Hybrid Relay Selection Scheme for Two-Hop Wireless Networks

Dimas Irion Alves, Renato Machado, Samuel Tumelero Valduga & Nelson Jorge Schuch

***Abstract*— This paper proposes a hybrid relay selection scheme for two-hop wireless networks. In our proposal, the system is composed by a source node, N relay nodes and one destination node. At each new frame, the two best relay nodes are selected, which perform a linear processing before forwarding the received signals to the destination node. The linear processing performed by the relays is based on the quantized channel state information (CSI) received from the destination node. The proposed scheme provides an overall signal-to-noise ratio (SNR) gain at the destination node for different kinds of fading distributions. In other words, the proposed scheme can provide performance gains for different $\alpha - \mu$ distribution configurations. Furthermore, the proposal presents another significant attribute, a low-complexity receiver which is based on linear processing as well.**

***Index Terms*— AF protocol, $\alpha - \mu$ distribution, relay selection schemes, two-hop cooperative networks.**

I. Introduction

Cooperative communication systems are based on the broadcast nature of the wireless communication channels [1]. Such a systems can be described as a spatially distributed multiple antennas array, where sparse nodes can interact with each other for relaying multiple independent copies of the received signal to a destination node. The interest on this topic is growing considerably, mainly by the spatial diversity that can be exploited through the design of transmit/receive schemes contributing for decreasing the negative effect caused by the fading in wireless networks [2] and [3]. Moreover, cooperative systems are a convenient solution to solve 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 [4]. These feature allows us considering new cooperative techniques/strategies for accessing the available wireless network resources.

Cooperative relaying has also 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 end-to-end SNR and achieve higher coverage areas. A major aspect of cooperative communication systems are the protocol considered for the processing of the received signal at the relay node [1]. The Amplify-and-Forward (AF) is one of the most used protocols due to its simplicity and low complexity. In the AF protocol relay nodes scale and transmit an amplified version of their received signals, including noise, to the destination node [1]. However, in certain scenarios, relays can provide a poor channel quality which may affect the transmission, eventually resulting in a decrease of the end-to-end SNR [5]. Therefore, the use of a relay selection scheme could be an attractive and promising way to overcome this problem, besides preserving the diversity gains and reducing the synchronization problems [6].

Several important issues regarding cooperative communications are been investigated in the last years. In [7], two important issues, maybe the two most important ones, were raised by the authors: when to cooperate? and which are the better relay nodes to cooperate? In [8], it was proposed solutions which take into account to whom and when it is advantageous to cooperate. Another important aspect is the spectral efficiency. In [1], it was proposed a cooperative diversity scheme which achieves higher bandwidth efficiency maintaining the same diversity order observed on the conventional cooperative schemes. Power allocation schemes are also proposed in the literature. In [10], for example, it is provided the best power distribution in MIMO systems leading to the optimal end-to-end SNR performance.

In this paper it is proposed a hybrid relay selection scheme for two-hop wireless networks. The hybrid scheme is based on relay selection, power allocation, and antenna selection techniques [5], [6], [9], and also on a pre-processing, quantized channel state information (CSI) and the feedback designs presented in [10] and [11], respectively. In this 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. It is shown through computer simulations, that the proposed scheme outperforms other good schemes, in terms of end-to-end SNR gain, for different kinds of channels, by using a fading model based on the $\alpha - \mu$ distribution, and for different numbers of relays. It is also demonstrated that the system is robust for the occurrence of errors in the feedback channel and that it does not need a large number of feedback bits to operate appropriately. Those features make the proposed scheme an interesting solution for two-hop wireless relay systems.

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

II. System Model

In this paper is studied a two-hop AF network, with N relays, 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 N single-antenna relay nodes, named relays $R_1, \ldots, R_N$.

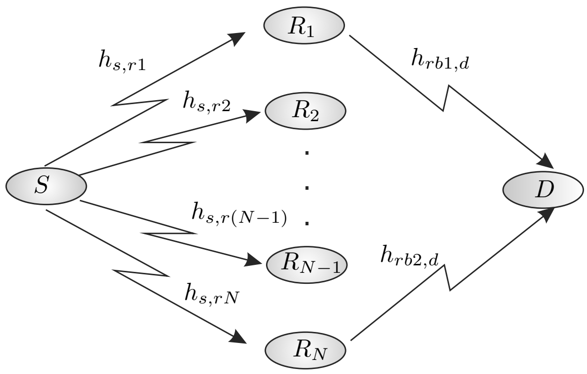


Fig. 1. System model.

We assume that the transmitted signal is sent through orthogonal resources, and in this manner the interference is avoided. Thus, a portion of the frequency or time, for instance, is divided among the neighboring transmitters, these methods are called Frequency Division Multiple Access (FDMA) and Time Division Multiple Access (TDMA), respectively. In this paper, it is assumed a TDMA transmission.

In the first time slot, the source node broadcast the signal to the relays. There is no direct link between the source and the destination node. Hence, the destination node cannot 'see' the signal coming from the source node. Before the second time slot takes place, the destination choose the two best relays, through a feedback channel, and informs they how the power allocation must be performed at the second time slot[1]. In the second time slot the selected relays, using the appropriate power allocation, amplify and retransmit the received signals to the destination node.

It is assumed that the channel coefficients are perfectly estimated by the destination node, the cooperative system is operating in the half-duplex mode, and that the total transmit power per time slot is P.

[1]After the selection, the system model is similar to the diamond network [13].

III. The $\alpha - \mu$ Distribution

The $\alpha - \mu$ distribution, proposed by Yacoub in [12], is a generic distribution used to better represent the possible variations of the small scale fading. In the fading model based on the $\alpha - \mu$ distribution, the α parameter is associated with the environmental nonlinearities and the μ parameter is associated with the number of multipaths components. The $\alpha - \mu$ probability density function (pdf) can be described as:

$$f_r(r) = \frac{\alpha \mu^{\mu} r^{\alpha\mu - 1}}{\hat{r}^{\alpha\mu}\Gamma(\mu)} e^{\left(-\mu \frac{r^{\alpha}}{\hat{r}^{\alpha}}\right)} \tag{1}$$

where $\Gamma(\,\cdot\,)$ is the Gamma function,

$$\hat{r} = \sqrt[\alpha]{E(R^{\alpha})} \tag{2}$$

where $E(\cdot)$ denotes the mathematical expectation operator and R is the envelope of a flat fading signal.

The $\alpha - \mu$ distribution presents several special cases: Nakagami-m distribution, Weibull distribution, Rayleigh distribution, Gaussian distribution, Gamma distribution, Chi-square distribution, Exponencial distribution. The distributions simulated in this paper are Nakagami-m, Weibull, Exponencial and Rayleigh. For the Nakagami-m case, the parameter α must be two and μ can vary for any integer number. The Weibull case, occur when μ is equal to one and α can assume any integer. When both α and μ are equal to one, it is obtained the exponencial distribution. When α is equal to two e μ is equal to one, it is obtained the Rayleigh distribution, which is an especial case of both Nakagami-m and Weibull distributions [12].

IV. Proposed Scheme

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

$$y_{ri} = \sqrt{P} s h_{s,ri} + \eta_{ri}, \tag{3}$$

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, zero-mean flat Rayleigh fading with unitary variance, and η_{ri} is the zero-mean additive white Gaussian noise (AWGN) with variance $N_0/2$ per complex dimension. The channel coefficient can also be described by the α - μ distribution [12], as depicted in Section II.

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

$$y_d = y_{rb1,d} + y_{rb2,d} + \eta_d, \tag{4}$$

where,

$$y_{rb1,d} = \beta_1 h_{rb1,d} \sqrt{P} s h_{s,rb1} + \beta_1 \eta_{rb1}, \tag{5}$$

and

$$y_{rb2,d} = \beta_2 h_{rb2,d} \sqrt{P} s h_{s,rb2} + \beta_2 \eta_{rb2}, \tag{6}$$

in which

$$\beta_1 = \sqrt{\frac{P}{P|h_{s,rb1}|^2 + N_0}} \cos(\theta) \tag{7}$$

and

$$\beta_2 = \sqrt{\frac{P}{P|h_{s,rb2}|^2 + N_0}} \sin(\theta), \quad (8)$$

where, R_{rb1} and R_{rb2} are the best relays (selected ones), where $|h_{N1}|$ and $|h_{N2}|$ are the best and the second best channel coefficients, respectively, θ is the feedback phase information sent to the relays by the destination node, and '$|\cdot|$' represents the absolute value. How the phase selection is performed will be explained in more details in Section III-B.

We can also describe the system model by using the equivalent noise function. Thus, the received signal can also be given by

$$y_d = s\sqrt{P}(\beta_1 h_1 + \beta_2 h_2) + \eta'_d, \quad (9)$$

where,

$$h_1 = h_{s,rb1} h_{rb1,d}, \quad (10)$$

and

$$h_2 = h_{s,rb2} h_{rb2,d}. \quad (11)$$

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

$$N'_0 = \left(\beta_1^2 |h_{rb1,d}|^2 + \beta_2^2 |h_{rb2,d}|^2 + 1\right) N_0. \quad (12)$$

The detection can be performed by applying the matched filter and the detector can be written as

$$y'_d = \varepsilon y_d, \quad (13)$$

where ε is determined such that the end-to-end SNR is maximized. Thus, ε can be specified as

$$\varepsilon = \frac{\beta_1 \sqrt{P} h^*_{s,rb1} h^*_{rb1,d} + \beta_2 \sqrt{P} h^*_{s,rb2} h^*_{rb2,d}}{N'_0}. \quad (14)$$

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

A. SNR analysis

By assuming that the transmitted symbol has unitary average energy, one can describe the instantaneous SNR at the output detector by

$$\gamma = \frac{P(\beta_1^2 |h_1|^2 + \beta_2^2 |h_2|^2 + 2\beta_1 \beta_2 \Re(h_1 h_2^*))}{N'_0}. \quad (15)$$

Note that 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 and then send this information to the relays. Therefore, in this sense, the average SNR is given by

$$\overline{\gamma} = E\{\gamma_{\max}(\theta)\}, \quad (16)$$

assuming a certain number of channel realizations [2].

[2]In this paper we ran 10^7 channel realizations per SNR.

B. Selection Schemes

The phase θ is quantized depending on the number of feedback bits available. Such bits can be used for relay selection, power allocation, or even for both, it will depends on the transmission technique is been taken into account. In this paper, we present the proposed hybrid scheme and other two schemes for comparison purposes. The other schemes are the best relay selection and power allocation schemes.

In the best relay selection scheme, at the beginning of each new 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 system, the best relay selection scheme requires 2^{N-1} feedback bits. Considering the system model presented in Section II, the best relay selection scheme can be performed through the phase selection, assuming that θ is chosen from a quantized set of bits as described below

$$\theta = \frac{i\pi}{2}, \quad (17)$$

where, $i \in [0, \ldots, 2^b - 1]$, and b is the number of feedback bits used in the phase selection. Note that some of the feedback bits will be used to select the two best relays.

The power allocation scheme considered in this work 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 positive numbers. The higher the number of feedback bits are, the closer to the maximum value the numerator in (14) is. For this scheme, θ can be described as

$$\theta = \frac{2j\pi}{2^{b+1}} - \frac{\pi}{2^{b+1}}, \quad (18)$$

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

In order to maximize (14), it is important to allocate resources in both relays using the power allocation scheme. However, when one relay has 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 of the combination of those schemes described previously. Thus, for the proposed scheme the phase θ set is defined as

$$\theta = \frac{k\pi}{2^b} - \frac{\pi}{2^b}, \quad (19)$$

where $k \in [1, \ldots, 2^b]$ is the set that maximizes the instantaneous SNR in (14). Note that part of the feedback bits is used for choosing the two best relays.

V. Simulation Results

This section presents some simulation results for illustrating the performance gain obtained by the proposed hybrid scheme when compared with the best relay selection and the power allocation schemes. It is also demonstrated that the system has good robustness and does not need a large number of feedback bits to work properly. It is already 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 can also achieve a full diversity order.

The performances are compared in terms of bit error rate (BER) versus SNR over a quasi-static flat Rayleigh fading channels. 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.

The results illustrate the performance obtained by the three schemes considered in this work, in Figure 2. 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. Note that in this work for the SISO scenario is considered a two-hop Decode-and-Forward network with one relay. In this network the relay receives the source information, decode and retransmit it to the destination node.

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 values. It occurs due to the θ selection criterion which does not take into consideration the denominator in (14).

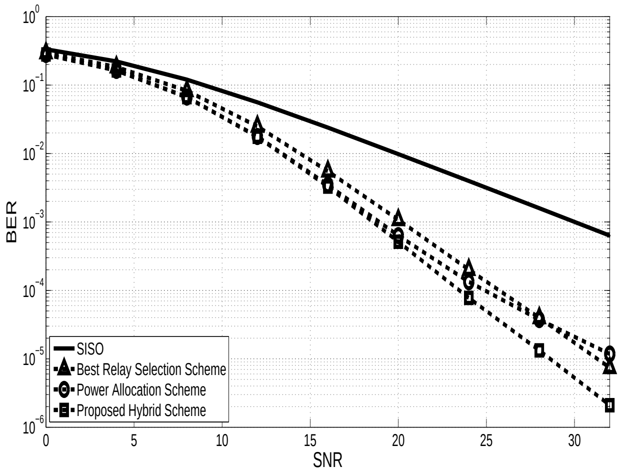
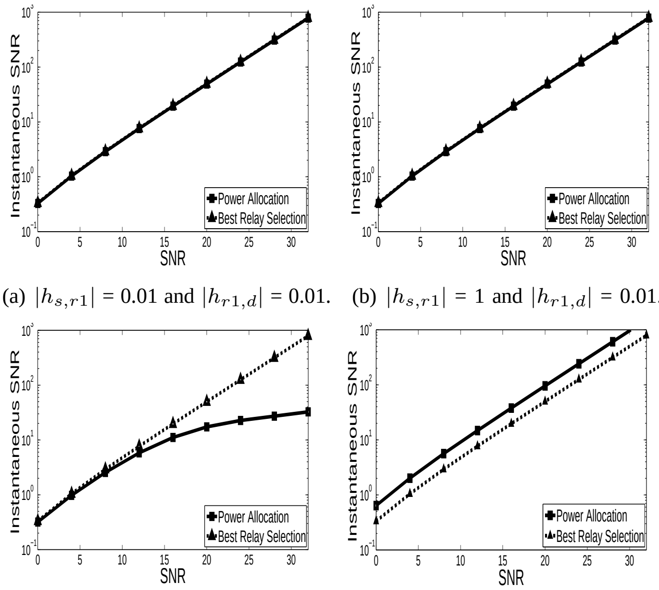


Fig. 2. BER performance for the three relay selection schemes.

It is presented, in Figure 3, the instantaneous end-to-end SNR for different average SNR and channel coefficients. This figure aims to explain the performance loss of the power allocation scheme for high SNR values. It is illustrated that this effect happens 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 for schemes for specific channels 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 should not retransmit their information when they have poor link quality between the source and relay.

The performance improvement obtained by the proposed scheme as the number of feedback bits is increased can be observed in Figure 4. The result for the non-quantized scenario is also presented in this figure. It is possible to notice that there is a performance improvement as the number of feedback bits increases. However, for more than three feedback bits, there is not a noticeable improvement of the BER performance. Thereby, the proposed scheme does not need a high number of feedback bits to achieve a good BER performance (which is very closed to the best one).

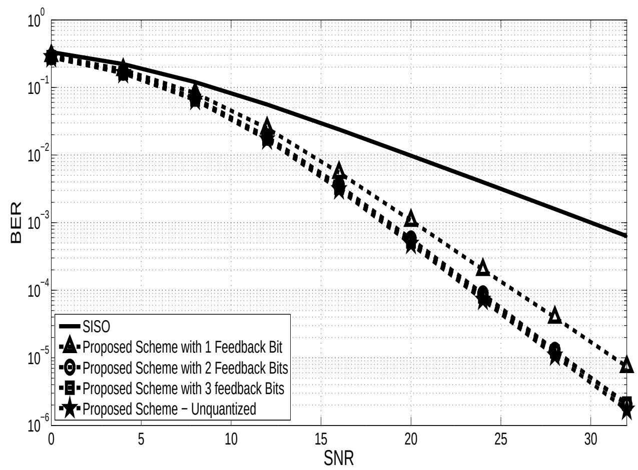


Fig. 4. BER of the proposed scheme with different number of feedback bits.

It is evaluated, in Figure 5, the proposed scheme for a non-ideal feedback channel condition. 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.

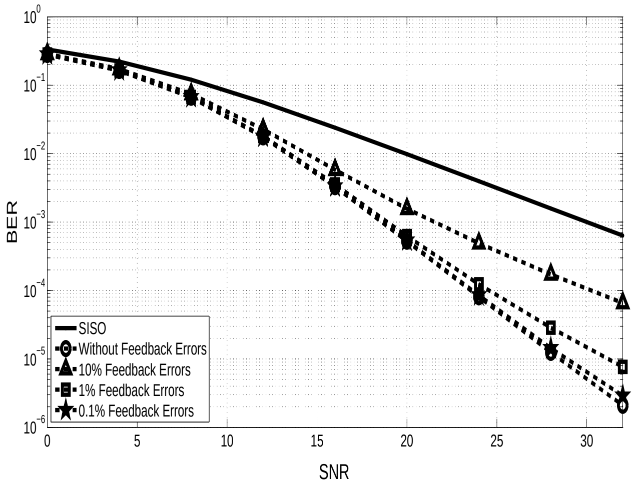


Fig. 5. BER of the proposed scheme with no ideal feedback channel.

It is assessed, in Figure 6, the influence of the number of relays over each scheme. It illustrates that for a higher number of relays the power allocation scheme has almost the same performance obtained by the hybrid scheme. Moreover, Figure 6 also demonstrates that for a higher number of relays the best relay selection scheme has a performance loss when compared to the other ones.

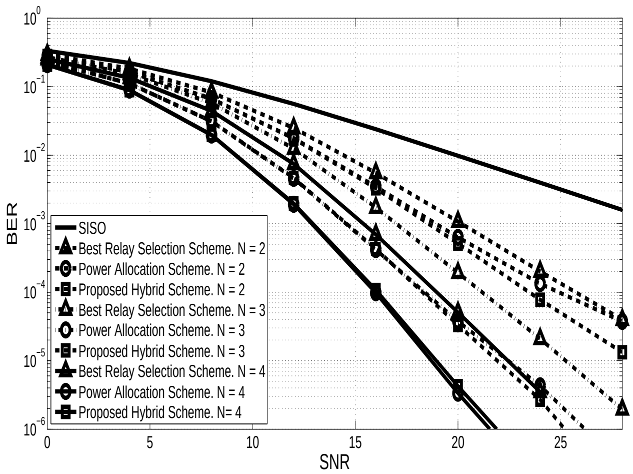


Fig. 6. BER of the proposed scheme for different number of relays.

The influence of the fading on the performance of each scheme are evaluated in Figures 7 and 8 by using the α - μ distribution. It is assessed, in Figure 7, the effect of the α parameter variation. It is shown that for higher α values (better channel conditions) the difference between the performance of the three systems decreases.

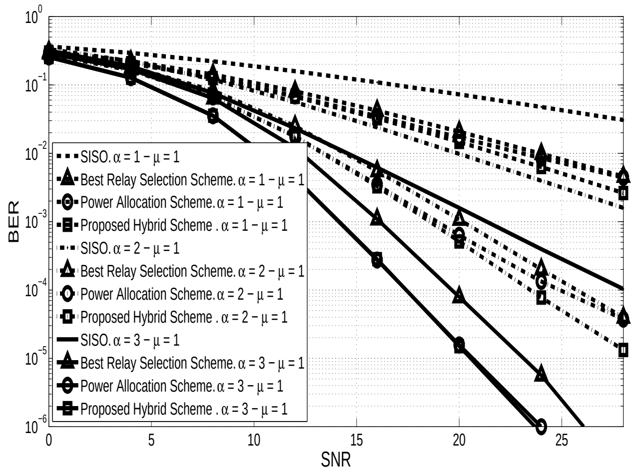


Fig. 7. BER of the proposed scheme for μ = 1 and different values of α.

In Figure 8, results present the influence of the μ parameter variations. It is illustrated that for higher μ values (better channel coefficients) the difference between the performance of the three systems decreases. It is also noticeable that the influence of μ is higher than α on the BER performance.

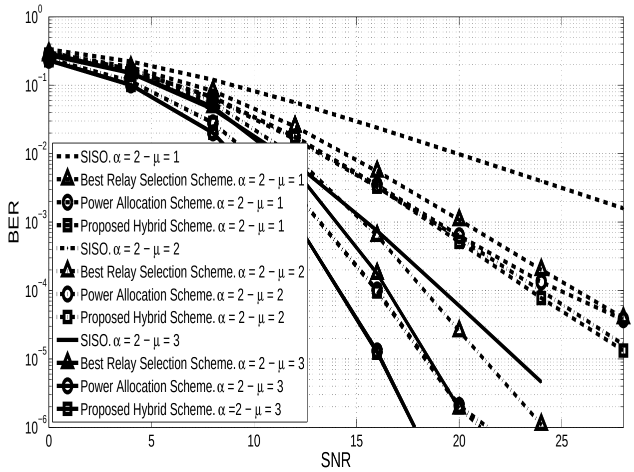


Fig. 8. BER of the proposed scheme for α = 2 and different values of μ.

It is presented the influence of the number of feedback bits for a system with four relays, in Figure 9. Results illustrate that for a higher number of relays the performance of the quantized system is almost the same of the unquantized one. Also, it is important to highlight here that the number of bits used for selecting the two best relays is disregarded here.

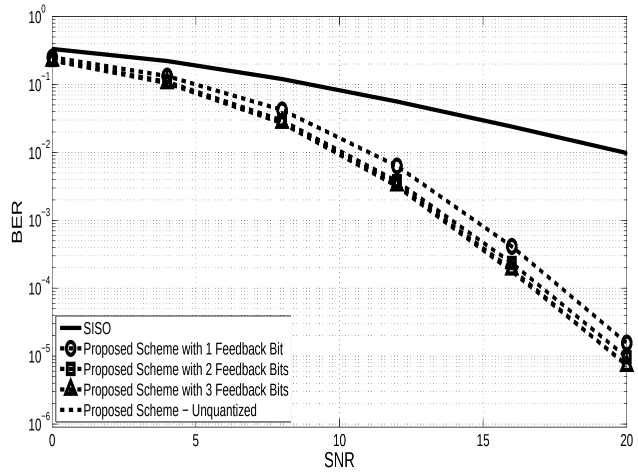


Fig. 9. BER of the proposed scheme with four relays and different number of feedback bits.

VI. Concluding Remarks

In this work it was proposed a hybrid AF relay selection scheme for two-hops wireless networks. The system considered has one source node, one destination node, N relay 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 were performed to compare the performance of the proposed scheme to other two schemes, i.e., the best relay selection and power allocation schemes. It is observed that the proposed hybrid scheme achieves a performance gain over the others for a small number of relays and has basically the same performance obtained by the power allocation scheme for a higher number of relays. Also, we could observe that the hybrid scheme achieves full diversity order.

The results also reveal 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, independently of the number of relays in the system. Moreover, the receiver presents a low-complexity design since it is based on a linear processing. Those features make the proposed scheme an interesting solution for two-hop relay networks.

VII. Acknowledgments

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