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A New Modification on Relay Selection by Considering the Effect of Relay Occupancy

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Authors' contributions

This work was carried out in collaboration between two authors. Authors SSM and FBY designed the study and managed the research procedure. Author FBY performed the numerical simulations in MATLAB software and wrote the first draft of the manuscript. Consequently, author SSM checked the analyses and simulation results and also rechecked the first draft of manuscript. Finally authors SSM and FBY read and approved the final manuscript.

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ABSTRACT

Aims: Considering the effect of relay occupancy at relay selection schemes and also proposing a new approach which helps the selection schemes to find the best free relay.
Study Design: Comparative study by simulation in MATLAB software.
Place and Duration of Study: Digital Communications Signal Processing (DCSP) Lab. of Shahid Rajaee Teacher Training University (SRTTU), Since 1st June 2012 up to 1st August 2014.
Methodology: In the existing research works, relay-based system is modeled by a pair of transmitter-receiver nodes and a number of relays. Also, it is assumed that the selected relays are always free. In this investigation, the effect of relay occupancy due to other pairs is considered. For this purpose, a uniform distribution is applied for all relays to show the effect of free or busy relay nodes. Then, the performance of the relay selection methods is obtained by using two well-known performance metrics, bit error rate (BER) and outage probability. As the main goal of this research, a new approach is proposed which first finds the free relays and then applies one of the selection

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methods, Max-Min SNR Selection (MMS), Max-Sum rate Selection (MSS) and Hybrid Selection (HS), to find the best relay which satisfies the optimization problem.
Results: For both Amplify and Forward (AF) and Decode and Forward (DF) relays, the new approach will reduce outage probability of HS scheme. For AF relays, BER of MMS and HS schemes will be decreased but it has neglected effect on the outage probability of MSS scheme. For DF relays, BER of MMS, MSS and HS schemes will be decreased.
Conclusion: According to optimization problem for each relay selection scheme, the proposed approach can significantly reduce the outage probability and BER in realistic conditions which the effect of other nodes is considered.

Keywords: Physical-layer network; outage probability; symbol error rate; two-way relay; amplify and forward; decode and forward.

1. INTRODUCTION

Cooperative communication has drawn a lot of interests in recent years due to its capability to increase the coverage of each base station in cellular systems, balance the network traffic distribution, enhance the quality of service, and increase the capacity as well as the data rate. A common approach to enable cooperative communication is to deploy some intermediate relay nodes which can potentially process their received signals and then retransmit them. As stated in [1], relay nodes can effectively reduce the effect of fading in wireless communication as they are providing several copies of the transmitted signal at the destination [2].

Two-way relay networks, where two source nodes exchange information via a single relay is a special case of the general relay networks, which significantly increase the system throughput. A two-way relay network has higher throughput and spectral channel coding techniques are usually used in order to enhance the transmission reliability; thus the relay nodes can perform the decoding algorithm to completely decode the transmitted signals in the presence of noise and other channel impairments [3]. Because the relay nodes cannot transmit and/or receive at the same time or frequency, half-duplex mode is considered for transmission. More specifically, these approaches are four time slot, three time slot (TDBC), and two time slot (MABC) schemes [4,5].

A relay can be either regenerative or non-regenerative. In non-regenerative or Amplify and Forward (AF) relays (See Fig. 1-a), signals which have been transmitted from source nodes to relay will be amplified and then the amplified version of combined signals will be transmitted to destination nodes. In AF relays, no further signal processing will be applied to the received signal; however, the received noise power will be amplified and transmitted to the destination. This method is used in the Analog Network Coding (ANC). In regenerative or Decode and Forward (DF) relays, after receiving the transmitted coded signals from both sources to the relay, the relay decodes a combination of them to overcome the noise (See Fig. 1-b). Then, relay sends the re-encoded combined signal to the destination nodes. Finally, received data will be decoded in both destinations. By the knowledge of the transmitted signal from each source node, the other signal will be found by subtracting the re-encoded signal and the first transmitted signal. However, this scheme requires a full codebook in both source nodes and it is used in Physical layer Network Coding (PNC) [4].

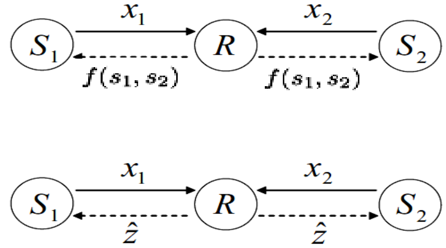

Fig. 1. System model (a) ANC (b) PNC [13]

Relay selection is a cooperative approach, which can help the network to achieve full diversity while it needs lower synchronization and less feedback data in comparison to other schemes [4]. In AF relays, one of the most common relay selection approaches is the Max-Min signal to noise ratio (SNR) Selection (MMS) strategy. In DF relays, different proposals have been presented, such as, the optimal selection, Max-Min Selection (MMS), Max-Sum rate Selection (MSS), Hybrid Selection (HS) which is a combination of the latter two selection schemes, and Max-Min distance between constellation points selection [6,7]. The focus of this paper is on MMS, MSS and HS, due to their lower complexity.

Outage probability and Bit Error Rate (BER) are two important criteria in evaluation the performance of a communication system. The non-regenerative relay network considering different relay selection schemes is investigated in [1] and Symbol Error Rate (SER) is evaluated for BPSK, QPSK and 8PSK (Two, Four and Eight level Phase Shift Keying) modulations. Similar approaches were used in [6,7] for regenerative relay networks. Also, the outage probability was expressed for regenerative relay networks for different relay selection schemes in [6].

In the previous studies [2-10], the relay selection scheme selects the best relay which offers less transmitted power, lower SER and outage probability or provides higher sum rate. In these works, the effect of the other transmitter-receiver pairs (or other neighbor cells in cellular structures) on the relay selection and final performance has not been considered. Hence, there is no additional restriction on the relay selection schemes. In this paper, two-way relay network is considered which uses two phases protocol (using two time slots) and considers the effect of other transmitter-receiver pairs. In practical systems, the selected relay might be busy, so it cannot service the requested source nodes, and accordingly the outage probability and SER will be increased. In this paper, first the performance of three relay selection schemes, MMS, MSS and HS are evaluated by considering the effect of other pairs using a uniform traffic model. In addition, a novel approach is proposed which improves the performance of relay selection scheme in both AF and DF relays by reducing BER and outage probability.

The rest of this paper is organized as follows. In Section 2, system model, relay selection schemes, MABC protocol and outage probability are presented. The new approach is described in Section 3. In Sections 4 and 5, simulation results and conclusions are explained.

2. SYSTEM MODEL

We consider a relay network with two users, where BPSK modulated data is exchanged between them via R intermediate relay nodes. It is assumed that all end nodes are transceivers equipped with a single antenna. The channels between user 1 and relay i and that between user 2 and relay i are denoted by f_i and g_i, respectively. Communication channel is modeled by a symmetric flat Rayleigh fading channel, where the channel gain is a complex Gaussian random variable with zero mean and unit variance. The relays and users' transmit power is also denoted by P.

For simplicity, we assume that two users have the same transmission rate. MABC protocol which consists of two time slots is considered for communication between users. In the first phase, both users transmit information to all relays. In the second phase, for AF mode, the selected relay amplifies the received signal and transmits it to the end nodes, whereas in the DF mode, the selected relay decodes the received signal and transmits the re-encoded signal to the end nodes [8].

2.1 Relay Selection Schemes

In this paper, three relay selection schemes, MMS, MSS and HS are considered. In MMS scheme, according to (1), a relay node is chosen such that the transmission rate is maximized [1,6].

$$r_0 = \arg\max\min\left[|f_r|^2, |g_r|^2\right] \tag{1}$$

In MSS scheme, according to (2), the relay node is chosen to maximize the instantaneous sum rate. This scheme is shown in [6] to be effective for low SNRs [6].

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

The HS relay selection scheme is a combination of MMS and MSS relay selection schemes. According to (3), this method uses MMS when $(\phi_1(r) > 2R_0)$, otherwise it uses MSS [4]. $\phi_1(r)$ is defined at equation (21).

$$r_0 = \begin{cases} \arg\max\min\left[|f_r|^2, |g_r|^2\right] & if\ \phi_1(r) > 2R_0 \\ \arg\max\left[|f_r|^2 + |g_r|^2\right] & elsewhere \end{cases} \quad (3)$$

2.2 MABC Protocol

In this protocol, the whole transmission is divided into two time slots. During the first phase, both source nodes send their data to relay nodes. In the second phase, depending on relay mode, AF or DF, the selected relay node amplifies or decodes information, respectively. Finally, relay transmits the data to both destination nodes.

In the first phase, the received signal at the relay node is as follows:

$$x_{r_i} = \sqrt{P} f_i s_1 + \sqrt{P} g_i s_2 + v_i \quad (4)$$

where, v_i, the noise at the i^{th} relay, is a complex Gaussian random variable with zero mean and unit variance.

2.2.1 Amplify and forward (AF) [1,11]

In the second phase, the selected relay node amplifies the combined received signals as follows:

$$\alpha_{r_0} = \sqrt{\frac{P}{1 + |f_{r_0}|^2 P + |g_{r_0}|^2 P}} \quad (5)$$

$$\begin{aligned} \tilde{x}_{1,r_0} &= \alpha_{r_0} \sqrt{P} f_{r_0} f_{r_0} s_1 + \alpha_{r_0} \sqrt{P} f_{r_0} g_{r_0} s_2 + \alpha_{r_0} f_{r_0} v_{r_0} + w_1 \\ \tilde{x}_{2,r_0} &= \alpha_{r_0} \sqrt{P} g_{r_0} g_{r_0} s_2 + \alpha_{r_0} \sqrt{P} f_{r_0} g_{r_0} s_1 + \alpha_{r_0} g_{r_0} v_{r_0} + w_2 \end{aligned} \quad (6)$$

Where w_i is noise at user i, when i=1,2. As above mentioned, these noises are complex Gaussian random variables with zero mean and unit variance.

Each user should then extract the data of the other source, so each user can cancel self-interference as follows:

$$\begin{aligned} \hat{x}_{1,r_0} &= \alpha_{r_0} \sqrt{P} f_{r_0} g_{r_0} s_2 + \alpha_{r_0} f_{r_0} v_{r_0} + w_1 \\ \hat{x}_{2,r_0} &= \alpha_{r_0} \sqrt{P} f_{r_0} g_{r_0} s_1 + \alpha_{r_0} g_{r_0} v_{r_0} + w_2 \end{aligned} \quad (7)$$

After canceling self-interference, by using the maximum likelihood (ML) criterion, the desired signal is obtained as follows:

$$\begin{aligned} \hat{s}_2 &= \arg\min\left|\hat{x}_{1,r_0} - \alpha_{r_0} \sqrt{P} f_{r_0} g_{r_0} s\right| \\ \hat{s}_1 &= \arg\min\left|\hat{x}_{2,r_0} - \alpha_{r_0} \sqrt{P} f_{r_0} g_{r_0} s\right| \end{aligned} \quad (8)$$

2.2.2 Decode and forward (DF) [7,9,10,12-14]

Information bit of s_i belongs to the set {1,0} and its modulated symbols will be $x_i \in \{-1,1\}$, where $x_i = 1-2s_i$. In this relaying scheme, the first time slot is quite similar to the AF protocol. If r_0 is the selected relay node, this relay decodes $s = s_1 \oplus s_2$. In other words, in the selected relay, symbol $z = 1-2s = x_1 x_2$ is decoded using the ML criterion as follows:

$$\sum_{\{(x_1,x_2)|x_1x_2=1\}} e^{-D_{r_0}(x_1,x_2)} \underset{\hat{z}=-1}{\overset{\hat{z}=1}{\gtrless}} \sum_{\{(x_1,x_2)|x_1x_2=-1\}} e^{-D_{r_0}(x_1,x_2)} \quad (9)$$

where

$$D_{r_0}(x_1,x_2) = \frac{1}{\sigma^2}\left|x_{r_0} - \sum_{i=1}^{2} \sqrt{P} h_{im} x_i\right| 2 \quad (10)$$

and

$$(x_1,x_2) \in \{(-1,-1),(-1,1),(1,-1),(1,1)\} \quad (11)$$

$\hat{z}$ is the detected BPSK symbol in the selected relay by employing the maximum likelihood criterion (9) and σ^2 is variance of additive noise at relays.

In the second phase, the selected relay node sends the symbol $\hat{z}$ to users. The received signal by two users is equal to equation (12).

$$y_i = \sqrt{P} f_{r_0} \hat{z} + n_i \quad (12)$$

Finally, user i obtains the transmitted bit of user j as follows:

$$\hat{x}_j = \hat{z}_i x_i \quad (13)$$

$\hat{z}_i = 1$, if $h^*_{i_{r_0}} y_i \geq 0$ and $\hat{z}_i = -1$ if $h^*_{i_{r_0}} y_i \leq 0$. (14)

2.3 Outage Probability

According to [6], in an AF two-way relay network with MABC protocol, the transmission rate region is found by using the following equations.

$$R_1 \le \frac{1}{2}\left\{C\left(\frac{|f_r|^2|g_r|^2 P_1 P_r}{|f_r|^2 P_1 + |g_r|^2 P_2 + |g_r|^2 P_r + 1}\right)\right\} \quad (15)$$

$$R_2 \le \frac{1}{2}\left\{C\left(\frac{|f_r|^2|g_r|^2 P_2 P_r}{|f_r|^2 P_1 + |g_r|^2 P_2 + |f_r|^2 P_r + 1}\right)\right\} \quad (16)$$

According to [6], in a DF two-way relay network with MABC protocol, the transmission rate region is found by using the following equations.

$$R_1 \le \min\left\{\Delta_1 C\left(P|f_{r_0}|^2\right), \Delta_2 C\left(P|g_{r_0}|^2\right)\right\} \quad (17)$$

$$R_2 \le \min\left\{\Delta_2 C\left(P|f_{r_0}|^2\right), \Delta_1 C\left(P|g_{r_0}|^2\right)\right\} \quad (18)$$

$$R_1 + R_2 \le \left\{\Delta_1 C(\left(P|f_{r_0}|^2 + P|g_{r_0}|^2\right)\right\} \quad (19)$$

Where f_i and g_i are channel coefficients which represent the communication link i→j, $C(x) = \log_2(1+x)$ and $0 < \Delta_i < 1$. The MABC protocol has two phases (i=2). We denote $\Delta_i \ge 0$, the relative time duration of the i[th] phase, where $\sum_i \Delta_i = 1$. For the same transmission rate R_0 for both users, we have

$$R_0 \le \frac{1}{2}\min\left\{\Delta_1 C\left(P|f_{r_0}|^2\right), \Delta_2 C\left(P|g_{r_0}|^2\right)\right\} \overset{\Delta}{=} \phi_0(r_0) \quad (20)$$

$$2R_0 \le \frac{1}{2}\left\{C\left(P|f_{r_0}|^2 + P|g_{r_0}|^2\right)\right\} \overset{\Delta}{=} \phi_1(r_0) \quad (21)$$

The outage probability for the block fading channel model can then be calculated as follows:

$$P_{out} = 1 - \mathrm{P}\left\{\phi_0(r_0) \ge R_0 \bigcap \phi_1(r_0) \ge 2R_0\right\} \quad (22)$$

3. THE ROPOSED MODIFICATION

In order to evaluate the SER and outage probability for the existing approaches, it has been assumed that all relays are free to listen to the transmitted signals and the selected relay processes the received signal in AF or DF modes, and then transmits it. In practical systems, all the relay nodes are not free and some of them are helping the other nodes (transmitter-receiver end points). Hence, the effect of occupancy of selected relays should be considered. It is clear that the outage probability and SER of three above-mentioned relay selection schemes, MMS, MSS and HS, will be increased, if the selected relay is not free.

Outage probability for AF and DF relays and SER for DF relays in practical systems can be obtained as equations (23) and (24), respectively

$$P_{outage,tot} = P_{busy} + (1 - P_{busy})P_{outage,RS} \quad (23)$$

$$P_{error,i} = P_{busy} + (1-P_{busy})\{P_{error,RS}(1-P_{error,j}) + (1-P_{error,RS})P_{error,j}\},\ i=1,2 \quad j=1,2 \quad i \neq j \tag{24}$$

$P_{outage,tot}$, P_{busy}, $P_{outage,RS}$, $P_{error,1}$, $P_{error,2}$ and $P_{error,RS}$ are total outage probability, probability of occupancy, outage probability of selected relay, symbol error probability of user 1, symbol error probability of user 2 and symbol error probability of selected relay, respectively.

As shown in Fig. 2, in the proposed method, the list of the free relay nodes are first updated, and then a relay is selected from this list by using one of the relay selection schemes. Finally, the transmitted information from source nodes will be processed by this relay.

4. SIMULATION RESULTS

For simulation purposes, the channels' gain between relay nodes and transceiver pairs are considered as complex Gaussian random variables with zero mean and unit variance. In the next subsections, it will be shown that outage probability of AF and DF relay networks does not change in MMS and MSS relay selection schemes with applying the proposed algorithm, but it is improved in HS relay selection. In other words, outage probability is reduced. Also, symbol error rate of AF and DF relay networks is reduced in MMS and HS relay selection schemes with applying the proposed algorithm. Symbol error rate of AF relay networks does not change in MSS relay selection scheme with applying the proposed algorithm, but it is reduced in DF relay networks.

4.1 Outage Probability

Fig. 3 shows the outage probability in two cases, 0% and 50% occupancy of AF and DF relays in MMS, MSS and HS relay selection schemes. As shown in Fig. 3, with a reduction of 50% freedom of relays in AF and DF relay networks, MMS, MSS and HS relay selection schemes will introduce increasing in outage probability according to equation (23).

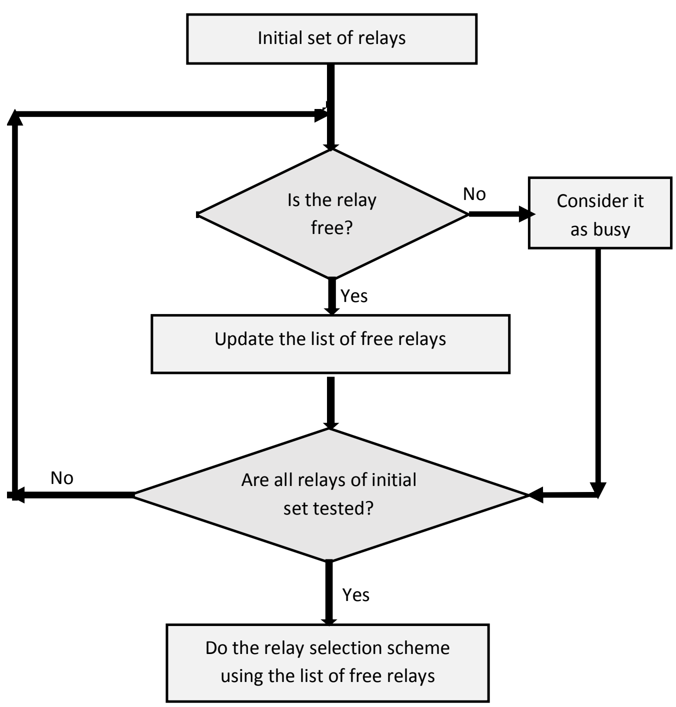

Fig. 2. The flowchart of the proposed algorithm

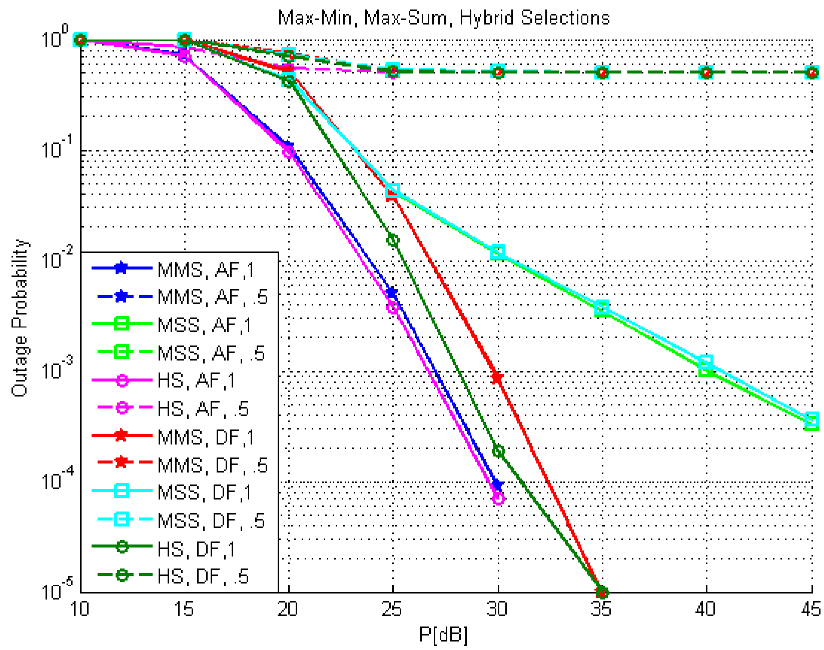

Fig. 3. Outage probability for 50% and 0% occupancy (or equally 50% or 100% freedom) of AF and DF relays in MMS, MSS and HS schemes

Fig. 4 is plotted based on 50% occupancy of relays in AF and DF relay networks. This figure discusses the effect of the proposed algorithm and the conventional one on outage probability of MMS, MSS and HS relay selection schemes. The proposed algorithm does not change the outage probability in MMS and MSS relay selection schemes, but the proposed algorithm reduces the outage probability in AF and DF two-way networks. It is the same for HS, too.

As shown in Fig. 4, by applying the proposed algorithm, outage probability will be reduced in high transmission rates. In addition, increasing the number of symbols in a fading block will further reduce outage probability.

Figs. 5 and 6 show outage probability for the case that 50% of relays in network are free. In Figs. 5 and 6, the performance of the proposed and the conventional algorithms are plotted for different number of relays, transmission rates and the number of symbols of fading blocks in AF and DF two-way relay networks. As it is previously expressed, the proposed algorithm will reduce the outage probability for HS relay selection scheme. It is obvious that the outage probability will be reduced when the number of relays increase. Moreover, increasing the transmission rate will increase the outage probability for medium SNRs.

4.2 Bit Error Rate

In this section, bit error rate is discussed for ideal and practical systems. By increasing the probability of occupancy of relays in AF and DF two-way relay networks at MMS, MSS and HS relay selection schemes, bit error rate will be increased as shown in Fig. 7.

Fig. 8 shows bit error rate in AF and DF two-way relay networks with 50% occupancy of relays, at MMS, MSS and HS relay selection schemes for the proposed and conventional algorithms. In AF two-way relay networks, by applying the proposed algorithm in MMS and HS relay selection schemes, bit error rate will be reduced, whereas it has no impact on the BER of MSS relay selection scheme. The proposed algorithm for DF two-way relay networks will decrease the symbol error rate at MMS, MSS and HS relay selection schemes.

In Fig. 9, bit error rate with 50% freedom of relays at AF two-way relay networks is shown for both cases, the proposed and conventional algorithms at different number of relays for MMS and HS relay selection schemes.

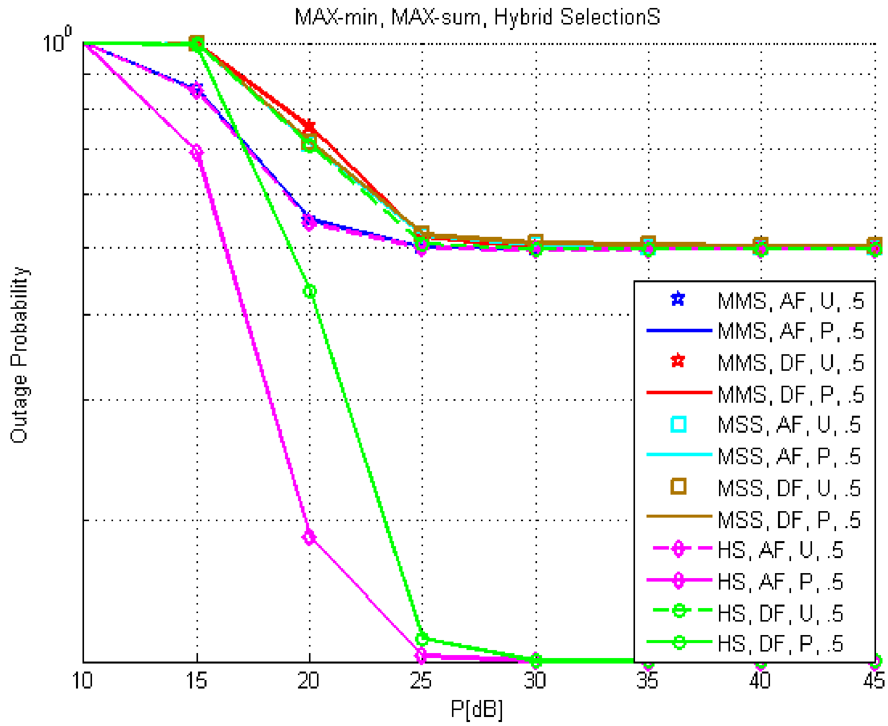

Fig. 4. Outage probability for 50% occupancy of AF and DF relays using the proposed and conventional algorithms in MMS, MSS and HS schemes

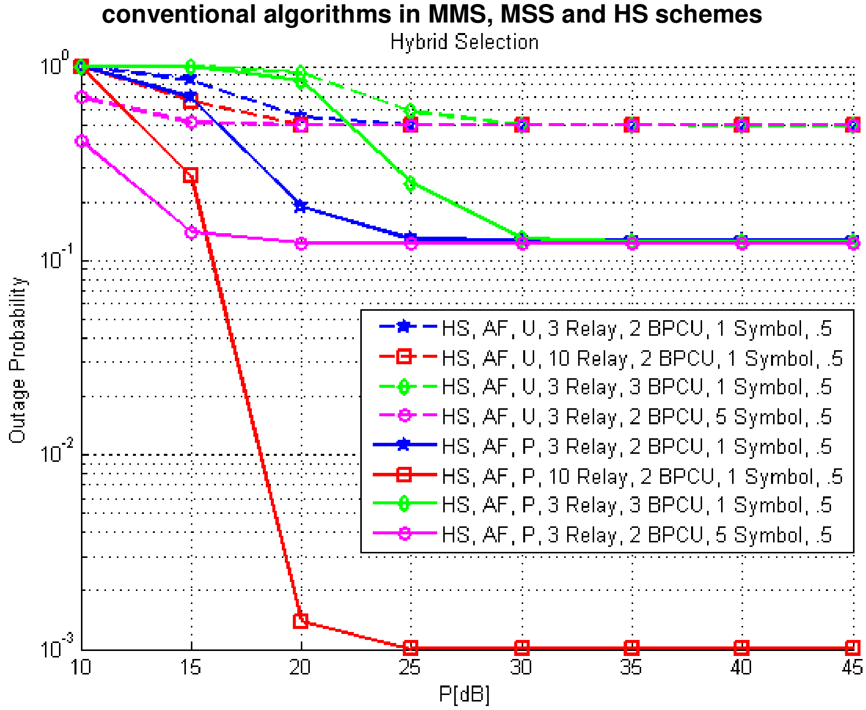

Fig. 5. Outage probability for 50% occupancy of AF two-way relays using the proposed and conventional algorithms in different number of relays, transmission rate and number of symbols at block fading for HS scheme

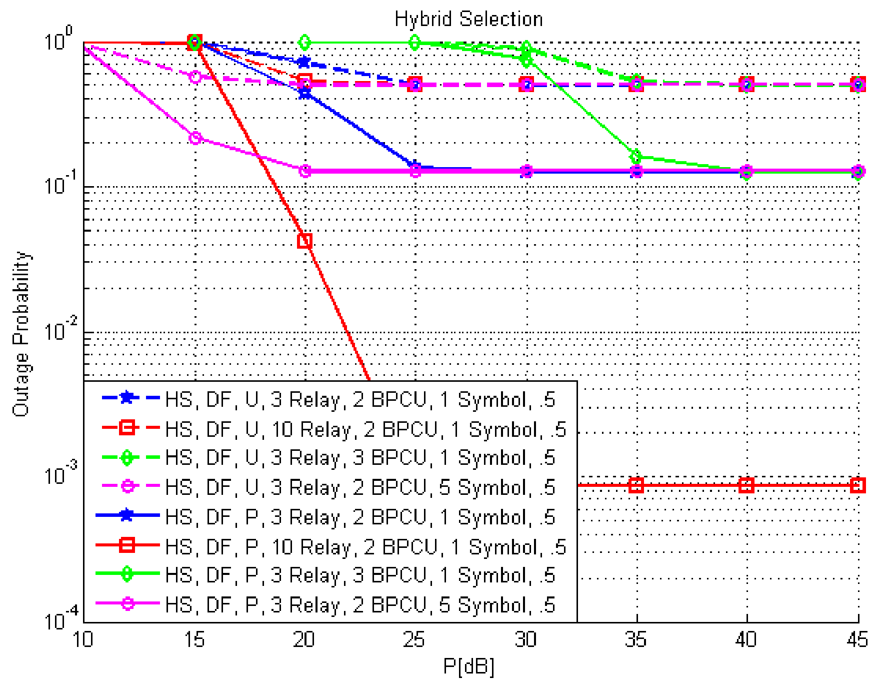

Fig. 6. Outage probability for 50% occupancy of DF two-way relays using the proposed and conventional algorithms in different number of relays, transmission rate and number of symbols at block fading for HS scheme

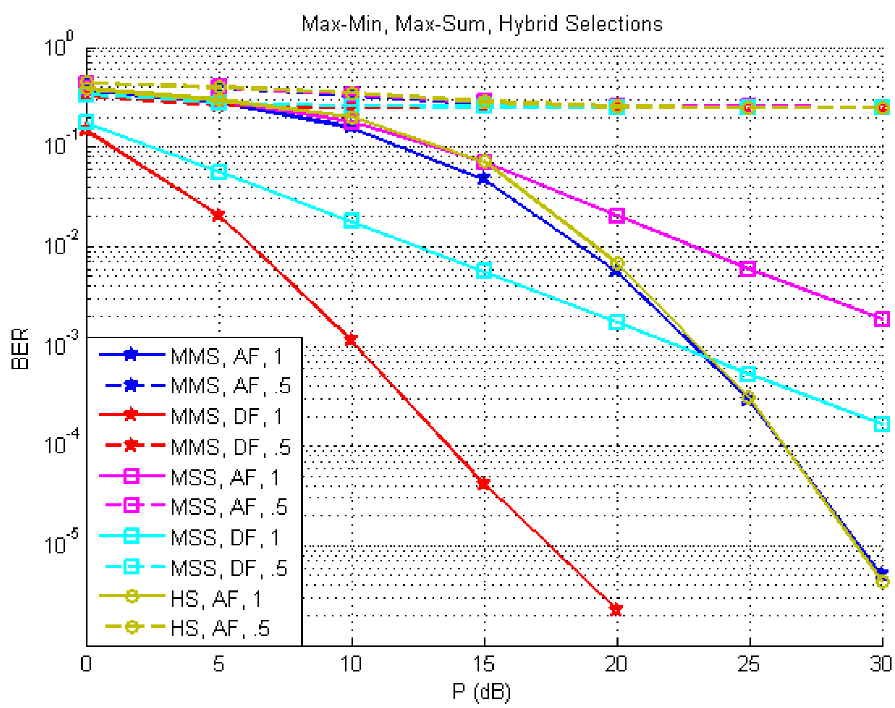

Fig. 7. Bit error rate for 50% and 0% occupancy of AF and DF two-way relays using MMS, MSS and HS schemes

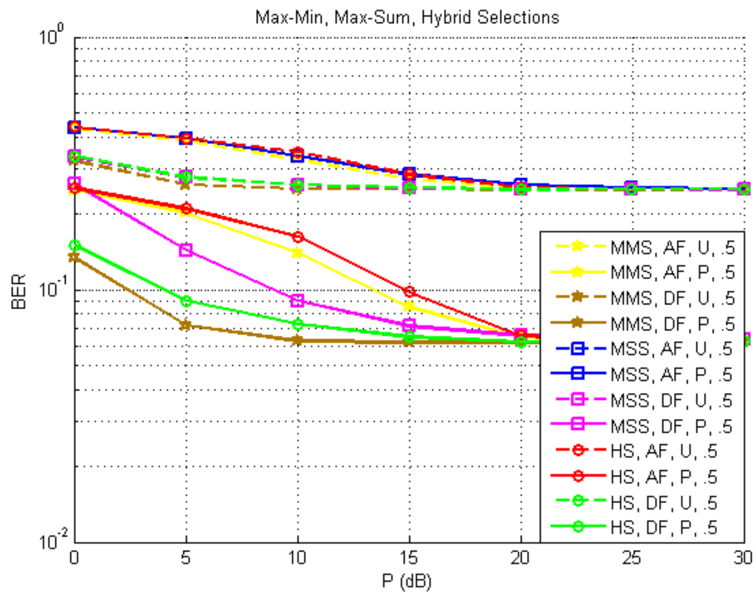

Fig. 8. Bit error rate for 50% occupancy of AF and DF two-way relays using the proposed and conventional algorithms in MMS, MSS and HS schemes

Increasing the number of relays will introduce appropriate selected relay. Therefore, at practical systems which consider conventional algorithm, increasing the number of relays causes decreasing the outage probability. This reduction on outage probability is higher when we use the proposed algorithm.

In Fig. 10, bit error rate at DF two-way relay networks with 50% freedom of relays is shown which use the proposed and conventional algorithms at MMS, MSS and HS relay selection schemes.

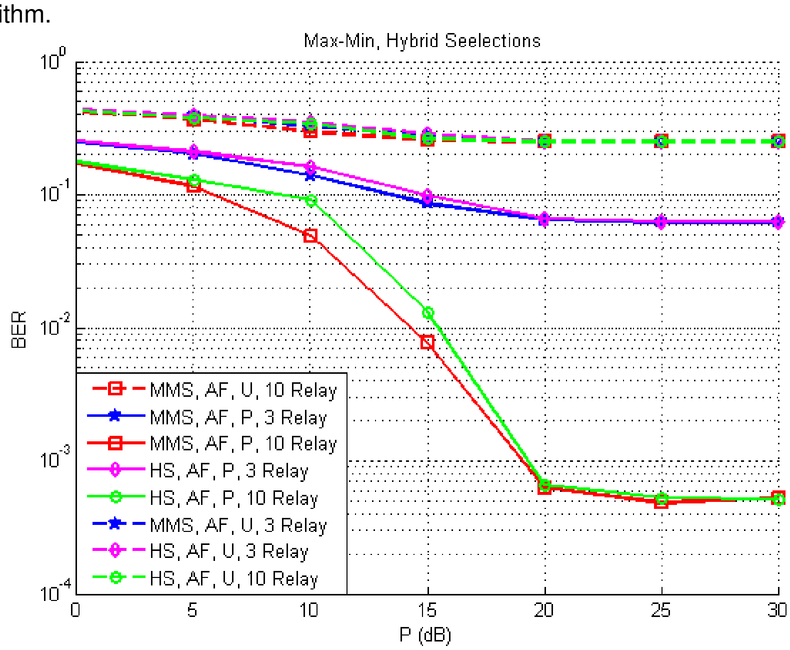

Fig. 9. Bit error rate for 50% occupancy of AF two-way relays using the proposed and conventional algorithms in different number of relays for MMS and HS schemes

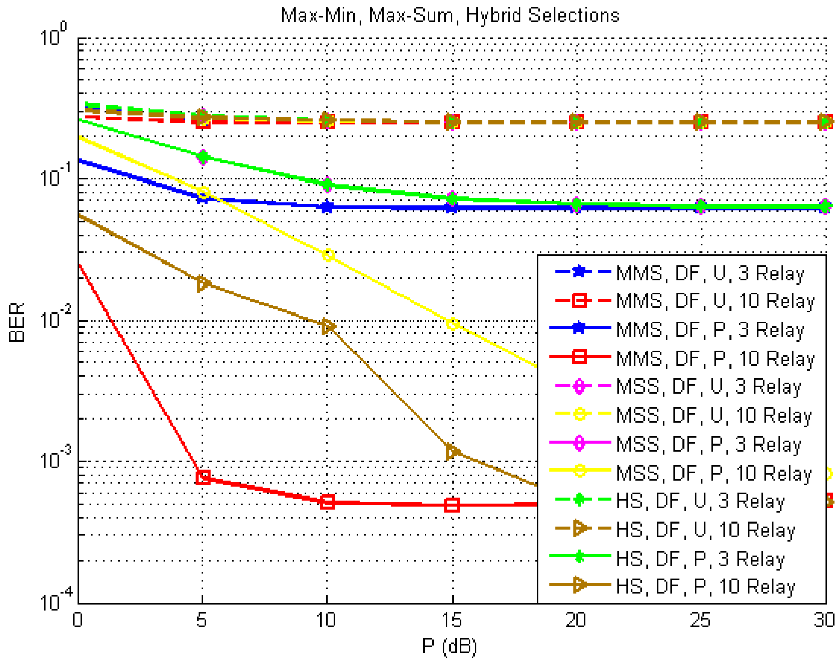

Fig. 10. Bit error rate for 50% occupancy of DF two-way relays using the proposed and conventional algorithms in different number of relays for MMS, MSS and HS schemes

5. CONCLUSION

In this investigation, by different examples, the effect of busy relays on the performance metrics, outage probability and BER of both AF and DF systems was evaluated. In order to find higher performance, a new approach was proposed which considers the effect of neighboring nodes at AF and DF relay networks. In this modification, the free relays will be specified and then a relay from this updated list will be selected according to one of the relay selection schemes, MMS, MSS and HS. According to optimization problem for each relay selection scheme, the proposed scheme was evaluated and it was shown that the proposed scheme can significantly reduce the outage probability and BER. It was shown that outage probability is reduced for AF and DF two-way relay network with HS relay selection scheme. By applying the proposed method to AF relay network, at two relay selection schemes, MMS and HS, BER will be reduced. In contrast, for MSS relay selection scheme, BER will not be changed in AF but will be changed in DF. The new proposed method shows an improvement in BER of AF and DF relay networks for both MMS and HS relay selection schemes.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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