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A Novel Cooperative Relaying Network Scheme with Inter-Relay Data Exchange

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SUMMARY In this paper, we propose a novel scheme of cooperative relaying network based on data exchange between relays before forwarding their received data to destination. This inter-relay data exchange step is done during an additional middle-slot in order to enhance the transmit signals from relays to the destination under low transmit power condition. To reduce the propagation errors between relays as well as the required transmit power during this data exchange, only the relay possessing the highest SNR is engaged into exchanging data by forwarding its received signal to the other relays. As for the remaining non-selected relays, i.e. with low SNR, the transmitted signal is estimated by using both signals received separately at different time slots (i.e., 1st and 2nd slot) from source and the 'best' selected relay, respectively, emulating virtual antenna array where appropriate weights for the antenna array are developed. In addition, we investigate distributed transmit beamforming and maximum ratio combining at the relays and the destination, respectively, to combine coherently the received signals. At the relay optimal location and for low SNR condition, the proposed method has significant better outage behavior and average throughput than conventional methods using one or two time slots for transmission.

key words: *cooperative relay network, transmit beamforming, MRC, adaptive antenna array, optimal relay locations*

1. Introduction

Cooperative fixed-relaying cellular networks are new advantageous technologies for future generation of cellular systems, where relays have to forward cooperatively the received data from source to destination. This cooperative relaying technique effectively provides transmission diversity through distributed wireless relay networks over quasi-static fading channel without relying on actual multiple antennas. The most common relaying strategies are Amplify-and-Forward (AF) [1] and Decode-and-Forward (DF) [2]. In AF scheme the relay amplifies the received signal and retransmits it while in DF the received message is decoded, processed and coded again before it is retransmitted to the destination. Accordingly, in the case of an AF relay scheme, since a relay retransmits a received signal without decoding it, the noise contained in the received signal is also amplified during a retransmission process. In the case of a DF relay scheme, when an error occurs during the decoding process, this error is also propagated during the retransmission process. Employing DF jointly with any error detecting method such as cyclic redundancy check (CRC) coding will avoid the error propagation while an extra layer of CRC coding is required to enable the relay to perform error detection [15]. After performing the CRC, the relay decides to forward the corrected data or wait for another slot if incorrect decoding is detected. Hence, if both source and relays are not transmitting at the 2nd slot, an inherent loss of transmission rate is produced and moreover the destination performs the decision using solely the signal received from the first slot of transmission.

AF does not require a complicated decoding and encoding and it is also shown in [3] that AF exhibits better performance than direct transmission and DF relaying schemes. Motivated by this, we assume AF relay protocol for its simplicity in the cooperative network scheme proposed in this paper.

Prior work on cooperative relay network mainly focuses on exploiting spatial diversity for wireless relaying network [4], jointly optimizing transmit beamforming weight and power allocation [5] and deriving the capacity of MIMO multiplexing relaying schemes [6]. By employing the distributed transmit beamforming in the cooperative relay network; the multiple relays coordinate their transmissions to allow coherent reception at the intended destination with an energy efficient communication. In other words, the multiple relay transmitters act as a virtual antenna array and the paths arriving from each relay are constructively combined at the destination and thus the received SNR is increased relatively to the involved relays. Maximum ratio combiner (MRC) can be also applied at the destination to combine coherently the signals arrived at different time slots. For instance, using TDMA system the destination MRC combines the delayed buffered signals received at different time slots.

In cooperative relay network TDMA system, the data transmission takes usually place in two steps. In the first step, the source transmits to the relays and destination while in the second step; the relays process and forward their received signals to the destination (in either the same or a different time slot). However, to improve the quality of the transmit signals from relays to the destination, and especially for fixed-relaying networks; where the propagation channels between relays can be assumed stationary, an additional step can be inserted for exchanging data between relays. Some basic ideas to this exchange scheme were published in [7] for source localization and tracking in sensor networks, in [8] for acoustic sensor underwater nodes localization, and in [9] for fixed relay-enabled user cooperation.

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In [9], an adaptive beamforming receiver was applied at the relay stations where each relay is dedicated to estimate one user signal (by using the beamforming technique), and then engaged into cooperation with the other relays using distributed space-time coding. During this data exchange step, each relay does not detect the data of other relays instead it simply forwards it to the destination.

The purpose of this paper is to study a novel scheme of cooperative relaying network based on data exchange between relays in order to enhance the link performance between relays and destination by using three-time slots. In contrast to other schemes [7]–[9], instead of having all the relays exchange their received signals, only one relay, with the highest SNR in the source-relays link, engages into cooperation by forwarding its received signal to the other relays. By selecting the 'best' relay for this data exchange process, one can reduce the required total transmit power and also limit the propagation error between relays. Also during this step, we develop a virtual antenna array processing at the non-selected relay nodes to estimate the transmitted signal by using both signals coming from source and the 'best' relay at different time slots (i.e., 1st and 2nd slot) [10]. In addition, we investigate distributed transmit beamforming and MRC at the relay and destination nodes, respectively, to combine coherently the received signals. Therefore, by maximizing the instantaneous SNR at the destination to the total transmitted power used in the whole cooperative network, we derive the transmit beamforming weight vector at the relay parts and the MRC reception weight vector at the destination part.

In addition, relay location is an important issue for wireless relay networks performance. Deploying a cooperative relay in the proper location will boost the benefits from cooperation and reduce the needed transmit power in the cooperative network. To achieve this aim, the optimum relay locations relative to the source and the destination have to be determined. Hence, according to the measured BER performance, the impact of relay location is discussed and optimal locations are found through a simple line placement technique[†].

The rest of the paper is organized as follows. Section 2 introduces the system model and describes the proposed cooperative network. Section 3 analyzes and evaluates the proposed method by computer simulation. Finally, Sect. 4 concludes the paper.

2. Cooperative Relaying with Data Exchange

2.1 System Model

Consider a wireless system where a source node transmits to a destination assisted by m relay nodes. For the sake of simplicity suppose that m=2. Figure 1 illustrates the proposed cooperative relaying TDMA scheme where each transmission block is divided into three non-overlapping steps in time. In step I, the source node transmits the unit power signal s to the destination and both relays. The received signals

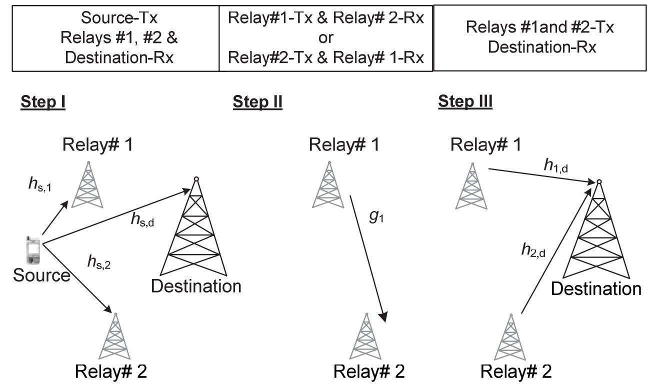


Fig. 1 Illustration of the novel cooperative relaying network.

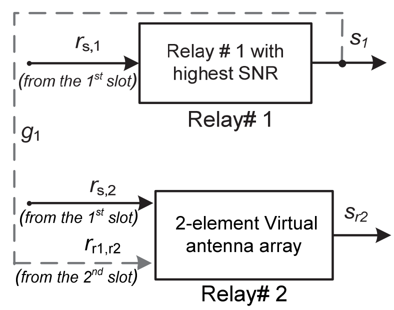


Fig. 2 Data exchange between relays during step II.

at relay node i and the destination are, respectively, given by

$$r_{s,i} = \sqrt{P_s} \cdot h_{s,i} \cdot s + \eta_{s,i}, \quad i = 1, 2 \tag{1}$$

$$r_{s,d} = \sqrt{P_s} \cdot h_{s,d} \cdot s + \eta_{s,d}, \tag{2}$$

where P_s is the transmit power used by the source node, $h_{s,i}$ and $h_{s,d}$ are complex path gains, including path-loss and Rayleigh fading[††], of the source-relay and source-destination channels, respectively, where the square of path-loss inversely proportional to the power of the distance is assumed, and $\eta_{s,i}$ and $\eta_{s,d}$ are the AWGN's in the corresponding channels with variance N_0.

By using the AF relay scheme in step II, the 'best' relay, having the highest *SNR* for source-relay channel, normalizes and retransmits its received signal to the other relay. Without loss of generality, we assume that the relay #1 is selected as the best relay, as shown in Fig. 2, and consequently its transmitted signal to the 2nd relay is given by

$$s_1 = \sqrt{P_1} \cdot \frac{r_{s,1}}{\sqrt{P_s \cdot \left|h_{s,1}\right|^2 + N_0}}, \tag{3}$$

where P_1 is the transmit power used by relay 1 during step II. The received signal at the 2nd relay is expressed as

$$r_{r1,r2} = g_1 \cdot s_1 + \eta_{r,2}, \tag{4}$$

[†]The relays move from source to destination according to certain lines that are parallel to the line joining the source and the destination.

[††]We ignore the shadowing effect and study the effect due to the path loss and fading.

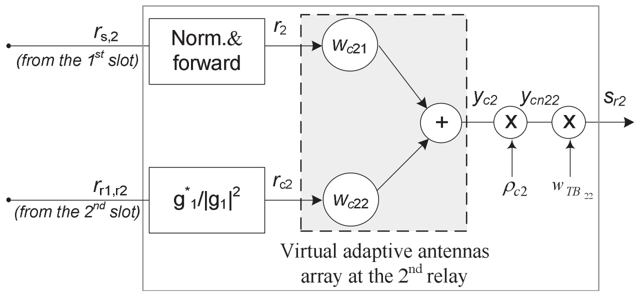


Fig. 3 Signals processing at the 2nd relay station.

where g_1 is complex path gain of the relay1-relay2 channel, which can be periodically estimated in our fixed-relay deployment topology and $\eta_{r,2}$ is an AWGN with variance N_0. Subsequently, the 2nd relay enhances its received signal by combining the signals received separately through steps I and II; emulating the usage of 2-element virtual antennas array, as shown in Fig. 2, where each virtual antenna element output may undergo independent fading. By doing so, an adaptive antennas array (AAA) algorithm is applied in this stage to combine coherently the received signals as illustrated in Fig. 3. The virtual AAA output can be expressed as follows

$$y_{c2} = w_{c_{21}} \cdot r_2 + w_{c_{22}} \cdot r_{c2}, \tag{5}$$

where

$$r_2 = \sqrt{P_1} \cdot \frac{r_{s,2}}{\sqrt{P_s \cdot \left|h_{s,2}\right|^2 + N_0}}, \tag{6}$$

and $[w_{c_{21}}, w_{c_{22}}]$ represents the AAA weight vector, and

$$r_{c2} = r_{r1,r2} \cdot \frac{g_1^*}{|g_1|^2} = (g_1 \cdot s_1 + \eta_{r,2}) \cdot \frac{g_1^*}{|g_1|^2}, \tag{7}$$

where g_1^* represents the conjugate of g_1.

By substituting (1), (3), (4) and (6), (7) into (5), we obtain

$$y_{c2} = \sqrt{P_s} \cdot s \cdot \boldsymbol{h}_2 \cdot \boldsymbol{w}_{c2}^H + \boldsymbol{\eta}_2 \cdot \boldsymbol{w}_{c2}^H, \tag{8}$$

where

$$\boldsymbol{h}_2 = \left[\sqrt{P_1}\rho_2 h_{s,2},\ \sqrt{P_1}\rho_1 h_{s,1}\right], \quad \boldsymbol{w}_{c2} = [w_{c_{21}}^*, w_{c_{22}}^*],$$
$$\boldsymbol{\eta}_2 = \left[\sqrt{P_1}\rho_2\eta_{s,2},\ \sqrt{P_1}\rho_1\eta_{s,1} + \frac{g_1^*}{|g_1|^2}\right],$$
$$E\left[\left|\eta_{s,i}(k)\right|^2\right] = N_0, \text{ for } i = 1,\ 2, \text{ and}$$
$$\rho_i = \left(\sqrt{P_s \cdot \left|h_{s,i}\right|^2 + N_0}\right)^{-1} \text{ for } i = 1,\ 2.$$

The relays 1 and 2 normalize their received signals and retransmit at the 3rd time-slot the signals s_{r1} and s_{r2}, with the i-th complex transmit beamforming weight w_{TB2i}, respectively, to the destination as follows

$$s_{r1} = w_{TB_{21}} \cdot y_{cn21}, \tag{9}$$

$$s_{r2} = w_{TB_{22}} \cdot y_{cn22}, \tag{10}$$

where

$$y_{cn21} = \rho_1 \cdot r_{s,1}, \tag{11}$$
$$y_{cn22} = \rho_{c2} \cdot y_{c2}, \tag{12}$$

$\rho_{c2} = \left(\sqrt{E\left[y_{c2}^* \cdot y_{c2}\right]}\right)^{-1}$ and $P_2 = \boldsymbol{w}_{TB2} \cdot \boldsymbol{w}_{TB2}^H$ represents the total transmitted power used by the relay nodes during step III. Then, the received signal at the destination at step III is expressed as

$$r_{r,d} = \sum_{i=1}^{2} w_{TB_{2i}} \cdot h_{i,d} \cdot y_{cn2i} + \eta_{r,d}, \tag{13}$$

where $h_{i,d}$ is a complex path gain of the relay (i)-destination channel and $\eta_{r,d}$ is an AWGN with variance N_0. By substituting (11), (12) into (13), we obtain

$$r_{r,d} = \sqrt{P_s} \cdot s \cdot \boldsymbol{a}_2 \cdot \boldsymbol{w}_{TB2}^H + \boldsymbol{\gamma}_2 \cdot \boldsymbol{A}_2 \cdot \boldsymbol{w}_{TB2}^H + \eta_{r,d}, \tag{14}$$

where

$$\boldsymbol{a}_2 = [\rho_1 \cdot h_{s,1} \cdot h_{1,d}, \rho_{c2} \cdot \boldsymbol{h}_2 \cdot \boldsymbol{w}_{c2}^H \cdot h_{2,d}],$$
$$\boldsymbol{w}_{TB2} = [w_{TB_{21}}^*, w_{TB_{22}}^*],\ \boldsymbol{\gamma}_2 = \left[\eta_{s,1}, \boldsymbol{\eta}_2 \cdot \boldsymbol{w}_{c2}^H\right],$$
$$\text{and } \boldsymbol{A}_2 = diag[\rho_1 \cdot h_{1,d}, \rho_{c2} \cdot h_{2,d}]_{2\times 2}.$$

In order to combine constructively the signals $r_{s,d}$ and $r_{r,d}$ from the source and relay channels, respectively, MRC combining cooperative diversity is considered. Thus the final detection is given by

$$y = w_{MRC_{21}} \cdot r_{s,d} + w_{MRC_{22}} \cdot r_{r,d}. \tag{15}$$

By substituting (2) and (14) into (15), we obtain

$$y = \sqrt{P_s} \cdot s \cdot \boldsymbol{H}_2 \cdot \boldsymbol{w}_{MRC2}^H + \boldsymbol{N}_2 \cdot \boldsymbol{w}_{MRC2}^H, \tag{16}$$

where $\boldsymbol{H}_2 = \left[h_{s,d}, \boldsymbol{a}_2 \cdot \boldsymbol{w}_{TB2}^H\right]$, $\boldsymbol{w}_{MRC2} = \left[w_{MRC_{21}}^*, w_{MRC_{22}}^*\right]$, and $\boldsymbol{N}_2 = [\eta_{s,d}, \boldsymbol{\gamma}_2 \cdot \boldsymbol{A}_2 \cdot \boldsymbol{w}_{TB2}^H + \eta_{d,2}]$.

2.2 Derivation of the Virtual AAA Weight Vector w_{c2}

Many various weight adaptation algorithms are developed in literature to determine the optimal complex weight for the AAA. They all combine the received signals from multiple antenna elements to satisfy specific optimization criteria. These criteria may include methods for minimizing the mean square error (MMSE), maximizing the SNR, and minimizing the variance of interference. Among them, we employ here the maximizing SNR criterion based on generalized Eigen-value problem [11]. From (8) and for a given weight vector $\boldsymbol{w}_{c2}$, the instantaneous SNR at the virtual AAA output for 2nd Relay is expressed as

$$\gamma_{c2} = P_s \cdot \frac{\boldsymbol{w}_{c2} \cdot \boldsymbol{h}_2^H \cdot \boldsymbol{h}_2 \cdot \boldsymbol{w}_{c2}^H}{\boldsymbol{w}_{c2} \cdot \boldsymbol{\Omega}_{c2} \cdot \boldsymbol{w}_{c2}^H}, \tag{17}$$

where

$$\boldsymbol{\Omega}_{c2} = diag\left(P_1 N_0 \rho_2^2,\ P_1 N_0 \rho_1^2 + \frac{N_0}{|g_1|^2}\right)_{2\times 2}.$$

The weight optimization can be estimated by maximizing (17), in the form of Rayleigh quotient, by solving the generalized Eigen-value problem [11]. Hence, for any weight vector $\boldsymbol{w}_{c2}$, we have

$$\gamma_{c2} \leq P_s \lambda_{max}, \tag{18}$$

where λ_{max} is the largest Eigen-value of $\left(\boldsymbol{\Omega}_{c2}^{H/2}\right)^{-1} \boldsymbol{h}_2^H \boldsymbol{h}_2 \left(\boldsymbol{\Omega}_{c2}^{1/2}\right)^{-1}$. The equality holds if $\boldsymbol{w}_{c2} = c.\boldsymbol{h}_2 (\boldsymbol{\Omega}_{c2})^{-1}$ where c can be any non-zero constant [5]. Then the optimum weight vector $\boldsymbol{w}_{c2}$ derived by maximizing the *SNR* (i.e., γ_{c2}) based on generalized Eigen-value problem is given by

$$\boldsymbol{w}_{c2} = \left[\frac{h_{s,2}}{\sqrt{P_1}\cdot \rho_2 \cdot N_0}, \frac{h_{s,1}}{\sqrt{P_1}\cdot\rho_1\cdot N_0 + \frac{N_0}{|g_1|^2\cdot\sqrt{P_1}\cdot\rho_1}}\right]. \tag{19}$$

2.3 Derivation of MRC and Transmit Beamforming Weight Vectors

From (15), the instantaneous *SNR* at the destination is expressed as

$$\gamma_{d2} = P_s \cdot \frac{\boldsymbol{w}_{MRC2}\cdot \boldsymbol{H}_2^H \cdot \boldsymbol{H}_2 \cdot \boldsymbol{w}_{MRC2}^H}{\boldsymbol{w}_{MRC2}\cdot\boldsymbol{\Omega}_{d2}\cdot\boldsymbol{w}_{MRC2}^H}, \tag{20}$$

where $\boldsymbol{\Omega}_{d2} = diag\left[N_0, \boldsymbol{w}_{TB2}\cdot \boldsymbol{A}_2^H \cdot \boldsymbol{\Gamma}_2 \cdot \boldsymbol{A}_2 \cdot \boldsymbol{w}_{TB2}^H + N_0\right]_{2\times 2}$ and

$$\boldsymbol{\Gamma}_2 = \Big[N_0,\ \sqrt{P_1}\rho_1 N_0 w_{c_{22}};\ \sqrt{P_1}\rho_1 N_0 w_{c_{22}}^*,$$
$$P_1 \left|w_{c_{21}}\right|^2 N_0 \rho_2^2 + N_0 \left|w_{c_{22}}\right|^2 \left(P_1\rho_1^2 + \frac{1}{|g_1|^2}\right)\Big].$$

The optimized weight vectors are derived as

$$(\boldsymbol{w}_{TB2}, \boldsymbol{w}_{MRC2}) = \underset{(\boldsymbol{w}_{TB2},\boldsymbol{w}_{MRC2})}{\arg\max}\ (\gamma_{d2}),\ s.b.t\ P_s + P_1 + P_2 = P_t, \tag{21}$$

where P_t represents the total transmit power used in the whole cooperative relay network.

Solving the optimization problem (21) in closed form appears to be complex. Hence we relaxed the optimization problem by finding a sub-optimally closed form. The optimum MRC weight vector $\boldsymbol{w}_{MRC2}$ is derived first by maximizing the instantaneous *SNR* given in (20) and then by substituting the derived expression of $\boldsymbol{w}_{MRC2}$ in (20), we determine consecutively the transmit beamforming weight vector $\boldsymbol{w}_{TB2}$. Using the same presented principle to derive the weight vector by means of maximizing (20) based on the generalized Eigen-value problem, we obtain for any weight vector $\boldsymbol{w}_{MRC2}$

$$\gamma_{d2} \leq P_s \lambda_{dmax}, \tag{22}$$

where λ_{dmax} is the largest Eigen-value of $\left(\boldsymbol{\Omega}_{d2}^{H/2}\right)^{-1} \boldsymbol{H}_2^H \boldsymbol{H}_2 \left(\boldsymbol{\Omega}_{d2}^{1/2}\right)^{-1}$. Under the assumption that $\boldsymbol{H}_2^H\boldsymbol{H}_2$ is symmetrical, λ_{dmax} is expressed by [11]

$$\lambda_{dmax} = Trace\left[\left(\Omega_{d2}^{H/2}\right)^{-1} \boldsymbol{H}_2^H \cdot \boldsymbol{H}_2 \cdot \left(\Omega_{d2}^{1/2}\right)^{-1}\right], \tag{23}$$

where (23) can be simplified as

$$\lambda_{dmax} = \frac{\left|h_{s,d}\right|^2}{N_0} + \frac{\boldsymbol{w}_{TB2}\cdot \boldsymbol{a}_2^H \cdot \boldsymbol{a}_2 \boldsymbol{w}_{TB2}^H}{\boldsymbol{w}_{TB2}\cdot\boldsymbol{A}_2^H\cdot\boldsymbol{\Gamma}_2\cdot\boldsymbol{A}_2\cdot\boldsymbol{w}_{TB2}^H + N_0}. \tag{24}$$

And by following the same analysis previously described above the optimum MRC vector is given by

$$\boldsymbol{w}_{MRC2} = \left[\frac{h_{s,d}}{N_0}, \frac{\boldsymbol{a}_2\cdot\boldsymbol{w}_{TB2}^H}{\boldsymbol{w}_{TB2}\cdot\boldsymbol{A}_2^H\cdot\boldsymbol{\Gamma}_2\cdot\boldsymbol{A}_2\cdot\boldsymbol{w}_{TB2}^H + N_0}\right]. \tag{25}$$

Therefore, to maximize λ_{dmax}, (i.e., find the upper bound of (22)), we simply maximize the 2nd right-hand side element of (24). Let define

$$\boldsymbol{\Omega}_2 = \boldsymbol{A}_2^H \cdot \boldsymbol{\Gamma}_2 \cdot \boldsymbol{A}_2 + N_0 \cdot I_{2\times 2}/P_2, \tag{26}$$

and then the 2nd right-hand side element of (24) can be expressed as

$$\frac{\boldsymbol{w}_{TB2}\cdot\boldsymbol{a}_2^H\cdot\boldsymbol{a}_2\boldsymbol{w}_{TB2}^H}{\boldsymbol{w}_{TB2}\cdot\boldsymbol{A}_2^H\cdot\boldsymbol{\Gamma}_2\cdot\boldsymbol{A}_2\boldsymbol{w}_{TB2}^H + N_0} = \frac{\boldsymbol{w}_{TB2}\cdot\boldsymbol{a}_2^H\cdot\boldsymbol{a}_2\boldsymbol{w}_{TB2}^H}{\boldsymbol{w}_{TB2}\cdot\boldsymbol{\Omega}_2\cdot\boldsymbol{w}_{TB2}^H}, \tag{27}$$

since $P_2 = \boldsymbol{w}_{TB2}\cdot\boldsymbol{w}_{TB2}^H$.

As a result, maximization of (24) can be achieved by maximizing a form of Rayleigh quotient given by (27). Then by following the same analysis previously described above we obtain

$$\boldsymbol{w}_{TB2} = c\boldsymbol{a}_2 (\boldsymbol{\Omega}_2)^{-1}, \tag{28}$$

where $c = \sqrt{\frac{P_2}{\left|\boldsymbol{a}_2(\boldsymbol{\Omega}_2)^{-1}\right|^2}}$.

2.4 Increasing the Path Diversity at the Destination

The proposed method performance can be further improved if the destination allows receiving data from the 'best' relay during step II. This increasing in path diversity at the destination will enhance the received SNR when all paths are coherently combined using MRC and as a result the throughput can be increased. To this end, based on similar analysis as the one described above, the new optimal MRC weight vector at the destination is developed in (29) where the signal from the selected relay in step II is also received by the destination.

$$\boldsymbol{w}_{MRC} = \left[\frac{h_{s,d}}{N_0}, \frac{\sqrt{P_1}\cdot\rho_1\cdot h_{r_1,d}\cdot h_{s,1}}{\left|h_{r_1,d}\right|^2\cdot P_1\cdot\rho_1^2\cdot N_0 + N_0}, \frac{\boldsymbol{a}_2\cdot\boldsymbol{w}_{TB2}^H}{\boldsymbol{w}_{TB2}\cdot\boldsymbol{A}_2^H\cdot\boldsymbol{\Gamma}_2\cdot\boldsymbol{A}_2\cdot\boldsymbol{w}_{TB2}^H + N_0}\right], \tag{29}$$

where $h_{r1,d}$ represents the path gain between the selected relay (relay 1 in this case) and the destination during step II. We note that the above condition does not affect the optimal transmit beamforming weight that will be still given by (28).

In the following section, the benefit of increasing the path diversity at the destination is also investigated and is labeled as *proposed method with option* (2).

3. Simulation Results

In this section we evaluate the performance of the proposed method with comparison of the two approaches presented in [5] and [12] with a target comparison of the direct transmission when the source sends the information to the destination with the total transmit power P_t, without help from relays. The approach [5] uses 2-time slots with distributed transmit beamforming and MRC reception at the relays and destination, respectively. The approach [12] uses 3-time slots with an MRC at the destination and equal power allocation across the relay terminals, i.e. $P_i = P_r/m$, for $i = 1, \ldots, m$ where $P_r = P_s = P_t/2$ and m is the number of the relays. We will study first and analyze by computer simulation the impact of relay location on the BER performance and then evaluate the outage probability and throughput for the optimal relay location that gives the lowest BER by using these four aforementioned techniques. We assume all channels have spatially uncorrelated Rayleigh fading which are constant within one slot, but varying between slots. The path loss exponent is assumed to be 3 and the modulation scheme of the transmit signal is QPSK. The source node is located at coordinates $(0, 0)$ and the destination node at $(0, r_0)$ within a square of side length of r_0, while the two relays are located between source and destination as shown in Fig. 4.

To obtain the maximum benefit of the inter-relay data exchange, the minimum distance between relays is set to be half of the source-destination distance[†]. Thus the y-axis of the relay 1 and 2 are set to be equal to $(r_o/4)$ and $(-r_o/4)$, respectively, as illustrated in Fig. 4.

3.1 BER vs. Relay Locations

Relay node placement introduced in wireless cellular network has been studied by many researchers to achieve more profit from relay deployment in wireless networks [13], [14]. In the relay location problem, the objective is to find optimal relay locations minimizing a utility function representing the error probability or outage probability, or maximizing the one representing the capacity, throughput, or energy and lifetime of the relay sensor network.

Optimum relay location is mainly studied with optimum power allocation. The principal aim is to find out the optimal relay locations jointly with the optimal energy provided to them so that the wireless network is efficiently operational with minimum sum of total energy and while maintaining good performance[††]. Usually, the transmit power is equally shared among source and all relays. However, in a homogeneous environment where the path loss exponent is

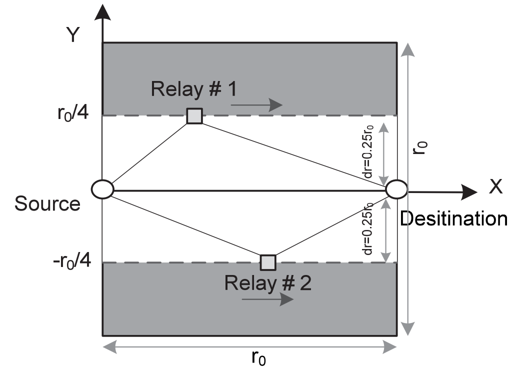


Fig. 4 Square cell.

a constant, and when coherent AF with orthogonal channels and equal power among relays are used, the optimal relay locations minimizing the error probability are shown to be on the right bisector line between source and destination [14].

In what follows, we find the optimal relay locations (x-axis) for our proposed method that gives the lowest BER in the environment presented above and that to perform an unbiased comparison with the other methods. Thus for each approach, the optimal relay location that gives the lowest BER is identified and then the throughout and the outage probability are measured when the relays are positioned at their optimal locations.

For the proposed method, the power allocation[†††] is set to be $P_s = P_t/2$ and $P_2 = 2P_1 = P_t/3$, where P_t represents the sum total transmit power used by the whole relay network. To achieve such aim, we conduct several channel realizations with a statistical averaging, where locations of relay 1 and relay 2 are changed according to their corresponding dashed lines with equation ("y" $= r_0/4$) and ("y" $= -r_0/4$), from source ($x = 0$) to destination ($x = r_0$), respectively, as illustrated in Fig. 4. With a relay displacement resolution equal to $0.1\, r_0$, we obtain $11 \times 11 = 121$ pair locations of the two relays. For each pair relay location we average over 100 channel realizations. Without loss of generality, we assume all distances are normalized to r_0.

Figures 5(a), (b) and (c) illustrates the BER in terms of relay locations using the three schemes when the sum total normalized transmit power P_t/P_0 is set to be 8 dB[††††]. We can see from this figure that the BER surfaces using three schemes possess different characteristics depending on the relay locations where several interesting observations can be extracted.

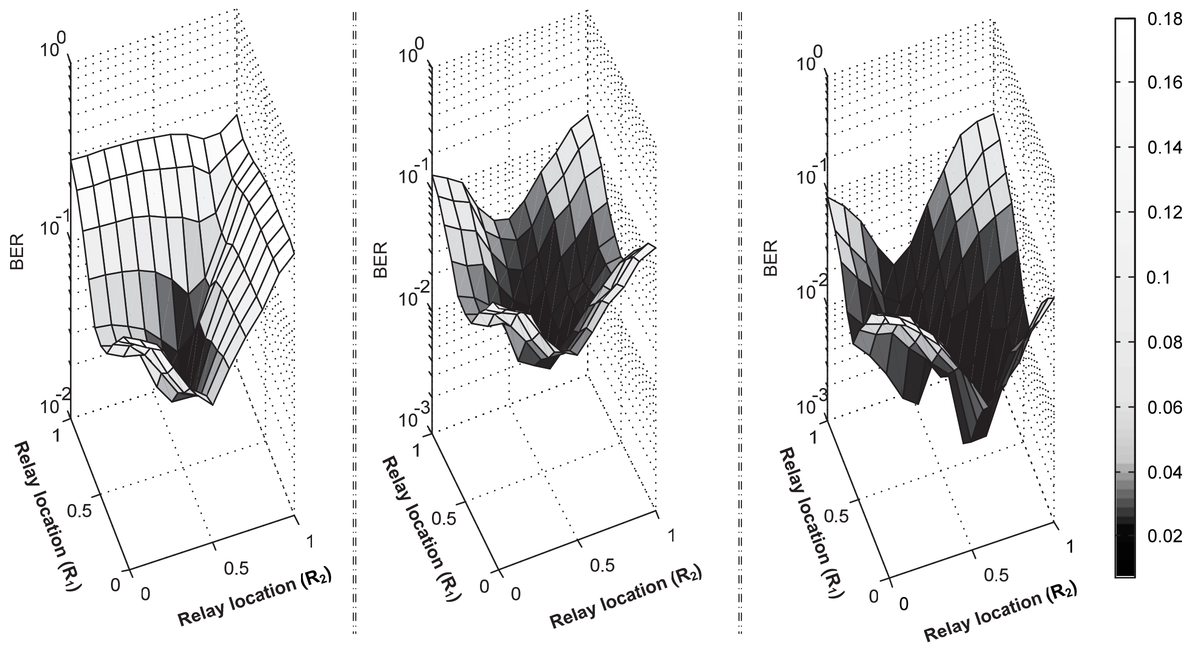
For instance, the BER surface resulting by using [12]

[†]This minimum distance value makes a good choice since the distance between relays should not be so far to get the benefit from data exchange.

[††]As a performance measure, we can adopt the BER, throughout, outage probability or capacity.

[†††]The optimum power allocation is beyond the scope of this paper.

[††††]This represents the normalized transmit power to P_0, where we set $P_0 r_0^{-\alpha}/N_0 = 1$, and P_0 represents the transmit power from source to destination and α is the path loss exponent value.



(a) Approach presented in [12] (b) Approach presented in [5] (c) Proposed method

Fig. 5 Surfaces defined by the measured BER in terms of relay locations using different relay network schemes.

(Fig. 5(a)) is diagonally symmetrical where the minimum BER values are obtained at this diagonal line and particularly when the relays are far from the source. The symmetrical characteristic means that if the relays 1 and 2 are located at $x_1 = \alpha$ and $x_2 = \beta$, respectively, the BER value is almost the same when the relay locations are swapped (i.e., $x_1 = \beta$ and $x_2 = \alpha$) and that can be explained by the equal power allocated at both relays. Also, the optimal relay locations are set to be in the right bisector line between source and destination (see the deep black color in this figure). Moreover, we observe that having a high BER is highly probable especially when one of the relay is close to destination (at any location for the other relay) stemming from the fact that both relays are transmitting with orthogonal channels without cooperation.

While using the approach [5] (Fig. 5(b)), we can see the benefit of cooperative relay scheme with transmit beamforming. Hence, we get a BER improvement compared to Fig. 5(a) and especially when one of the relay is placed close to the destination. However, in case of having one of the relays close to source and the other one close to destination, the BER is high due to the large distance between relay nodes that outweighs the benefit of the transmit beamforming. The minimum BER values are achieved when both relays are located close to the right bisector line (see the deep black color in this figure).

However, by employing our proposed method, (Fig. 5(c)), we can see the great enhancement in measured BER for all relay locations compared to the other approaches (5(a) and 5(b)). We observe two symmetric deep dark regions representing the minimum BER values. They

Table 1 Relays' optimal locations normalized by r_0.

	Proposed method	[5]	[12]
Relay#1	x =0.3	x =0.4	x =0.5
	y=0.25	y =0.25	y =0.25
Relay#2	x =0.7	x =0.5	x =0.5
	y =-0.25	y =-0.25	y =-0.25

are not located at the right bisector line, but at the 2nd quarter (i.e., relay 1 and relay 2 are near source and destination, respectively) and at the 4th quarter (relay 1 and relay 2 are near destination and source, respectively). That can be explained by: 1- Due to the path loss, the relay that engages into cooperation should receive signal with high power (near the source), 2- To maximize the benefit from the distributed transmit beamforming, and to compensate for placing 1st relay near source, the 2nd relay has to be near destination.

The optimal location (normalized to the source- destination distance) giving the lowest BER for each method is presented in Table 1. We notice from Table 1 that the optimal relay location using method [12] is obtained at the right bisector line between source and destination while the one for method [5] is almost near this line. In contrast, the optimal locations for the proposed method are positioned far from this line and thus it is due to the exchange data between relays.

3.2 BER Performance at the Optimal Relay Location

Figure 6 compares the average BER in terms of the normalized total transmit power used in the complete cooperative network using the above three techniques in addition with

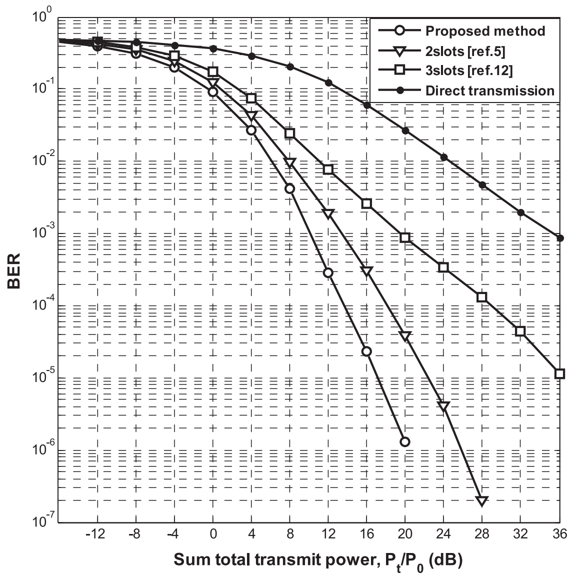


Fig. 6 BER as a function of the sum total normalized transmit power by using the four schemes.

direct transmission. The results are obtained by averaging over 2000 channel realizations and the relay locations for each method are positioned at their optimal value given in Table 1. From this figure it is shown that for a required BER equal to 0.001, the proposed method outperforms the ones presented in [5] and [12] by approximately 4 dB and 10 dB, respectively.

3.3 Outage Probability Performance at the Optimal Relay Location

The measured BERs are used to compute the outage probability where an outage may occur at a source location if the measured BER exceeds 10^{-2}. For this outage probability analysis, Monte-Carlo simulation was conducted in a unit square cell. The source is placed randomly in 1000 locations inside this cell while the results (measured BERs) are obtained by averaging over 20 channel realizations for each source location. Also the relay locations for each method are positioned at their optimal locations given in Table 1. The tolerable outage probability is assumed to be 0.1. Figure 7 evaluates the outage probability in terms of the normalized total transmit power used in the cooperative network using the four schemes. As can be seen from this figure, for this tolerable outage probability the normalized total transmit power is approximately equal to 4 dB, 7 dB, 13 dB and 26 dB by using the proposed method, two slots [5], three slots [12] and direct transmission, respectively.

3.4 Throughput Performance at the Optimal Relay Location

Figure 8 compares the average normalized throughput in terms of the normalized total transmit power used in the cooperative network using the four schemes. The normalized

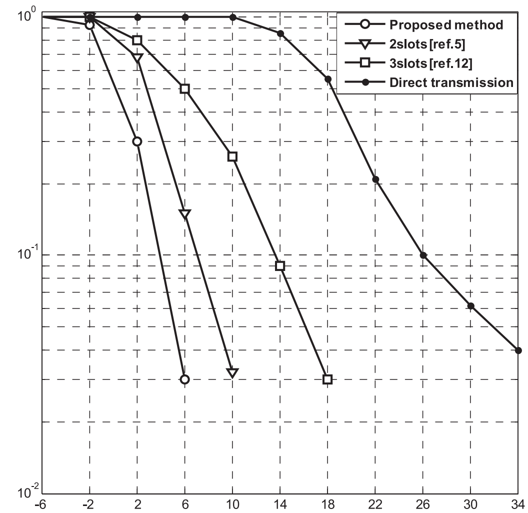


Fig. 7 Outage Probability as a function of the sum total normalized transmit power by using the four schemes.

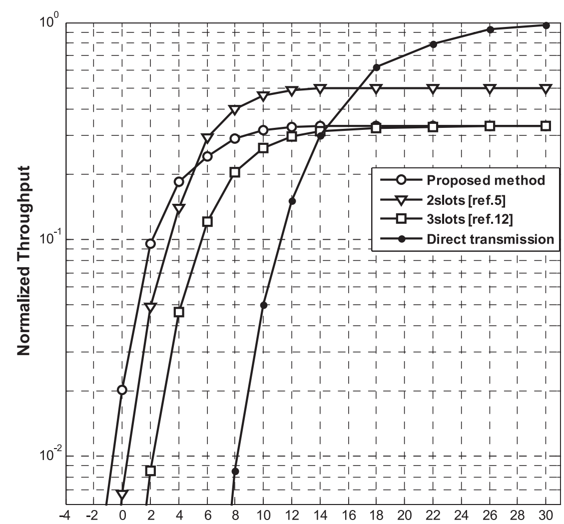


Fig. 8 Average normalized throughput of the four schemes as a function of the sum total normalized transmit power.

throughput is defined as the number of the correct received packets divided by the number of the transmitted ones during same period and divided by the number of the slots used for this transmission. The results are obtained by averaging over 2000 channel realizations where the relay locations for each method are positioned at their optimal value given in Table 1. We notice from this figure that the proposed method outperforms the ones presented in [5] and [12] by 1 dB and 3 dB, respectively at low SNR†. Note that the approach [5] has greater throughput at high SNR (i.e., $P_t > 5$ dB) compared to the proposed method, but far poor outage probability. However lower transmit power is extremely desirable in highly dense new communication system to reduce inter-

†Since all nodes stations are assumed to have same noise variance, than low total transmit power is equivalent to low *SNR* condition.

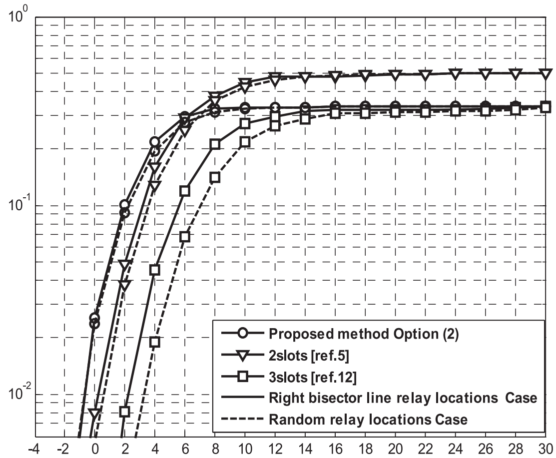


Fig. 9 Average normalized throughput of the three schemes as a function of the sum total normalized transmit power where the relays are located at the right bisector line or randomly inside the square cell.

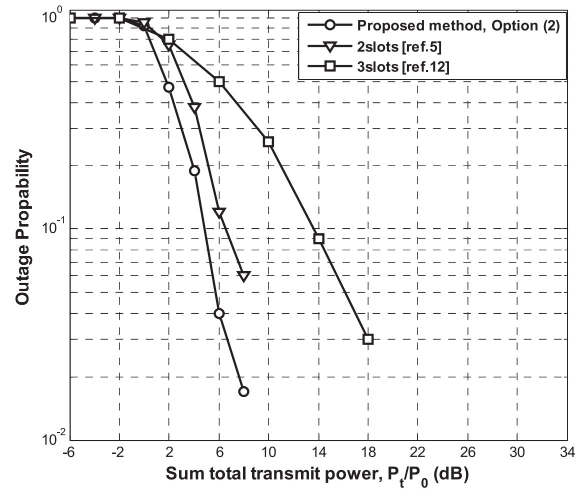


Fig. 10 Outage Probability as a function of the sum total normalized transmit power where the relays are located at the right bisector line.

ference and increase battery life of portable devices as well as of relay nodes and that shows the importance of the proposed method.

3.5 Proposed Method with Option 2

In this section, we evaluate the improvement obtained using the proposed method with option (2). We used the same simulation environment described above, and we analyze the system performance where both relays are located at the right bisector line and randomly inside the square cell as illustrated in Fig. 4.

Figure 9 compares the average normalized throughput in terms of the normalized total transmit power using three schemes; the proposed method with option (2) and the methods presented in [5] and [12]. When the relays are located at the right bisector line, the results are obtained by averaging over 1000 channel realizations. In case of relays randomly located, the results are averaging over 100 channel realizations and where for each random relay location 100 pairs of relay locations are generated randomly. We notice from this figure that the proposed method with option (2) outperforms the ones presented in [5] and [12] for both relay location cases. Moreover, for random relay locations case, the proposed method with option (2) presents a slight degradation compared to the result obtained for right bisector line case, while the approaches presented in [5] and [12] exhibit some degradation approximately equal to 1 dB.

For the outage probability analysis, the source is placed randomly in 100 locations inside a square cell while the relays are placed at the right bisector line. For each source location, the results (measured BERs) are obtained by averaging over 20 channel realizations for each source location. Figure 10 evaluates the outage probability in terms of the total transmit power used in the cooperative network using the three aforementioned methods analyzed in Fig. 9. This figure illustrates that for the tolerable outage probability equal to 0.1, the total transmit power should be approximately equal to 5 dB, 7 dB by using the proposed method with option (2) and the reference [5] using two slots, respectively. Despite locating the relays at the right bisector line instead of their optimal location identified in Sect. 3.1, the proposed method still outperforms the method using two time slots with optimal relay locations.

4. Conclusion

In this paper, we proposed a novel scheme of cooperative relaying network based on exchanging data between relays before forwarding their received signals to destination. The obtained results showed that at low transmit power levels; the proposed method has significantly better outage behavior and average throughput than conventional methods using one or two time slots for transmission. It is worth mentioning that when communication lines between source and relays are broken, conventional methods suffer severe performance degradation while the proposed method owing to superior exchange and adaptation schemes succeeds in maintaining good quality of service.

This proposed method can be generated for using more than two relays. For instance, the relay possesses the highest SNR is selected and engages into cooperation while the remaining non selected relays estimate the transmitted signal as described above. The complexity of the 'best' relay selection may be increased if the number of relays is higher. But since we assume a fixed-relay deployment, the channels between base station (BS) and relay nodes can be assumed stationary and periodically estimated. Thus the proposed approach is easily applied in downlink access where best-relay selection can be performed by the BS and hence complexity and signaling overheads are largely reduced.

The optimal relay location has been also studied by computer simulation to perform an unbiased comparison with other methods. Though deriving a closed form expression for the optimal relay location using our proposed approach is an interesting subject but it is left as future work when power allocation will be introduced to the proposed method.

This proposed method can be implemented based on the DF technique as well. However, among the advantage of AF strategy is that this relay does not require performing detection and decoding. In our study, AF is employed first for its simplicity but jointly with the channel estimation and weight detection processing, the hardware complexity will be increased. However, using DF strategy, the relay requires as well channel estimation for the distributed transmit beamforming and MRC combining and therefore, AF and DF approaches require almost the same degree of complexity. In addition, since we assume a fixed-relay deployment, the relay size and the implementation complexity will be tolerable for performance enhancement purpose.

By introducing this data exchange between relays, the outage probability is improved with a small degradation in throughput. Increasing the system throughput can be achieved for instance by allowing the destination to also combine the signal of the 'best' relay in phase II as we evaluated in this paper. Also the total throughput can be increased by using relays with simultaneous transmitting and receiving capability and using CDMA or OFDMA employing different subcarriers transmitting and receiving and that is left for future work.

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