Relay Selection in Multiuser Two-Way Cooperative Relaying Systems

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***Abstract*—In this paper, we study a relay selection (RS) problem in multi-user two-way cooperative relaying systems. We consider a more practical scenario in which multiple users, multiple relays and a single destination are involved in the two-way network. In this paper, the code division multiple access (CDMA) system with non-orthogonal spreading sequences is employed to handle the multiuser interference. Relay selection based on maximizing the SINR of the worse link is proposed in this research. Besides, aiming at mitigating the interference, we consider the design of linear filter at each relay such that the minimum SINR of the worst link in the two-way transmission is maximized. The result shows that the linear filter is similar to minimum mean-square error (MMSE) detector. Furthermore, we simulate the proposed scheme with several different parameters such as the numbers of users and relays, and the length of spreading sequences. Also, we compare the proposed RS method with random RS approach, and the result shows that our proposed method has better performance in terms of the bit error rate (BER).**

***Index Terms*—Relay selection, two-way cooperative relaying system, multiuser interference.**

I. Introduction

The idea of communications with cooperative relays has attracted much attention recently for the its ability to combat channel fading and to realize multiple transmit antennas in a distributed fashion. Depending on the number of information flows, there exist two different communication schemes. One is the unidirectional relay network, and the other is the bidirectional relay network. Since bidirectional relay network is more bandwidth efficient than unidirectional relay network, it has received considerable attention recently. Depending on the number of transmission time slots, three bidirectional relay network protocols have been proposed: the traditional technique, the time division broadcast (TDBC) protocol and the multiple access broadcast schemes (MABC). A traditional bidirectional relay network requires four time slots to accomplish the information exchange between the two end-sources. In the first two time slots, the first source broadcasts its symbol to the relay, and then the relay retransmits a new signal to the second source after performing some kinds of relaying strategies about the received signal. In the last two time slots, the same procedure as in the first two time slots is conducted again, with the information flow sending from the second source. The TDBC protocol based on the concept of network coding reduces the number of time slots to three. In the first two time slots, two end-sources transmit their symbols to the relay sequentially. It is worth noting that the relay has to decode the received symbols and perform an XOR operation on the decoded signals before retransmitting a new signal to the two sources. After receiving the signal from the relay, each source can retrieve its desired signal easily by performing an XOR operation on the received signal and its transmitted signal. The MABC schemes are most bandwidth efficient among these three protocols. There are two well-known protocols in the MABC schemes: the analog network coding (ANC) [1] and the physical-layer network coding (PNC) [2], [3]. For both protocols, two time slots are required to accomplish the information exchange between the two end-sources. In the first time slot, the two end-sources transmit their signals to the relay simultaneously. In the second time slot, the relay retransmits the mixed version of two incoming signals to the two end-sources.

When multiple relays exist in the network, several strategies which utilize multiple relays are developed to achieve different goals. These strategies including distributed space time coding [2], distributed beamforming [4], [5], and relay selection [6], [7] are widely studied in the literature. One of the major challenges encountered when all relays participate in relaying is the handling of interference. Most of the works assume that the relays transmit on orthogonal channels such that the interference can be avoided. However, this assumption reduces the capacity of the network. Relaxing the orthogonality constraint can increase the capacity while the implementation complexity is raised as well. On the other hand, ideal frequency or time synchronization across the relays should be taken into consideration if all relays are used in the network. RS has been proposed and recognized as an effective method to overcome these difficulties. Because of its ability to facilitate the system design and achieve full diversity with less synchronization requirement and overhead, RS has attracted much attention. RS for bidirectional relaying was first introduced in [7]. Oechtering *et al.* considered a system using superposition encoding at relay nodes. The RS criterion in [7] was to maximize the weighted sum rate for any bidirectional rate pair on the boundary of the achievable rate region. Oechtering *et al.* showed that in the case of independent and identical distribution (i.i.d) Rayleigh fading, RS could achieve the same diversity order as that offered by the distributed beamforming. In [1], RS with ANC and TDBC in amplify-and-forward (AF)-based bidirectional relay networks was studied. The RS was based on a max-min criterion to minimize the outage

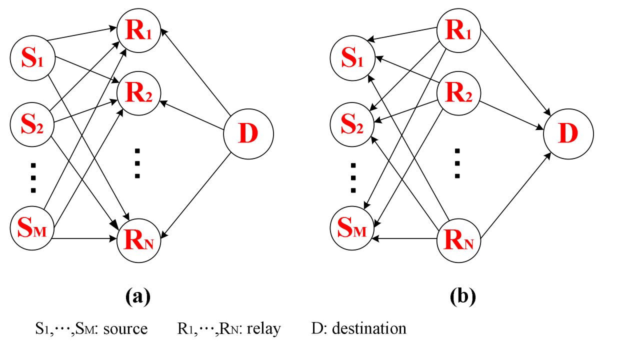


Fig. 1. A multi-source, multi-relay and single destination network. (a) 1st time slot. (b) 2nd time slot.

probabilities.

Although RS has attracted much attention recently, still very few work investigate the issue of RS in multi-user multi-relay networks, where how to assign a relay to a pre-determined partner or select the best source-relay pair to access the channel are among the main issues [8], [9]. Most work in multi-user multi-relay networks didn't consider the effect of interference by assuming orthogonal channels. Motivated by this, we tackle the relay selection problem in multi-user two-way cooperative relaying systems by considering multi-user interference. Our main goal is to select the best relay based on maximizing the received SINR of the worse link. We show that our proposed method has better performance in terms of the bit error rate (BER) when comparing to the random RS approach.

II. System Model

We consider a multi-user multi-relay two-way relaying network which consists of M sources, N relays and a single destination as shown in Fig. 1. The sources and destination can be regarded as the mobile handsets and the base-station, respectively. There are no direct links between the sources and the destination because of the poor quality of channels. We use the AF relaying protocol with RS. The information exchange between all end-nodes is completed in two time slots. In the first time slot, all sources and destination transmit to all relays simultaneously. After performing the AF relaying strategy, the selected relay transmits a new signal to all sources and the destination. In order to accommodate the communication of multiple users simultaneously, direct sequence (DS)-CDMA is employed. Taking the effect of interference into consideration, we assume that the signatures are nonorthogonal. For convenience, we take the source S_1 as the desired user and other users S_2 to S_M as interference. All nodes in the network are single antenna units and half-duplex such that they can only transmit or receive the signals at a time. We assume a flat-fading scenario and the channel coefficients are complex reciprocal (i.e., the channel coefficients from the ith user/desitination to the jth relay and from the jth relay to the ith user/destination are the same). The channel gains from the jth relay to the ith source and destination are denoted as f_{ij} and g_{jD} for $i = 1, ..., M$, and $j = 1, ..., N$, respectively. We assume that all sources and the destination know all channel coefficients f_{ij} and g_{jD} for $i = 1, ..., M$ and $j = 1, ..., N$ and the relay j only knows its local channel coefficients f_{ij} for $i = 1, ..., M$ and g_{jD}.

A. Phase One

During the first time slot, all sources and the destination transmit their signals to the relays simultaneously. The signals received at relay j can be represented as

$$\mathbf{y}_{R_j} = \sum_{i=1}^{M} \sqrt{P} f_{ij} x_i^{(U)} \mathbf{s}_i + \sqrt{P} g_{jD} \sum_{i=1}^{M} x_i^{(D)} \mathbf{s}_i + \mathbf{n}_{R_j} \quad (1)$$

where $\mathbf{s}_i$ denotes a $K \times 1$ vector of unit norm spreading sequence. The transmitted power is P at all source nodes and MP at the destination. $x_i^{(U)}$ denotes the transmitted symbol for source S_i, and $x_i^{(D)}$ is the symbol that the destination wants to transmit to source S_i. For each symbol, $\mathbf{E}\{|x_i^{(U)}|^2\} = \mathbf{E}\{|x_i^{(D)}|^2\} = 1$ for $i = 1, ..., M$. $\mathbf{n}_{R_j}$ is a $K \times 1$ zero mean complex vector at the jth relay noise with $\mathbf{E}\{\mathbf{n}_{R_j} \mathbf{n}_{R_j}^H\} = \sigma_{R_j}^2 \mathbf{I}$.

Upon receiving $\mathbf{y}_{R_j}$, the relay j employs linear filter $\mathbf{c}_j$ to obtain y'_{R_j} as

$$\begin{aligned} y'_{R_j} &= \mathbf{c}_j^H \mathbf{y}_{R_j} \\ &= \sum_{i=1}^{M} \sqrt{P} f_{ij} x_i^{(U)} \mathbf{c}_j^H \mathbf{s}_i + \sqrt{P} g_{jD} \sum_{i=1}^{M} x_i^{(D)} \mathbf{c}_j^H \mathbf{s}_i + \mathbf{c}_j^H \mathbf{n}_{R_j} \end{aligned} \quad (2)$$

where $\mathbf{c}_j$ is a $K \times 1$ complex vector.

B. Phase Two

During the second time slot, the jth relay regenerates a new signal x_{R_j} and transmits it to all sources and the destination. The new transmitted signal for relay j is

$$x_{R_j} = \sqrt{P_{R_j}} y'_{R_j} \quad (3)$$

where P_{R_j} is the power for relay j to amplify the received signals. Actually, assuming that all information symbols and noises are independent, the total transmit power which relay j requires can be shown as

$$\begin{aligned} P_{t,R_j} &= \mathbf{E}\{x_{R_j} x_{R_j}^H\} \\ &= P P_{R_j} \left[\sum_{i=1}^{M} \left(|f_{ij}|^2 |\mathbf{c}_j^H \mathbf{s}_i|^2 + |g_{jD}|^2 |\mathbf{c}_j^H \mathbf{s}_i|^2 \right) \right] \\ &\quad + P_{R_j} \sigma_{R_j}^2 \mathbf{c}_j^H \mathbf{c}_j \end{aligned} \quad (4)$$

In our work, we assume that source S_1 is the desired user for convenience. Therefore, we only consider the received signals at source S_1 and the destination in the following discussion.

The signal y_{S_1} received at source S_1 can be expressed as

$$\begin{aligned} y_{S_1} &= f_{1j} x_{R_j} + n_{S_1} \\ &= \sqrt{PP_{R_j}} f_{1j}^2 x_1^{(U)} \mathbf{c}_j^H \mathbf{s}_1 + \sqrt{PP_{R_j}} f_{1j} g_{jD} x_1^{(D)} \mathbf{c}_j^H \mathbf{s}_1 \\ &\quad + \sum_{i \neq 1} \sqrt{PP_{R_j}} \left(f_{1j} f_{ij} x_i^{(U)} \mathbf{c}_j^H \mathbf{s}_i + f_{1j} g_{jD} x_i^{(D)} \mathbf{c}_j^H \mathbf{s}_i \right) \\ &\quad + \left(\sqrt{P_{R_j}} f_{1j} \mathbf{c}_j^H \mathbf{n}_{R_j} + n_{S_1} \right) \end{aligned} \tag{5}$$

where n_{S_1} is the noise at source S_1 with zero mean and variance $\sigma_{S_1}^2$. Consider the received signal y_D at the destination, it can be represented as

$$\begin{aligned} y_D &= g_{jD} x_{R_j} + n_D \\ &= \sum_{i=1}^{M} \sqrt{PP_{R_j}} g_{jD}^2 x_i^{(D)} \mathbf{c}_j^H \mathbf{s}_i + \sqrt{PP_{R_j}} f_{1j} g_{jD} x_1^{(U)} \mathbf{c}_j^H \mathbf{s}_1 \\ &\quad + \sum_{i \neq 1} \sqrt{PP_{R_j}} f_{ij} g_{jD} x_i^{(U)} \mathbf{c}_j^H \mathbf{s}_i + \left(\sqrt{P_{R_j}} g_{jD} \mathbf{c}_j^H \mathbf{n}_{R_j} + n_D \right) \end{aligned} \tag{6}$$

where n_D is the noise at the destination with zero mean and variance σ_D^2. In (5), the first term is known as self-interference and can be subtracted from y_{S_1}. The second term is the desired signal for source S_1, the third term is the interference caused by other sources and the last term represents the noise. Consider the communication between the source S_1 and the destination, similarly, the first term in (6) can be subtracted from y_D through self-interference cancelation. The second term is the signal that we are interested in, the third term depicts the interference and the last term is the noise. After canceling the self-interference terms in (5) and (6), the residual signals $\tilde{y}_{S_1}$ and $\tilde{y}_D$ can be shown as

$$\begin{aligned} \tilde{y}_{S_1} &= \sqrt{PP_{R_j}} f_{1j} g_{jD} x_1^{(D)} \mathbf{c}_j^H \mathbf{s}_1 \\ &\quad + \sqrt{PP_{R_j}} \sum_{i \neq 1} \left(f_{1j} f_{ij} x_i^{(U)} \mathbf{c}_j \mathbf{s}_i + f_{1j} g_{jD} x_i^{(D)} \mathbf{c}_j^H \mathbf{s}_i \right) \\ &\quad + \left(\sqrt{P_{R_j}} f_{1j} \mathbf{c}_j^H \mathbf{n}_{R_j} + n_{S_1} \right) \end{aligned} \tag{7}$$

$$\begin{aligned} \tilde{y}_D &= \sqrt{PP_{R_j}} f_{1j} g_{jD} x_1^{(U)} \mathbf{c}_j^H \mathbf{s}_1 + \sqrt{PP_{R_j}} \sum_{i \neq 1} f_{ij} g_{jD} x_i^{(U)} \mathbf{c}_j^H \mathbf{s}_i \\ &\quad + \left(\sqrt{P_{R_j}} g_{jD} \mathbf{c}_j^H \mathbf{n}_{R_j} + n_D \right) \end{aligned} \tag{8}$$

Therefore, the residual signals $\tilde{y}_{S_1}$ and $\tilde{y}_D$ can be used to decode the desired symbols $x_1^{(D)}$ and $x_1^{(U)}$ at source S_1 and the destination, respectively.

III. Proposed Algorithm

As mentioned earlier, our goals are to do relay selection and to design the linear filter at each relay based on the maximization of the smaller received SINR of the desired source S_1 and the destination. Taking the interference into account, the SINR is a benchmark of performance in the communication system intuitively. As a result, we choose the SINR as a selection criterion. The main problem can be represented as

$$\begin{aligned} \max_{\mathbf{c}_j, j} \quad & \min\left(SINR_{S_1,j}, SINR_{D,j}\right) \\ subject \quad to \quad & 2MP + P_{t,R_j} \leq P_T \end{aligned} \tag{9}$$

where P_T is the total available power in the network. The $SINR_{S_1,j}$ and the $SINR_{D,j}$ are denoted as the received SINRs at source S_1 and the destination due to the transmission from relay j, respectively. In order to make a clearer derivation, we assume that the noise variances at all nodes are normalized. That is, $n_{S_1}, n_D \sim \mathcal{CN}(0,1)$ and $\mathbf{n}_{R_j} \sim \mathcal{CN}(\mathbf{0}, \mathbf{I})$. By calculating from $\tilde{y}_{S_1}$ and $\tilde{y}_D$, the SINRs can be written as

$$SINR_{S_1,j} = \frac{PP_{R_j} |f_{1j}|^2 |g_{jD}|^2 |\mathbf{c}_j^H \mathbf{s}_1|^2}{PP_{R_j} |f_{1j}|^2 \sum_{i \neq 1} \left(|f_{ij}|^2 |\mathbf{c}_j^H \mathbf{s}_i|^2 + |g_{jD}|^2 |\mathbf{c}_j^H \mathbf{s}_i|^2 \right) + \left(P_{R_j} |f_{1j}|^2 \mathbf{c}_j^H \mathbf{c}_j + 1 \right)} \tag{10}$$

$$SINR_{D,j} = \frac{PP_{R_j} |f_{1j}|^2 |g_{jD}|^2 |\mathbf{c}_j^H \mathbf{s}_1|^2}{PP_{R_j} |g_{jD}|^2 \sum_{i \neq 1} |f_{ij}|^2 |\mathbf{c}_j^H \mathbf{s}_i|^2 + \left(P_{R_j} |g_{jD}|^2 \mathbf{c}_j^H \mathbf{c}_j + 1 \right)} \tag{11}$$

In the following, we divide the optimization problem into two parts and deal with them separately. We firstly optimize (9) over $\mathbf{c}_j$ and then over j to solve the problem.

A. Design of Linear Filter at Relay Nodes

For optimizing over $\mathbf{c}_j$, the problem can be presented as

$$\max_{\mathbf{c}_j} \quad \min\left(SINR_{S_1,j}, SINR_{D,j}\right) \tag{12}$$

We denote the smaller one between $SINR_{S_1,j}$ and $SINR_{D,j}$ as $SINR_j$. It is easily to show that

$$\begin{aligned} SINR_j &= \min\left(SINR_{S_1,j}, SINR_{D,j}\right) \\ &= \begin{cases} SINR_{S_1,j}, & \text{if } SINR_{D,j} - SINR_{S_1,j} \geq 0; \\ SINR_{D,j}, & \text{if } SINR_{D,j} - SINR_{S_1,j} < 0. \end{cases} \end{aligned} \tag{13}$$

Consider $SINR_{D,j} - SINR_{S_1,j} \geq 0$ firstly, we can find the following criterion:

$$\begin{aligned} & SINR_{D,j} - SINR_{S_1,j} \geq 0 \\ \Rightarrow\ & PP_{R_j} |f_{1j}|^2 \sum_{i \neq 1} \left(|f_{ij}|^2 |\mathbf{c}_j^H \mathbf{s}_i|^2 + |g_{jD}|^2 |\mathbf{c}_j^H \mathbf{s}_i|^2 \right) \\ & + \left(P_{R_j} |f_{1j}|^2 \mathbf{c}_j^H \mathbf{c}_j + 1 \right) \\ & \geq PP_{R_j} |g_{jD}|^2 \sum_{i \neq 1} |f_{ij}|^2 |\mathbf{c}_j^H \mathbf{s}_i|^2 + \left(P_{R_j} |g_{jD}|^2 \mathbf{c}_j^H \mathbf{c}_j + 1 \right) \\ \Rightarrow\ & \mathbf{c}_j^H \left\{ P |f_{1j}|^2 \left[\sum_{i \neq 1} \left(|f_{ij}|^2 \mathbf{s}_i \mathbf{s}_i^H + |g_{jD}|^2 \mathbf{s}_i \mathbf{s}_i^H \right) + |f_{1j}|^2 \mathbf{I} \right] \right\} \mathbf{c}_j \\ & \geq \mathbf{c}_j^H \left(P |g_{jD}|^2 \sum_{i \neq 1} |f_{ij}|^2 \mathbf{s}_i \mathbf{s}_i^H + |g_{jD}|^2 \mathbf{I} \right) \mathbf{c}_j \end{aligned} \tag{14}$$

From the derivation above, we know that $SINR_j = SINR_{S_1,j}$ if it satisfies

$$\begin{aligned} \mathbf{A} \triangleq P \sum_{i \neq 1} & \left(|f_{1j}|^2 |f_{ij}|^2 + |f_{1j}|^2 |g_{jD}|^2 - |g_{jD}|^2 |f_{ij}|^2 \right) \mathbf{s}_i \mathbf{s}_i^H \\ & + \left(|f_1 j|^2 - |g_{jD}|^2 \right) \mathbf{I} \succcurlyeq \mathbf{0} \end{aligned} \tag{15}$$

In other words, if matrix $\mathbf{A}$ is positive semi-definite, then $SINR_j = SINR_{S_1,j}$, otherwise $SINR_j = SINR_{D,j}$.

Taking (15) into (13), the linear filter $\mathbf{c}_j$ can be designed for two cases separately. When matrix $\mathbf{A}$ is p.s.d, (12) can be reduced to

$$\max_{\mathbf{c}_j} \quad SINR_{S_1,j} \tag{16}$$

where

$$\begin{aligned} SINR_{S_1,j} &= \frac{PP_{R_j}|f_{1j}|^2|g_{jD}|^2|\mathbf{c}_j^H\mathbf{s}_1|^2}{PP_{R_j}|f_{1j}|^2\sum_{i\neq1}\left(|\mathbf{c}_j^H\mathbf{s}_i|^2+|g_{jD}|^2|\mathbf{c}_j^H\mathbf{s}_i|^2\right)+\left(P_{R_j}|f_{1j}|^2\mathbf{c}_j^H\mathbf{c}_j+1\right)} \\ &\approx \frac{P|f_{1j}|^2|g_{jD}|^2\mathbf{c}_j^H\mathbf{s}_1\mathbf{s}_1^H\mathbf{c}_j}{P|f_{1j}|^2\sum_{i\neq1}\left(|f_{ij}|^2\mathbf{c}_j^H\mathbf{s}_i\mathbf{s}_i^H\mathbf{c}_j+|g_{jD}|^2\mathbf{c}_j^H\mathbf{s}_i\mathbf{s}_i^H\mathbf{c}_j\right)+|f_{1j}|^2\mathbf{c}_j^H\mathbf{c}_j} \\ &= \frac{\mathbf{c}_j^H\left(P|g_{jD}|^2\mathbf{s}_1\mathbf{s}_1^H\right)\mathbf{c}_j}{\mathbf{c}_j^H\left[P\sum_{i\neq1}\left(|f_{ij}|^2+|g_{jD}|^2\right)\mathbf{s}_i\mathbf{s}_i^H+\mathbf{I}\right]\mathbf{c}_j} \end{aligned} \tag{17}$$

where the approximation in (17) is rational by assuming the effect of noise (i.e., factor 1 in the denominator) at source S_1 can be ignored in high SNR regimes. By modifying (17), the problem in (16) is rewritten as

$$\min_{\mathbf{c}_j} \frac{\mathbf{c}_j^H\left[P\sum_{i\neq1}\left(|f_{ij}|^2+|g_{jD}|^2\right)\mathbf{s}_i\mathbf{s}_i^H+\mathbf{I}\right]\mathbf{c}_j}{\mathbf{c}_j^H\left(P|g_{jD}|^2\mathbf{s}_1\mathbf{s}_1^H\right)\mathbf{c}_j} \tag{18}$$

Similar derivation procedure as in [10], the linear filer $\mathbf{c}_j$ can be found as

$$\mathbf{c}_j = \left[P\sum_{i\neq1}\left(|f_{ij}|^2+|g_{jD}|^2\right)\mathbf{s}_i\mathbf{s}_i^H+\mathbf{I}\right]^{-1}\sqrt{P}g_{jD}\mathbf{s}_1 \tag{19}$$

On the other hand, when matrix $\mathbf{A}$ is not p.s.d, (12) is reduced to

$$\max_{\mathbf{c}_j} \quad SINR_{D,j} \tag{20}$$

The same approximation in the first case is used, we can obtain the $SINR_{D,j}$ as

$$\begin{aligned} SINR_{D,j} &= \frac{PP_{R_j}|f_{1j}|^2|g_{jD}|^2|\mathbf{c}_j^H\mathbf{s}_1|^2}{PP_{R_j}|g_{jD}|^2\sum_{i\neq1}|f_{ij}|^2|\mathbf{c}_j^H\mathbf{s}_i|^2+\left(P_{R_j}|g_{jD}|^2\mathbf{c}_j^H\mathbf{c}_j+1\right)} \\ &\approx \frac{P|f_{1j}|^2|g_{jD}|^2|\mathbf{c}_j^H\mathbf{s}_1\mathbf{s}_1^H\mathbf{c}_j}{P|g_{jD}|^2\sum_{i\neq1}|f_{ij}|^2\mathbf{c}_j^H\mathbf{s}_i\mathbf{s}_i^H\mathbf{c}_j+|g_{jD}|^2\mathbf{c}_j^H\mathbf{c}_j} \\ &= \frac{\mathbf{c}_j^H\left(P|f_{1j}|^2\mathbf{s}_1\mathbf{s}_1^H\right)\mathbf{c}_j}{\mathbf{c}_j^H\left(P\sum_{i\neq1}|f_{ij}|^2\mathbf{s}_i\mathbf{s}_i^H+\mathbf{I}\right)\mathbf{c}_j} \end{aligned} \tag{21}$$

Performing the similar derivation as in the first case, the linear filter $\mathbf{c}_j$ can be found as

$$\mathbf{c}_j = \left[P\sum_{i\neq1}|f_{ij}|^2\mathbf{s}_i\mathbf{s}_i^H+\mathbf{I}\right]^{-1}\sqrt{P}f_{1j}\mathbf{s}_1 \tag{22}$$

As can be observed from (19) and (22), the linear filter $\mathbf{c}_j$ maximizes $SINR_j$ and is similar to MMSE detector.

B. Relay Selection

With the linear filter $\mathbf{c}_j$ found for two different cases, the problem in (9) is reduced to the following RS problem:

$$\max_{j\in\{1,\dots,N\}} SINR_j \tag{23}$$

The steps in conducting relay selection are as follows. The destination which knows all channel coefficients and the spreading sequences for different sources can select the optimum relay by calculating $SINR_j$ for $j=1,...,N$. First, the destination can examine the criterion in (15) to decide which one of $SINR_{S_1,j}$ and $SINR_{D,j}$ is smaller for each relay. Second, upon knowing which is the smaller one, the destination calculates the filter $\mathbf{c}_j$ and $SINR_j$ for $j=1,...,N$. Comparing all SINRs, the destination picks up the relay which results in the maximum SINR. Then, the destination broadcasts the best relay index to all relays over a control channel. Here, we assume the relays resemble base station, thus, they are capable of knowing all spreading sequences for different users. Therefore, the one hears its index can employ linear filer to obtain a new signal and transmit it, others do not hear their own indices will be quiet and not participate in relaying.

IV. Simulations

A. Simulation Setup

We present some numerical results to demonstrate the performance in terms of BER of our proposed algorithm. A multiuser two-way relay network employing CDMA is considered. The digital modulation used here is quadrature phase shift keying (QPSK). To best of our knowledge, the scenario in this work has not been discussed, hence no comparison between other studies and ours is made in the simulations. Here, we focus on simulating the effects of different parameters (e.g., the number of sources, the number of relays and the length of spreading sequences) in the network. The channel coefficients f_{ij} and g_{jD} for $i=1,...,M$ and $j=1,...,N$ in the simulations are generated as zero mean normal complex random variables with unit variance (i.e., $f_{ij}, g_{jD} \sim \mathcal{CN}(0,1)$). All noises at each node are assumed to be i.i.d Gaussian with zero-mean and unit variance (i.e., $n_{S_1}, n_D \sim \mathcal{CN}(0,1)$ and $\mathbf{n}_{R_j} \sim \mathcal{CN}(\mathbf{0},\mathbf{I})$). The spreading sequences are $K \times 1$ vectors with unit norm and generated randomly. All spreading sequences for different sources are assumed to be non-orthogonal. Noting that the power assumption here is presented in [11]. Let all nodes except the relays use half of total available power, and the remaining half power is used for the selected relay to transmit. Therefore, $2MP = 0.5P_T$ and $P_{t,R_j} = 0.5P_T$. Parameters M and N denote the number of users and relays, respectively. Parameter K stands for the length of spreading sequences.

B. Numerical Results

The effects of different parameters are presented in the following simulation results. In each figure, BER_{S_1} and BER_D denote the bit error rates at the desired user S_1 and the destination, respectively.

1) Number of Users: Fig. 2 shows the comparison of our proposed algorithm to an interference-free case (i.e., the number of user is one). As expected, the interference-free case is a lower bound for our work. Because of the effect of interference, full diversity order can not be achieved in our study. In other words, the BER does not decrease with the increase of SNR in our scheme since there is an error floor in high SNR regimes induced by interference. However, it is not the case for interference-free case, full diversity order can be achieved in this ideal scheme.

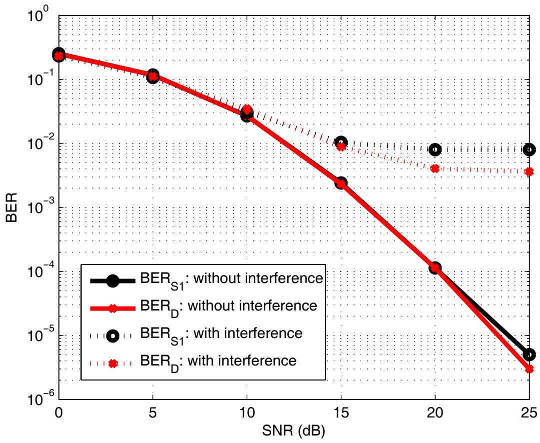
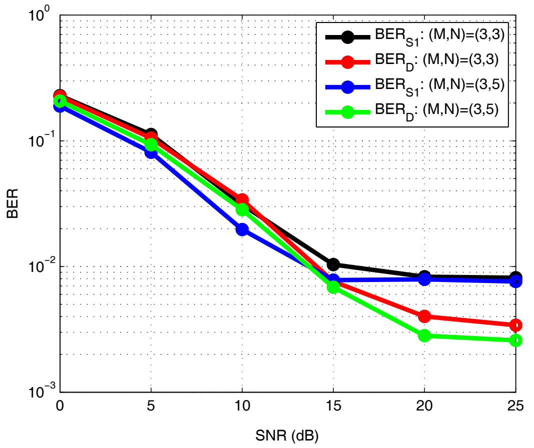
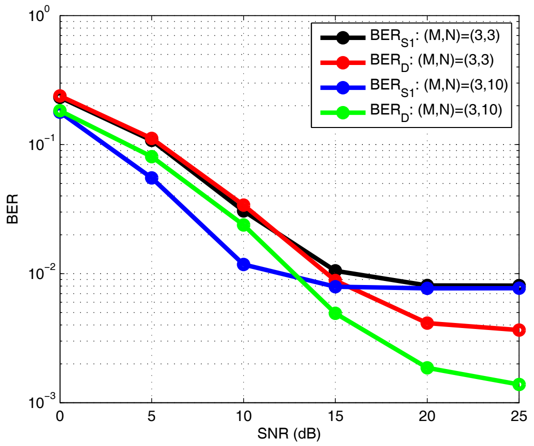


Fig. 2. Comparison of the proposed algorithm to an interference-free case.

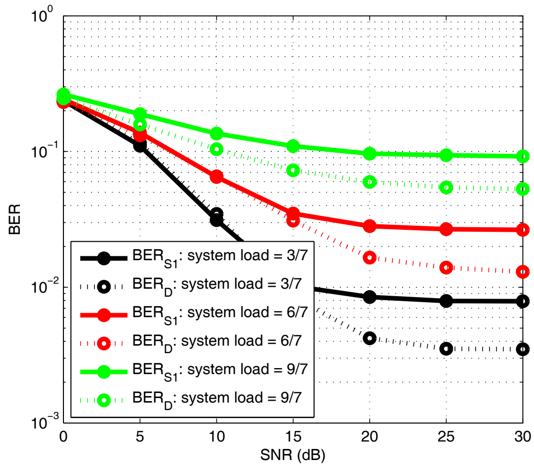


(a)

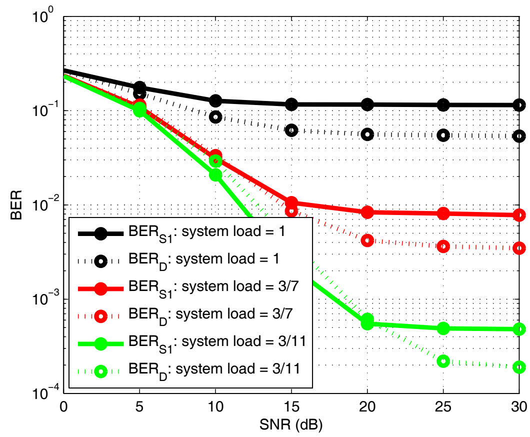


(b)

Fig. 3. Performances of multi-relay two-way network with multiuser interference. (a) BER of the system with the number of relays: $N = 3$ and $N = 5$. (b) BER of the system with the number of relays: $N = 3$ and $N = 10$.



(a)



(b)

Fig. 4. Performance of multi-relay two-way network with multiuser interference. (a) BER of the system with the number of users: $M = 3$, $M = 6$ and $M = 9$. (b) BER of the system with the length of spreading sequence: $K = 3$, $K = 7$ and $K = 11$.

2) Number of Relays: The simulation environment of this part is as follows: the number of users is 3, the length of spreading sequences is 7, and the number of relays is 5 in Fig. 3 (a) but 10 in (b). As expected, although full diversity order can not be achieved, the BER still decreases with an increase of SNR. Moreover, it is interesting to find that BER at the desired user S_1 encounters an error floor at SNR 15 dB when there exist 10 relays in the network. As a result, even more relays exist in the network, the BER at the destination when there exist 5 relays is still better than the BER at the desired user S_1 when there exist 10 relays in the network. One of the possible reasons may be the destination node can get more benefits from the self-interference cancelation compared to the node S_1. And in high SNR regimes, the effect of interference dominates the performance, thus, the interference mitigation is more important.

3) System Load: In CDMA system, system load is a benchmark parameter which stands for the performance of the system. Larger system load leads to the worse performance.

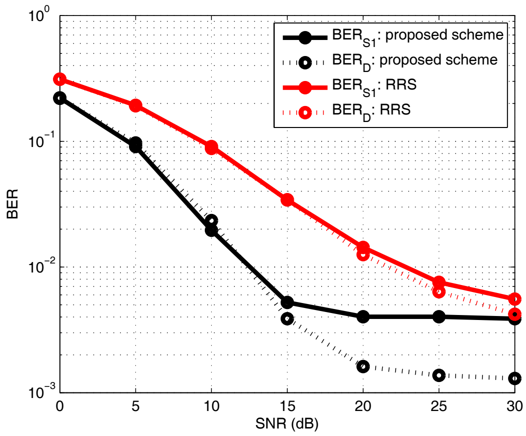


Fig. 5. Comparison of the proposed algorithm to random RS method.

The definition of the system load is

$$system \quad load = \frac{M}{K} \tag{24}$$

where M is the number of users and K is the length of spreading sequences. In this part, we make a comparison of the effect of different system loads. In Fig 4 (a), different numbers of users are compared. The simulation environment of Fig. 4 (a) is as follows: the numbers of users are 3, 6, and 9; the length of spreading sequences is 7; the number of relays is 3. The result shows that the existence of more users in the network degrades the performance. On the other hand, in Fig. 4 (b), different lengths of spreading sequences are compared. The simulation environment of Fig. 4 (b) is as follows: the number of users is 3; the lengths of spreading sequences are 3, 7, and 11; the number of relays is 3. According to the result, it indicates that the BER performance is better when the length of spreading sequence is longer. To conclude, the simulation results in Fig. 4 exhibit that the BER performance is better when the system load is smaller.

4) Different RS Methods: In this part, we compare our proposed algorithm with random RS method. Random RS technique means that the selection is conducted randomly without any criterion. The result in Fig. 5 shows that the proposed algorithm is much better than random RS approach in terms of BER. In high SNR regimes, the proposed algorithm outperforms the random RS method in terms of SNR by around 15 dB. It indicates that our proposed algorithm offers a selection gain indeed.

V. Conclusion

We have investigated the problem of RS in multiuser two-way cooperative relaying systems, which consists of multiple sources, multiple relays and a single destination, in this paper. Different from most existing work, we consider the multiuser interference when performing RS. The proposed RS approach is based on the $max\ min$ SINR criterion. The linear filter employed at each relay is designed to mitigate the interference. In the simulation results, we have shown the effectiveness of the proposed scheme with several different parameters including the numbers of users and relays, and the length of spreading sequences. Also, we compare the proposed method with the random RS approach. The result shows that the proposed method outperforms the random RS approach in terms of SNR by around 15 dB in high SNR regimes. This demonstrates that the proposed algorithm is an effective method to mitigating the interference while doing RS in multiuser multi-relay two-way relaying networks.

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