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***Abstract*—We propose a dynamic hybrid antenna/relay selection scheme for multiple-access relay systems. The proposed scheme aims to boost the system throughput while keeping a good error performance. By using the channel state information, the destination node performs a dynamic selection between the signals provided by the multi-antenna relay, located in the inter-cell region, and the relay nodes geographically distributed over the cells. The multi-antenna relay and the single-antenna relay nodes employ the decode-remodulate-and-forward and amplify-and-forward protocols, respectively. Results reveal that the proposed scheme offers a good tradeoff between spectral efficiency and diversity gain, which is one of the main requirements for the next generation of wireless communications systems.**

I. INTRODUCTION

Along the last years, cooperative communications have received considerable attention from the 3rd Generation Partnership Project (3GPP) mainly due to the spatial diversity that can be explored by distributed single-antenna nodes [1], [2]. More specifically, by exploiting the broadcast nature of the wireless medium some nodes can be placed between the source and destination in order to mimic a virtual antenna array alleviating, among other things, the negative effect caused by multipath fading.

An important issue is the signal processing performed by the relay nodes [3], where a cooperative protocol is typically employed. Owing to its simplicity and low complexity, the amplify-and-forward (AF) protocol is the most used one. The AF protocol amplifies the received signal (including noise) and retransmits its amplified version to the destination [3].

Emerging wireless communications standards, such as Long Term Evolution Advanced (LTE-Advanced), are incorporating relay-assisted techniques which includes advanced MIMO techniques, relay stations, enhanced inter-cell interference coordination, and coordinated multipoint (CoMP) transmission/reception [4]- [6]. In these systems, fixed relays (refereed to relay stations (RSs)) are deployed as intermediate nodes to forward data among mobile users (referred to user equipment (UE)) and base stations (refereed to evolved NodeB (eNB)), thus extending the service coverage of a cell and enhancing the overall throughput performance of the system [5], [7].

Notwithstanding the several benefits obtained through cooperative diversity, its use with multiple relays may reduce the system spectral efficiency. To circumvent this problem, new transmission schemes are highly desirable. An attractive way to overcome this issue is by considering joint processing, which can be performed in the form of simultaneous transmission or cell selection [9]- [11]. In addition, the spectral efficiency can also be increased by using dynamic relay selection, preserving the diversity gain and reducing the synchronization and coordination problems [8].

Recently, several works have proposed good strategies for improving the spectral efficiency by exploring feedback-assisted relaying techniques. A cooperative communication scheme for multiuser systems was proposed in [12], in which the authors exploited the feedback channel state information (CSI) for improving the system performance through an adaptive power allocation algorithm. Renzo et al. [13] contributed to the theoretical understanding, the design, and the performance evaluation of multi-source multi-relay cooperative diversity protocols. They have shown that those protocols are useful to counteract the spectral inefficiency of repetition-based cooperation. They also provided a general analytical framework for analyzing and designing of wireless networks using the demodulate-and-forward (DemF) protocol with binary network coding at the relays and cooperative maximal-ratio combining at the destination. A selective decode-and-forward (SDF) scheme was presented in [14]. In this scheme, the sources broadcast their information in the first time slot and, in the $(N+1)$th time slot, if the channel threshold is satisfied, the N-th relay decodes and retransmits the signal to the destination node, with N denoting the number of relays. In [15], the decode-remodulate-and-forward (DreMF) protocol was proposed, which is similar to the SDF one, however, before the RSs retransmit their information, in the DreMF protocol they first re-modulate the detected signals.

In order to further improve the performance of relay-based schemes, recently, hybrid protocols have been proposed where different protocols are combined, aiming to mitigate the respective disadvantages, increasing the system capacity and/or robustness [16], [17]. In [19] and [20], clustered relay configurations were considered as an interesting solution for mobile and sensor networks applications. In addition, it is worth mentioning that the use of multiple relay stations received a lot of attention in the LTE-Advanced standardization, in order to improve the throughput performance and also to increase the coverage of a cellular network [18].

In this paper, a dynamic hybrid antenna/relay selection scheme for the multiple-access relay channel is proposed, aiming to boost the system throughput while keeping a good error performance. By using the CSI, the destination node performs a dynamic selection between the signals provided by the multi-antenna relay (MR), located in the inter-cell region, and by the single-antenna RS's geographically distributed over two cells. The MR and the single-antenna RS's employ the DreMF and AF protocols, respectively.

The remainder of this paper is organized as follows. Section 2 introduces the system model. Section 3 presents the proposed scheme, a signal-to-noise ratio (SNR) and the protocol usage analyses. In Section 4, simulation results are presented, from which insightful discussions are provided. Finally, Section 5 draws some concluding remarks.

Throughout this paper, '$*$' and '$|\cdot|$' represent the complex conjugate operator and the absolute value, respectively.

II. System model

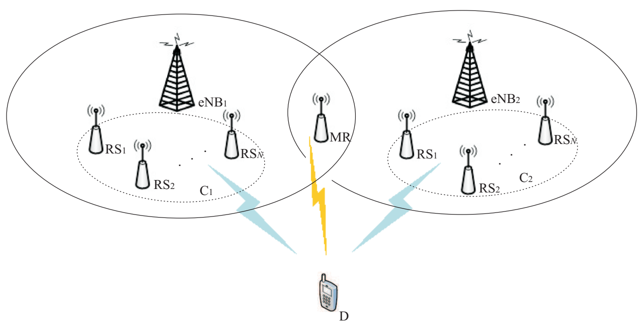

Fig. 1. System model.

Fig. 1 illustrates the system model considered in this work, which is composed of two single-antenna source nodes, eNB_1 and eNB_2, one single-antenna destination node[1], UE, one multiple-antenna relay station, MR, and single-antenna relay nodes, RSs. The RSs are geographically spread over two cells, organized in clusters, namely C_1 and C_2, and MR is situated at the inter-cell region (see Fig. 1). More specifically, C_1 is composed of single-antenna relay nodes which receive the signals from eNB_1 only; C_2 is also composed of single-antenna relay nodes, and they hear the signals from eNB_2 only; and MR, located at the inter-cell region, receives jointly the signals from both sources.

The channels are assumed to undergo quasi-static, flat Rayleigh fading so that the channels are constant over a frame and vary randomly from one frame to the other. We also assume that the information bits are mapped into a base-band unitary average energy constellation S, such as phase shift keying (PSK) or quadrature amplitude modulation (QAM) constellations, given rise to Q data symbols $\{s_q\}, q = 1, \ldots, Q$, to be transmitted over T symbol periods. The spatial transmission rate ($R = Q/T$) of the proposed scheme can range from $2/3$ to 1, depending on how often the DreMF and AF protocols are used.

We consider that there is no direct link between the sources and destination, such that the information coming from the sources is only received by the relay nodes. Thus, the relays are expanding the coverage area of the system. The sources transmit simultaneously in the first time slot. Based on the CSI, the destination node selects an antenna from the MR or one RS from each cluster to forward the signals. The AF protocol is employed at the relays pertaining to C_1 and C_2, which retransmit an amplified version of the received signal to the destination, and the DreMF protocol is used by MR to forward the signals, where the detected symbol is first remodulated (re-mapped) into a higher-order constellation S_h[2] and then retransmitted to the destination.

In addition, it is also assumed that i) the forward channel fading coefficients are known at the receiver, ii) the detection is performed by means of maximal-ratio combining (MRC), iii) the cooperative node is in half-duplex mode, iv) the transmission mode is the time-division multiple-access relay channel (MARC) protocol, where source nodes and relay node transmit at different time-slots, v) the total transmit power per transmission period is P, vi) an error- and delay-free feedback channel between the destination and relays is available, and vii) the transmissions are synchronized.

III. The Proposed Scheme

The proposed scheme is described as follows. In the first time slot (T_1), eNB_1 and eNB_2 transmit their symbols to the relays. The received signal at the RS's in C_1 and C_2, and at the MR station, in the inter-cell region, can be written, respectively, as

$$y_{C(1,i)}(T_1) = \sqrt{P_1} s_1 h_{(1,i)} + \eta_{(1,i)}, \tag{1}$$

$$y_{C(2,j)}(T_1) = \sqrt{P_1} s_2 h_{(2,j)} + \eta_{(2,j)}, \tag{2}$$

and

$$y_{MR}(T_1) = \sum_{m=1}^{M} \sqrt{P_1} (s_1 h_{(1,m)} + s_2 h_{(2,m)}) + \eta_{MR}, \tag{3}$$

[1]The destination node could be an UE or an eNB station, depending on the application.

[2]For example, if s_1 and s_2 belong to a QPSK constellation, after the estimation, those symbols are combined and re-mapped to a 16-QAM constellation.

where s_1 and s_2 are the signals transmitted from eNB$_1$ and eNB$_2$, respectively, $h_{(1,i)}$ and $h_{(2,j)}$ denote the channel coefficients from eNB$_1$ and eNB$_2$ to the i-th and j-th RS's, located at C$_1$ and C$_2$, respectively, $h_{(1,m)}$ and $h_{(2,m)}$ are the channel coefficients from eNB$_1$ and eNB$_2$ to the m-th antenna of the MR station, $\eta_{(1,i)}$, $\eta_{(2,j)}$ and η_{MR} are independent and identically distributed (i.i.d) zero-mean complex Gaussian noises with variance N_0, $y_{C(1,i)}$ and $y_{C(2,j)}$ are the signals received by the i-th and j-th relay nodes at C$_1$ and C$_2$, respectively, and y_{MR} is the signal received by the MR station, located at the inter-cell area. M is the number of antennas at MR and P_1 represents the transmit power of the sources. The channel coefficients $h_{(.,.)}$ are assumed as zero-mean circularly-symmetric complex Gaussian random variables with variance σ^2 per dimension. Throughout this paper, we assume $\sigma^2 = 1/2$.

Before the transmission takes place in the second time slot, the destination estimates the channel coefficients of the relay-destination links. The antennas at MR that satisfies the channel quality constraint (threshold) are considered potential candidates to forward the signals to the destination. Specifically, if a given threshold is satisfied by at least one antenna, then the best antenna, which provides the high channel quality $(\max_{(m=1,...,M)} |h_{(m,d)}|)$, is selected by the UE to forward the signal by performing the DreMF protocol at the second time slot. Otherwise, the destination selects the best RS's from C$_1$ and C$_2$ $(\max_{(i=1,...,N_1)} |h_{(1,i)}h_{(i,d)}|)$ and $(\max_{(j=1,...,N_2)} |h_{(2,j)}h_{(j,d)}|)$ to forward the signals by using the AF protocol at the second and third time slots, respectively.

Thus, the signal received at the destination node, in the second time slot, can be represented as

$$y_d(T_2) = \sqrt{P} s_r h_{(m,d)} + \eta_d, \tag{4}$$

if $|h_{(l,m)}|^2 \geq \tau_l$, and $|h_{(m,d)}|^2 \geq \tau_3$. Otherwise,

$$y_d(T_2) = \beta_1 h_{(1,d)} y_{C(1,b)}(T_1) + \eta_{(1,d)} \tag{5}$$

where $h_{(m,d)}$ is the channel coefficient from the selected antenna to the destination node, $h_{(l,m)}$ is the channel coefficient from the l-th source node to the best antenna (selected one) at the MR station, $h_{(1,d)}$ denotes the channel coefficient from the selected node in C$_1$ to the UE, τ_l, $l = 1, 2, 3$, are the system thresholds, η_d and $\eta_{(1,d)}$ are i.i.d zero-mean complex Gaussian noise with variance N_0, s_r is the re-mapped symbol (DreMF protocol), $y_{C(1,b)}(T_1)$ is the signal received by the selected RS at C$_1$ and β_1 is an amplification factor, which can be expressed as

$$\beta_1 = \sqrt{\frac{P_2}{P_1|h_{(1,b)}|^2 + N_0}}, \tag{6}$$

where $h_{(1,b)}$, $(b \in \{1, ..., N_1\})$, denotes the best source-relay channel coefficient from eNB$_1$ to the selected relay at C$_1$ and P$_2$ is the transmit power used by the selected RS. If the thresholds in (4) were not satisfied, we have an additional third time slot transmission. The received signal at the destination in the third time slot can be represented as

$$y_d(T_3) = \beta_2 h_{(2,d)} y_{C(2,b)}(T_1) + \eta_{(2,d)} \tag{7}$$

where $h_{(2,d)}$ denotes the channel coefficient from the selected node in C$_1$ to the UE, $\eta_{(2,d)}$, is an i.i.d zero-mean complex Gaussian noise with variance N_0, and β_2 is an amplification factor, which can be expressed as

$$\beta_2 = \sqrt{\frac{P_2}{P_1|h_{(2,b)}|^2 + N_0}}, \tag{8}$$

where $h_{(2,b)}$, $(b \in \{1, ..., N_2\})$, denotes the best source-relay channel coefficient from eNB$_2$ to the selected relay at C$_2$. By substituting (6) and (8) into (5) and (7), it follows that

$$y_d(T_2) = \frac{\sqrt{P_1 P_2}}{\sqrt{P_1|h_{(1,b)}|^2 + N_0}} h_{(1,b)} h_{(1,d)} s_1 + \eta'_{(1,d)}, \tag{9}$$

$$y_d(T_3) = \frac{\sqrt{P_1 P_2}}{\sqrt{P_1|h_{(2,b)}|^2 + N_0}} h_{(2,b)} h_{(2,d)} s_2 + \eta'_{(2,d)}, \tag{10}$$

in which

$$\eta'_{(1,d)} = \frac{\sqrt{P_2}}{\sqrt{P_1|h_{(1,b)}|^2 + N_0}} h_{(1,d)} \eta_{(1,b)} + \eta_{(1,d)},$$

and

$$\eta'_{(2,d)} = \frac{\sqrt{P_2}}{\sqrt{P_1|h_{(2,b)}|^2 + N_0}} h_{(2,d)} \eta_{(2,b)} + \eta_{(2,d)},$$

where $\eta'_{(1,d)}$ and $\eta'_{(2,d)}$ are i.i.d zero mean complex Gaussian random variables with variance

$$N'_0 = \left(\frac{P_2 |h_{(i,d)}|^2}{P_1 |h_{(i,b)}|^2 + N_0} + 1 \right) N_0.$$

A. Detection

With knowledge of the channel coefficients $h_{(1,b)}$, $h_{(1,d)}$, $h_{(2,b)}$, $h_{(2,d)}$ and $h_{(m,d)}$ at the destination node, the detection can be performed by applying a matched filter. Thus, if $|h_{(1,m)}|^2 \geq \tau_1$, $|h_{(2,m)}|^2 \geq \tau_2$ and $|h_{(m,d)}|^2 \geq \tau_3$, the decision variables can be written as

$$\tilde{y}_d(T_2) = \alpha_m^* y_d(T_2), \tag{11}$$

otherwise

$$\tilde{y}_d(T_2) = \alpha_1^* y_d(T_2), \tag{12}$$

$$\tilde{y}_d(T_3) = \alpha_2^* y_d(T_3), \tag{13}$$

and the detection can be performed as

$$\hat{y}_d(T_2) = \arg \min_{s'_r \in S_h} \{|s'_r - \tilde{y}_d(T_2)|^2\}, \tag{14}$$

otherwise

$$\hat{y}_d(T_2) = \arg \min_{s'_1 \in S} \{|s'_1 - \tilde{y}_d(T_2)|^2\}, \tag{15}$$

$$\hat{y}_d(T_3) = \arg \min_{s'_2 \in S} \{|s'_2 - \tilde{y}_d(T_3)|^2\}, \tag{16}$$

where where S_h is the higher order constellation, which depends on the constellations that have been used by the source nodes. The factors α_1, α_2 and α_m are determined such that the SNR at the detector output is maximized. Hence, the factors α_1, α_2 and α_m can be specified as

$$\alpha_1 = \frac{\sqrt{\frac{P_1 P_2}{P_1|h_{(1,b)}|^2+N_0}}h^*_{(1,b)}h^*_{(1,d)}}{\left(\frac{P_2|h_{(1,d)}|^2}{P_1|h_{(1,b)}|^2+N_0}+1\right)N_0}, \quad (17)$$

$$\alpha_2 = \frac{\sqrt{\frac{P_1 P_2}{P_1|h_{(2,b)}|^2+N_0}}h^*_{(2,b)}h^*_{(2,d)}}{\left(\frac{P_2|h_{(2,d)}|^2}{P_1|h_{(2,b)}|^2+N_0}+1\right)N_0}, \quad (18)$$

and

$$\alpha_m = \frac{\sqrt{P}h^*_{(m,d)}}{N_0}. \quad (19)$$

B. SNR Analysis

By assuming that the transmitted symbols, s_1 and s_2, have unitary average energy, the instantaneous SNR at the detector output of the destination node is given by

$$\gamma_{DreMF} = \frac{P|h_{(m,d)}|^2}{N_0}, \quad (20)$$

if $|h_{(1,m)}|^2 \geq \tau_1$, $|h_{(2,m)}|^2 \geq \tau_2$ and $|h_{(m,d)}|^2 \geq \tau_3$; otherwise

$$\gamma_{AF} = \gamma_{AF_1} + \gamma_{AF_2}, \quad (21)$$

where

$$\gamma_{AF1} = \frac{1}{N_0}\left(\frac{P_1 P_2|h_{(1,b)}|^2|h_{(1,d)}|^2}{P_1|h_{(1,b)}|^2+P_2|h_{(1,d)}|^2+N_0}\right), \quad (22)$$

and

$$\gamma_{AF_2} = \frac{1}{N_0}\left(\frac{P_1 P_2|h_{(2,b)}|^2|h_{(2,d)}|^2}{P_1|h_{(2,b)}|^2+P_2|h_{(2,d)}|^2+N_0}\right). \quad (23)$$

Note that the average SNR expression depends on how often each relaying protocol, AF or DreMF, is selected. In other words, it depends on how often the thresholds $|h_{(1,m)}|^2 \geq \tau_1$, $|h_{(2,m)}|^2 \geq \tau_2$ and $|h_{(m,d)}|^2 \geq \tau_3$ are obeyed. Therefore, the average SNR can be defined as

$$\overline{\gamma} \triangleq \Omega_1\gamma_{DreMF} + \frac{\Omega_2}{2}\gamma_{AF}, \quad (24)$$

in which

$$\Omega_1 + \Omega_2 = 1, \quad (25)$$

where Ω_1 and Ω_2 are the weighting select factors, which represent the use percentage of each protocol.

Recall that we have assumed that the channel coefficients, $h_{(i,j)}$, are i.i.d. Gaussian random variables. Then, the probability density function of $|h_{(i,j)}|$ is given by

$$y(x) = \frac{x}{\sigma^2}e^{-\frac{x^2}{2\sigma^2}} \quad (26)$$

and its cumulative distribution function is given by

$$P(|h_{(i,j)}| \leq x) = \int_0^x y(x)dx = 1 - e^{-\frac{x^2}{2\sigma^2}}. \quad (27)$$

In our problem, the destination considers the event $|h_{(i,j)}|^2 < x^2$, where x is related to the thresholds τ_k, $k = 1, 2, 3$, according to

$$x = \sqrt{\tau_k}. \quad (28)$$

By substituting (28) into (27), the following probabilities of the events $|h_{(1,m)}|^2 < \tau_1$, $|h_{(2,m)}|^2 < \tau_2$, and $|h_{(m,d)}|^2 < \tau_3$ can be obtained, and are given by

$$P(|h_{(1,m)}|^2 < \tau_1) = 1 - e^{-\frac{\tau_1}{2\sigma^2}}, \quad (29)$$

$$P(|h_{(2,m)}|^2 < \tau_2) = 1 - e^{-\frac{\tau_2}{2\sigma^2}}, \quad (30)$$

and

$$P(|h_{(m,d)}|^2 < \tau_3) = 1 - e^{-\frac{\tau_3}{2\sigma^2}}, \quad (31)$$

respectively.

As presented in Section III, the AF protocol is considered when $|h_{(1,m)}|^2 < \tau_1$, $|h_{(2,m)}|^2 < \tau_2$ or $|h_{(m,d)}|^2 < \tau_3$. If we assume that there is only one antenna at the relay station, then Ω_2 can be given by

$$\begin{aligned}
&+P(|h_{(m,d)}|^2 < \tau_3)\\
&-P(|h_{(1,m)}|^2 < \tau_1, |h_{(2,m)}|^2 < \tau_2)\\
&-P(|h_{(2,m)}|^2 < \tau_2, |h_{(m,d)}|^2 < \tau_3)\\
&-P(|h_{(1,m)}|^2 < \tau_1, |h_{(m,d)}|^2 < \tau_3)\\
&+P(|h_{(1,m)}|^2 < \tau_1, |h_{(2,m)}|^2 < \tau_2, |h_{c,d}|^2 < \tau_3).
\end{aligned}$$

Since the channel coefficients are independent (32) can be rewritten as

$$\begin{aligned}
\Omega_2 \;=\; & P(|h_{1,m}|^2 < \tau_1) + P(|h_{2,m}|^2 < \tau_2) \quad (32)\\
&+P(|h_{m,d}|^2 < \tau_3)\\
&-P(|h_{1,m}|^2 < \tau_1)P(|h_{2,m}|^2 < \tau_2)\\
&-P(|h_{2,m}|^2 < \tau_2)P(|h_{m,d}|^2 < \tau_3)\\
&-P(|h_{1,m}|^2 < \tau_1)P(|h_{m,d}|^2 < \tau_3)\\
&+P(|h_{1,m}|^2 < \tau_1)P(|h_{2,m}|^2 < \tau_2)\\
&.P(|h_{m,d}|^2 < \tau_3).
\end{aligned}$$

Assuming that the thresholds are the same, it follows that

$$P(|h_{(1,m)}|^2 < \tau) = P(|h_{(2,m)}|^2 < \tau) = P(|h_{(m,d)}|^2 < \tau) \quad (33)$$

and Ω_2 is simply given by

$$\Omega_2 = 3P(|h|^2 < \tau) - 3P(|h|^2 < \tau)^2 + P(|h|^2 < \tau)^3. \quad (34)$$

By extending this to the case where the relay station has M antennas, (34) can be written as

$$\begin{aligned}
\Omega_2 \;=\; & 3(P(|h|^2 < \tau))^M - 3(P(|h|^2 < \tau)^2))^M\\
&+(P(|h|^2 < \tau)^3)^M \quad (35)
\end{aligned}$$

and Ω_1 results in

$$\begin{aligned}
\Omega_1 \;=\; & 1 - 3(P(|h|^2 < \tau))^M - 3(P(|h|^2 < \tau)^2))^M\\
&+(P(|h|^2 < \tau)^3)^M \quad (36)
\end{aligned}$$

IV. SIMULATION RESULTS

In this section, simulation results are presented in order to assess the performance of the proposed scheme. Monte Carlo simulations are performed by considering the transmission of 10^7 symbols by each source node per average SNR. We assume that the source symbols are mapped to a BPSK constellation and the channel threshold is set to 0.1. For all simulations, we assume that $P_1 = P/2$ and $P_2 = P$.

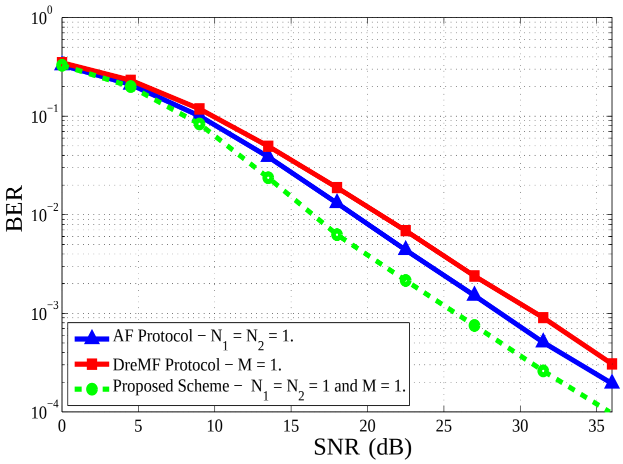

Fig. 2. BER performance of the proposed scheme. $N_1 = N_2 = 1$ and $M = 1$.

Fig. 2 presents the bit error rate (BER) performance for the proposed scheme, with $N_1 = N_2 = M = 1$. Results illustrate that the proposed scheme has an SNR gain around 2.84 and 5.23 dB (in an asymptotical point of view) over the AF and DreMF schemes, respectively. Furthermore, the proposed scheme has an average transmission rate of 0.914 (see Table I), which is higher than $2/3$ (the transmission rate of the two-source AF scheme) and bit smaller than 1 (the transmission rate of the two-source DreMF relay scheme).

TABLE I
TRANSMISSION RATE OF THE PROPOSED SYSTEM

System configuration	Average rate	Protocol use
$N_1 = N_2 = 1;\ M = 1$	0.914	$\Omega_1 = 0.741;\ \ \Omega_2 = 0.259$
$N_1 = N_2 = 3;\ M = 3$	0.995	$\Omega_1 = 0.985;\ \ \Omega_2 = 0.015$
$N_1 = N_2 = 5;\ M = 5$	0.999	$\Omega_1 = 0.998;\ \ \Omega_2 = 0.020$

TABLE II
TRANSMISSION RATE: $N_1 = N_2$ AND $M = 3$

System configuration	Average rate	Protocol use
$N_1 = N_2 = 1;\ M = 3$	0.995	$\Omega_1 = 0.985;\ \ \Omega_2 = 0.015$
$N_1 = N_2 = 3;\ M = 3$	0.995	$\Omega_1 = 0.985;\ \ \Omega_2 = 0.015$
$N_1 = N_2 = 5;\ M = 3$	0.995	$\Omega_1 = 0.985;\ \ \Omega_2 = 0.015$
$N_1 = N_2 = 7;\ M = 3$	0.995	$\Omega_1 = 0.985;\ \ \Omega_2 = 0.015$

Fig. 3 presents the BER performance of the proposed scheme by setting $N_1 = N_2 = 3$ and $M = 3$. Observe that when multiple antennas are considered at MR the proposed scheme has a diversity gain over the AF and DreMF schemes.

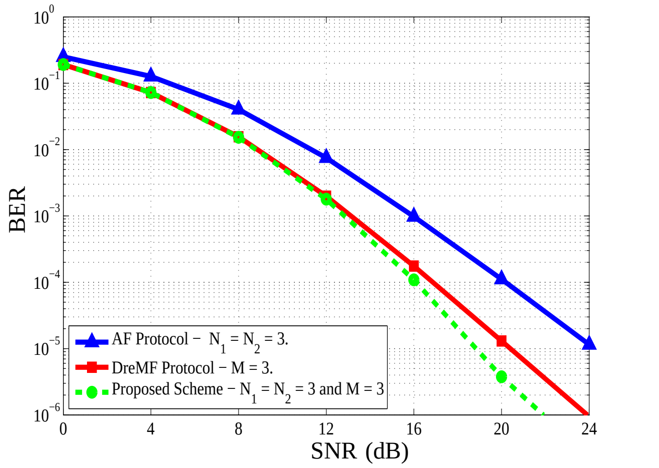

Fig. 3. BER performance of the proposed scheme. $N_1 = N_2 = 3$ and $M = 3$.

In Table I, the transmission rate is related to the usage of each protocol, i.e., the greater the DreMF protocol usage, the closer to 1 the transmission rate.

Fig. 4 depicts the BER performance for $N_1 = N_2 = M = 5$. Note that the proposed scheme has no BER gain over the DreMF scheme. The small differences in the BER performance and the transmission rate occur due to the threshold value adopted for the simulations, which was not optimized for each system configuration.

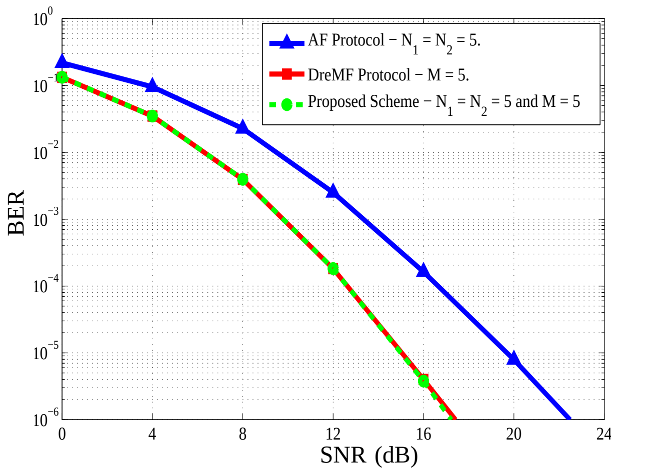

Fig. 4. BER performance of the proposed scheme. $N_1 = N_2 = 5$ and $M = 5$.

Fig. 5 presents the BER performance for the proposed scheme, where MR is equipped with three antennas and the number of relays at C_1 and C_2 is 1, 3, 5, and 7. Results are compared to the DreMF protocol with a relay station with M = 3. It can be seen that the proposed scheme has a diversity loss only when the number of nodes at C_1 and C_2 is lower than the number of antennas at MR.

However, if $N_1 = N_2 = M$, one can observe a performance gain over the DreMF scheme. Moreover, we can still have a

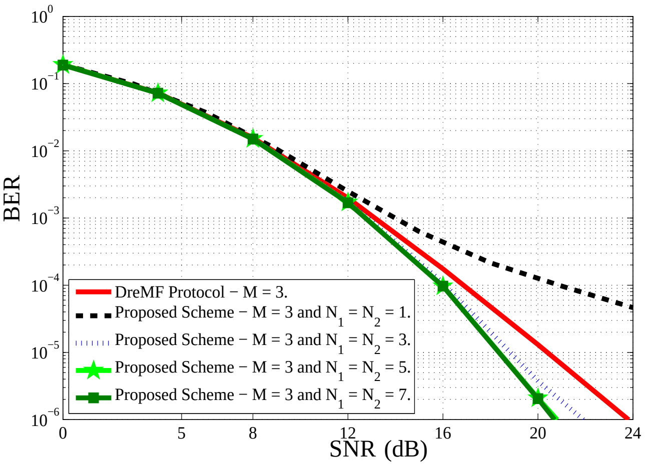

Fig. 5. BER performance of the proposed scheme. $N_1 = N_2 = 1, 3, 5, 7$, and $M = 3$.

performance improvement when $N_1 = N_2 > M$ (this is the case when $N_1 = N_2 = 5$). In addition, there is a saturation on the performance gain when the number of relay nodes is $N_1 = N_2 = 7$.

Table II shows that the average rate is associated to the number of antennas at MR, regardless the number of relay nodes arranged in the cells.

Obviously, the threshold value also interferes on the selection realized by the destination node, which can compromise the system performance if it is not chosen appropriately. Thus, it is essential to have a good threshold (ideally, it must be optimized) such that the scheme can provide a good balance between average rate and BER performance.

V. Conclusions

In this paper, a dynamic hybrid antenna/relay selection scheme for the multiple-access relay channel was proposed. We observed that the proposed scheme provides a good tradeoff between spectral efficiency and diversity gain, and outperforms the AF and DreMF schemes even if the number of relays per cluster region is one and the MR station has only one antenna. Also, we verified that non-symmetric relays node distribution can produce interesting results. Thus, regardless the number of antennas at MR, it is possible to exploit some extra benefits from the RS's if N_1 and N_2 are greater than M. The best tradeoff between performance gain and system complexity for the proposed scheme is an interesting issue which is already under investigation.

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