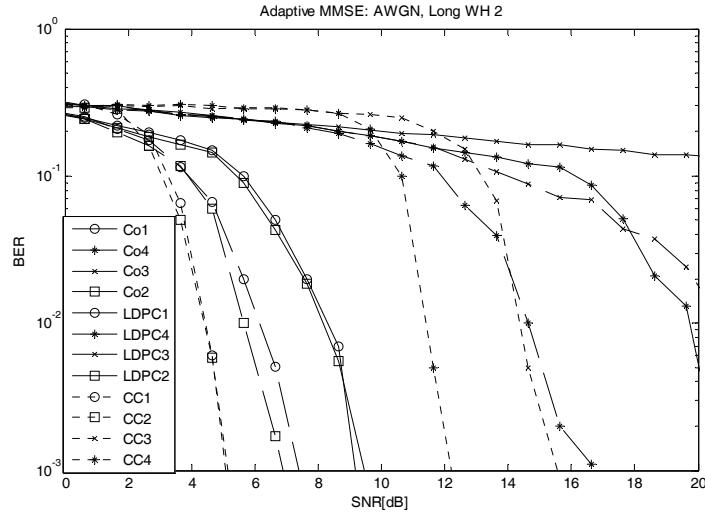


Fig.3. BER vs SNR: Co/LDPC/CC (Long WH2)

For highly inter-correlated signals, we obtain a coding gain of 9dB for LDPC only technique, 8dB for convolutional only and 18 for the combined technique, justifying thus the implementation effort.

Fig. 4 graphically illustrates the performances of the system when PN sequences are used to separate the users' signals. The performances achieved when PN sequences are used are slightly worse, but close to those obtained with Long WH1 codes, shown in Fig.1. This is due to the correlation matrix in Eq. (6) that shows a small correlation degree between all users' signals $\rho_{12}=\rho_{13}=\rho_{14}=0.0323$.

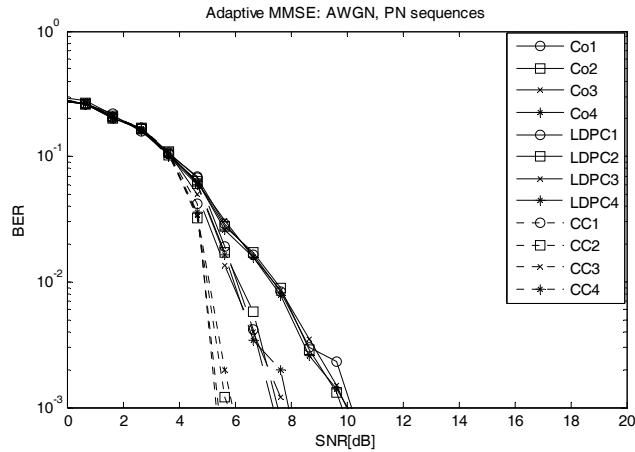


Fig.4. BER vs SNR: Co/LDPC/CC (PN sequences)

Still, the decrease of BER is slower than in Fig.1 and for CC technique $\text{BER} \approx 10^{-3}$ is reached for $\text{SNR} \approx 6\text{dB}$ therefore 1dB larger than in Long WH 1 codes case. It can be noticed that all techniques perform roughly the same for SNR between 0 and approx. 6dB unlike in Fig.1 where the range varies between 0 and 4dB. This means that the use of Long WH1 codes is preferable for such SNRs values.

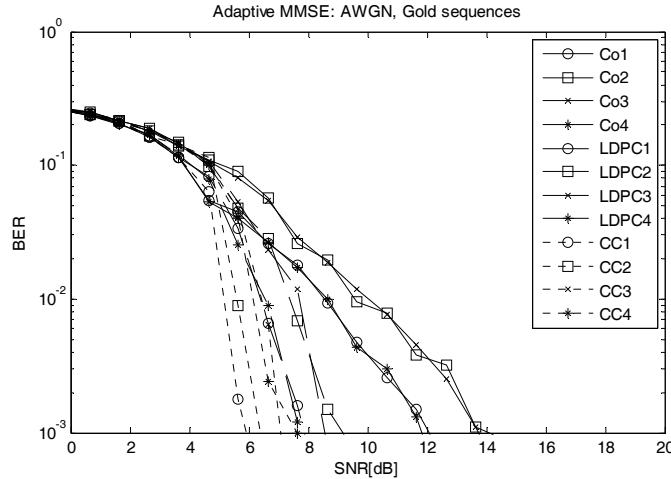


Fig.5. BER vs SNR: Co/LDPC/CC (Gold sequences)

In Fig. 5 are shown the variations of BERs versus SNRs in conditions of Gold sequences use. Since from Eq. (7) we can see that $\rho_{12}=\rho_{23}=\rho_{34}=0.2258$, it is expected that the more correlated the signals are, the more degraded the performances of the system became.

The performances of the systems can be evaluated in terms of coding gains. There can be observed (from Fig. 5) that, for the strongly correlated signals with correlation degree 0.2258, the coding gain achieved when using CC increases up to 7.5dB in comparison with the convolutional case and up to 6dB for the signals with correlation degree 0.0323.

4. Conclusions

The proposed hybrid implementation of combining two coding/decoding techniques (convolutional and LDPC) has proved to be highly efficient for multiple access transmission and the performances are improved based on the fact that the complexity of the system (the mathematical implementation effort) is not increased following this juxtapose. This is justifying by the high coding gain achieved (up to 18dB) even for strongly correlated signals.

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