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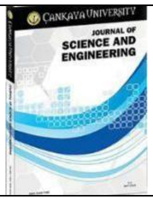

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The Research and Design of Multi Relays in Cooperative Communication System Based on Polar Codes

Ali Sameer Hadi HADI[1*], Orhan GAZI[1]

[1] Department of Electronics and Communication Engineering, Cankaya University, Ankara, Turkey

Keywords

Polar codes,
Linear block code,
Cooperative coding,
BER,
FER,
SC.

Abstract

In this paper, we propose a method to increase the performance of cooperative communication using polar codes. For this purpose, we consider non-line-of sight (NLOS) cooperative communication scheme where destination node does not receive signal from source directly. The relay nodes use decodes and forward approach. We propose a voting scheme for the relay nodes, which share information among them. It is shown by the simulation results that the proposed approach significantly improves the performance of relayed communication.

1. Introduction

Polar codes are the first class of channel codes whose performances are mathematically proved, and they achieve the channel capacity of the binary input discrete memoryless channels. Polar codes have less encoding and decoding complexity compared to Turbo and LDPC codes [1]. Polar codes are implemented in a variety of communication environments. They are implemented in wiretap channel in [2, 3] and they are also used for deep space communication [4]. Polar codes are one of the best types of codes suitable for cooperative communication systems.

In [5] polar codes are used with single relay (decoding and forward) cooperative channel communication systems. In sequel, more advanced work was proposed in [6]. Further, any number of relay channels were considered for cooperative communication systems utilizing polar codes. It is also shown that polar codes can achieve the capacity of single relay communication systems. Multi antenna cooperative communication systems are candidates to improve the utilization of spectrum in the improved 4G communication systems.

Recently, the cooperative coding techniques have become the focus of the widespread cooperative wireless communication networks. Cooperative communication provides spatial gain diversity. Use of cooperative coding enhances the performances of cooperative communication systems providing coding gain [7]. In [8] simple relay network consisting of a single source, a relay and a destination node is studied. Furthermore, source sends information bearing signal X_R to the relay and destination, and the relay gets the signal from source and passes it to the destination. Thus, the relay acts as a broadcast component. The received signals at the destination side are combined and an enhanced signal is formed.

* Corresponding Author: ali.alsamraai@gmail.com
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Turbo codes are used in a distributed manner in [9, 10] for cooperative communication employing relays. The use of low-density-parity-check codes for relayed communication appeared in [11] where decode and forward method is utilized at relays. Polar codes are also considered for relayed cooperative communication systems after its introduction. Nested polar codes are introduced in [12] and they are used wiretap relay channels. It is shown in [13] that nested polar codes show bad performance for decision-forward (DF), and compress-and-forward (CF) relay techniques.

Polar codes are employed for Gaussian degraded relay channels in relay transmission schemes in [14]. It is shown in [15] that polar codes can achieve the channel capacity for half-duplex relay channel when time and information division parameters are used in an optimized manner. Belief propagation (BP) algorithms are also used for the decoding of polar codes [16]. However, the complexity of BP algorithms is greater than the complexity of successive cancelation (SC) algorithms, and SC algorithms when used as successive cancelation list with CRC concatenation show better performance than that of the BP algorithms. On the other hand, BP algorithms are more suitable for hardware implementation since they can be decoded in a parallel manner.

Researchers also focus on the use of polar codes for full duplex communication employing relayed channels. The studies show that polar codes improve the performances of relayed cooperative communication systems significantly. To simplify the design of the communication systems and at the same time considering the implementation issues for practical application, the half-duplex communication mode is the preferred choice for relayed communication. In this paper, we propose a new method for the use of polar codes in cooperative communication systems. We show by computer simulations that the proposed approach improves the performance of relayed communication systems significantly.

The rest of the paper is as follow.
Section 2 described the design modes of the systems, while the first mode has described several cases where each case has a specific number of relays. In addition, the second mode is the suggested system that improved the system performance.
Section 3 shows the results of all the systems, BER and FER with SNR.
While section 4 is the conclusion of the paper.

2. Cooperative System Mode of Polar Code

In our study, polar codes are employed for cooperative communication systems and half-duplex communication mode is chosen. There are two transmission time slots, and in the first time slot, data is transmitted from source to relays. Relays perform decode and forward operation. In the second time slot, relays perform the transmission operation. The cooperative communication system, used in this paper, employing polar codes is depicted in Figure 1.

2.1. Classical Cooperative Channel Systems Based on Polar Code

The capacity of the channel from source S to the relay R_i is denoted by W_{S-R}, the code rate satisfies

$$R_C < I(W)$$

The index of the frozen bits are determined according to

$$A_{S-R}^{C} = \{i | i \in \{0, 1, \dots, N-1\} \quad \text{and} \quad Z\left(W_{S-R}^{i}\right) \tag{1}$$

$Z(W_{S-R}^{i})$ are Bhattacharyya parameters, which are used for the determination of frozen bit locations, of the split channels W_{S-R}^{i}. AWGN channels are used between nodes of the cooperative communication systems.
The Bhattacharyya parameters of the split channels can be calculated in a recursive manner as

$$Z\left(W_N^{2k-1}\right) = 2Z\left(W_{\frac{N}{2}}^{k}\right) - \left[Z\left(W_{\frac{N}{2}}^{k}\right)\right]^2 \tag{2}$$

$$Z\left(W_N^{2k}\right) = \left[Z\left(W_{\frac{N}{2}}^{k}\right)\right]^2 \tag{3}$$

where the initial value is chosen as

$$Z_1^1 = e^{-R\frac{E_b}{N_0}} \tag{4}$$

where R is the code rate of the system, and a value of 2dB for E_b/N_0 is preferred for the calculation of split channel parameters in the literature.

The indices of the frozen bits for the channels W_{R-D}^{i}, i.e., the channels from relay to the destination, are calculated using

$$A_{R-D}^{C} = \{\mathrm{i} \mid \mathrm{i} \in \{0, 1, \dots, \mathrm{N}-1\}:\ Z\left(W_{R-D}^{i}\right) \tag{5}$$

The frozen bits can be regarded as parity bits and as the number of frozen bits increase, better performance is obtained for polar codes. However, large number of frozen bits means lower transmission speed and less efficient use of the transition bandwidth.

At the relay/relays, the signal received from the source S is decoded, information bits are recovered and in sequel, polar encoding is performed again, and the codewords are transmitted to the destination. At the destination, the received signals are combined, and the resulting signal is passed to a polar decoder.

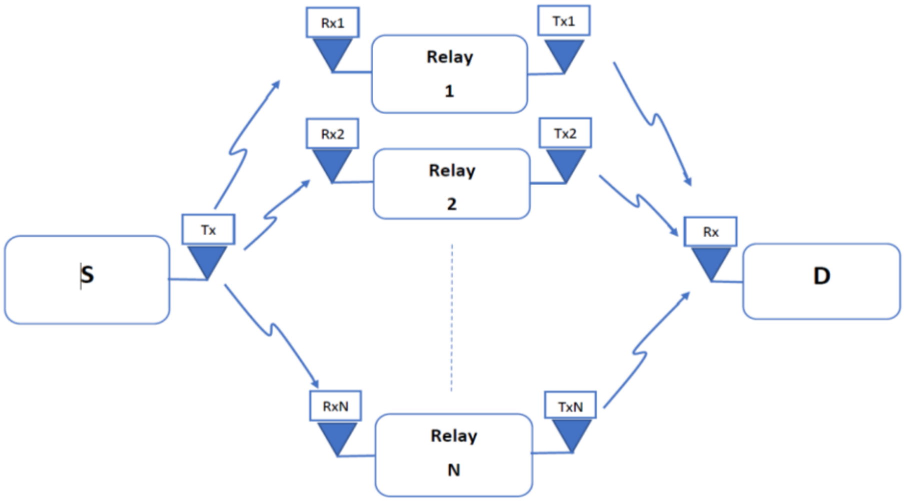

Figure 1. The cooperative system based on Polar codes

The first transmission time slot is used to send data from source to relays, and the second transmission time slot is used to send data from relays to destination. For the cooperative communication system used in Figure-1, BPSK modulation is used, and AWGN communication channels are employed.

The data at the source is encoded using polar codes parameters

$$C_1(N_1, K_1, m_A, m_{A^c})$$

and code-bits, represented by the vector X^{N_1}, are BPSK modulated and transmitted to the relays.
The signals received at the relays can be written as [9]

$$Y_{R_i} = \sqrt{P_S}\,.X_S + n_i \quad (6)$$

where i represents the index of the relay.

P_S and P_{R_i} represents the powers of the transmitted signals at the source S and the relay(s) R_i. In our study take P_S and P_{R_i} as 1.

The relays decode the received signal by themselves whenever they get it [17, 18]. The data frames obtained by the relays are re-encoded and BPSK modulated and transmitted.

The signals transmitted by the relays are received by the destination, and they are combined as in

$$Y_D = [(\sqrt{P_R}\,.X_{R_1} + n_{R_1-D}) + (\sqrt{P_R}\,.X_{R_2} + n_{R_2-D}) + \cdots + (\sqrt{P_R}\,.X_{R_M} + n_{R_M-D})]/M \quad (7)$$

where M is the number of relays.

2.2. Information Exchange Between Relays for Cooperative Systems Employing Polar Codes

In this section, we propose a method, which involves the exchange of decoding information between relays, for the cooperative communication systems employing polar codes. For the simplicity of the illustration, we consider cooperative communication systems employing three relay nodes.

The signals received by the first, second and third relays can be written as

$$Y_{R_1} = \sqrt{P_S}\,.X_S + n_{S-R_1} \quad (8)$$

$$Y_{R_2} = \sqrt{P_S}\,.X_S + n_{S-R_2} \quad (9)$$

$$Y_{R_3} = \sqrt{P_S}\,.X_S + n_{S-R_3} \quad (10)$$

By connected three relays to each other via cable, relays can change decoding information as shown in Figure-2 where bold block arrows connecting the relays indicate the exchange of the decoding information between relays. To understand the way of working this system clearly, assuming that the signals are received by the relays and each relay passed the received signal to its decoder using SC decoding algorithm.

Decoding of the information bits are performed in a sequential manner by each relay using the SC algorithm. The likelihood of the information bits are calculated and the hard decisions are made by all the relays separately.

After decoding of the i^{th}bit, relay decoders compare their decoding results. There are three decision results and at least two of them are the same. Moreover, the relays update their decision, if necessary, regarding common value of two decision results.

That is, if two relays decide as '0' for the value of current bit, and the third relay decides it as '1', then the third relay changes its decision to '0'.

This process is continued until all the bits are decoded by all the relays. Upon completion of the decoding and information exchange process, the relays encode the information bits and the code-words are transmitted after BPSK modulation.

The received signals are combined at the destination node according to

$$Y_D = \frac{[(\sqrt{P_R}.X_{R_1} + n_{R_1-D}) + (\sqrt{P_R}.X_{R_2} + n_{R_2-D}) + (\sqrt{P_R}.X_{R_3} + n_{R_3-D})]}{3} \quad (11)$$

and the resulting signal is sent to the polar decoder.

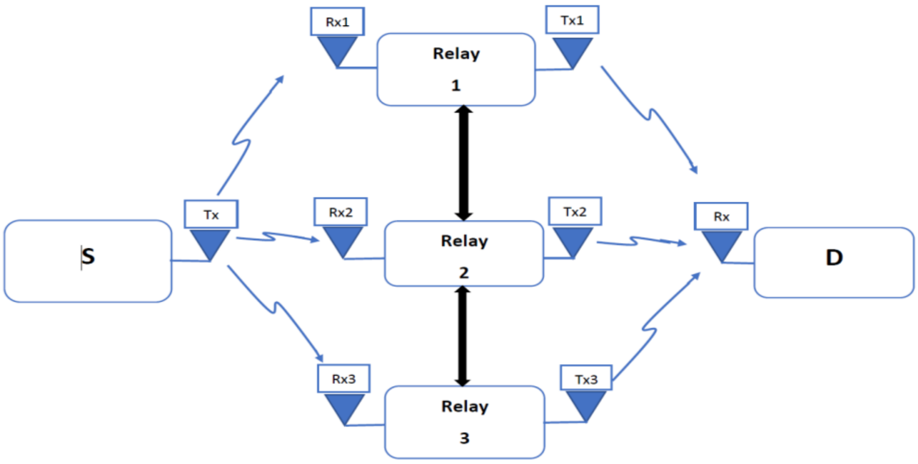

Figure 2. The cooperative system employing polar codes, information is shared between relays

3. Simulation Results

We measured the performance of the proposed approach via computer simulations. We considered the relayed communication systems involving, 1, 2, and 3 relays. The performances of the relayed communication systems are compared to that of the non-cooperative communication system, which involves a single source and destination node.

The rate of the polar code employed in cooperative communication system is R=1/2, the code length N=1024 bits, and SC decoding algorithm is used in the decoders.
AWGN channel model is employed for simulations and $E_b/N_0 = 0.891250$ is used for the initial value of the Bhattacharyya parameter defined as $Z = e^{-R\frac{E_b}{N_0}}$ which is used for the determination of data and frozen bit locations.

The simulation results are depicted in Figure-3 and Figure-4 where BER and FER performance curves of cooperative and non-cooperative systems are compared. It is seen from Figure-3 and 4 that increasing the number of relays increases the performance of the communication system when compared to non-cooperative communication system. Besides, it is seen that incrementing the relay number for 1 and 2 does not have significant performance boost. On the other hand, when relay number is incremented from 2 to 3, performance of the system increases significantly.

In addition, it is also seen Figures-3 and 4 that the proposed approach improves the performance of relayed communication system, employing 3 relays, for low E_b/N_0 values, and it achieves almost the same performance for high E_b/N_0 values.

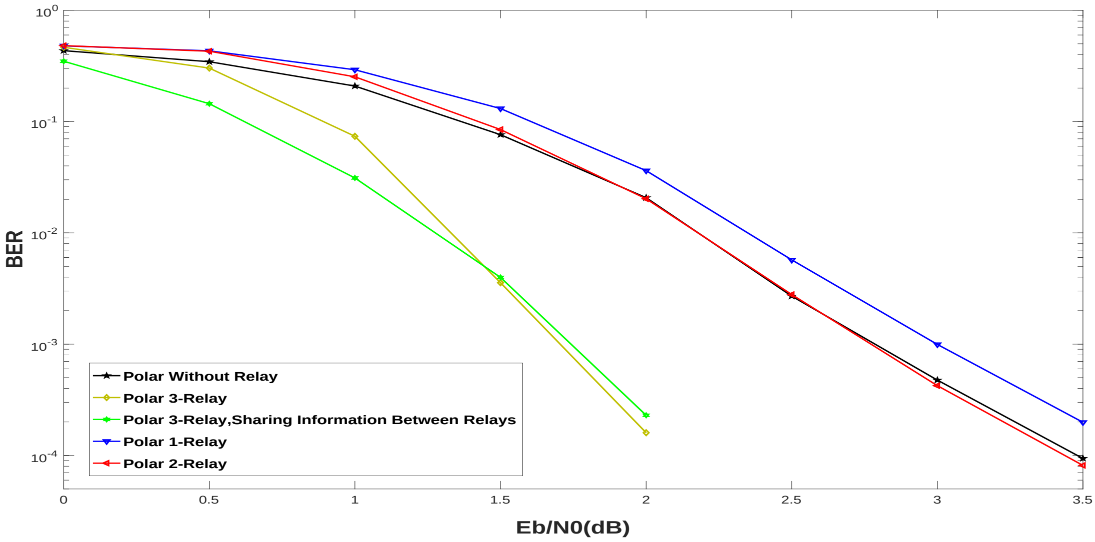

Figure 3. The BER performance comparison for relayed communication systems where effect of polar codes on the performance improvement is observed.

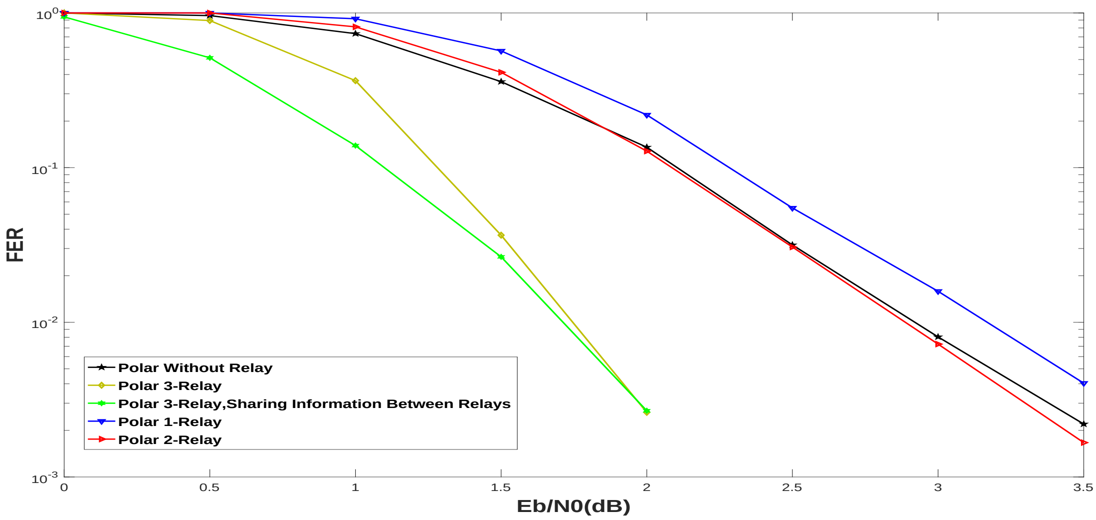

Figure 4. The FER performance comparison for relayed communication systems where effect of polar codes on the performance improvement is observed.

4. Conclusions

In this paper, we study on improving the performance of cooperative communication systems employing polar codes. We propose a method in which the relays exchange their decision results. Considering all the decision results, the number of decisions for the favor of 0 and 1 are counted. The relays whose decisions are for the lower count value change their decision results, i.e., they adapt just the opposite bit value for decision results. It is seen from the computer simulation results that the proposed approach significantly improves the performance of relayed communication systems for low and moderate E_b/N_0 values.

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Declaration of Competing Interest

No conflict of interest was declared by the authors.

Authorship Contribution Statement

Ali Sameer Hadi HADI: Writing, Data Preparation, Simulations, Reviewing, Methodology
Orhan GAZI: Writing, Reviewing, Methodology, Supervision

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