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TRILHA PRINCIPAL

A Distributed Quaternary Turbo Coded Cooperative Scheme

R. Baldini Filho and Z. S. Penze

***Abstract*— Cooperative communications achieve MIMO-like diversity gains by introducing a relay that creates an independent faded path between the source and the destination. Coded cooperation integrates cooperation with channel coding in order to increase the bit error rate (*BER*) performance of cooperative communications. Turbo codewords can be built efficiently at the destination using encoded portions of the information sent by the source and the relay. This paper presents a distributed turbo cooperative coding scheme that utilizes convolutional codes defined over the finite ring of integers Z_4 that performs better than its equivalent binary counterparts.**

***Index Terms*—Cooperative coding, coded cooperation, turbo code, quaternary codes.**

I. INTRODUCTION

THE basic idea of cooperative communication is to allow mobile devices to share their single antennas emulating a multiple-input multiple-output (MIMO) system. Therefore, the cooperation in a multiuser system produces spatial diversity by replicating the transmitted signal by using one or more relays between source and destination. This generates different independent fading versions of the signal at the destination that are combined to better estimate the transmitted information [1] [2]. The simplest cooperative communication scheme utilizes a single relay between source and destination as shown in fig. 1.

Coded cooperation integrates channel coding to cooperation in order to increase the bit error rate (*BER*) performance of such cooperative communication systems [3] [4]. The process proceeds as follows:

1. The source encodes the information symbols and broadcasts a codeword to both destination and relay;
2. The relay decodes the received sequence and re-encodes the estimated information;
3. The new codeword is then transmitted to the destination;
4. At the destination both codewords from source and relay are combined to obtain the best estimate of the original information.

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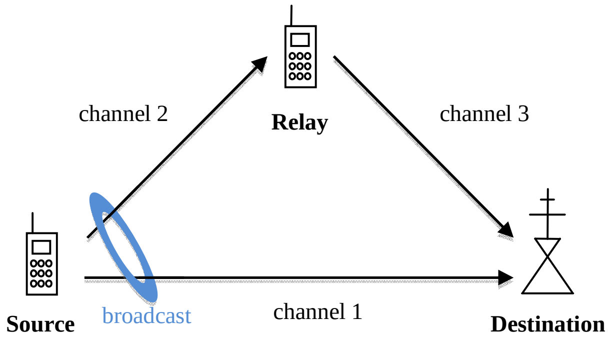

Fig. 1 *Single relay cooperative communication scheme.*

There are several ways to combine such codewords and to decode the resulting codeword to estimate the transmitted information.

The data transmission of both source and relay are based on frames of length $n = n_1 + n_2$ symbols, where each frame is divided into two sub-frames of length n_1 and n_2 symbols, respectively [1]. Depending on the cooperation level, the relay can transmit data related to the source in one of its sub-frames or even in its whole frame. Notice that the encoding processes at source and relay do not need to be the same.

This letter presents a cooperative coding scheme that builds turbo codewords at the destination making use of quaternary convolutional encoding schemes at the source and relay. This coded cooperation scheme is known as distributed turbo coded cooperation [5]. At the destination both codewords are combined as a turbo codeword and iteratively decoded. The quaternary convolutional codes are defined over a finite ring of integers Z_4 [6].

These convolutional codes allow shorter codewords than their binary equivalent counterparts and provide a perfect match between their symbols and the quadrature phase-shift keying (QPSK) modulation signals [6].

The way that the relay establishes cooperation is not in the scope in this paper.

II. QUATERNARY TURBO CODED COOPERATION SCHEME

The proposed distributed coded cooperative scheme is shown in fig. 2. The source broadcasts coded information using a ½-rate recursive systematic convolutional (RSC) encoder defined over Z_4. The relay receives the faded noise-corrupted codeword and decodes it using the Viterbi algorithm. The estimated information is then interleaved and re-encoded by an identical ½-rate RSC encoder but solely the parity check portion of the codeword is transmitted to the destination. Therefore, the relay provides a sub-frame of length $n_2 = n/2$ symbols during cooperation process.

At destination, the n-length encoded sequence transmitted by the source is combined to the $n/2$-length parity portion sent by the relay and decoded iteratively. The quaternary turbo code is only realized on the input of the destination. The turbo code has coding rate equal to 1/3. Noise and fading introduced by each channel are considered to be mutually independent.

Notice that the interleaver in the relay could be eliminated because of the independence of the channels. However, it is kept in the proposed scheme to facilitate the iterative decoding implementation.

As already stated the modulation is QPSK. Moreover, the information bits are assigned to the symbols of Z_4 following the Gray mapping in order to minimize the bit error rate (*BER*).

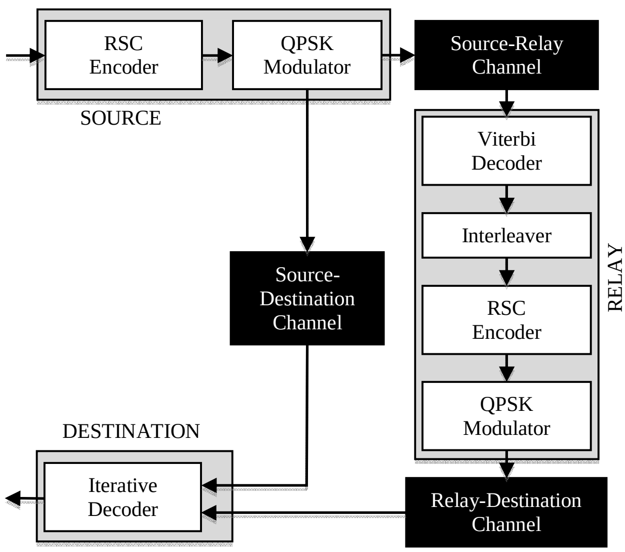

Fig. 2 *Quaternary coded cooperative scheme.*

III. SIMULATION RESULTS

Three simulation scenarios are presented on table 1. Each scenario is a combination of 3 dB attenuation applied to the channels. The 3 dB attenuation value was chosen for convenience to facilitate the simulation and it has been shown to suitably represent the effects of a flat fading on the channels without loss of generality. The results are presented by curves plotted in terms of bit error rate (*BER*) versus energy per bit to unilateral noise power spectral density ratio (E_b/N_0). For the sake of reducing the simulation delay, the number of iterations was set to 3 for the iterative decoding process.

Table 1: Three attenuations scenarios applied to each channel.

	Channel Attenuation		
	Channel 1 Source/Destination	Channel 2 Source/Relay	Channel 3 Relay/Destination
Scenario - 1	3 dB	0 dB	3 dB
Scenario - 2	3 dB	3 dB	0 dB
Scenario - 3	3 dB	0 dB	0 dB

Fig. 3 presents the performance of the quaternary turbo coded cooperative scheme. This quaternary cooperative coding scheme follows the block diagram of fig. 2, where the ½-rate quaternary recursive systematic convolutional encoders (RSC) are identical with generator matrix given by [6]:

$$g(D) = \left[1 \; \frac{2 + D + 2D^3}{1 + D + 3D^2} \right] \tag{1}$$

The length of the codeword transmitted by the source is $n = n_1 = 1024$ symbols, whereas the codeword (redundancy only) transmitted by the relay has length $n_2 = 512$ symbols. Therefore, the turbo codeword formed at the input of the destination has length equal to 1536 symbols.

Notice that the source does not cooperate with the relay, only for the sake of simplicity and to make calculations simpler. All three channels are perturbed by additive Gaussian white noise (AWGN). For the sake of comparison, fig. 3 also presents the performance of an equivalent quaternary turbo encoding scheme without cooperation, i. e., a (1536, 512) turbo encoder in the source generates codewords that are transmitted straight to destination.

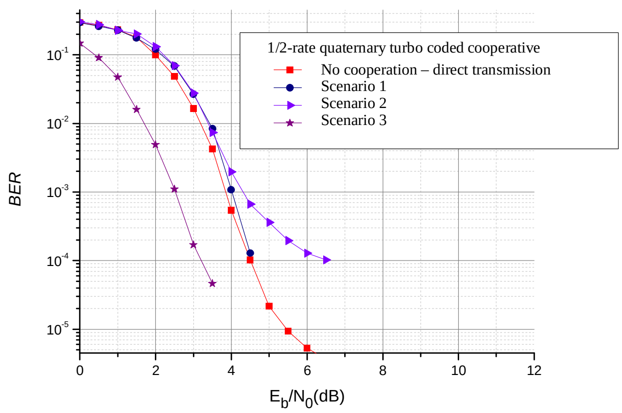

Fig. 3 *Performance of quaternary turbo coded cooperative scheme.*

Fig. 3 shows that the proposed quaternary turbo coded cooperative scheme performs better in scenario 3, where only the direct channel (channel-1) suffers 3 dB attenuation. Moreover, the quaternary turbo coded cooperative scheme has slightly lower performance than the non-cooperative turbo encoding scheme when a 3 dB attenuation is present in channel 2 (scenario 2) or in channel 3 (scenario 1). Notice also that the proposed scheme has presented a higher error floor for scenario 2.

Fig. 4 presents a performance comparison of the quaternary and an equivalent binary coded cooperation scheme. The binary encoded cooperative scheme is similar to that given in fig. 2. The binary coded cooperation scheme uses ½-rate recursive binary systematic convolutional (RSC) encoders with generator matrix given by [7]:

$$g(D) = \left[1 \frac{1 + D + D^3 + D^4}{1 + D^2 + D^4} \right] \tag{2}$$

The length of the binary codeword transmitted by the source is $n = n_1 = 2048$ bits, whereas the codeword (redundancy only) transmitted by the relay has length $n_2 = 1024$ bits. Then, the binary turbo codeword formed at the input of the destination has length equal to 3072 bits. The lengths for the binary codewords are made double of the quaternary coded cooperation scheme because each quaternary symbol carries 2 bits. The modulation at source and relay are binary phase-shift keying (BPSK). Scenario-3 was chosen for the comparison only.

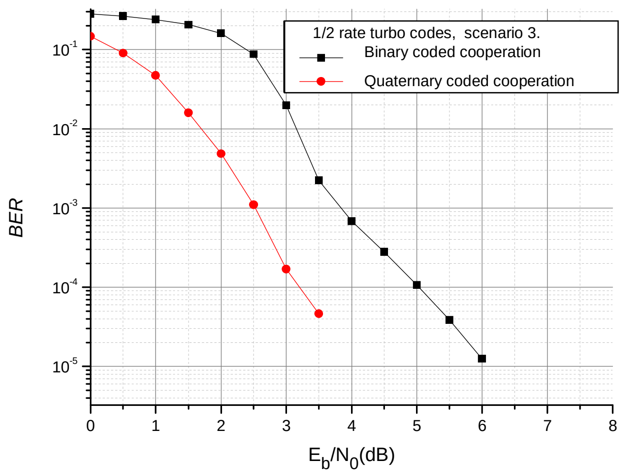

Fig. 4 *Performance comparison between quaternary and binary turbo coded cooperation schemes.*

Fig. 4 shows that the proposed quaternary turbo coded cooperation scheme performs around 1.7 dB better than its equivalent binary turbo coded cooperation scheme.

For a fair comparison both binary and quaternary recursive systematic encoders have 16 trellis states. Moreover, the coding rates and the lengths are the same, in terms of bits, for both turbo codes. However, the minimum Euclidean distance for BPSK modulation is 2 whereas for QPSK it is $\sqrt{2}$ which gives a certain performance advantage for the binary over the quaternary turbo code scheme.

IV. Conclusion

The proposed distributed quaternary turbo coded cooperative scheme defined over ring of integers Z_4 has shown better *BER* performance than its equivalent binary turbo coded cooperative. Moreover, quaternary codes associated to QPSK modulation allows a more efficient way to accommodate the redundancy produced by the encoding process than its binary equivalent counterparts associated to BPSK modulation, for the same amount of information bits.

There is also sufficient evidence that coded cooperation is more effective when the source-destination channel has more severe impairments than the source-relay and/or the relay-destination channel.

Notice that if the source and relay presented in fig. 2 perform the encoding process using full turbo code, the proposed cooperative scheme can still be implemented. At the relay, the received turbo codeword could be decoded and the estimated information re-encoded using only one of the constituent RSC encoder where only the parity check symbols are sent to destination. This iterative decoding process at the relay improves even further the *BER* performance.

Acknowledgment

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