Comparison of BER Performance of Cooperative Wireless Systems Based on D-OSTBC, D-EOSTBC and DF Relaying Protocol

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ABSTRACT

The end-to-end bit error rate (BER) performance analysis of cooperative wireless communication networks based on distributed orthogonal space time block coding (D-OSTBC) (Alamouti) scheme, distributed extended orthogonal space time block coding (D-EO-STBC) and decode-and-forward (DF) relaying protocol, are addressed. There are two main relaying techniques which are amplify-and-forward (AF) and decode-and-forward (DF). Opposed to that in conventional multi-input multi-output (MIMO) systems, cooperative systems, the antennas are distributed among different terminals, which easy to establish cooperative MIMO. This paper will deal with three system models of wireless communications. The first model is conventional single-input single-output (SISO) system, which consists of one source and one destination. The second model is cooperative MIMO based on two relays and D-OSTBC (Alamouti) scheme. This system consists of one source, two relays and one destination. The third model is cooperative open loop MIMO based on four relays and D-EO-STBC technique. This system consists of one source, four relays and one destination. All these schemes are based on DF protocol and analyzed over flat fading channels. Also, QPSK digital modulation scheme is used for all schemes. MATLAB simulations confirm that the BER performance of cooperative SISO is the worst, whereas, the best BER performance is achieved by the system with four relays and based on D-EO-STBC techniques.

Keywords: pair relays cooperation; four relays cooperation; D-OSTBC, D-EO-STBC; decode and forward technique

1 Introduction

MIMO communications are applied in real-world wireless communications systems, such as standards, WiFi and LTE/LTE-advanced, which are used extensively for wireless LAN applications and conventional cellular communications, respectively. The version of WiFi that employs MIMO is defined by the IEEE 802.11n standard. IEEE 802.11n supports a wide variety of antenna configurations, ranging from SISO arrangements to $m \times n$ MIMO configurations with various combinations of STBC [1]. More specifically, as in [1], the antenna configurations of IEEE 802.11n is up to four antennas at either the transmitter, receiver, or both.

Cooperative communication is a new communication paradigm which generalizes conventional MIMO communications to much broader applications [2]. Conventional MIMO system may not always be practical to accommodate multiple antennas at the mobile stations, due to cost, size and other hardware limitations. Therefore, the distributed orthogonal space time block coding (D-OSTBC) techniques provide promising solutions to achieve cooperative MIMO systems requiring reliable wireless communications at high rates. As in [3], an attempt to attain a better communication efficiency, the concept of cooperative MIMOs has been proposed for cellular systems. More specifically, a group of mobile nodes shares their antennas with other users to create a virtual antenna array to provide spatial diversity gain, this group of mobile nodes known as relays. Figure 1 demonstrates the concept of relay system and potential applications of various cooperative MIMO systems in a cellular network.

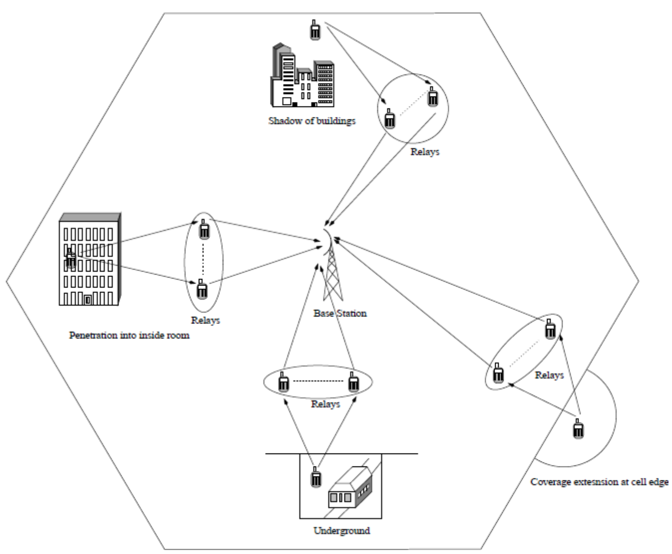

Figure 1: *Cooperative MIMO systems in a cellular network* [2].

For example, when a user is behind buildings or underground, as in Figure 1, direct communication with the base station (BS) becomes unreliable, due to severe shadow fading and path loss. In order to maintain reliable wireless communications, a group of neighbour users may form a virtual antenna array in order to fixe reliable connection to transmit the data between the source node and the BS. There are several types of relaying cooperation protocols such as Amplify-and-Forward (AF), Decode-and-Forward (DF) and Compressand-Forward (CF). AF cooperation scheme, the relay nodes simply amplify the received signal waveforms, but they amplify the signal and noise jointly and hence are unable to improve the SNR. Whereas, in the DF cooperation strategy, the signals received at the relays are decoded and possibly re-encoded using different Forward Error Correction (FEC) codes, before being forwarded to the destination. Finally, the CF arrangement, the relay compresses, estimates or quantizes its observations without decoding the information. However, most routing protocols use a DF strategy at each relay node, where packets received by the relay are decoded to remove errors through error correction and retransmissions requested when errors are detected that cannot be corrected. Therefore, in this work, DF is exploited. However, DF strategy suffers from the error propagation problem because the relays do use a hard-decision operation on the received signal [4], [5].

1.1 The Focus of This Paper

In wireless digital communication system, the common measure of performance is a BER. Therefore, this paper focus on measurements of BER performance of conventional SISO system, cooperative MIMO systems based on D-OSTBC (Alamouti) scheme and cooperative open loop MIMO systems based on D-EO-STBC technique. These systems exploit QPSK modulation scheme and DF relaying protocol. Moreover, the analysis is based on flat fading channels. In addition, the performance of these systems is compared with cooperative SISO systems and cooperative system with one relay and direct link between the source and destination. Finally, simple mathematical analysis of transmission and receive process of cooperative open loop MIMO wireless system with four relays over flat fading channel is presented.

1.2 Organization of the Paper

The rest of this paper is organized as follows: In Section 2, the system model of cooperative open loop MIMO systems based on D-EO-STBC techniques over flat fading channel is described. In Section 3, the Mathematical model of cooperative open loop MIMO systems based on fours relay, D-EO-STBC techniques and DF relaying protocol, over flat fading channel. is explained. Simulation results are drawn in Section 4 and conclusions are given in Section 5.

1.3 Common Notations

Common notations that have been used in this paper are $(\cdot)^*$, $(.)^T$ and $(.)^H$ which denote complex conjugate, transpose and Hermitian transpose operations, respectively.
Next, system model of cooperative open loop MIMO systems based on four relays, open loop D-EO-STBC techniques over flat fading channel will be presented.

2 System Model of Cooperative Open Loop MIMO System

The wireless cooperative communication system with one source node *S*, four relays nodes *R*, and one destination node *D*. In this system, each node has only one antenna as in Figure 2. The faded channel coefficient from the source node to the i^{th} relay and the faded channel coefficient from the i^{th} relay to the destination node are denoted as h_{SRi} and h_{RiD}, respectively. The system works under assumptions, the terminals operate in a half-duplex mode and the channel between any two terminals is quasi-static flat fading. Therefore, assume that h_{SRi} and h_{RiD} are independent complex Gaussian random variable with mean zero and variance one. The transmission process of the information from the source node to the destination node, they experience two phases. Phase one, the source node broadcast the information $\boldsymbol{s} = [s_1\ s_2^*]^T$ to the relay nodes. Then, phase two relay nodes resend the information to destination node, which called relaying or cooperative phase.

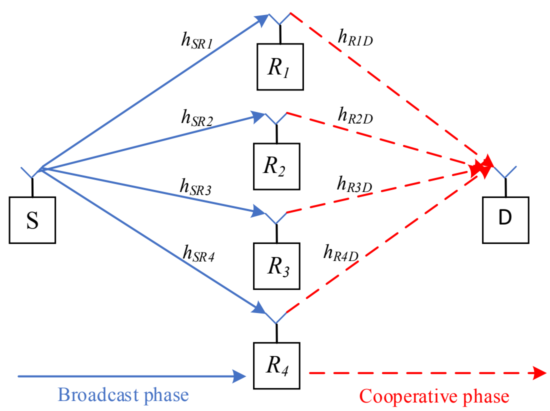

Figure 2: *System model of cooperative open loop MIMO systems based on four relays, D-EO-STBC techniques and DF relaying protocol, over flat fading channel.*

Next, mathematical model of cooperative open loop MIMO systems based on four relays, D-EO-STBC and DF relaying protocol, over flat fading channel will be explained.

3 Mathematical Model of Cooperative Open Loop MIMO System

Mathematical Model is obtained from the schematic diagram of cooperative open loop MIMO system based on four relays, D-EO-STBC technique, over flat fading channel. As in Figure 2., cooperation strategies involve two phases of transmission. Phase one, the source node broadcast the information $\boldsymbol{s} = [s_1\ s_2^*]^T$ after modulation onto complex symbols to the relay nodes, R_1, R_2, R_3 and R_4, where (.)T denotes vector transpose. The received signal at the R_1, R_2, R_3 and R_4, is corrupted by both the fading coefficient $h_{SR1}, h_{SR2}, h_{SR3}, h_{SR4}$ and the noise $n_{R1}, n_{R2}, n_{R3}, n_{R4}$, respectively. The received signals in the first time slot: at i^{th} relay is:

$$r_{Ri} = h_{SRi}\, s + n_{Ri} \tag{1}$$

Then, the received signal is decoded at i^{th} relay by exploiting an STBC code matrix which it takes on the following form as in [6], [7]:

$$D_i = A_i \, r_{Ri} + B_i \, r_{Ri}^*, \tag{2}$$

where $\boldsymbol{s} = [s_1 \; s_2^*]^T$ is a set of symbols to be transmitted, and $\{A_i \, , B_i\}$ are fixed code matrices at relays of dimension number of data signal ($\boldsymbol{s}$) and number of transmission time slots (T_i). Then,

$$D_i = h_{SRi} \, A_i \, s + h_{SRi}^* B_i \, s^*. \tag{3}$$

In this system two relay pairs are used. These relay nodes are designed to use the following A_i and B_i matrices at the i^{th} relays:

$$A_1 = A_2 = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}, \quad \& \quad B_1 = B_2 = \begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix}, \tag{4}$$

where, matrices A_i and B_i are at R_1, R_2, R_3 and R_4, respectively. Then, the received signal at R_1 and R_2 during 1st time slot:

$$r_{Rij} = D_{ij} \, , \tag{5}$$

where, i and j denote number of relays and time slots, respectively. So, the received signal at R_1, R_2, R_3 and R_4, during 1st time slot:

$$r_{Ri1} = h_{SRi} \, A_1 \, s + n_{Ri} = h_{SRi} s_j + n_{R1} \, , \; i = 1, 2 \text{ and } j = 1, \tag{6}$$

$$r_{Ri1}^* = h_{SRi}^* \, B_1 \, s^* + n_{Ri} = h_{SRi} \, s_j + n_{Ri}^* \, , \; i = 3, 4 \text{ and } j = 2. \tag{7}$$

Then, the estimated received signals $\widehat{s_{11}}$, $\widehat{s_{12}}$, $\widehat{s_{23}}$ and $\widehat{s_{24}}$ at R_1, R_2, R_3 and R_4, respectively, during 1st time slot, can be expressed as follows:

$$\widehat{s_{11}} = h_{SR1}^* r_{R11} \, , \quad \widehat{s_{12}} = h_{SR2}^* r_{R21} \, , \quad \widehat{s_{23}} = h_{SR3} \, r_{R31}^* \quad \text{and} \quad \widehat{s_{24}} = h_{SR4} \, r_{R41}^* \tag{8}$$

Then, the received signal at R_1, R_2, R_3 and R_4, during 2nd time slot:

$$r_{Ri2} = h_{SRi} \, A_1 \, s + n_{Ri} = h_{SRi} \, s_j + n_{Ri} \, , \; i = 1, 2 \text{ and } j = 2, \tag{9}$$

$$r_{Ri2}^* = h_{SRi}^* \, B_1 \, s^* + n_{Ri} = -h_{SRi}^* \, s_j + n_{Ri}^* \, , \; i = 3, 4 \text{ and } j = 1. \tag{10}$$

Then, the estimated received signals $\widehat{s_{21}}$, $\widehat{s_{22}}$, $\widehat{s_{13}}$ and $\widehat{s_{14}}$ at R_1, R_2, R_3 and R_4, respectively, during 2nd time slot, can be expressed as follows:

$$\widehat{s_{21}} = h_{SR1}^* \, r_{R12} \, , \; \widehat{s_{22}} = h_{SR2}^* \, r_{R22} \, , \; \widehat{s_{13}} = h_{SR3} \, r_{R32}^* \quad \text{and} \quad \widehat{s_{14}} = h_{SR4} \, r_{R42}^*. \tag{11}$$

The matrix form of EO-STBC, which will be performed at relays, is

$$\boldsymbol{S} = \begin{bmatrix} s_1 & s_1 & s_2 & s_2 \\ s_2^* & s_2^* & -s_1^* & -s_1^* \end{bmatrix}. \tag{12}$$

EO-STBC is performed at relays by sending the decoded signal at each relay in time slots. In the first time slot R_1, R_2, R_3 and R_4, send $\widehat{s_{11}}$, $\widehat{s_{12}}$, $\widehat{s_{23}}$ and $\widehat{s_{24}}$, respectively. Then, the received signal at the destination can be stated as follows:

$$r_{1D} = \widehat{s_{11}}\, h_{R1D} + \widehat{s_{12}}\, h_{R2D} + \widehat{s_{23}}\, h_{R3D} + \widehat{s_{24}}\, h_{R4D} + w_1. \tag{13}$$

In the second time slot R_1, R_2, R_3 and R_4, send $-\widehat{s_{21}}^*$, $-\widehat{s_{22}}^*$, $\widehat{s_{13}}^*$, and $\widehat{s_{14}}^*$, respectively. Then, the received signal at the destination can be stated as follows:

$$r_{2D}^* = \widehat{s_{13}}\, h_{R3D}^* + \widehat{s_{14}}\, h_{R4D}^* - \widehat{s_{21}}\, h_{R1D}^* - \widehat{s_{22}}\, h_{R2D}^* + w_2^*. \tag{14}$$

Hence, the received signal at destination can be written in matrix form as follows:

$$\boldsymbol{r_D} = \boldsymbol{Hs} + \boldsymbol{w}_i, \tag{15}$$

where, $\boldsymbol{r_D} = [r_{1D}\ \ r_{2D}^*]^T$, $\boldsymbol{s} = [s_1\ \ s_2^*]^T$, $\boldsymbol{w_i} = [w_1\ \ w_2^*]^T$ and

$$\boldsymbol{H} = \begin{bmatrix} h_{R1D} + h_{R2D} & h_{R3D} + h_{R4D} \\ h_{R3D}^* + h_{R4D}^* & -h_{R1D}^* - h_{R2D}^* \end{bmatrix}. \tag{16}$$

The estimated received signal at destination can be represented as follows:

$$\hat{\boldsymbol{s}} = \boldsymbol{H^H r_D}, \tag{17}$$

where, $(.)^{\boldsymbol{H}}$ is the Hermitian transpose. By substituting (16) in (17), yields (18)

$$\hat{\boldsymbol{s}} = \boldsymbol{H^H H}\, \boldsymbol{s} + \boldsymbol{H^H}\, \boldsymbol{w_i}\ , \tag{18}$$

$$\begin{bmatrix} \widehat{s_1} \\ \widehat{s_2} \end{bmatrix} = \begin{bmatrix} \alpha + \beta & 0 \\ 0 & \alpha + \beta \end{bmatrix} \begin{bmatrix} s_1 \\ s_2 \end{bmatrix} + \boldsymbol{H^H} \begin{bmatrix} w_1 \\ w_2 \end{bmatrix}, \tag{19}$$

where, $\alpha = \sum_{i=1}^{4} |h_{RiD}|^2$ is the channel gain. $\beta = \beta_1 + \beta_2$, are the channel interferences, $\beta_1 = 2Re\{h_{R1D}\, h_{R2D}^*\}$ and $\beta_2 = 2Re\{h_{R3D}\, h_{R4D}^*\}$. Then, the estimated received signals are:

$$\widehat{s_1} = (\alpha+\beta)\, s_1 + (h_{R1D}^* + h_{R2D}^*) w_1 + (h_{R3D} + h_{R4D})\, w_2^*. \tag{20}$$

$$\widehat{s_2} = (\alpha+\beta)\, s_2 + (h_{R3D}^* + h_{R4D}^*) w_1 - (h_{R1D} + h_{R2D})\, w_2^*. \tag{21}$$

In next subsection, simulation results will be presented.

4 Simulation Results and Discussion

4.1 Comparison of simulation results of conventional SISO, cooperative SISO and cooperative MIMO systems

In this section, simulation results, by using MATLAB, are provided to demonstrate the comparison of BER performance conventional SISO system, cooperative SISO system, cooperative system consists of one source, one relay, one destination, and direct path between source and destination, cooperative MIMO based on D-OSTBC, and cooperative open loop MIMO based on D-EO-STBC. All these schemes are based on DF protocol and analysed over flat fading channels. Also, QPSK digital modulation schemes is exploited for all schemes. The perfect channel state information (CSI) is assumed to be perfectly available at relays and at the receiver side.

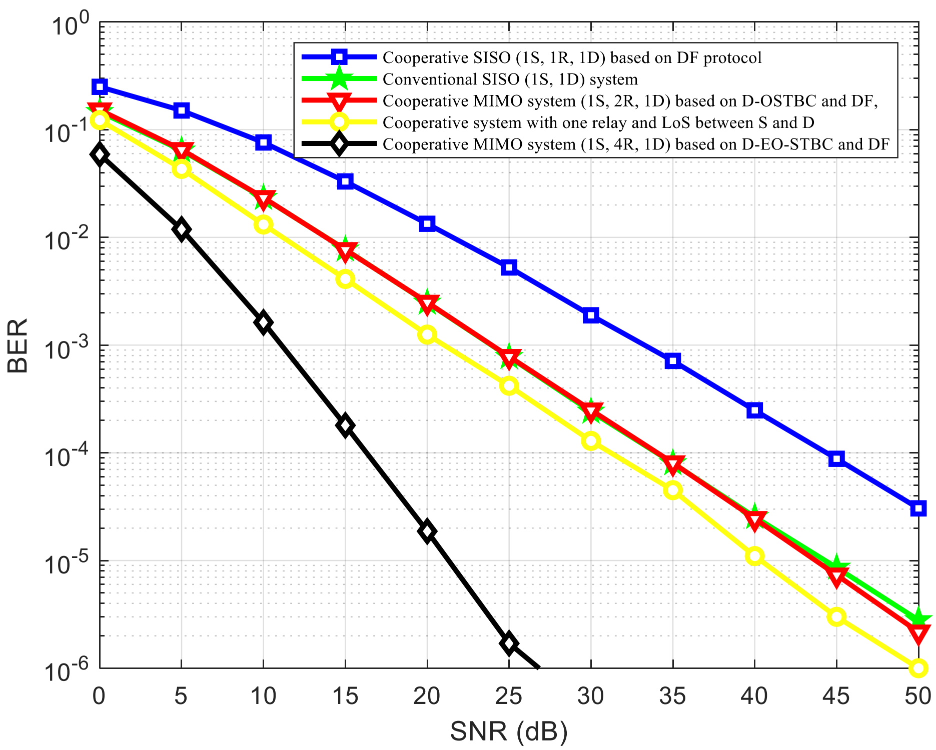

Figure 3: *Performance of BER vs SNR of conventional SISO system with single transmit and receive antenna and cooperative SISO, cooperative MIMO (1S, 2R, 1D) systems based on D-OSTBC (Alamouti) scheme, and cooperative MIMO (1S, 4R, 1D) systems based on open loop D-EO-STBC scheme, over flat fading channel.*

Figure 3 depicts the comparison of the BER performance of conventional SISO system, cooperative SISO system and cooperative system with one relay and direct link between the source and destination, cooperative MIMO systems based on D-OSTBC (Alamouti) and cooperative open loop MIMO system based on D-EO-STBC technique. All systems effected by flat fading channel. From the graph, it is clearly seen that the cooperative SISO scheme has the worst BER performance. Whereas, the performance of cooperative MIMO systems based on D-OSTBC (Alamouti) is almost identical to conventional SISO system. Also, cooperative open loop MIMO system based on D-EO-STBC technique has the best BER performance. For example, at 10^{-5} BER reference, cooperative SISO needs approximately 47 dB, whereas cooperative system with one relay and direct link between the source and destination needs about 41 dB. However, cooperative open loop MIMO system based on D-EO-STBC needs just only 22 dB. This means that, the cooperative open loop MIMO system based on D-EO-STBC improves the BER performance by about 18 dB compared with cooperative system with one relay and direct link between the source and destination.

5 Conclusions

The end-to-end BER performance analysis of cooperative MIMO based on two relays and D-OSTBC scheme and cooperative open loop MIMO based on four relays and distributed extended orthogonal (D-EO-STBC) technique, over flat fading channels, were studied. QPSK digital modulation scheme was exploited. The results confirmed that the cooperative open loop MIMO scheme with four relays had the better BER performance. In contrast, the cooperative SISO has had the worst BER performance. Moreover, cooperative MIMO systems based on Alamouti scheme and conventional SISO system had almost identical performance. Cooperative closed loop MIMO system based on D-EO-STBC and DF relaying protocol, is a subject of our ongoing study.

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