

Relay Selection Based on the Secrecy Rate Criterion for Physical-Layer Security in Buffer-Aided Relay Networks

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Abstract—In this paper, we investigate an opportunistic relay and jammer scheme along with relay selection algorithms based on the secrecy rate criterion in multiple-input multiple-output buffer-aided down link relay networks, which consist of one source, a number of relay nodes, legitimate users and eavesdroppers, with the constraints of physical layer security. The opportunistic relay and jammer scheme is employed to improve the transmission rate and different relay selection policies are performed to achieve better secrecy rate with the consideration of eavesdroppers. Among all the investigated relay selection policies, a relay selection policy which is developed to maximize the secrecy rate based on exhaustive searches outperforms other relay selection policies in terms of secrecy rate. Based on the secrecy rate criterion, we develop a relay selection algorithm without knowledge of the channels of the eavesdroppers. We also devise a greedy search algorithm based on the secrecy rate criterion to reduce the computational complexity of the exhaustive search technique. Simulations show the superiority of the secrecy rate criterion over competing approaches.

Index Terms—Physical layer security, relay selection, buffer relay systems

I. INTRODUCTION

Secure transmission is difficult to achieve in broadcast channels due to the nature of wireless communications. Traditional encryption techniques are implemented in the network layer with complex algorithms and high cost. To reduce such cost, researchers are exploring novel security techniques in the physical layer. Physical-layer security has been first illustrated by Shannon using an information theoretic viewpoint [1]. The feasibility of physical-layer security has been discussed by Shannon on a theoretical level in [1]. Later on in [2] a wire-tap channel, which can achieve positive secrecy rate, has been proposed by Wyner under the assumption that the users have a better statistical channel than eavesdroppers. Since then further research has been devoted to the wire-tap model and techniques such as broadcast channels [3], MIMO channels, artificial noise, beamforming as well as relay techniques. This paper focuses on relay techniques.

Recently, the concept of physical-layer security with multi-user wireless networks has been investigated [4]. Relay systems are an important evolution of secure transmission strategies and techniques to further improve the performance of

relay systems such as relay selection [5] and buffer-aided relay nodes [6] are drawing significant attention. Opportunistic relay schemes have been applied to buffer-aided systems [7], [8] and [9]. In opportunistic relay schemes, the inter-relay interference (IRI) is an important aspect that should be taken into account.

In our previous work [10], we have introduced an opportunistic relay and jammer scheme and investigated its potential for improving secrecy rate. In this work, we employ the same scheme and focus our research on different relay selection algorithms. Unlike the prior art which relies on the signal-to-interference-plus-noise (SINR) and channel state information [11] approaches, we examine the potential of using the secrecy rate as the criterion for the selection of relays. In particular, a relay selection strategy is developed to maximize the secrecy rate based on exhaustive searches. A greedy search algorithm is then developed to reduce the computational complexity of the exhaustive search approach.

This paper is organized as follows. Section II details the system model, describes the opportunistic relay and jammer buffer-aided relay system. We focus on the transmission from the source to the relays and from the relays to the users. Section III presents all investigated conventional as well as the proposed relay selection criterion, whereas Section IV details the proposed secrecy rate based criterion with partial channel information. Section V shows and discusses the numerical results, while the conclusions are drawn in Section VI.

II. SYSTEM MODEL AND PERFORMANCE METRICS

In this section, a brief introduction of the buffer-aided relay system model is given to describe the data transmission. The performance metrics illustrate the assessment of the proposed and existing techniques described in this paper.

A. System Model

Fig. 1 gives a description of a source node with N_t antennas that transmits the data streams to M users in the presence of N eavesdroppers. With T relays and K jammers, in each time slot, the selected relays will receive signals from both the source and the jammers. Each relay and jammer are equipped with N_i and N_k antennas. At the receiver side, each user and eavesdropper are equipped with N_r and N_e receive antennas. The quantities $\mathbf{H}_i \in \mathbb{C}^{N_i \times N_t}$ and $\mathbf{H}_e \in \mathbb{C}^{N_e \times N_t}$ denote the channel matrices of the i th relay and the e th

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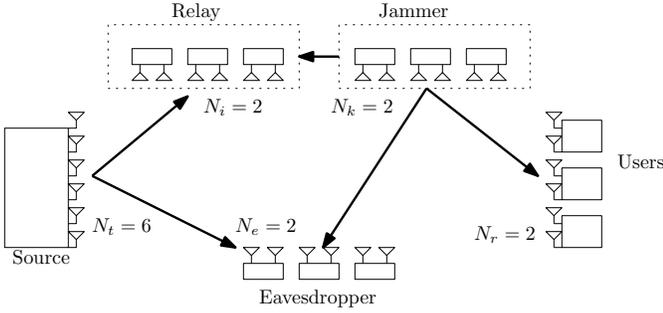


Fig. 1: System model of an MU-MIMO system with M users, N eavesdroppers T relays and K jammers

eavesdropper, respectively. The quantities $\mathbf{H}_{ke} \in \mathbb{C}^{N_e \times N_k}$ and $\mathbf{H}_{kr} \in \mathbb{C}^{N_r \times N_k}$ denote the channel matrices of the e th eavesdropper to the k th jammer and the r th user to the k th jammer, respectively. The channel between the k th relay to the i th relay is modeled by $\mathbf{H}_{ki} \in \mathbb{C}^{N_i \times N_k}$. To support M users transmission, the source is equipped with $N_t \geq N_r M$ antennas.

The vector $\mathbf{s}_r^{(t)} \in \mathbb{C}^{N_r \times 1}$ represents the data symbols to be transmitted corresponding to each user in time slot t . The total transmit signal at the transmitter can be expressed as

$$\mathbf{s}^{(t)} = \begin{bmatrix} \mathbf{s}_1^{(t)T} & \mathbf{s}_2^{(t)T} & \mathbf{s}_3^{(t)T} & \cdots & \mathbf{s}_M^{(t)T} \end{bmatrix}^T. \quad (1)$$

In prior work, several precoding techniques have been considered to eliminate the interference between different users [12]–[17]. In this work, we use linear zero-forcing precoding and the precoding matrix is described by

$$\mathbf{U}_i = \mathbf{H}_i^H (\mathbf{H}_i \mathbf{H}_i^H)^{-1}. \quad (2)$$

The channels of the selected jammers to the r th user are given by

$$\mathbf{H}_r^{(t)} = \begin{bmatrix} \mathbf{H}_{k_1 r}^{(t)T} & \mathbf{H}_{k_2 r}^{(t)T} & \mathbf{H}_{k_3 r}^{(t)T} & \cdots & \mathbf{H}_{k_M r}^{(t)T} \end{bmatrix}. \quad (3)$$

The channels of the jammers to the i th relay channel are

$$\mathbf{H}_{Ki}^{(t)} = \begin{bmatrix} \mathbf{H}_{k_1 i}^{(t)T} & \mathbf{H}_{k_2 i}^{(t)T} & \mathbf{H}_{k_3 i}^{(t)T} & \cdots & \mathbf{H}_{k_M i}^{(t)T} \end{bmatrix}. \quad (4)$$

To simplify the calculation, we assume that each relay will have the same antenna as each user which means $\mathbf{s}_i^{(t)} = \mathbf{s}_r^{(t)}$. In each phase, the received signal $\mathbf{y}_i^{(t)} \in \mathbb{C}^{N_i \times 1}$ at each relay node can be expressed as:

$$\mathbf{y}_i^{(t)} = \mathbf{H}_i \mathbf{U}_i \mathbf{s}_i^{(t)} + \sum_{j \neq i} \mathbf{H}_i \mathbf{U}_j \mathbf{s}_j^{(t)} + \mathbf{H}_{Ki}^{(t)} \mathbf{y}_k^{(pt)} + \mathbf{n}_i \quad (5)$$

In (5), the value pt represents the previous time slot when the signal is stored as a jamming signal in the buffer at the relay nodes. The term $\mathbf{H}_{Ki} \mathbf{y}_k^{(pt)}$ is regarded as the inter-relay interference (IRI) between the i th relay and K jammers and $\mathbf{y}_k^{(pt)}$ is determined as the jamming signal according to a SINR criterion as in [7]. With the theorem in [7], the IRI can be eliminated.

The channel of the jammers to the e th eavesdropper is described by

$$\mathbf{H}_{Ke}^{(t)} = \begin{bmatrix} \mathbf{H}_{k_1 e}^{(t)T} & \mathbf{H}_{k_2 e}^{(t)T} & \mathbf{H}_{k_3 e}^{(t)T} & \cdots & \mathbf{H}_{k_M e}^{(t)T} \end{bmatrix}. \quad (6)$$

The received signal at the e th eavesdropper is given by

$$\mathbf{y}_e^{(t)} = \mathbf{H}_e \mathbf{U}_i \mathbf{s}_i^{(t)} + \sum_{j \neq i} \mathbf{H}_e \mathbf{U}_j \mathbf{s}_j^{(t)} + \mathbf{H}_{Ke}^{(t)} \mathbf{y}_k^{(pt)} + \mathbf{n}_e. \quad (7)$$

For the eavesdropper, the term $\mathbf{H}_{Ke}^{(t)} \mathbf{y}_k^{(pt)}$ acts as the jamming signal and this jamming signal can not be removed without the knowledge of the channel from the k th jammer to the e th eavesdropper.

In (5) and (7), the IRI term between the relay nodes or the jamming signal to the eavesdropper is simultaneously the transmit signal from the relay nodes to the destination. We assume that the transmit signal from the relay nodes is given by

$$\mathbf{r}^{(t)} = \begin{bmatrix} \mathbf{y}_1^{(pt_1)T} & \mathbf{y}_2^{(pt_2)T} & \mathbf{y}_3^{(pt_3)T} & \cdots & \mathbf{y}_T^{(pt_T)T} \end{bmatrix}^T. \quad (8)$$

Note that pt represents the previous time slot and due to the characteristics of buffer relay nodes, the values can be different for each relay node. The received signal at the destination can be expressed as:

$$\mathbf{y}_r^{(t)} = \mathbf{H}_r \mathbf{y}_k^{(pt_k)} + \sum_{j \neq r} \mathbf{H}_r \mathbf{y}_j^{(pt_j)} + \mathbf{n}_r. \quad (9)$$

III. SELECTION WITH JAMMING FUNCTION RELAYS IN MULTIUSER MIMO BUFFER-AIDED RELAY SYSTEM

In this section, a novel selection approach with jamming function relays is introduced. We first consider a simple single-antenna scenario and then the selection approach is extended to a MIMO scenario. After that, a further exploration of the relay selection in a multiuser MIMO buffer-aided relay system is undertaken.

A. Relay Selection Criteria

1) *Conventional Relay Selection Criterion:* The conventional selection relies only on the knowledge of channel information between the source to the relays and the relays to the users. In [18], a max-min relay selection is considered as the optimal selection scheme for conventional decode-and-forward (DF) relay setups. With a single-antenna scenario the relay selection policy is given as:

$$R_i^* = \arg \max_{R_i \in \Psi} \min(\|h_{S,R_i}\|^2, \|h_{R_i,D}\|^2), \quad (10)$$

where h_{S,R_k} is the link between the source to the relay and $h_{R_k,D}$ is the relay to the destination.

With the consideration of the eavesdropper, a max-ratio selection policy is proposed in [12] and given by

$$R_i^{\max\text{-ratio}} = \arg \max_{R_i \in \Psi} (\eta_{\max\text{-ratio}_1}, \eta_{\max\text{-ratio}_2}) \quad (11)$$

with

$$\eta_{\max\text{-ratio}_1} = \frac{\max_{R_i \in \Psi: \varphi(Q_p) \neq L} \|h_{S,R_i}\|^2}{\|h_{se}\|^2} \quad (12)$$

$$\eta_{\max\text{-ratio}_2} = \max_{R_i \in \Psi: \varphi(Q_p) \neq 0} \frac{\|h_{R_i,D}\|^2}{\|h_{R_i,e}\|^2} \quad (13)$$

The aforementioned relay selection are based on the channel state information. In [11] there is also a conventional selection as well as optimal selection based on the SINR criterion.

2) *Maximum Likelihood (ML) Relay Selection Criterion:* Based on the conventional relay selection criterion, we substitute the channel state information with the ML rule which can be expressed as:

$$R_i^{\text{ML}} = \arg \min_{R_i \in \Psi} (\eta_{\text{ML}_1}, \eta_{\text{ML}_2}) \quad (14)$$

with

$$\eta_{\text{ML}_1} = \min_{R_i \in \Psi: \varphi(Q_p) \neq L} \|y_i - h_{S,R_i} s_i\| \quad (15)$$

$$\eta_{\text{ML}_2} = \min_{R_i \in \Psi: \varphi(Q_p) \neq 0} \|y_r - h_{R_i,D} y_k^{(pt)}\| \quad (16)$$

the ML relay selection selects the relay which gives the minimum ML rule value.

3) *Secrecy Rate Based Relay Selection Criterion:* Similar to the ML relay selection criterion, the secrecy rate (SR) relay selection criterion is proposed to achieve better secrecy rate performance. The selection procedure can be expressed as:

$$R_i^{\text{SR}} = \arg \min_{R_i \in \Psi} (\eta_{\text{SR}_1}, \eta_{\text{SR}_2}) \quad (17)$$

with

$$\eta_{\text{SR}_1} = \max_{R_i \in \Psi: \varphi(Q_p) \neq L} \frac{\|1 + h_{S,R_i} s_i\|}{\|1 + h_{S,e} s_i\|} \quad (18)$$

$$\eta_{\text{SR}_2} = \min_{R_i \in \Psi: \varphi(Q_p) \neq 0} \frac{\|1 + h_{R_i,D} y_k^{(pt)}\|}{\|1 + h_{R_i,e} y_k^{(pt)}\|} \quad (19)$$

Based on the single-antenna scenario, the criterion for MIMO system is given by

$$\phi_m = \arg \max_{m \in \Psi} \left((\mathbf{I} + \mathbf{\Gamma}_{e,i}^{(t)})^{-1} (\mathbf{I} + \mathbf{\Gamma}_{r,i}^{(t)}) \right), \quad (20)$$

where $\mathbf{\Gamma}_{r,i}^{(t)}$ is given as:

$$\mathbf{\Gamma}_{r,i}^{(t)} = \sum_{k=1}^{k=K} \frac{P}{N_k} \mathbf{H}_{kr} \mathbf{H}_{kr}^H (\mathbf{I} + \frac{P}{N_t} \mathbf{H}_i^{(pt)} \mathbf{H}_i^{(pt)H}). \quad (21)$$

and

$$\mathbf{\Gamma}_{e,i}^{(t)} = (\mathbf{I} + \mathbf{\Delta})^{-1} \frac{P}{N_t} \mathbf{H}_e \mathbf{H}_e^H, \quad (22)$$

where

$$\mathbf{\Delta} = \sum_{e=1}^N \sum_{k=1}^K \frac{P}{N_k} \mathbf{H}_{ke} \mathbf{H}_{ke}^H (\mathbf{I} + \frac{P}{N_t} \mathbf{H}_i^{(pt)} \mathbf{H}_i^{(pt)H}). \quad (23)$$

4) *Proposed Secrecy Rate Based Relay Selection Criterion without Knowledge of Eavesdroppers:* Based on (5) and (7), the covariance matrix of the interference and the signal can be obtained as $\mathbf{R}_I = \sum_{j \neq i} \mathbf{U}_j \mathbf{s}_j^{(t)} \mathbf{s}_j^{(t)H} \mathbf{U}_j^H$ and $\mathbf{R}_d = \mathbf{U}_i \mathbf{s}_i^{(t)} \mathbf{s}_i^{(t)H} \mathbf{U}_i^H$. When the matrices are square and have equal size we can obtain the proposed secrecy rate based relay selection criterion as described by

$$\phi_i = \max_i \left[\log \left(\det \left[\mathbf{I} + \mathbf{R}_I + (\mathbf{H}_i \mathbf{R}_d \mathbf{H}_i^H) \right] \right) - \log \left(\det \left[\mathbf{I} + \mathbf{R}_d + (\mathbf{H}_i \mathbf{R}_I \mathbf{H}_i^H) \right] \right) \right], \quad (24)$$

which can be achieved without knowledge of the channels of the eavesdroppers. The details of the derivation of the above expression are given in Section IV.

B. Greedy Algorithm in Relay Selection

When the relay selection criterion is determined, we will give an example using the greedy search algorithm. Here we choose relays according to the SR criterion. When the K relays that forward the signals to the users are selected, the relays used for signal reception are chosen based on the SR criterion, as given by

$$\phi_m = \arg \max_{m \in \Psi} \left((\mathbf{I} + \mathbf{\Gamma}_{e,i}^{(t)})^{-1} (\mathbf{I} + \mathbf{\Gamma}_m^{(t)}) \right), \quad (25)$$

where ϕ_m represents the selected relays and $\mathbf{\Gamma}_m^{(t)}$ is the SINR corresponding to the m th relay which is given by

$$\mathbf{\Gamma}_m^{(t)} = (\mathbf{I} + \mathbf{\Delta}'_m)^{-1} (\mathbf{H}_m \mathbf{H}_m^H), \quad (26)$$

where

$$\mathbf{\Delta}'_m = \sum_{k=1}^K \mathbf{H}_{km} \mathbf{H}_m^{(pt)} \mathbf{H}_m^{(pt)H} \mathbf{H}_{km}^H, \quad (27)$$

with the SINR calculated for the e th eavesdropper described by

$$\mathbf{\Gamma}_{e,i}^{(t)} = (\mathbf{I} + \mathbf{\Delta}'_e)^{-1} \left(\frac{P}{N_t} \mathbf{H}_e \mathbf{H}_e^H \right), \quad (28)$$

where

$$\mathbf{\Delta}'_e = \sum_{e=1}^N \sum_{k=1}^K \frac{P}{N_k} \mathbf{H}_{ke} \mathbf{H}_{ke}^H (\mathbf{I} + \mathbf{\xi}), \quad (29)$$

and

$$\mathbf{\xi} = \frac{P}{N_t} \mathbf{H}_m^{(pt)} \mathbf{H}_m^{(pt)H}, \quad (30)$$

The main steps are described in Algorithm 1.

IV. RELAY SELECTION CRITERION ANALYSIS

The details of the conventional relay selection criterion, ML relay selection criterion as well as the secrecy rate-based relay selection criterion have been introduced in Section III. Following this, here we will mainly focus on the proposed secrecy rate based relay selection criterion with partial channel information. To simplify the derivation, in the following formulas, we did not take interference from jammers into

Algorithm 1 Greedy Algorithm

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for  $k = 1 : T$  do
  for  $m = 1 : M$  do
     $\mathbf{\Gamma}_m^{(t)} = (\mathbf{I} + \mathbf{\Delta}'_m)^{-1} (\mathbf{H}_m \mathbf{H}_m^H)$ 
     $\boldsymbol{\xi} = \frac{P}{N_e} \mathbf{H}_m^{(pt)} \mathbf{H}_m^{(pt)H}$ 
     $\mathbf{\Gamma}_{e,i}^{(t)} = (\mathbf{I} + \mathbf{\Delta}'_e)^{-1} (\frac{P}{N_t} \mathbf{H}_e \mathbf{H}_e^H)$ 
     $\phi_m = \arg \max_{m \in \Psi} \det \left( (\mathbf{I} + \mathbf{\Gamma}_{e,i}^{(t)})^{-1} (\mathbf{I} + \mathbf{\Gamma}_m^{(t)}) \right)$ 
  end for
   $k = \phi_m$ 
end for

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consideration and we take the transmission from the source to the relay as an example. Therefore, we have

$$\mathbf{\Gamma}_{r,i} = (\mathbf{H}_i \mathbf{R}_I \mathbf{H}_i^H)^{-1} (\mathbf{H}_i \mathbf{R}_d \mathbf{H}_i^H), \quad (31)$$

and

$$\mathbf{\Gamma}_{e,i} = (\mathbf{H}_e \mathbf{R}_I \mathbf{H}_e^H)^{-1} (\mathbf{H}_e \mathbf{R}_d \mathbf{H}_e^H), \quad (32)$$

From the original expression for the MIMO secrecy rate performance and our system structure, we can write the expression as

$$\phi_i = \arg \max_{i \in \Psi} \left\{ \log \left[\frac{\det(\mathbf{I} + \mathbf{\Gamma}_{r,i})}{\det(\mathbf{I} + \mathbf{\Gamma}_{e,i})} \right] \right\}. \quad (33)$$

Since the maximization of the log of an argument is equivalent to the maximization of the argument (33) can be simplified to

$$\phi_i = \arg \max_{i \in \Psi} \left\{ \frac{\det(\mathbf{I} + \mathbf{\Gamma}_{r,i})}{\det(\mathbf{I} + \mathbf{\Gamma}_{e,i})} \right\}, \quad (34)$$

Similar to the max-ratio criterion expressed in [12], in order to release the assumption of eavesdroppers channel, instead of (34) we consider the following criterion:

$$\phi_i = \arg \max_{i \in \Psi} \left\{ \frac{\det(\mathbf{\Gamma}_{r,i})}{\det(\mathbf{\Gamma}_{e,i})} \right\}, \quad (35)$$

which can be rewritten as

$$\phi_i = \arg \max_{i \in \Psi} \left\{ \frac{\det[(\mathbf{H}_i \mathbf{R}_I \mathbf{H}_i^H)^{-1} (\mathbf{H}_i \mathbf{R}_d \mathbf{H}_i^H)]}{\det[(\mathbf{H}_e \mathbf{R}_I \mathbf{H}_e^H)^{-1} (\mathbf{H}_e \mathbf{R}_d \mathbf{H}_e^H)]} \right\}, \quad (36)$$

Using linear algebra properties and by further manipulation, we arrive at

$$\phi_i = \arg \max_{i \in \Psi} \left\{ \frac{\det[(\mathbf{H}_e \mathbf{R}_I \mathbf{H}_e^H) (\mathbf{H}_i \mathbf{R}_d \mathbf{H}_i^H)]}{\det[(\mathbf{H}_i \mathbf{R}_I \mathbf{H}_i^H) (\mathbf{H}_e \mathbf{R}_d \mathbf{H}_e^H)]} \right\}, \quad (37)$$

If and only if the matrices are square and have equal size, we can write

$$\phi_i = \arg \max_{i \in \Psi} \left\{ \frac{\det(\mathbf{H}_e) \det(\mathbf{R}_I) \det(\mathbf{H}_e^H)}{\det(\mathbf{H}_e) \det(\mathbf{R}_d) \det(\mathbf{H}_e^H)} \times \frac{\det(\mathbf{H}_i \mathbf{R}_d \mathbf{H}_i^H)}{\det(\mathbf{H}_i \mathbf{R}_I \mathbf{H}_i^H)} \right\} \quad (38)$$

In the above expression, the determinant of the channels of the eavesdroppers can be eliminated, resulting in

$$\phi_i = \arg \max_{i \in \Psi} \left\{ \frac{\det(\mathbf{R}_I) \det(\mathbf{I} + \mathbf{H}_i \mathbf{R}_d \mathbf{H}_i^H)}{\det(\mathbf{R}_d) \det(\mathbf{I} + \mathbf{H}_i \mathbf{R}_I \mathbf{H}_i^H)} \right\}, \quad (39)$$

By adding the log to (39), we obtain

$$\phi_i = \arg \max_{i \in \Psi} \left\{ \log \left(\frac{\det(\mathbf{R}_I) \det(\mathbf{I} + \mathbf{H}_i \mathbf{R}_d \mathbf{H}_i^H)}{\det(\mathbf{R}_d) \det(\mathbf{I} + \mathbf{H}_i \mathbf{R}_I \mathbf{H}_i^H)} \right) \right\}, \quad (40)$$

which is equivalent to (24). Here we have the results for equal size channels. When the channels have different sizes we can add zero elements into the channel matrix and we can still obtain the same result as equal size channels.

V. SIMULATION RESULTS

In the simulation of the multiuser MIMO scenario, the transmitter is equipped with $N_t = 6$ antennas and each relay node is equipped with $N_i = N_k = 2$ antennas for receiving or transmitting signals. Each user is equipped with $N_r = 2$ antennas and the number of users is set to $M = 3$. In this scenario, $N = 3$ eavesdroppers equipped with $N_e = 2$ antennas each are also considered in the system. In order to mitigate the interference, a zero-forcing precoding technique is implemented at the source and also at the relays. To simplify the transmission scenario, in the selection we assume the number of selected relays and jammers are the same, which means we have $T = K$. In all the simulations, all the channels are generated as a flat-fading channel.

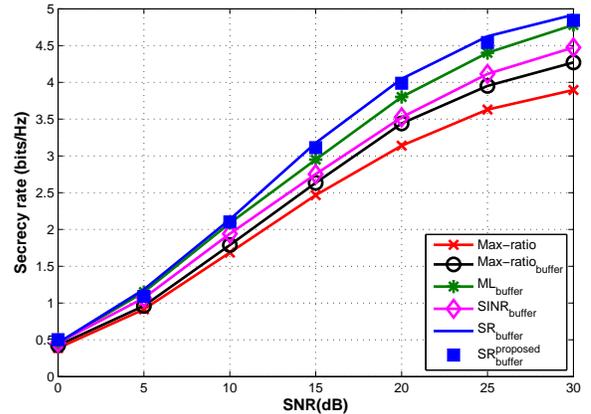


Fig. 2: Single-antenna secrecy rate with different thresholds

In Fig. 2, different relay selection criteria are compared in a single-antenna scenario. The secrecy rate performance has an improvement if buffers are employed in the relay nodes. Among all the investigated relay selection criteria, SR relay selection can achieve the best secrecy rate performance. Interestingly, this approach is typically not used because of the need for knowledge about the channels of the eavesdroppers.

In Fig. 3, with IRI cancellation the secrecy rate is better than the one without IRI cancellation. Compared with a single-antenna scenario, the multi-user MIMO system contributes to the overall improvement in the secrecy rate.

VI. CONCLUSION

In this work, we have employed an opportunistic relay and jammer scheme to enhance the physical-layer secrecy

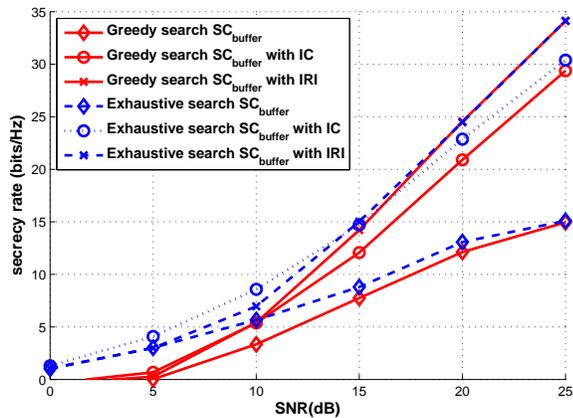


Fig. 3: Multi-user system scenario

rate performance. The proposed secrecy rate relay selection policy contributes to the improvement of the secrecy rate performance. Simulation results indicate that the secrecy rate criterion relay selection policy achieves the best secrecy rate performance and the greedy search can approach a higher secrecy rate performance in a multiuser MIMO relay system than existing buffer-aided relay systems.

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