Performance Evaluation of MIMO Receivers in Two-way Decode and Forward Relaying

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ABSTRACT

In this paper, error performance analysis of two-way cooperative communication system with decode-and-forward (DF) relaying is examined over frequency selective Rayleigh fading channels. It is considered that all the nodes in the system are equipped with two antennas. Zero forcing, maximum likelihood, minimum mean square estimator receiver are employed at the nodes. As mapping method Binary phase-shift keying (BPSK) is used. The end user node's bit error performance is studied. The system is simulated. The simulation plots are provided. The results show that for BPSK mapping maximum likelihood receiver produces better bit error rate performance.

Keywords: Two-way DF relaying, Rayleigh-m fading channels, MIMO, BER performance.

1. INTRODUCTION

Digital communication over wireless channels increases every day. Recent works enabled wireless network data transmission speed over Gigabit per second rate. Even though these achievements satisfy majority of users, the wireless communication has some disadvantages too. As an example, if a device is located far away from an ad-hoc hub or there are some obstacles between the wireless devices, the communication can be problematic. Actually, it may not connect the network due to very weak signal reception power. For a possible solution it is considered that any other wireless device between the hub and the destination can help which is a two-way communication (TWC) [1]. When there is no direct connection or signal is very weak, other devices located at midway receive signals, process and forward to the destination. This in-the-middle device is called as relay. When there is not a fixed relay device and each device is also relay to other systems, it becomes a cooperative network. TWC is one type of cooperative relaying. In contemporary TWC, physical layer network coding (PNC) is used [2]. PNC significantly increases the capacity of the transmission by reducing time slots required to exchange information down-to two time slots.

In cooperative two-way relaying, the data processing method at relay device names the type of used protocol. The two general cooperative protocols are; amplify and forward (AF) and decode and forward (DF). AF uses the available channel knowledge to amplify the received signal. The amplified signal is then sent to the destination. In DF, the received signal is first decoded then the decoded bits are mapped into symbols again and retransmitted to the destination [3], [4].

The cooperative system is also known as virtual multi-input multi-output (MIMO). It is well-known fact that when the received signal to noise power is low or the signal is distorted badly due to frequency selective fading, the bit error rate (BER) performance becomes very low. MIMO provides spatial diversity by employing more than one antenna at transceivers [5]. Spatial diversity significantly increases the system BER performance without having extra power or bandwidth cost. MIMO cannot be used in small size devices due to lack of spaces required to locate antennas. Antennas must be spaced such that one can make sure there is no correlation on the received signals at different antennas. Since this space cannot be provided, MIMO is not applicable to the small electronic devices. When there is a chance of using MIMO, the cooperative system can be employed. In CS, the wireless devices let their resources cooperate in order to create a virtual MIMO. Modern systems combine the power of MIMO with virtual MIMO [6], [7]. That is to say that a device can be a part of MIMO as well as a cooperative system.

The different versions of MIMO are; single-input multiple-output (SIMO), multi-input single-output (MISO). SIMO is the same with receiver diversity and MISO is used instead of transmitting diversity. The transmitting diversity is realized with the help of Alamouti code [7]. Signal combining technics employed at the receiver side leaded the diversity as a rather useful option. Selection combiner, maximum ratio combiner, and equal gain combiner are three well-known combining techniques [8].

The recent studies combine MIMO and CS to employ a different type of receiver. In [9], zero forcing receivers in MIMO two-way system is examined. In [10], MMSE receiver is examined only in MIMO two-way system with three phase communication. There is a need to compare the BER performance of the different type of receivers and to the best of our knowledge, it lacks on comparing zero-forcing, MMSE and ML in MIMO two-way decode and forward with PNC. Hence, in this study, we examined the MIMO-based two-way DF with PNC systems' bit error rate performance for three well-known receiver types [11].

The rest of paper is organized as follows. The next section, introduces a system model in which the receiver models of MIMO and CS protocols are given. Section III discusses simulation results and in the last section the work evaluation is given as conclusion.

2. THE SYSTEM MODEL

We consider three computers as computer one as the Transmitting computer (C1), computer two as the Relaying computer (CR) and computer three as the receiving computer (C3). This can be in reverse order too. Actually, all the computers do receive and transmit but to make it simple to explain we choose it as given. C1 has to communicate C3 through CR. CR receives the signal from C1 and forwards it to C3 by using DF protocol. This is given as in Fig.1. CR is the relaying computer and uses DF protocol. The system model is given as in Fig.2. As seen in the figure, DF will digitize or restore the signal back to original state and if the distortion on the signal is not much, the signal will be completely restored.

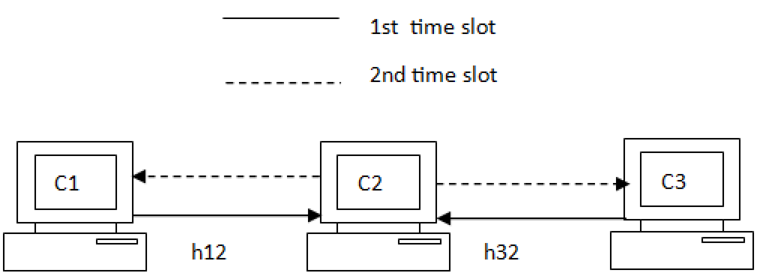

FIGURE 1. The System Model

In the first time slot, C1 and C3 broadcast to CR and in the second time slot CR broadcast back to C1 and C3. C2 separates two signals with PNC. In this example, we consider each computer has a wireless transceiver with two antennas.

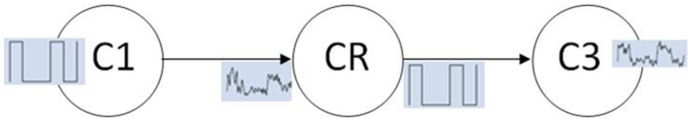

FIGURE 2. DF Protocol

Assuming a photo is to be transmitted, it will be converted to bits and mapped with binary phase shift keying (BPSK). The BPSK symbol vector is given as $X_n = \{x_1 , x_2 , ..., x_n \}$.

The symbols of message signal X_n is sent the transmitter antennas at C1 two by two. That means at the first time interval x_1, x_2 and at the second time interval, x_3, x_4, and so on. Since each computer has two antennas, between any two computers, there are available four channels. This can be shown as in Fig.3 where, for example, h_{11} means the channel between the first antenna of CR and the first antenna of C1. In the following, all the channels h_{ij} coefficients (the one causes distortion effect on the signal) have Rayleigh distribution with probability density function of

$$p(z) = \frac{z}{\sigma^2} e^{-\frac{z^2}{2\sigma^2}}, z \geq 0$$

and n_{Ci_j} is the independent and identically distributed additive white Gaussian noise with normal distribution.

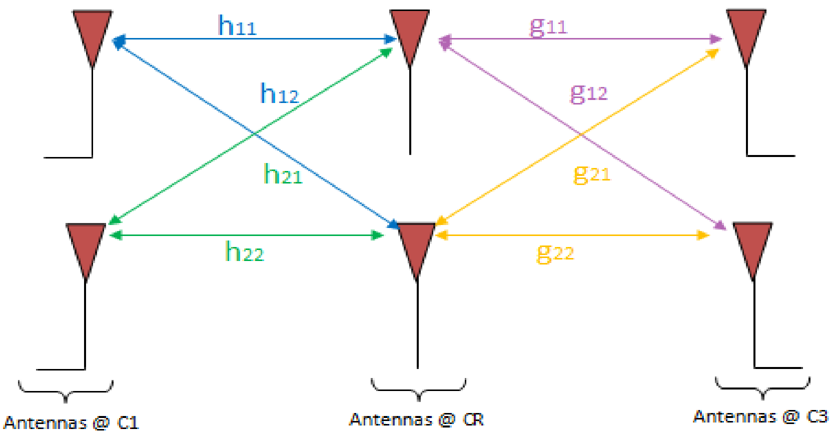

FIGURE 3. Two-way with MIMO with each node having two antennas

The received signal at first antenna of CR from C1 can be written as

$$\gamma_1 = h_{11}.x_1 + h_{12}.x_2 + n_{C1_1 1} \quad (1)$$

The received signal at second antenna of CR from C1 can be written as

$$\gamma_2 = h_{21}.x_1 + h_{22}.x_2 + n_{C1_2 1} \quad (2)$$

(1) and (2) can be put in matrix notation as

$$\begin{bmatrix}\gamma_1\\ \gamma_2\end{bmatrix} = \begin{bmatrix}h_{11} & h_{12}\\ h_{21} & h_{22}\end{bmatrix}\begin{bmatrix}x_1\\ x_2\end{bmatrix} + \begin{bmatrix}n_{C1\_1}\\ n_{C1\_2}\end{bmatrix} \quad (3)$$

The received signal at first antenna of CR from C3 can be written as

$$\lambda_1 = g_{11}.y_1 + g_{12}.y_2 + n_{C3_1 1} \quad (4)$$

The received signal at second antenna of CR from C3 can be written as

$$\lambda_2 = g_{21}.y_1 + g_{22}.y_2 + n_{C3_2 1} \quad (5)$$

(4) and (5) can be put in matrix notation as

$$\begin{bmatrix}\lambda_1\\ \lambda_2\end{bmatrix} = \begin{bmatrix}g_{11} & g_{12}\\ g_{21} & g_{22}\end{bmatrix}\begin{bmatrix}y_1\\ y_2\end{bmatrix} + \begin{bmatrix}n_{C3\_1}\\ n_{C3\_2}\end{bmatrix} \quad (6)$$

The signal sum up at antennas of C3 given as

$$\begin{bmatrix}h_{11} & h_{12}\\ h_{21} & h_{22}\end{bmatrix}\begin{bmatrix}x_1\\ x_2\end{bmatrix} + \begin{bmatrix}g_{11} & g_{12}\\ g_{21} & g_{22}\end{bmatrix}\begin{bmatrix}y_1\\ y_2\end{bmatrix} + \begin{bmatrix}n_1\\ n_2\end{bmatrix} \quad (7)$$

The C3 can separate the signals with PNC. Hence, the obtained signals re-encoded and send to the destination. The destination is used to indicate C3 if the sender is C1 or vice versa. The arrived signal from C1 at C3 can be given as

$$\begin{bmatrix}\hat{\lambda}_1\\ \hat{\lambda}_2\end{bmatrix} = \begin{bmatrix}g_{11} & g_{12}\\ g_{21} & g_{22}\end{bmatrix}\begin{bmatrix}\hat{y}_1\\ \hat{y}_2\end{bmatrix} + \begin{bmatrix}n_{C31}\\ n_{C32}\end{bmatrix} \quad (8)$$

where we assume the channel g_{ij} is stable for two time slot and $\hat{y}_i$ represent the re-encoded symbols sent from C1.

Below three most used receivers models are explained by decoding received signal at the destination.

A. ZERO FORCING RECEIVER

The receiver at the relaying computer has the data sent from C1 and separated from the one C3 can be given, in short form, as $\gamma = Hx + n$. The pseudo inverse of H is given $W = (H^H H)^{-1} H^H$ where

$$H^H H = \begin{bmatrix} |h_{11}|^2 + |h_{22}|^2 & h^*{}_{11}h_{12} + h^*{}_{21}h_{22} \\ h^*{}_{12}h_{11} + h^*{}_{22}h_{21} & |h_{12}|^2 + |h_{22}|^2 \end{bmatrix}$$

where the off-diagonals are not zero, hence zero-forcing can experience noise amplification ($(.)^H$ is hermitian operator).

$$\gamma = (H^H H)^{-1} H^H H_x + (H^H H)^{-1} H^H n = Ix + \tilde{n} = \tilde{x} \quad (9)$$

In (9), $\tilde{x}$ is estimated symbol at the relaying computer. $\tilde{x}$ is sent to the destination terminal. The received symbols at the destination are given as $\tilde{\gamma} = G\tilde{x} + n$. The zero forcing receivers is used once again at the destination and the estimated symbols can be given as

$$\tilde{\gamma} = (G^H G)^{-1} G^H G_x + (G^H G)^{-1} G^H n = I\tilde{x} + \tilde{n} = \tilde{\tilde{x}}$$

B. MMSE RECEIVER

The zero-forcing receiver may have poor performance due to noise amplification. This problem is handled in MMSE. Given that $\gamma = Hx + n$ is the received at relay, MMSE minimize $\mathrm{E}\{[W\gamma - \mathrm{x}].[W\gamma - \mathrm{x}]^{\mathrm{H}}\}$ where $\mathrm{W} = [\mathrm{H^H H} + \mathrm{N_0 I}]^{-1}\mathrm{H^H}$ which acts as zero-forcing receiver when the noise is zero.

This gives the estimated symbol $\tilde{\mathrm{x}}$ which is sent to the destination terminal and received again with MMSE receiver, given as $\tilde{\gamma} = \mathrm{G}\tilde{\mathrm{x}} + \mathrm{n}$. The MMSE receiver seeks to minimize $\mathrm{E}\{[\mathrm{W}\tilde{\gamma} - \tilde{\mathrm{x}}].[\mathrm{W}\tilde{\gamma} - \tilde{\mathrm{x}}]^{\mathrm{H}}\}$ where $\mathrm{W} = [\mathrm{G^H} + \mathrm{N_0 I}]^{-1}\mathrm{G^H}$ and the estimated symbols $\tilde{\tilde{\mathrm{x}}}$ is found.

C. ML RECEIVER

The maximum likelihood receiver looks for $\bar{x}$, to minimize $\epsilon = |\gamma - H\bar{x}|$. Since the BPSK is used, there are four possible options for $\bar{x}$ which are $[(1,1), (-1,-1), (1,-1), (-1,1)]$. The ϵ for all values of $\bar{x}$ is given as

$$\epsilon_{X_i,X_j} = \left\| \begin{bmatrix} \gamma_1 \\ \gamma_2 \end{bmatrix} - \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} X_i \\ X_j \end{bmatrix} \right\|^2.$$

The estimated transmit symbols are chosen based on $\min(\epsilon_{\mathrm{i,j}})$ which is, for example, if the minimum is $\epsilon_{1,1}$, then the symbols [1, 1] are transmitted.

The estimated symbols retransmitted again to the destination and received with ML as explained above.

3. SIMULATION RESULTS

In Fig.4, bit error rate performance of the proposed system for three receivers is given at relay station. There is also provided analytic results SIMO and SISO systems for comparison. It is seen that zero forcing performs like SISO which can be considered low performance taking into account that two antennas are located at the receiver. When we apply MMSE receiver instead of zero forcing, the performance increases. The best results are offered by ML receiver. For example, the ML receiver shows 20 times better performance at 10*dB*.

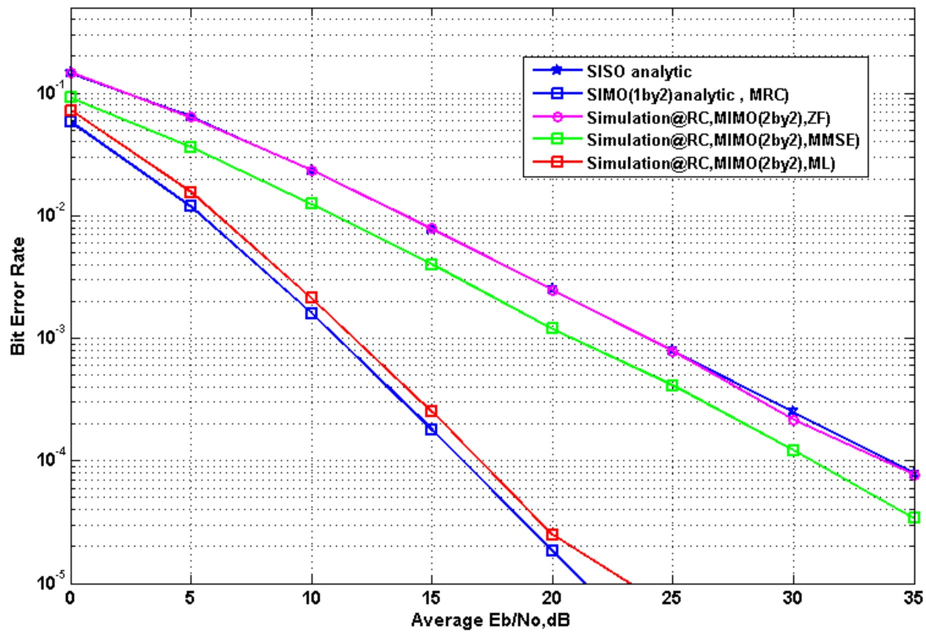

FIGURE 4. Three receiver's performance at the Relay

In Fig.5 bit error rate performance of the proposed system is given at destination station. The performance degrades for all receivers at D. The ML performance at 20dB is 10^{-4} meaning that one-bit error in ten thousand bit which is in acceptable level.

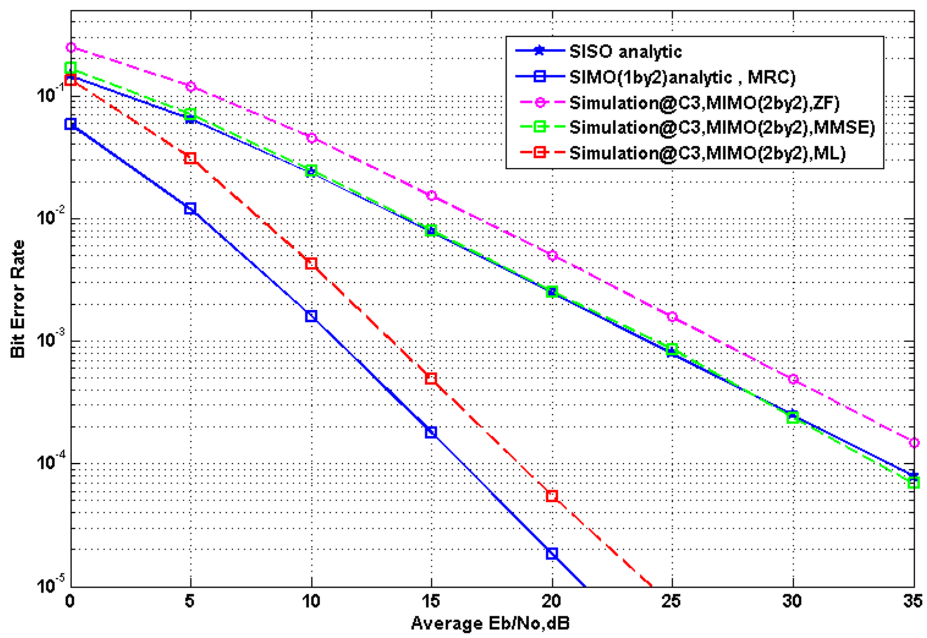

FIGURE 5. Three receiver's performance at the Destination

The last figure shows the performance of relay and destination node together for giving perspective in performance degrading from relay station to destination station. In the figure, it is clearly seen that ML in MIMO with 2 by 2 antennas can achieve the SISO direct transmission.

4. CONCLUSIONS

Two-way communication system with MIMO is implemented over Rayleigh fading channels where we have assumed each node has two antennas.

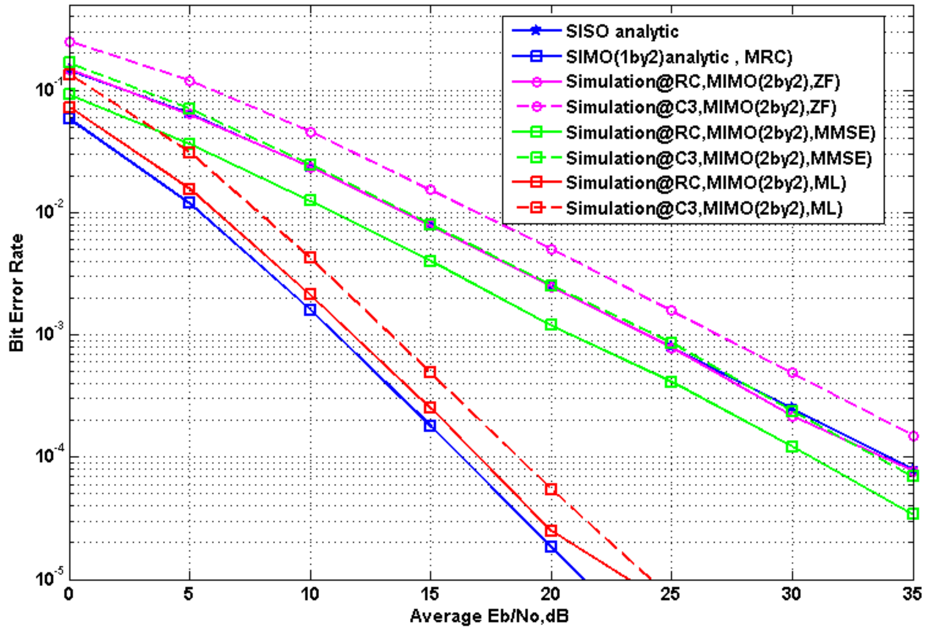

FIGURE 6. Three receiver's performance at the Relay and Destination

By employing MIMO, first of all the data transmission speed is doubled since two antennas send two different symbols for a given time. Considering the ML performance at the destination, it is seen the last station will have the bit error rate as low as a relay station of SIMO system with the diversity order of two. This shows that by employing MIMO, two-way communication can offer a healthy communication for a node which cannot receive service directly.

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