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Bit Error Rate Evaluation for Different Relay Selection Schemes in Two-Way DF Relay Networks

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Abstract: *In this paper, Bit Error Rate (BER) of five relay selection schemes, Non-selection, Optimal Selection (OS), Max-Min Signal to Noise Ratio (SNR) Selection (MMS), Max-Sum rate Selection (MSS), and Hybrid Selection (HS), for Decode and Forward (DF) two-way relay networks is evaluated. In the previous works, it was shown that MMS and hybrid schemes are the best selection schemes in the view of outage probability. In this study, we show that BER of MMS relay selection scheme is less than the other selection schemes. Moreover, it is investigated that the best relay selection scheme in the view of BER as well as outage probability is the MMS if the channel conditions and the number of cooperative relays change. Finally, this paper shows that the equal power for network components (source, destination and relay nodes) is the best power allocation scenario in the MMS scheme.*

Keywords: *Two-Way Relay Network, DF, Relay Selection, BER.*

1. Introduction

Comparing to wired communication system, transmission in a wireless communication system experiences some problems such as: limited frequency spectrum, low signal power over long distances, interference of co-channel and neighbor cells and also random behavior of the channels. For eliminating the channels fading effect, the best way is using multiple antenna, but it is not applicable in the side of mobile devices. Hence, a cooperative relay-based structure is needed which provides full diversity and reduces the power consumption [1, 2]. In the cooperative relay-based networks, an auxiliary node, namely relay, communicates between source and destination nodes. This type of communication will be performed by some cooperative protocols, such as Amplify and Forward (AF), Compute and Forward (CF), and Decode and Forward (DF) [2].

In AF, Information will be transmitted from one source to the relay. The received signal will be amplified by a relay and then the relay signal will be sent to destination. In this way, relay noise is also amplified at the relay and added to signal.

In DF protocol, the first phase is the same as AF but in the second phase, the relay decodes the received signal and then sends the encoded version to destination node. By this type of processing in relay node, noise effect will be decreased [2, 3].

In cooperative relay-based systems, two-way relay protocol where two source nodes exchange information via a single relay is more considered. A two-way relay network at comparison of one-way relay network has higher throughput and it can take advantage of advanced coding techniques. In these systems, coding allows to a relay that the received signal is decoded and after reducing the error, it is sent to the destination. Hence, the network transmission time can be reduced [4]. In these systems, the source nodes are able to send or receive data at the same time and frequency, if half - duplex mode is applied. Three important protocols (as shown in Fig. 2) are 4-time slot, 3-time slot (TDBC), and 2-time slot (MABC) [3, 5-6]. In this study, the most commonly protocol, MABC is used.

In 2-time slot (MABC) there is two time slot to transmit data between *A* to *B* and vice versa. In the first time slot, the both source nodes transmit their data to the relay, simultaneously. In the second time slot, the relay node processes the data and then the processed information will be sent to two sources.

In 3-time slot (TDBC), source *A* transfers its data to the relay node and source *B* transfers its data to the relay node, in the first and second time slots, respectively. In the third time slot, the relay node processes the self-combined information and sends them to *A* and *B* nodes.

In 4-time slot protocol, there are four time slots. In the first time slot, source *A* sends its data to the relay node. In the second time slot, the relay node processes its information and sends them to source *B*. In the third period, the data of source *B* will be sent to the relay node. Finally, the received information at the relay node will be processed and the processed information will be sent to source node *A*.

There are several relay selection schemes [8] which six more considered ones are Non-Selection (NS), Optimal Selection (OS), Max-Min SNR Selection (MMS), Max-Sum rate Selection (MSS), a combination of the latter two as Hybrid Selection (HS) and Max-Min distance between points of constellations. In this study, five relay selection scheme including the NS (or fixed relay), OS, MMS, MSS and HS are investigated.

Two performance metrics, outage probability and bit error rate (BER) are used to evaluate and also compare the performance of relay selection schemes. For DF relay networks, MMS was investigated considering the BER for different modulations [9, 10]. Also, outage probability for DF relays with different relay selection schemes was presented in [9]. In this paper, a two-way relay network, which has recently been attended by many researchers, is considered with a two slot time protocol. The simulation results show that MSS relay selection scheme outperforms relay selection scheme MMS, in low SNRs, but its diversity performance is weak. In the high SNRs, MMS relay selection scheme outperforms MSS scheme. Also, it was shown that the best relay selection scheme with less outage probability is HS that switches between MMS and MSS schemes. Here, we want to find the best selection scheme considering BER for above mentioned schemes.

At the rest of this paper, system model and relay selection schemes are presented in the Sections II and III, respectively. Section IV shows the BER performance evaluation results. Finally, Section V concludes this research work.

2. SYSTEM MODEL

Consider a two-way relay network with two users which the modulated BPSK data will be transferred between the source and destination nodes via L relay nodes. It is assumed that each node is equipped with a single antenna that they can also meet restrictions of half-duplex transmission. Channels between user A and relay i and user B and relay i are called f_i and g_i, respectively. It is assumed that the channel model is flat Rayleigh fading. In other words, the channels are complex Gaussian random variables with zero mean and unit variance. Power of users and relays are considered to be the same, p. For simplicity, we assume that two users have the same transmission rate. Thus, both sources have the same transmission rate equal to $R_A=R_B=R_0$ (BPCU).

Using MABC communication protocol (according to Fig. 2), in the first time slot (MA phase), transceivers A and B send information to relays (left figure) and in the second time slot (BC phase), the selected relay decodes information and then it encodes and resend it to transceivers A and B (right figure) [4]. S_A and S_B are data of two sources A and B and $M(S_A)$ and $M(S_B)$ are modulated signals. Received signal at the kth relay is defined as (1).

$$y_k = f_k M(S_A) + g_k M(S_B) + n_k \tag{1}$$

Where n_k is zero mean additive white Gaussian noise (AWGN) with unit variance.

In BC phase, one relay is selected for exchanging information between A and B. If the selected relay is considering as ith relay, the first ith relay decodes as soft decoding its received signal. In other words, after this soft decoding, the estimated signals SA and SB in relay are as (2). Then, the selected relay sends decoded $(\hat{S}_A, \hat{S}_B)$ by XOR operator, to two destinations A and B as (3), (4).

$$(\hat{S}_A, \hat{S}_B) = \arg\min \left| y_i - (f_i M(S_A) + g_i M(S_B)\right|^2 \tag{2}$$

$$y_A = f_i M(\hat{S}_A \oplus \hat{S}_B) + n_A \tag{3}$$

$$y_B = g_i M(\hat{S}_A \oplus \hat{S}_B) + n_B \tag{4}$$

n_A and n_B are AWGN noises at destinations A and B. If B is assumed to be the desired destination, the desired signal S_B is estimated as $\hat{\hat{S}}_B$ by the (5). For A destination, the desired signal S_A is estimated as $\hat{\hat{S}}_A$.

$$\hat{\hat{S}}_B = \arg\min |y_A - (f_i M(S_A \oplus S))|^2 \qquad (5)$$

According to Ref. [11], in a DF two-way relay network with protocol MABC, the rate region is calculated according (6) to (10).

$$R_1 \le \min\left\{\Delta_1 C(P|f_{r_0}|^2), \Delta_2 C(P|g_{r_0}|^2)\right\} \qquad (6)$$

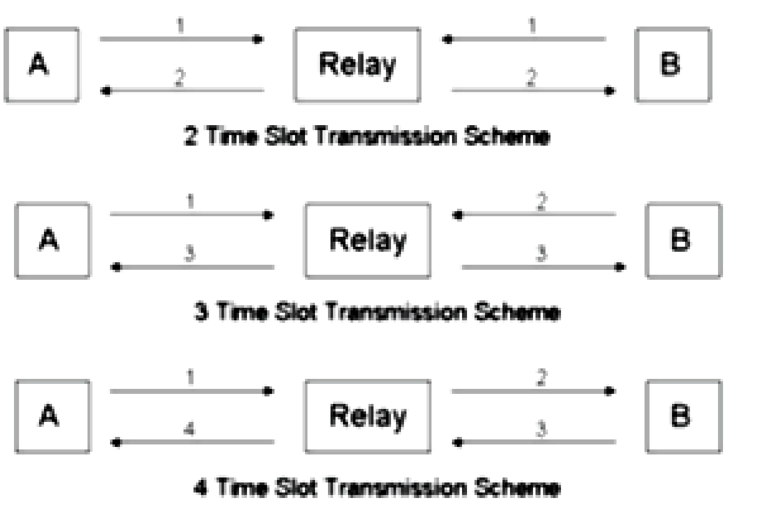
$$R_2 \le \min\left\{\Delta_2 C(P|f_{r_0}|^2), \Delta_1 C(P|g_{r_0}|^2)\right\} \qquad (7)$$

$$R_1 + R_2 \le \Delta_1 C(P|f_{r_0}|^2 + P|g_{r_0}|^2) \qquad (8)$$

$C(x) = \log_2(1+x)$ and $0 < \Delta_i < 1$.

$$R_0 \le \tfrac{1}{2}\min\left\{C(P|f_{r_0}|^2), C(P|g_{r_0}|^2)\right\} \overset{\Delta}{=} \phi_0(r_0) \qquad (9)$$

$$2R_0 \le \tfrac{1}{2} C\left\{(P|f_{r_0}|^2) + (P|g_{r_0}|^2)\right\} \overset{\Delta}{=} \phi_1(r_0) \qquad (10)$$



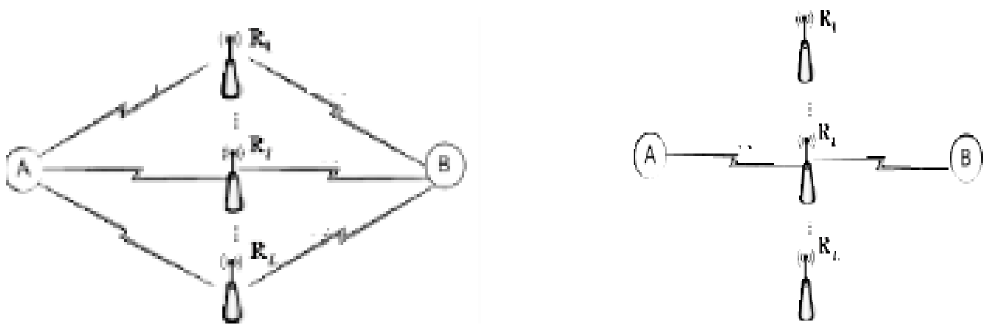


Fig. 2. *System Model*

3. Relay Selection Schemes

Relay selection has main impact on the performance of relay-based networks. It is useful especially for networks with high number of nodes and complexity. Comparing to relay-based networks which uses all relay nodes in beamforming, the consumed power is less [7]. Five more popular relay selection schemes are as follows.

1.Non-Selection (NS) scheme: In this scheme, a fixed relay node is assumed for all times. Hence, we assume that only one relay exists for sending data [9].

2.Optimal Selection (OS) scheme: In this scheme, the best relay node is that node which can decode the information at destination, correctly. First, new relays set will be made from relays that can meet two conditions ((11)). Then, a relay is selected from new set, randomly [9].

$$\phi_0(r_0) \geq R_0, \phi_1(r_0) \geq 2R_0 \tag{11}$$

3. Max-Min SNR Selection (MMS) scheme: In MMS, according to (1), a relay is chosen that it maximizes the minimum transmission rates. It was shown that it has full diversity [1, 9].

$$r_0 = \arg\max\min\left[|f_r|^2, |g_r|^2\right] \tag{12}$$

4. Max-Sum rate Selection (MSS) scheme: In this scheme, according to (2), a relay is chosen that it maximizes the minimum transmission rates. This design is suitable for low SNRs and supports full diversity [9].

$$r_0 = \arg\max\max\left[|f_r|^2 + |g_r|^2\right] \tag{13}$$

5. Hybrid Selection (HS) scheme is a combination of MMS and MSS. In this scheme, it switches between two previous schemes. According to (14), when $\phi_1(r) = 2R_0$ it uses MMS, otherwise it uses MSS [9].

$$r_0 = \begin{cases} \arg\max\min\left[|f_r|^2, |g_r|^2\right] if \phi_1(r) > 2R_0 \\ \arg\max\max\left[|f_r|^2 + |g_r|^2\right] elsewhere \end{cases} \tag{14}$$

4. Simulation Results

In this section, BER of the proposed scheme is presented using Monte Carlo simulation. In Fig. 3, BER is investigated according to five relay selection schemes, namely, NS, OS, MMS, MSS and HS. It is assumed that 3 relays have been used in cooperative networks. Channels variance is unit. As can be seen, BER of MMS is lower than the other relay selection schemes. Also, it can be seen that the performance difference between MMS and HS in the view of outage probability is the same as it in the view of BER.

In Fig. 4, BER is investigated based on the different number of relays. It shows that MMS is the best one. However, increasing the number of relay nodes is the reason for decreasing the BER. In Fig. 5, BER is plotted at different symmetric channel conditions. It shows that the performance of MMS is higher than the other relay selection schemes at high or low gain of channels.

Fig. 6 shows the BER of different relay selection schemes in different asymmetric channels variations. BER for MMS is the lowest. As the final result, Fig. 7 illustrates BER of MMS at different power allocation scenarios. Fig. 7 shows that the best performance (lower BER) will be achieved when power is divided equally between two transceivers and selected relay.

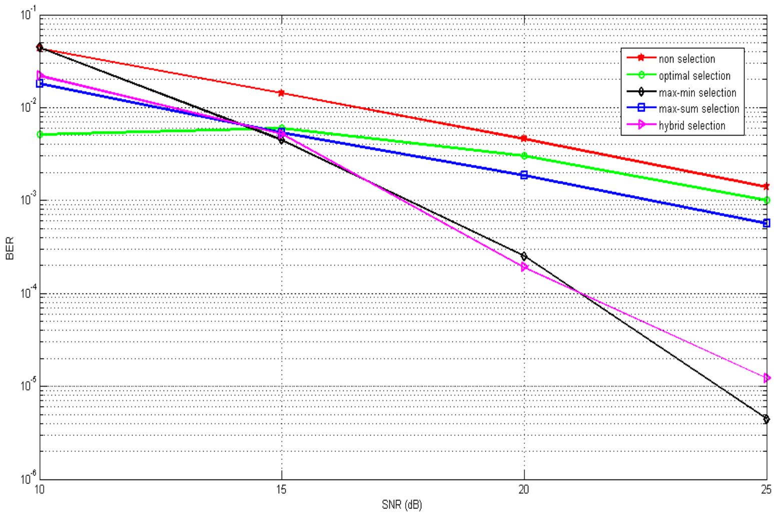


Fig. 3. *BER of five relay selection schemes*

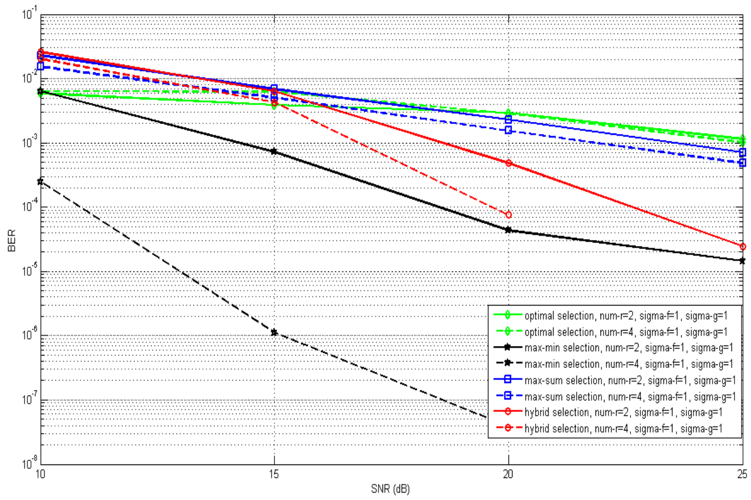


Fig. 4. *BER of five relay selection schemes in two cases (2 and 5 cooperative relays)*

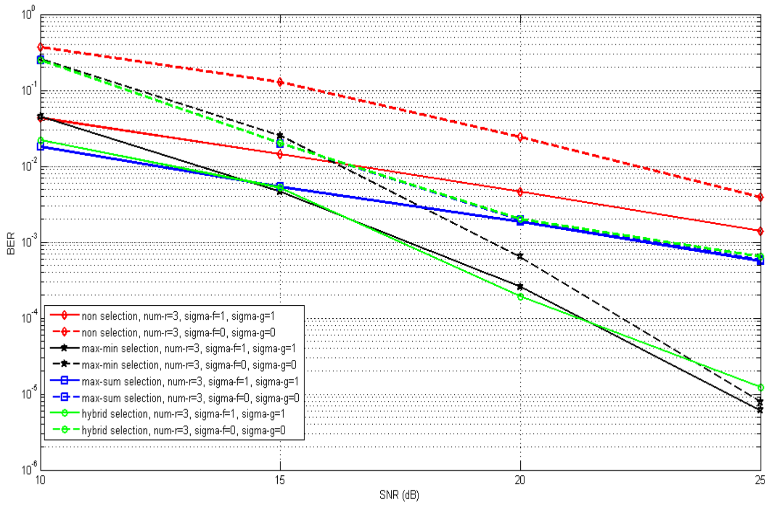


Fig. 5. *BER of five relay selection schemes in low gain and high gain symmetric channels*

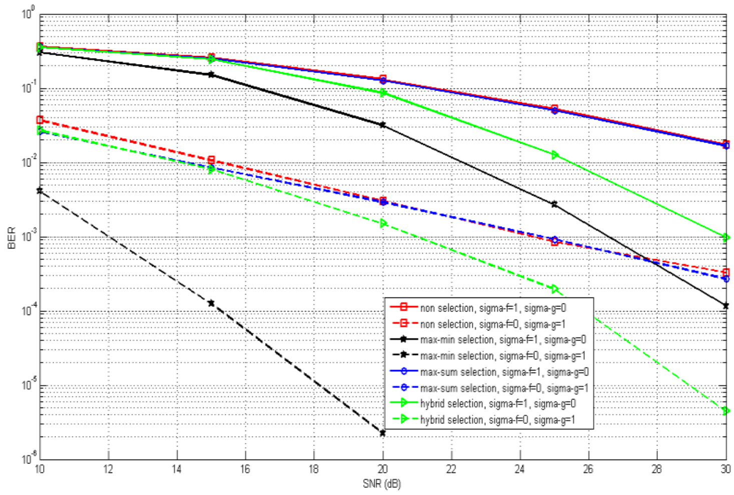


Fig. 6. *BER of five relay selection schemes in different asymmetric channels*

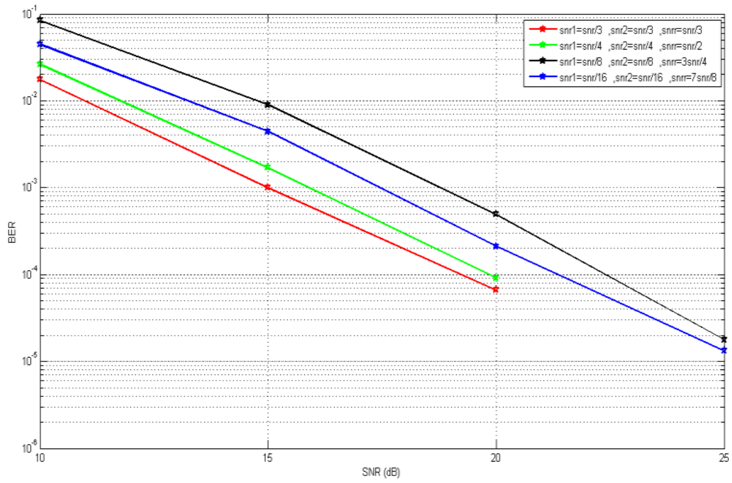


Fig. 7. *BER of MMS scheme for different power allocation scenarios*

5. Conclusion

In this paper, five relay selection schemes, NS, OS, MMS, MSS and HS were investigated. Among all the schemes, MMS relay selection scheme is the best one in the view of BER and outage probability for DF relay networks. Moreover, different relay selection schemes were also studied for different number of relays and channels conditions. Moreover, at MMS-based DF two-way relay networks, lowest BER will be achieved if the total power is equally divided to source, destination and relay nodes.

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