A Simple Cooperative LDPC Coding Scheme

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***Abstract*—Cooperative communication makes use of the broadcast nature of wireless communication to improve the reliability of the data transmitted between two users. It utilizes intermediate nodes as relays to produce diversity in a point-to-point communication link. This diversity produced by the relays allows an increase in capacity, speed and performance. The aim of this paper is to exploit the characteristics of a single-relay cooperative communication associated to LDPC codes. The amount of data retransmitted by the relay is variable. The cooperative coding scheme is analyzed on different combinations of fading levels for the independent channels produced. The results show that even using a very simple way to combine the codewords that reach the destination before the iterative decoding process it is possible to achieve significant performance gains.**

***Index Terms*—Cooperative coding, Coded Cooperation, LDPC.**

I. INTRODUCTION

The basic idea of cooperative communication is to allow mobile devices to share their antennas creating a multiple-input multiple-output (MIMO) system. The cooperative communication generates spatial diversity by using retransmissions of a signal from distinct locations, obtaining different independent fading versions of the transmitted signal at the receiver. Fig. 1 shows a cooperative communication scheme represented by two users and a destination. Each user transmits its data and can act as a relay. The cooperation among users increases the spectral efficiency due to diversity and may increase the channel coding rate [1], [2], [3], [4].

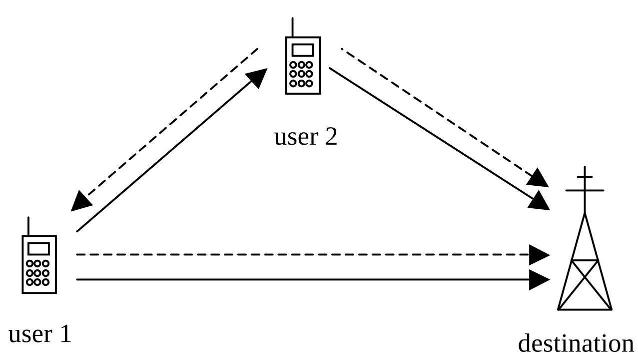

Fig. 1 Cooperative communication scheme

There exist basically three cooperative schemes among users: detect-and-forward, amplify-and-forward and coded cooperation. In the detect-and-forward method the relay detects the partner's data and retransmits them to the destination. Both data from the source and relay are detected by the destination that makes a final decision on the transmitted information. Notice that no data processing is performed on the detected symbols at the relay. In the amplify-and-forward method, the relay receives a noisy version of the signal transmitted by the source and amplifies and sends it to the destination. The destination combines the signals sent by the source and relay, and makes a final decision on the transmitted information. In the coded cooperation scheme there is an integration of cooperation and channel coding. The source encodes the information bits and sends a codeword to the destination and relay. The relay decodes the received codeword and re-encodes the recovered information. The new codeword (or part of it) is transmitted to the destination. At the destination the codewords from the source and relay are used to obtain the best estimate of original information. This paper will focus on this third scheme.

The users represented in fig. 1 can implement simultaneously both functions of source and relay in the coded cooperation scheme. Therefore, their roles can be interchanged.

II. CODED COOPERATION

Coded cooperation integrates a cooperative strategy with error correcting codes by sending coded data of a user through two independent paths to the destination. This integration may achieve significant improvement in bit error rate (*BER*) performance.

Fig. 2 shows an example of a possible block coded cooperation scheme. User 1 encodes n_1 information bits into a systematic codeword by adding n_2 redundant bits. This codeword of length $n = n_1 + n_2$ is broadcasted in a frame to the relay (user 2) and destination. If the relay cooperates, it receives the codeword, decodes it and re-encodes the information producing a new codeword of n_2 redundant bits. These redundant bits are accommodated in a frame of the relay together with its own data, and sent to the destination. The destination receives the codeword from user 1 plus the redundant bits from the relay. These two sequences are combined to decode the n_1 information bits from user 1. A cyclic redundancy check code (CRC) may be added to signalize the cooperation status between users [1]. In this example, user 2 (relay) cooperates to user 1 (source) but the reverse is not true. However, coded cooperation is generally very flexible and can be used virtually with any channel coding scenario [1] [2].

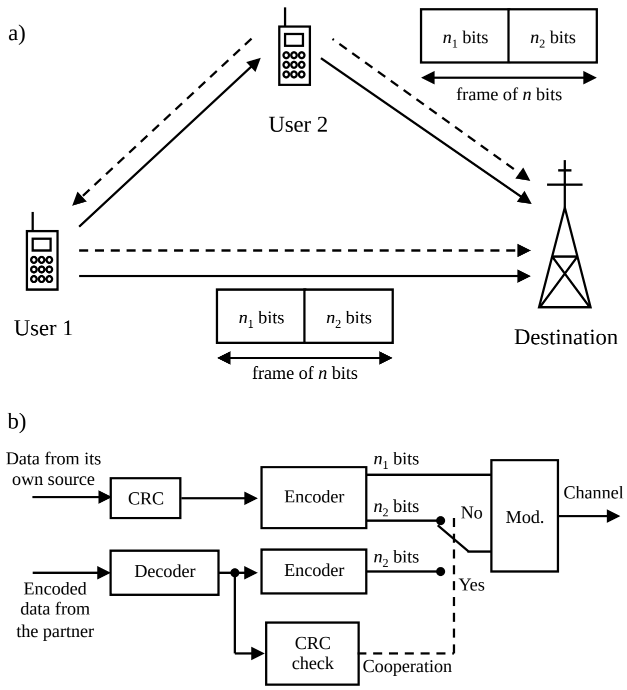

Fig. 2 Example of coded cooperation [1].

III. Proposed Coded Cooperation Scheme

For the sake of analysis, the scheme of fig. 1 is simplified, without loss of generality, as presented in fig. 3. The source and the relay use LDPC encoders and the relay and the destination use iterative decoders. It is also considered a 2-PSK modulation to convey the data on the channels.

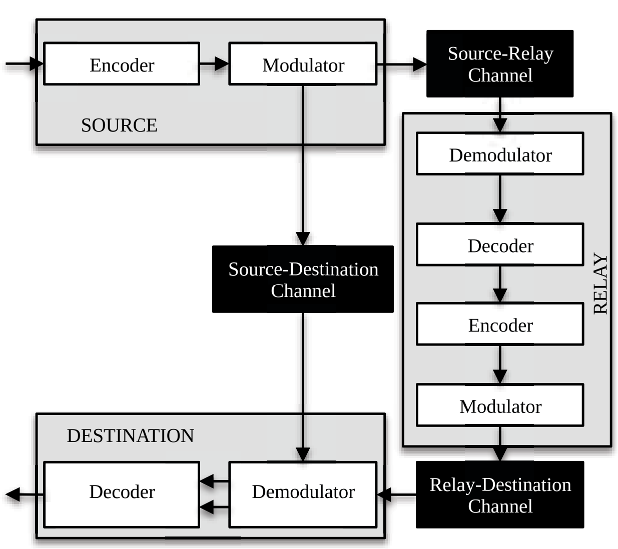

Fig. 3 Simplified coded cooperation scheme.

The source broadcasts k information bits in a codeword **c** of length equal to n bits, therefore the coding rate is $r = k/n$. The source does not cooperate in the system. The codeword reaches both destination and relay by distinct channels. At the relay, the noise-corrupted codeword is detected, decoded, re-encoded in a codeword $\mathbf{c_1}$ of length n_2 bits ($n_2 \leq n$) using a convenient encoding process and transmitted to the destination. The length n_2 of $\mathbf{c_1}$ is related to the level of cooperation provided by the relay. If the relay is not transmitting data, then its whole frame is available for cooperation with the source, i.e., $n_2 = n$.

In the proposed cooperative coding scheme, both codewords **c** and $\mathbf{c_1}$ received by the destination are combined based on the reliability of equivalent bits. The new codeword formed is then fed into the iterative decoder. The encoding process at the relay does not need to be the same of the source. The destination receives the noise-corrupted version of both codewords **c** and $\mathbf{c_1}$ and uses them to best estimate the k information bits sent by the source.

The source-destination, source-relay and relay-destination channels are assumed to be independent additive white Gaussian noise (AWGN). The relay demodulates the received sequence, iterative decodes it to estimate the original k information bits and then re-encodes this estimate using the same LDPC code. Two situations are analyzed:

a) full cooperation is performed by the relay, that is, it generates and sends a n-bits length codeword to the destination;
b) partial cooperation is performed by the relay, that is, the relay sends a $n/2$-bits length codeword to the destination, using only half of its frame.

The binary (4512, 2256) LDPC code utilized in the proposed cooperative coding scheme has the parity check matrix **H** as described in the standard IEEE 802.16e [6]. This parity check matrix **H** has row weight $w_r = 6$ and column weight $w_c = 3$. Therefore, the source encodes $k = 2256$ information bits into a codeword of length $n = 4512$ bits. This codeword is modulated using a 2-PSK modulator and broadcasted to destination and relay.

IV. Results

Fig. 4 shows the performance, in terms of bit error rate (*BER*) per energy per bit to unilateral noise power spectral density ratio (E_b/N_0), of the proposed cooperative coding scheme. The destination receives the noise-corrupted sequences **r** and $\mathbf{r}_1$, related to the codewords **c** and $\mathbf{c_1}$, respectively. The received symbols of **r** and $\mathbf{r}_1$ are firstly compared based on their reliabilities and then only the more reliable symbol in each position is used to build the final sequence. This final sequence is then iteratively decoded to obtain the best estimate of the information sequence transmitted by the source. The decoder is based on the belief propagation algorithm. In this figure, all three channels have no fading. The performance curve for the straight encoded source-destination transmission with no cooperation is also drawn as reference for performance comparisons. Notice that for $BER = 10^{-3}$ the coded cooperation produces a gain of 1.5

dB and 1.3 dB for full or half (only redundant bits) codeword transmitted by the relay, respectively.

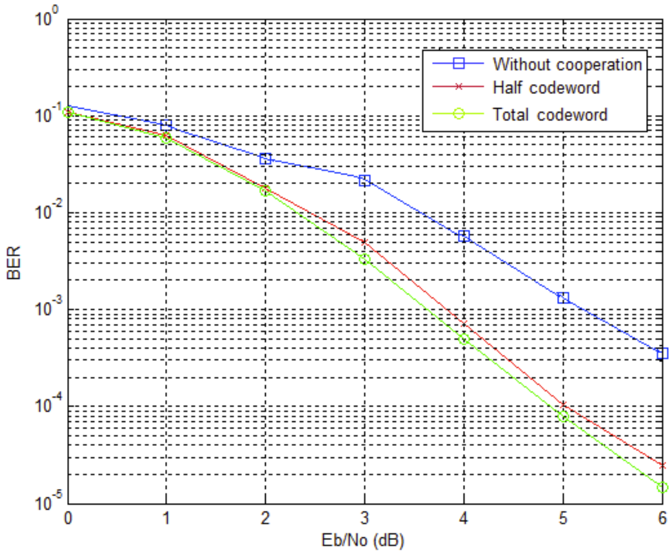

Fig. 4 Cooperative coding using a (4512, 2256) LDPC code with the three channels having no fading.

Fig. 5 shows performance curves *BER* versus E_b/N_0 for the proposed cooperative coding scheme where channel 1 and 3 have no fading while channel 2 has flat fading of 3 dB below them. Notice that the coded cooperation scheme performs worse for full or half codeword transmitted by the relay in comparison to no cooperation. Therefore, there is no advantage in cooperate when channel 2 has a higher level of fading than the other two. This poor performance can be explained by the fact that the estimate of the information obtained by the relay has some uncorrectable errors that are encoded and re-transmitted to the destination causing more errors.

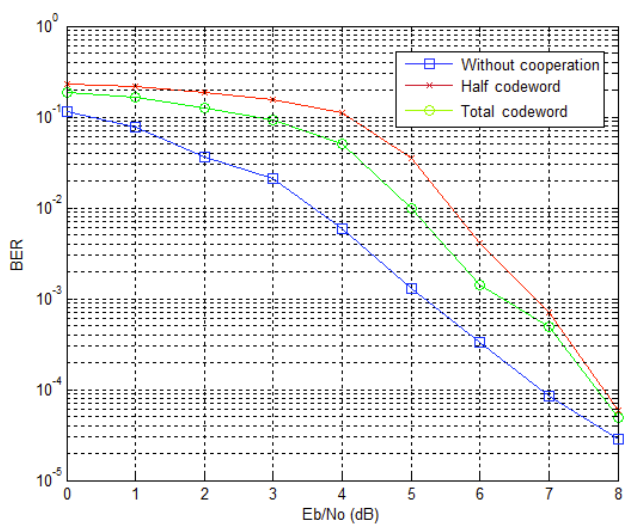

Fig. 5 Cooperative coding using a (4512, 2256) LDPC code with channel 2 fading 3 dB below the other two channels.

Finally, fig. 6 shows performance curves *BER* versus E_b/N_0 of a cooperative coding scheme where channel 2 and 3 have no fading while channel 1 has a flat fading 3 dB below them. Notice that for $BER = 5x10^{-3}$ the coded cooperation produces a gain of 5.25 dB and 4.75 dB for full or half codeword transmitted by the relay, respectively. When the direct channel suffers the highest level of fading, the coded cooperation has an awesome performance.

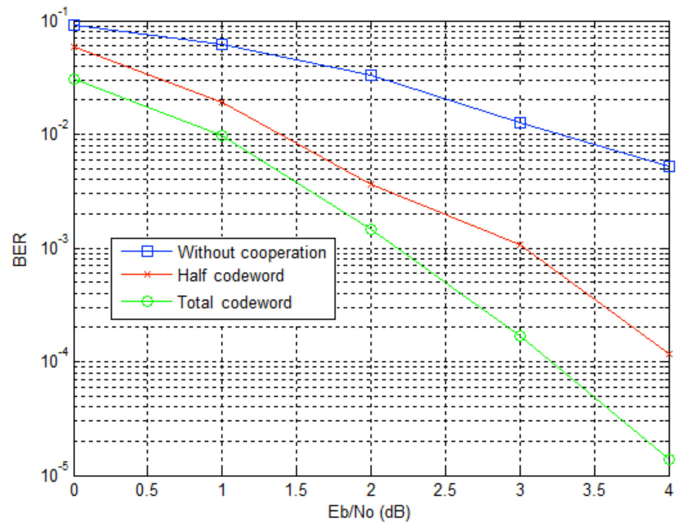

Fig. 6 Cooperative coding using a (4512, 2256) LDPC code with channel 1 fading 3 dB below the other two channels.

V. Conclusion

The preliminary results presented in this paper have shown that even using a very simple way to combine the received sequences **r** and $\mathbf{r}_1$ that reach the destination, it is possible to achieve significant improvements in *BER* performance when the source-destination channel is under worse fading effect than via relay channels. Generally cooperative communications make use of a multiple access schemes (CDMA, OFDMA, TDMA) to transmit data between users and base station. For convenience and simplicity, it was considered a 2-PSK modulation to convey the data on the channels.

These promising results show that there is a wide range of possibilities to be exploit to improve the performance in cooperative communications, such that, the use of quasi-cyclic LDPC codes based on latim square that can allow more flexible coding rates [6], and a more efficient decoding process that makes use more efficiently of the reliabilities of codewords from both channels.

VI. Acknowledgements

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