Hybrid Relay Selection Scheme with Feedback Channel for Amplify-and-Forward Two-Hop Networks

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***Abstract*— This paper proposes a hybrid relay selection scheme with feedback channel for two-hop networks. The proposed scheme is based on relay selection, pre-processing design, and quantized channel state information (CSI). In our proposal, the signal is decoded only in the destination node. The relay nodes amplify, perform a linear processing, and forward the received signals to the destination node. The processing performed by the relays is based on the quantized channel state information received from the destination node. The proposed scheme provides an overall signal-to-noise ratio (SNR) gain at the destination node. Furthermore, the receiver has low complexity since it is based on linear processing.**

***Index Terms*— AF protocol, cooperative communication, power allocation, relay selection.**

I. Introduction

Cooperative communication systems can be seen as an array of multiple antennas which are spatially distributed. In this scenario sparse nodes can interact with each other for relaying information to the destination node [1]. The interest in cooperative communications is growing considerably, mainly by the distributed spatial diversity that can be exploited through transmit/receive techniques contributing for decreasing the negative effect caused by the fading in wireless networks. Moreover, distributed antenna system is a convenient solution to resolve the problem of installing multiple antennas on small terminals, where the diversity is achievable by the user ability, when not operating, to acting as a relay [2]. Cooperative relaying has been used, as a way of users with no direct (or weak) connection, to obtain a more reliable link by using relay nodes to forward the source information in order to improve the overall SNR and achieve higher coverage areas.

A major aspect of a cooperative communication system is the processing of the signal received at the relay node [3]. The Amplify-and-Forward (AF) is one of the most used protocols due to its simple and low complexity. In the AF protocol relay nodes scales and transmits an amplified version of their received signals, including noise, to the destination [3]. However, sometimes, relays provide a poor channel quality which can affect the end-to-end transmission [4]. Therefore, the use of a relay selection scheme is an attractive and promising way to overcome this problem, preserving the diversity gains and reducing the synchronization problem [5].

Some important issues regarding cooperative communications are been investigated in the last years, e.g., when to cooperate? or which are the better relay nodes to cooperate? [6]. In [7], it was proposed solutions which take into account to whom and when to cooperate. Another important aspect is the spectral efficiency. In [3], it was proposed a cooperative diversity scheme which achieves higher bandwidth efficiency maintaining the same diversity order obtained by the conventional cooperative schemes. Power allocation schemes are also proposed in the literature. In [10], for example, it is provided the best power distribution for cooperative systems leading to the optimal end-to-end SNR performance.

In this paper we propose a hybrid relay selection scheme with feedback channel for two-hop diamond network. The hybrid scheme is based on relay selection, power allocation, and antenna selection techniques [4], [5], [9], and also on the pre-processing, and quantized channel state information (CSI) feedback designs presented in [10] and [11], respectively.

In our proposal, we consider the AF protocol, i.e., the signal is only decoded in the destination node. The relay nodes perform a low complexity linear pre-processing that provides a signal-to-noise ratio (SNR) gain at the destination node. Furthermore, the receiver has low complexity, which is based on linear processing too. We show, through computer simulations, that the proposed scheme outperforms other good schemes in terms of SNR gain. Those features make the proposed scheme an interesting solution for two-hop relay systems.

The remainder of this paper is organized as follows. In Section II is presented the system model. Section III presents the proposed transmission scheme for the amplify-and-forward diamond network, its analytical SNR derivation, and other two schemes considered for comparison purposes. Section IV presents the simulation results. Finally, in Section V, it is presented some concluding remarks.

II. System Model

In this paper we study a specific two-hop AF network, known as diamond network [8], as illustrated in Figure 1. It consists of one single-antenna source node, named node S, one single-antenna destination node, named node D, and two single-antenna relay nodes, named relays R_1 and R_2.

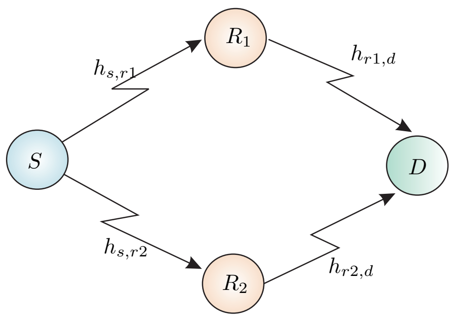


Fig. 1. Diamond Network

It is assumed a time-division multiple access transmission. In the first time slot, the source node broadcast its signal to the relays. There is no direct link between the source and the destination node. Hence, the source cannot transmit directly to the destination node. In the second time slot, the destination estimates the channel coefficients from the relays to the destination node.

We also assume that the channel coefficients are perfectly estimated by the destination node. Based on this information, the destination node informs the relays, through a feedback channel, how the power allocation must be performed at each relay node before the relay transmission takes place. With this information the relays amplify and retransmit the received signals to the destination node, considering the appropriate power allocation.

It is important to mention that the cooperative node is operating in the half-duplex mode and the total transmit power per time slot is P.

III. Proposed Scheme

This section presents how the proposed scheme is performed. As mentioned earlier, in the first time slot the source node broadcasts its information symbol, s, to the relay nodes:

$$y_{r1} = \sqrt{P} s h_{s,r1} + \eta_{r1}, \tag{1}$$

and

$$y_{r2} = \sqrt{P} s h_{s,r2} + \eta_{r2}, \tag{2}$$

where, y_{ri} is the received signal at the *i*-th relay, P is the total transmit power, $h_{s,ri}$ is the channel coefficient from the source to the *i*-th relay. The channel is assumed to undergo quasi-static, flat Rayleigh fading, and η_{ri} is the additive white Gaussian noise (AWGN) with variance $N_0/2$ per complex dimension.

The received signal at the destination node, in the second time slot, can be described as

$$y_d = y_{r1,d} + y_{r2,d} + \eta_d, \tag{3}$$

where,

$$y_{r1,d} = \beta_1 h_{r1,d} \sqrt{P} s h_{s,r1} + \beta_1 \eta_{r1}, \tag{4}$$

and

$$y_{r2,d} = \beta_2 h_{r2,d} \sqrt{P} s h_{s,r2} + \beta_2 \eta_{r2}, \tag{5}$$

in which

$$\beta_1 = \sqrt{\frac{P}{P|h_{s,r1}|^2 + N_0}} \cos(\theta) \tag{6}$$

and

$$\beta_2 = \sqrt{\frac{P}{P|h_{s,r2}|^2 + N_0}} \sin(\theta), \tag{7}$$

where, θ is the feedback phase informed to the relays by the destination node, and '$|\cdot|$' represents the absolute value. The pre-processing will be explained in more details in Section III-B.

Other way to describe this system model is considering the equivalent noise model. Thus, the received signal can be given by

$$y_d = s\sqrt{P}(\beta_1 h_1 + \beta_2 h_2) + \eta'_d, \tag{8}$$

where,

$$h_1 = h_{s,r1} h_{r1,d}, \tag{9}$$

and

$$h_2 = h_{s,r2} h_{r2,d}. \tag{10}$$

Hence, the variance of noise η'_d is given by

$$N'_0 = \left(\beta_1^2 |h_{r1,d}|^2 + \beta_2^2 |h_{r2,d}|^2 + 1\right) N_0. \tag{11}$$

The detection can be performed by applying the matched filter. Hence, the detector is written as

$$y'_d = \alpha y_d, \tag{12}$$

where α is determined such that the output SNR is maximized. Therefore, α can be specified as

$$\alpha = \frac{\beta_1 \sqrt{P} h^*_{s,r1} h^*_{r1,d} + \beta_2 \sqrt{P} h^*_{s,r2} h^*_{r2,d}}{N'_0}. \tag{13}$$

where '$*$' represents the complex conjugate operation.

A. SNR analysis

By assuming that the transmitted symbol has unitary average energy the instantaneous SNR of the output detector is given by

$$\gamma = \frac{P(\beta_1^2 |h_1|^2 + \beta_2^2 |h_2|^2 + 2\beta_1 \beta_2 \Re(h_1 h_2^*))}{N'_0}. \tag{14}$$

As we can observe, the instantaneous SNR expression depends basically on the phase information θ. Ergo, the ideal relay selection scheme selects the optimal θ, which maximizes Equation (14). In other words, at each frame, the destination node estimates the channel coefficients and based on this information it calculates the θ which maximizes the instantaneous SNR. Therefore, in this sense, the average SNR is given by

$$\overline{\gamma} = E\{\gamma_{\max}(\theta)\}, \quad (15)$$

assuming a certain number of channel realizations [1].

B. Selection Schemes

The phase θ varies according to the considered selection and power allocation schemes. In this work, it is considered two good schemes for comparison purposes, that is, best relay selection and power allocation schemes.

In the best relay selection scheme, at each frame, the relay which provides the best link (source-relay and relay-destination) is chosen. All the system resources are allocated in a unique relay, the best one. Note that for a two-hop network the system needs only one feedback bit to achieve a good performance, very closed to the ideal one which is obtained with $b = \infty$. In real world systems, the phase θ is chosen from a quantized set. Therefore, θ can be described as

$$\theta = \frac{i\pi}{2}, \quad (16)$$

where, $i \in [0, \ldots, 2^b - 1]$, and b is the number of feedback bits.

The power allocation scheme considered here is a modified version of the scheme proposed by Choi [10]. In this paper, the available power is allocated among the available relays in order to maximize the numerator in (14). Thus, θ must be chosen to ensure that the amplification factors β_1 and β_2 are positives. The higher the number of feedback bits is the closer to the maximum value the numerator in (14) is. For this scheme, θ can be described as

$$\theta = \frac{2j\pi}{2^{b+1}} - \frac{\pi}{2^{b+1}}, \quad (17)$$

where $j \in [1, \ldots, 2^b]$ is the set that maximizes the numerator in (14).

To maximize (14) it is interesting, sometimes, to allocate resources in both relays using the power allocation scheme. However, when one or more relays have a poor link between source and relay, the instantaneous SNR can decreases drastically. Thus, in this case, it is interesting to allocate all the resources to a single relay, as considered in the best relay selection scheme.

The proposed hybrid scheme consists in the combination of those schemes described previously. For the proposed scheme the phase θ is defined as

$$\theta = \frac{k\pi}{2^b} - \frac{\pi}{2^b}. \quad (18)$$

where, $k \in [1, \ldots, 2^b]$ is the set that maximizes the instantaneous SNR in (14).

[1]In this paper we ran 10^7 channel realizations.

IV. Simulation Results

This section presents some simulation results for illustrating the performance gain obtained by the proposed hybrid scheme. It is well known that the best relay selection and power allocation schemes achieve full diversity order [10]. Hence, we present the BER performance curves of those schemes to show that the proposed scheme also achieves full diversity order. The performances are compared in terms of bit error rate (BER) versus SNR over quasi-static flat Rayleigh fading channels with unitary variance. The symbols are mapped to a BPSK constellation. Monte Carlo simulations are performed by considering the transmission of 10^7 symbols per average SNR point.

In Figure 2, the results illustrate the performance obtained by the three schemes considered in this work. The BER for the no-diversity (SISO) scenario is also plotted as a reference curve. The hybrid relay selection and the power allocation schemes use three feedback bits, and the best relay selection scheme uses one feedback bit.

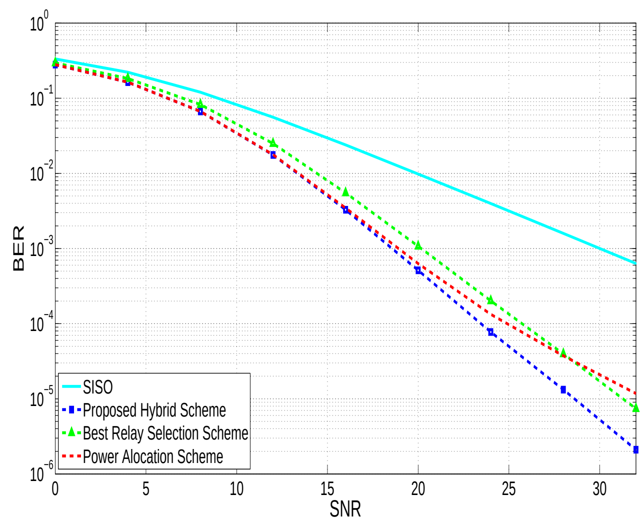
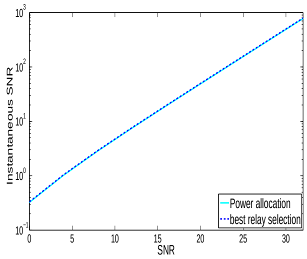


Fig. 2. BER performance for the three relay selection schemes.

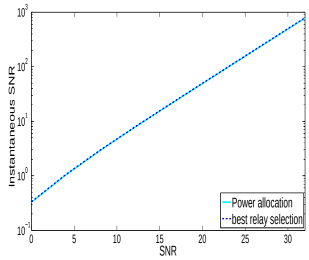
It is clearly noticeable that the hybrid and the best relay selection schemes have the same diversity order, and the proposed one has an SNR gain over the best relay selection scheme. It is important to emphasize that the power allocation scheme has a performance loss for high SNR. It occurs due to the θ selection criterion, which does not take into consideration the denominator in (14).

Figure 3 presents the instantaneous SNR for different average SNR and channel coefficients. This figure aims to show the performance loss when the signal is been transmitted under weak source-relay channels. In these simulations it was assumed $|h_{S,R2}| = 1$ and $|h_{R2,D}| = 1$ for all scenarios.

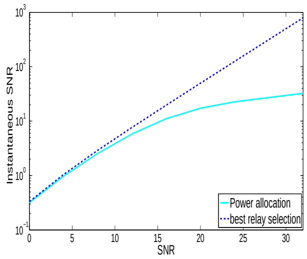
From the results presented in Figure 3, it is observed that the higher the average SNR is, the higher the percentage of use of the best relay selection scheme is (in the hybrid relay selection scheme). Another important issue is that the power



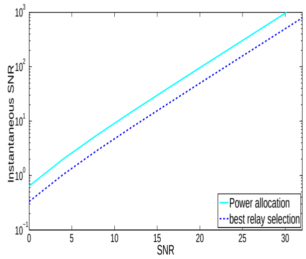
(a) $|h_{s,r1}|$ = 0.01 and $|h_{r1,d}|$ = 0.01.



(b) $|h_{s,r1}|$ = 1 and $|h_{r1,d}|$ = 0.01.



(c) $|h_{s,r1}|$ = 0.01 and $|h_{r1,d}|$ = 1.



(d) $|h_{s,r1}|$ = 1 and $|h_{r1,d}|$ = 1.

Fig. 3. SNR comparison: specific channel coefficients.

allocation scheme has instantaneous SNR gain only when both source-relay and relay-destination links have a good quality. Moreover, Figure 3 shows that relays do not retransmit their information when they have poor link quality between the source and relay.

Figure 4 shows the performance improvement obtained by the proposed scheme as the number of feedback bits is increased. The result for the non-quantized scenario is also presented in this figure. It is possible to observe that there is a performance improvement as the number of feedback bits increases. However, for more than three feedback bits, practically, there is no more improvement on the BER performance. Thereby, the proposed scheme does not need a high number of feedback bits to achieve a good BER performance (very closed to the best one).

In Figure 5, it is presented an evaluation of the proposed scheme assuming that the feedback channel is not ideal. Results assure the robustness of the hybrid scheme. We can observe that the proposed scheme, even with 1% of feedback errors, has a better performance than the best relay selection and power allocation schemes.

V. Concluding Remarks

In this work it was proposed a hybrid AF relay selection scheme for a two-hop diamond network. The system has one source node, one destination node, two relays nodes and a feedback channel between the destination and the relays. An SNR analysis was performed and it was used to define the relay selection/power allocation criteria.

Furthermore, Monte Carlo simulations was performed to compare the performance of the proposed scheme to the other two schemes, i.e., the best relay selection and power allocation schemes. It was demonstrated that the hybrid scheme achieves

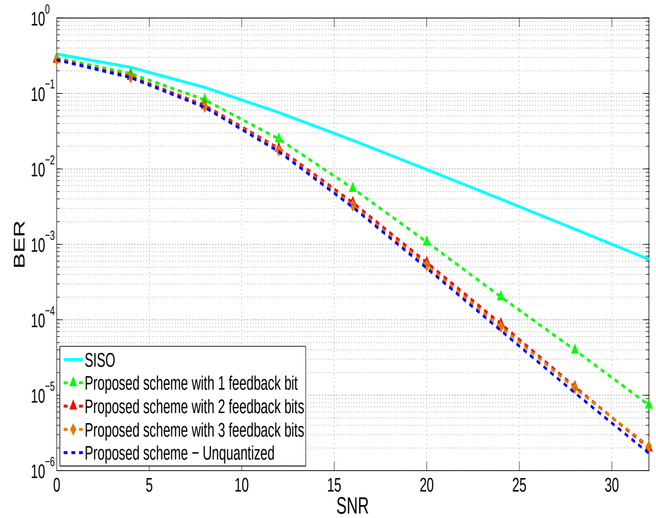


Fig. 4. BER of the proposed scheme with different number of feedback bits.

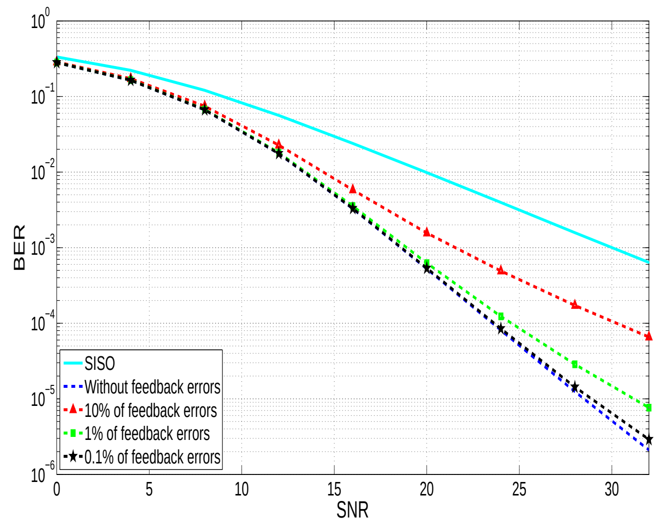


Fig. 5. BER of the proposed scheme with no ideal feedback channel.

full diversity order and a performance gain over the other two good schemes considered in this paper. It was also observed that the hybrid scheme does not need more than three feedback bits to achieve a very good BER performance and that it has a good robustness even when the feedback channel is not ideal. Furthermore, the receiver has low complexity since it is based on linear processing. Those features make the proposed scheme an interesting solution for two-hop relay networks.

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