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BER Performance Analysis of a New Hybrid Relay Selection Protocol

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***Abstract*—Recently, cooperative communication have attracted significant attention to tackle the limitations imposed by multiple-input-multiple-output (MIMO) technology. To eliminate these limitations and increase spectral efficiency, best relay selection technique was proposed. In this paper, the performance of a new hybrid relay selection protocol is investigated. In particular, closed-form expressions for bit error probability (BEP) are developed. The results of the BEP were presented to demonstrate the proposed system.**

***Index Terms*—BEP, best relay selection, hybrid relay selection**

I. INTRODUCTION

A common approach to mitigate the undesirable effect of fading in wireless communications is the use of diversity techniques such as antenna diversity and cooperative diversity [1]. Spatial diversity is a widely used technique to mitigate fading in wireless channels, which requires multiple co-located antennas at the transmitter and/or receiver, namely the multiple-input and multiple-output technique. It has been proven that transmission diversity is clearly advantageous at the base station and can be easily implemented. However, in practical applications, implementing multiple antennas on mobile stations, like cell phones, may not be possible due to limitations on hardware, software and size. Subsequently, an alternative form of spatial diversity referred to as “cooperative diversity” [2]-[4] has emerged as a promising technique to overcome such limitations.

Cooperative communications have attracted significant attention to tackle the limitations imposed by MIMO technology. However, the advantages of cooperative diversity protocols come at the expense of a reduction in spectral efficiency, especially when there are a large number of intermediate nodes distributed in an arbitrary form. In this case, the source and relays must transmit on orthogonal channels to avoid interference with each other. To eliminate these drawbacks and increase spectral efficiency, best-relay selection schemes are proposed in [5]-[8].

Cooperative relay communication has become a widely used technique in wireless communication systems to combat fading effects induced by multipath propagation. It is also used to improve the reliability of data transmission. There are two main types of relay used: amplify-and-forward (AF) and decode-and-forward (DF). In AF protocol, the relay simply amplifies the received signal as well as its own received noise and then forwards it to the destination.

The first part of this process is the major drawback of AF protocol. In DF protocol, the relay decodes the received signal, which experiences error propagation, then re-encodes it and forwards it to the destination. Recently, an alternative relay selection scheme based on a hybrid relay protocol has received a lot of attention. The proposed algorithm divided the relays into two groups, which are AF and DF relay groups, and then exploits the merits of both relay groups. In this case, noise amplification in AF relay, and error propagation in DF relay, will be avoided [9]-[11].

II. RELATED WORK

Performance analysis of best-relay selection schemes has been widely undertaken in the research literature [5], [6], [12]. The first best-relay scheme is proposed by Bletsas, *et al.* in [5], where the best-relay with the highest SNR is chosen at the destination to assist in the transmission of source signals. It is shown that the proposed system achieves the same diversity order as the regular cooperative diversity in terms of the outage probability. In [6], closed-form expressions of the symbol error rate (SER), error probability, and outage capacity of AF cooperative diversity systems with best-relay selection, are derived. However, in some practical cases, the best relay may be unavailable due to some scheduling or load balancing conditions. As a result, the selection may be made to choose the second or more generally the N^{th} best relay. In [12], the performance of AF with N^{th} best-relay selection over independent and identical Rayleigh fading channels is analyzed, where approximate expressions of the error probability and outage probability are derived.

By incorporating relay selection with hybrid relaying protocol, its performance can be further improved. This process is known as hybrid relay selection [13]-[17]. In [13], [14], the hybrid relay selection scheme has been proposed. In this scheme, all relays are classified into two relay groups (AF and DF relay groups) based on whether it decodes correctly or not. Among all relays in both AF and DF groups, the best relay will be selected in [13],

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while in [14], all relays of two groups can participate in communication. In [15], the authors analyzed the performance of hybrid relaying protocol with distributed turbo coding. In order to avoid channel estimation, differential modulation with hybrid relay selection was proposed in [16]. The single relay scenario was extended to a multiple relay scenario in [17], where all relays participate in the transmission process without relay selection.

In this paper, a new hybrid relay selection protocol is proposed. The difference of this work, compared with those in [9]-[17], is the use of DF and AF relays together and the exploitation of the merits of both. The performance analysis of the proposed hybrid relaying protocol is presented. Specifically, analytical expressions of the BER of the SNR for indirect links are given in closed-form. The BEP results show that the performance of the proposed technique is superior to other schemes proposed in [9]-[17].

The remainder of this paper is organized as follows: Section III describes the proposed hybrid relay selection; Section IV discusses the performance of BER; Simulation results are presented in Section V. Section VI presents concluding remarks.

III. HYPRID RELAY SELECTION PROTOCOL

The block diagram of the proposed system is shown in Fig. 1. A general two-hop relay network consists of one source node, denoted as S, one destination node denoted as D, and N relays, distributed between S and D. The encoded bitstreams are transmitted through hybrid relay networks. Each node in the proposed two-hop multi relay network is assumed to be equipped with a single antenna and the half-duplex transmission mode is considered. All links will experience quasi-static Rayleigh fading.

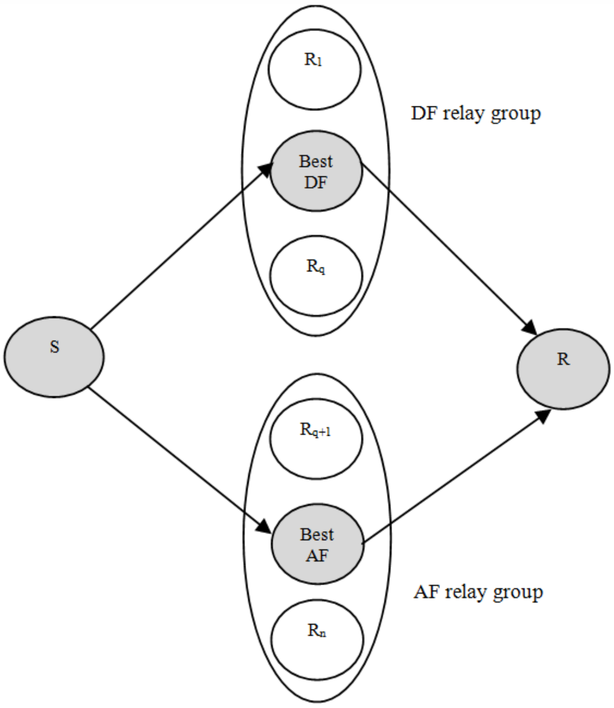

Figure 1. The proposed system model.

Let $h_{s,ri}$ and $h_{ri,d}$, (i=1, ….n) denote the channel gains between the source and relays, and the relay nodes and destination, respectively.

Let $w_{s,d}(t)$ and $w_{ri,d}(t)$ denote the AWGN with zero-mean and with variance of N_0 between the source and destination and the relay and the destination, respectively.

Then, the corresponding received signal at the relay i, at time t, denoted by $y_{s,r_i}(t)$, can be expressed as

$$y_{s,r_i}(t) = \sqrt{P_{s,r_i}} h_{s,r_i} x(t) + w_{s,r_i}(t) \tag{1}$$

where P_{s,r_i} is the received signal power at the relay i and $x(t)$ is the signal transmitted by the source at time t.

The received signal at the destination at time t, represented by $y_{ri,d}$, can be written as

$$y_{r_i,d}(t) = h_{r_i,d} x_{r_i}(t) + w_{r_i,d}(t) \tag{2}$$

where $h_{r_i,d}$ is the channel fading between the relay i and the destination and $w_{r_i,d}(t)$ is the AWGN at the destination.

For the proposed HRSP, each relay is included into either AF or DF relay group and then two relays among the groups will be selected by achieving maximum SNR at the destination. The first one is the best relay from AF group and the second is the best relay from DF group.

The instantaneous SNR at the destination from the i^{th} relay can be evaluated as

$$\gamma_s^{AF} = \underset{i}{max} \frac{\gamma_{s,r_i}\gamma_{r_i,d}}{\gamma_{s,r_i}+\gamma_{r_i,d}+1} \tag{3}$$

where $\gamma_{s,r_i} = \frac{P_{s,r_i}\left|h_{s,r_i}\right|^2}{N_0}$ and $\gamma_{r_i,d} = \frac{P_{r_i,d}\left|h_{r_i,d}\right|^2}{N_0}$

From (3), the corresponding SNR at the destination is equal to

$$\gamma_s^{DF} = \underset{i}{max} \gamma_{r_j,d} \tag{4}$$

where $\gamma_{r_j,d} = \frac{P_{s_j,r}\left|h_{r_j,d}\right|^2}{N_0}$ is the instantaneous SNR of the $r_{j--\rightarrow D}$ link.

After the two relays are selected, the overall received signal at the destination can be expressed as

$$y_d = \begin{cases} \sqrt{P_{r_i,d}} h_{r_j,d} s(t) + w_{r_j,d}, \\ \beta_i h_{r_i,d}\left(\sqrt{P_{s,r_i}} h_{s,r_i}\right) s(t) + \beta_i h_{r_i,d} w_{s,r_i} + w_{r_i,d}. \end{cases} \tag{5}$$

IV. BER PERFORMANCE

To obtain the BER of the system, CDF and PDF for the end-to-end SNR of the best relay of each group are first calculated.

The maximum instantaneous SNR of the selected relay from AF group can be written as

$$\gamma_{AF,(q)}^{max} = max_{i=1,\dots q}\left[\min\left(\gamma_{si,r}, \gamma_{ri,d}\right)\right] \tag{6}$$

The CDF and PDF of the link between any two nodes can be generally written, respectively as

$$F_{\gamma ij}(\gamma) = 1 - exp\left(-\frac{\gamma}{\bar{\gamma}_{ij}}\right), i \in [S,R], j \in [R,D] \tag{7}$$

$$f_{\gamma ij}(\gamma) = \frac{1}{\bar{\gamma}_{ij}} exp\left(-\frac{\gamma}{\bar{\gamma}_{ij}}\right), i \in [S,R], j \in [R,D] \quad (8)$$

By substituting (7) into (6), then the CDF of (6) can be approximated at high SNR as follows

$$F_{\gamma_{AF,(q)}^{max}}(\gamma) = \prod_{i=1}^{q}\left[1-\left(e^{-\gamma\left(\frac{1}{\gamma_{sr}}+\frac{1}{\gamma_{rd}}\right)}\right)\right] \quad (9)$$

By differentiating (9) with respect to γ, the PDF of (6) can be obtained as

$$f_{\gamma_{AF,(q)}^{max}}(\gamma) = \sum_{i=1}^{q}\binom{q}{i}(-1)^{i}\frac{i}{\gamma_{eq}}e^{-i\frac{\gamma}{\gamma_{eq}}} \quad (10)$$

In the same manner, the CDF and PDF of the selected relay from DF group which depend on the second time slot can be written respectively as

$$F_{\gamma_{DF,(n-q)}^{max}}(\gamma) = \prod_{i=q+1}^{n}\left[1-e^{-\frac{\gamma}{\gamma_{rd}}}\right] \quad (11)$$

$$f_{\gamma_{DF,(n-q)}^{max}}(\gamma) = \sum_{j=q+1}^{n-q}\binom{n-q}{j}(-1)^{j}\frac{j}{\gamma_{rd}}e^{-j\frac{\gamma}{\gamma_{rd}}} \quad (12)$$

By using the convolution method, the PDF at the destination is given by

$$f_{\gamma^{HRS}}(\gamma) = \int_0^{\gamma} f_{\gamma_{DF,(n-q)}^{max}}(\gamma-y) f_{\gamma_{AF,(q)}^{max}}(y)dy \quad (13)$$

By substituting (10) and (12) into (13), then the PDF at the destination is obtained as follows

$$f_{\gamma^{HRS}}(\gamma) = \sum_{i=1}^{q}\sum_{j=q+1}^{n-q}\binom{q}{i}\binom{n-q}{j}(-1)^{i+j}\frac{ij}{j\gamma_{eq}-i\gamma_{rd}} \times \left(e^{-i\frac{\gamma}{\gamma_{eq}}}-e^{-j\frac{\gamma}{\gamma_{rd}}}\right) \quad (14)$$

Using the conditional error probability, then closed-form expression of the error probability can be obtained as

$$P_b(e) = \frac{1}{2}\sum_{i=1}^{q}\sum_{j=q+1}^{n-q}\binom{q}{i}\binom{n-q}{j}(-1)^{i+j}\frac{ij}{j\gamma_{eq}-i\gamma_{rd}} \times \left[\left(1-\sqrt{\frac{\gamma_{eq}}{i+\gamma_{eq}}}\right)-\left(1-\sqrt{\frac{\gamma_{rd}}{j+\gamma_{rd}}}\right)\right] \quad (15)$$

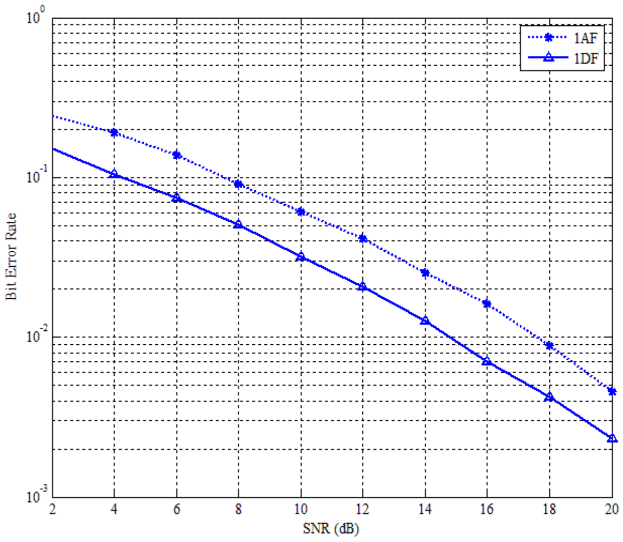

Figure 2. BER performance of HRSP with one relay.

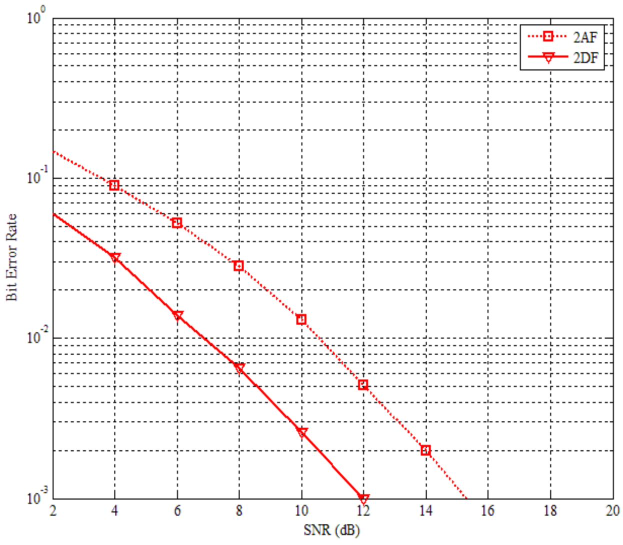

Figure 3. BER performance of HRSP with two relays.

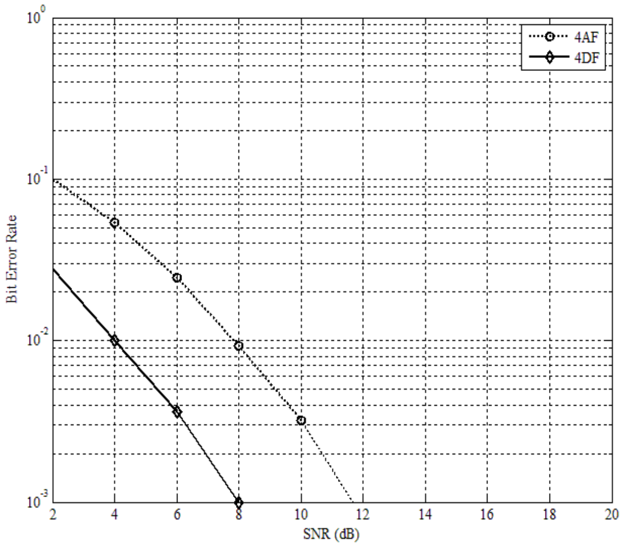

Figure 4. BER performance of HRSP with four relays.

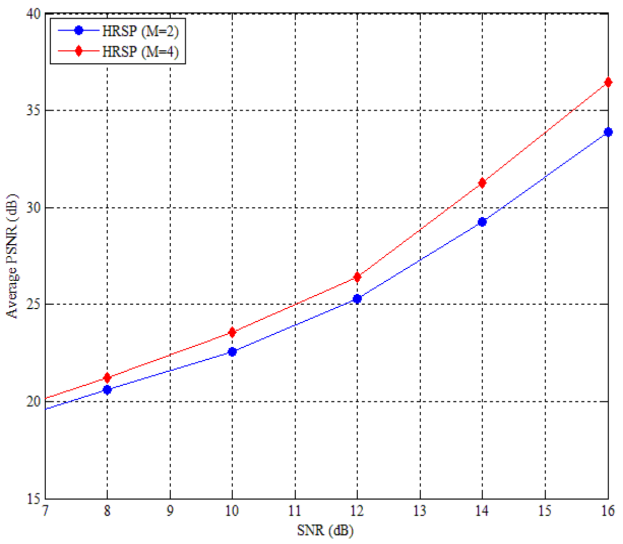

Figure 5. PSNR performance of HRSP with different numbers of relays.

V. RESULTS

Fig. 2, Fig. 3 and Fig. 4 show the BER performance of the proposed HRSP discussed in Section III with different numbers of relays versus SNR. Increasing the number of relays in each group, results in increased performance of the system. For example, the DF relay achieves a gain of about 2dB compared with AF relay in the case of single relay in each group. Increasing the number of relays in each group to 2 and 4, results in performance gains of 3 and 3.5dB, respectively.

Fig. 5 represents the average PSNR performance against SNR for HRSP with 2 and 4 relays in each group. It is observed that the proposed scheme has the best performance compared with EEP for all SNR values. The performance gap widens with the increase of SNR.

VI. CONCLUSION

In this paper, the diversity gains of wireless relay selection were exploited. Specifically, a new hybrid relay selection was proposed. Closed-form expressions for the PDF, CDF, and MGF of the end-to-end SNR were deduced. Then, closed-form expression of the BEP is derived for the proposed system in Rayleigh fading channels.

Results demonstrate that the BEP performance of the proposed system decreases significantly with the increase in the number of relays M, and increases linearly with N. Also, it can be seen that the new hybrid relay selection scheme achieves significant PSNR performance gains comparable to those of EEP, particularly at medium to high SNRs.

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