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Impact of estimation error on two-way relaying with relay antenna selection☆

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Abstract

This paper presents the performance analysis of two-time-slot two-way relaying while considering dual antennas at the relay and imperfect channel state information (CSI) at the receivers. We consider the Max–Min antenna selection scheme at the relay. For this scheme, we show the analytical symbol error probability in the presence of imperfect CSI and observe a close match between the analytical and numerical results. We also find that Max–Min antenna selection scheme is robust against CSI error and performs better than the maximum ratio transmission (MRT) based beamforming scheme in the presence of CSI error.

Keywords: Two-way relaying; Maximum ratio transmission; Max–Min antenna selection

1. Introduction

The two-way relaying, where two end nodes exchange their information via a relay node, has attracted much attention in recent years due to its ability to enhance the performance of relay communication. Based on the transmission strategy, the relay node performs either binary network coding (BNC) [1] or analog network coding (ANC) [2]. It has been well-established that the BNC based two-way relaying performs better than its ANC counterpart. With a single relay antenna, traditional BNC two-way relaying requires three time slots,[1] where the two end nodes transmit separately in the first two time slots and after detection, the relay node forwards the bit-wise XOR message in the third time slot. With dual antennas at the relay, the end nodes can transmit simultaneously and joint detection can be performed. Thus, the total number of time slots is reduced to two time slots and hence results in boost in the throughput. For the above reasons, this paper considers BNC two-way relaying with dual antennas at the relay.

Several studies have been carried out on the two-time-slot two-way relaying including [1–9]. However, perfect channel state information (CSI) was assumed in most of the previous works. Although [5–7,10] showed the impact of estimation error on the two-way relaying, they considered analog network coding. In this paper, we investigate the performance of two-time-slot two-way relaying in the presence of imperfect CSI while considering binary network coding.

Particularly, we investigate the performance while considering the Max–Min antenna selection scheme shown by [4]. This antenna selection scheme is practically promising since it requires partial CSI at the relay during the selection procedure and thus expected to be robust against CSI error. However, the impact of CSI error was not considered in [4]. This work investigates the analytical and simulated performance of Max–Min antenna selection scheme in the presence of CSI error. Theoretical analysis of the symbol error probability is presented, and a close match between the analytical and simulation results is observed. From the comparison it is shown that the Max–Min antenna selection scheme exhibits superior performance than other schemes in the presence of CSI error.

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[1] Note that utilizing error correcting codes, [3] presented the binary network coded two-time-slot two-way relaying using single relay antenna. In contrast, this paper does not consider error correcting codes.

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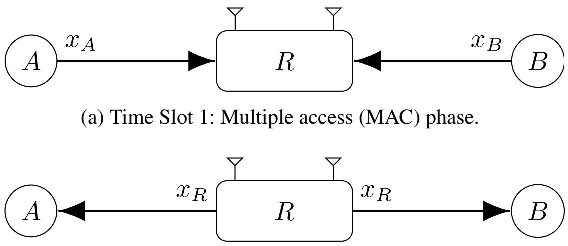

(a) Time Slot 1: Multiple access (MAC) phase.

(b) Time Slot 2: Broadcast (BC) phase.

Fig. 1. Two-time-slot two-way relay communication.

The remainder of this paper is organized as follows. In Section 2, we present the system model of the two-time-slot two-way relaying scheme. We analyse the multiple access phase in the presence of CSI error in Section 3. In Section 4, the antenna selection scheme is presented with symbol error probability analysis. Along with the necessary comparisons, we present the simulation and analytical results in Section 5.

2. System model

The two-way communication scenario is illustrated in Fig. 1, where two end nodes A and B exchange their information via a relay node R. We consider that each end node is equipped with a single antenna while the relay has dual antennas. Half-duplex communication is considered and all nodes are assumed to be perfectly synchronized. No direct link exists between the end nodes and the exchange of information between them is accomplished in two-time-slot. In the first time slot, known as multiple access (MAC) phase, nodes A and B simultaneously transmit symbols x_A and x_B, respectively to the relay node R. The received signal $\mathbf{y}_R$ at the relay is given by

$$\mathbf{y}_R = \mathbf{H}_M \mathbf{x} + \mathbf{n}_R, \tag{1}$$

where $\mathbf{x} = [x_A \quad x_B]^T$, $\mathbf{n}_R = \left[n_{R_1} \quad n_{R_2}\right]^T$ is a noise vector where each component is identically independent zero mean complex Gaussian distributed with variance σ_R^2 and $\mathbf{H}_M = [\mathbf{h}_{AR} \quad \mathbf{h}_{BR}]$, where we denote $\mathbf{h}_{AR} = \left[h_{AR_1} \quad h_{AR_2}\right]^T$ as the channels from A to R and $\mathbf{h}_{BR} = \left[h_{BR_1} \quad h_{BR_2}\right]^T$ as the channels from B to R. More precisely, h_{iR_j} indicates the channel from node i to relay antenna j, where $i \in \{A, B\}$ and $j \in \{1, 2\}$. Each of the channel coefficients is assumed to be identically independent Rayleigh distributed with $h_{iR_j} \sim \mathcal{CN}(0, 1)$. The relay node performs maximum likelihood (ML) detection to estimate x_A and x_B. Let $\hat{x}_A$ and $\hat{x}_B$ be the estimated symbols corresponding to x_A and x_B.

In the second time slot, known as broadcast (BC) phase, the relay broadcasts $x_R = \mathrm{f}(\hat{x}_A,\ \hat{x}_B)$ to both nodes A and B. The function $\mathrm{f}(\hat{x}_A,\ \hat{x}_B)$ depends on network coding strategy adopted by the relay. In this paper, we consider binary network coding (BNC), where the relay first demodulates both estimated symbols and performs a bit-wise X-OR operation. Then the X-OR bits are modulated by the relay to generate x_R. Thus, the binary network coding can be described in the following manner

$$x_R = \mathrm{f}(\hat{x}_A,\ \hat{x}_B) = \mathrm{f}_m\left(\mathrm{f}_d(\hat{x}_A) \oplus \mathrm{f}_d(\hat{x}_A)\right)$$

where f_m and f_d are the modulation and demodulation operations, respectively and $\oplus$ is the bit-wise X-OR operation. In the broadcast phase, the received signal (y_A) at the end node A is given by

$$y_A = \mathrm{f}_R(x_R, h_{R_1A} \text{ or } h_{R_2A}) + n_A,$$

where h_{R_jA}, $j \in \{1, 2\}$ is the Rayleigh channel from the relay antenna j to node A with $h_{R_jA} \sim \mathcal{CN}(0, 1)$, and n_A is the complex Gaussian distributed noise at node A with zero mean and variance σ_A^2. In the above equation, the characteristics of $\mathrm{f}_R(x_R, h_{R_1A} \text{ or } h_{R_2A})$ depend on the antenna selection scheme. In a similar fashion, the received signal at node B can be defined.

In this paper, we consider unit transmission power for each node with $E[|x_A|^2] = E[|x_B|^2] = E[\|x_R\|^2] = 1$. Note that, we only analyse the performance of the two-way relaying for the information flow from node B to node A. For $\sigma_A^2 = \sigma_B^2$, all the presented results are also valid for the information flow from node A to node B due to the symmetry of the end nodes.

Estimation Error Model: We now present the estimation error model considered in this paper. Let h and $\hat{h}$ denote the actual and estimated channel coefficients, respectively. Following [11], the relationship between h and $\hat{h}$ is given by

$$h = \hat{h} + e, \tag{2}$$

where e is the estimation error which can be modelled as a complex Gaussian random variable with $e \sim \mathcal{CN}(0, \sigma_e^2)$. This estimation error model is particularly valid for the pilot symbol based minimum mean square error (MMSE) channel estimators. Using (2), we introduce the CSI error in the above two way relaying model. For $i \in \{A, B\}$ and $j \in \{1, 2\}$, we get

$$h_{iR_j} = \hat{h}_{iR_j} + e_{iR_j} \text{ and } h_{R_ji} = \hat{h}_{R_ji} + e_{R_ji}$$

where $\hat{h}_{iR_j}$ is the estimation of h_{iR_j} and e_{iR_j} is the corresponding estimation error. In a similar way $\hat{h}_{R_ji}$ and e_{R_ji} can be defined. We consider that each of the estimation errors is identically independent complex Gaussian distributed with zero mean and variance σ_e^2.

3. Multiple access phase

In the MAC phase, the received signal (1) can be written as

$$\begin{aligned}\mathbf{y}_R &= \mathbf{H}_M \mathbf{x} + \mathbf{n}_R \\ &= \begin{bmatrix} h_{AR_1} & h_{BR_1} \\ h_{AR_2} & h_{BR_2} \end{bmatrix} \begin{bmatrix} x_A \\ x_B \end{bmatrix} + \begin{bmatrix} n_{R_1} \\ n_{R_2} \end{bmatrix} \\ &= \begin{bmatrix} \hat{h}_{AR_1} + e_{AR_1} & \hat{h}_{BR_1} + e_{BR_1} \\ \hat{h}_{AR_2} + e_{AR_2} & \hat{h}_{BR_2} + e_{BR_2} \end{bmatrix} \begin{bmatrix} x_A \\ x_B \end{bmatrix} + \begin{bmatrix} n_{R_1} \\ n_{R_2} \end{bmatrix}.\end{aligned}$$

The above scenario can also be seen as a perfect CSI case while considering the estimated channel coefficient as actual coefficient with noise variance $\sigma_R^2 + 2\sigma_e^2$. The relay performs the following ML decoding on the received vector $\mathbf{y}_R$ to obtain the estimated symbols [12]

$$\begin{aligned}\hat{\mathbf{x}} = \left(\hat{x}_A \ \hat{x}_B\right)^{\mathrm{T}} &= \arg\min_{\mathbf{x}} |\mathbf{y}_R - \hat{\mathbf{H}}_M \mathbf{x}|^2 \\ &= \arg\min_{\mathbf{x}} \left\| \begin{bmatrix} y_{R_1} \\ y_{R_2} \end{bmatrix} - \begin{bmatrix} \hat{h}_{AR_1} & \hat{h}_{BR_1} \\ \hat{h}_{AR_2} & \hat{h}_{BR_2} \end{bmatrix} \begin{bmatrix} x_A \\ x_B \end{bmatrix} \right\|.\end{aligned}$$