Journal of Engineering Technology

ASEE AMERICAN SOCIETY FOR ENGINEERING EDUCATION

Volume 6, Special Issue (Emerging Trends in Engineering Technology) March. 2018, PP. 31-49

RESEARCH ARTICLE -ENGINEERNG TECHNOLOGY

Guiding Blind Transmitters: Relay-aided Topological Interference Alignment for K-User Downlink MIMO Channel.

Poongundran Selvaprabhu[1], Sunil Chinnadurai[1], MD.Abdul Latif Sarker[1], Kil To Chong[1] and Moon Ho Lee[1]*

[1]Department of Electronics and Information Engineering, Chonbuk National University, Jeonju, South Korea.
*Corresponding author: Moon Ho Lee

Abstract: In this paper, we characterize multi-user broadcast interference relay channels that are managed using multi-antenna interference alignment strategies. A new transmission method is proposed, which we refer to as the relay space-time interference alignment (R-STIA) technique, that supports K-user multiple-input and multiple-output (MIMO) interference relay channels with multiple antennas at the transmitter and relay. By introducing additional receivers and limited channel state information at the relay (CSIR), knowledge of the network settings is used to recover interference signals from the source and relay. Conventional approaches that detect symbols in the presence of interference require the use of optimal reception techniques at the transmitter, such as the linear minimum mean square error (MMSE) technique. In contrast, the R-STIA technique is applied to the interference signals so that the received signal information can be aligned and decoded perfectly at all receivers. We implement the Chordal distance scheduling algorithm at the destination to minimize the distance between the source and relay precoders, which aids in the measurement of the orthogonality between different users. Since the proposed scheme relies on limited CSIR knowledge, it can be used to efficiently reconstruct the interference signals at additional unintended receivers. Furthermore, we show that the computational complexity analysis for the proposed Chordal distance scheduling algorithm is compared with existing optimal, suboptimal scheduling algorithms. The numerical results show that the proposed R-STIA technique and Chordal distance scheduling algorithm significantly increase the sum-rate performance and reduces run time compared with existing MIMO broadcast channel schemes.

Keywords: K-user MIMO downlink relay channel; minimum mean square error(MMSE); interference alignment; limited CSIR knowledge; Chordal distance.

I. Introduction

When optimizing the performance of wireless broadcast channels, it is essential for the transmitter to have knowledge of the channel state information (CSI). This is particularly true for K-user multiple-input and multiple-output (MIMO) broadcast channels (BCs) with a shared relay. The authors in [1], [2] used outdated channel state information to design a beam forming matrix and multiuser interference signals for the space-time interference alignment (STIA) technique. They reported that for fully-connected interference networks where the transmitter and relay are equipped with multiple antennas, the received signals are forwarded without delay to the receiver [3] and outdated CSI from all transmitters is sent back to the relay after some processing delay for use in estimating the current CSI. In [4] and [5], the authors reported that each receiver can pass decoded messages to other receivers. They also evaluated the topology interference management with message passing (TIMMP) technique for partially connected BCs in which the transmitter only has access to the topological information. Under certain conditions, the minimum mean square error (MMSE) pre-equalization method was employed to encode the transmitted signal information, while the interference signals were recovered at the receiver using the Alamouti code with the precoded spatial-multiplexing technique [6]– [8]. Reference [9]-[13] introduces the concept of retrospective interference alignment and the ability of spatial multiplexing techniques to reconstruct interference signals using outdated knowledge of the CSI at the transmitter (CSIT). In particular [14]- [16], the authors evaluated the downlink performance of cell edge users with quasiorthogonal space-time codes, and the MIMO system performance was evaluated without an inter-cell interference coordination scheme using cooperative base stations. Furthermore, in [17], [20], the authors discussed topological interference alignment for MIMO broadcast channels using the span interference alignment method and multiple relays. In this method, the desired signal information is recovered without knowledge of the CSIT. The authors in [21] - [27] investigated the K-user optimal sum-rate for the abundant power allocation technique and determined that the allocated power for the source and relay was proportional to P and P^2, respectively. A limitation of the above techniques is that it is difficult to use them to reconstruct a linear combination of undesired symbols due to the distributed nature of the information and the delayed knowledge of the CSIT.

The common assumption in previous works is that multiple relays, knowledge of all transmitted signals, and synchronization between the transmitter nodes or delayed CSI knowledge, are required to reconstruct the desired signal information at the receiver. Nevertheless, the aforementioned techniques are capable of delivering high throughput for K-user multi-input-single-output (MISO) interference channels, although at the receiver, the complexity is extremely high and the signal strength of the recovered signal is low. The main purpose of the proposed relay space-time transmission technique is to provide assistance in aligning the interference signals in both the time and space domains based on knowledge of the limited channel state information at the relay (CSIR). An important feature of this study is to recover the interference signals from an unknown receiver on the basis of imperfect channel knowledge. The system model shown in Fig. 1 has N_{tx} transmitters and N_R relays that are multiple antennas, whereas the receivers N_{rx} consist of a single antenna. To recover the interference signals, a combination of two unknown co-interference receiver signals from the transmitter and relay facilitates the recovery of the desired signal information. The recovered information is employed to increase the signal strength by efficiently incorporating two unknown transmitter and relay signals as per the relay space-time alignment technique. Furthermore, the proposed technique does not require proper CSIT knowledge, but only relies on imperfect CSIR knowledge, and the multiple antennas at the transmitter and relay are sufficient to allow the receiver to recover the desired signal information for K-user MIMO broadcast relay interference channels.

A. Contribution

The main contributions of this paper are summarized as follows:

- ❖ The performance of the zero forcing linear precoding method ($ZF-LP$) for MIMO-BCs degrades as the number of antennas at the base station (BS) increases. To take advantage of the multiple antennas at the base station, we propose to apply an MMSE linear precoder method to the MIMO BCs.

- The power allocation for user scheduling at the transmitter side actives only two transmitters over each case described in Section IV, which allows the sum-rate strategy to be maximized.
- We describe the proposed scheme for $K = 3$ users in which two transmitters are active while the other is silent. The term γ represents the total transmitter power constraint, i.e., a power normalization factor, for the MMSE linear precoder.
- In contrast to the conventional approaches described in [1], by suggesting additional receivers, the proposed scheme improves the recovered signal strength by efficiently incorporating two unknown receiver signals based on a space-time alignment technique. Among several possible techniques, the R-STIA method is the best technique for recovering the desired signal information despite imperfect CSIR knowledge.
- Therefore, we focus on a simple Alamouti space-time transmission scheme for the asynchronous transmitter cooperative system, which provides full diversity and very low complexity decoding algorithm.
- The computational complexity analysis for the proposed Chordal distance scheduling algorithm is compared with existing algorithms such as Frobenius norm, Water-filling, Optimal scheduling and Suboptimal scheduling Algorithms.
- In order to minimize the distance between the source and relay precoders, the Chordal distance scheduling algorithm is used at the destination. Furthermore, the results of the numerical analysis show that the proposed R-STIA technique achieve high sum-rate when compared to existing MIMO broadcast channel schemes.

B. Organization

The remainder of this paper is organized as follows. Section II defines the system model and definitions for K-user MIMO interference channel model with a relay. In section III, the proposed Relay-aided three user MIMO channel is characterized. In section IV, we describe precoding for the spatial-multiplexing MIMO channel that provides assistance in recovering a linear combination of the intended and unintended symbols from the transmitter and relay. Section V describe aligning interference: relay space-time transmission scheme using the Alamouti space-time relay transmission technique, and the Chordal based scheduling algorithm and prior work is briefly discussed. In Section VI, we compute the computational complexity analysis for the proposed chordal distance scheduling algorithm existing scheduling algorithms. In section VII, describes numerical results for sum-rate compression between the different MIMO scheduling schemes verses the proposed R-STIA technique and run-time comparison for Chordal distance scheduling algorithm. Finally, the paper is concluded in Section VIII.

II. **System model and Definitions**

Fig. 1 depicts a K-user MIMO interference channel model with a shared relay, which is a perfect example for illustrating the scenario in which BS shares information with associated users using a shared relay. In this example, the transmitter N_{tx} and relay N_R have multiple antennas that transmit independent messages to a single receiver antenna N_{rx}.

In our proposed method, we assume that the relay functions in a half-duplex amplify and forward mode, and forwards an amplified version of the transmitted signal to the receiver after a processing delay [1]. In addition, the

Journal of Engineering Technology

Volume 6, Special Issue (Emerging Trends in Engineering Technology) March. 2018, PP. 31-49

RESEARCH ARTICLE -ENGINEERNG TECHNOLOGY

relay depends only on past received signals, but not on the current received signals. The term $\mathbf{X}^{[K]}[n]$ denotes the transmitted signal received from source S_i, where $\mathbf{X}^{[k]}[n] \in C^{\mathbf{Ntx}\times 1}$ represents the signal sent by transmitter K and $\mathbf{h}^{K}[n]^T = [h_1^k[n], ..., h_{N_t}^k[n]]$ represents the vector transmitted to user K. The term $\mathbf{X}^{[R]}[n]$ represents the relay signal from transmitter $\mathbf{X}^{[K]}[n]$, where $\mathbf{X}^{[R]}[n] \in C^{\mathbf{N}\times 1}$ indicates the signal sent by the relay and $\mathbf{h}^{R}[n]^T = [h_1^R[n], ..., h_{N_t}^R[n]]$ represents the relay channel vector sent to receiver K. We assume that the channel matrix $\mathbf{H}^{[R,K]}n$ contains independent and identically distributed (i.i.d.) complex Gaussian signals with zero mean and unit variance.

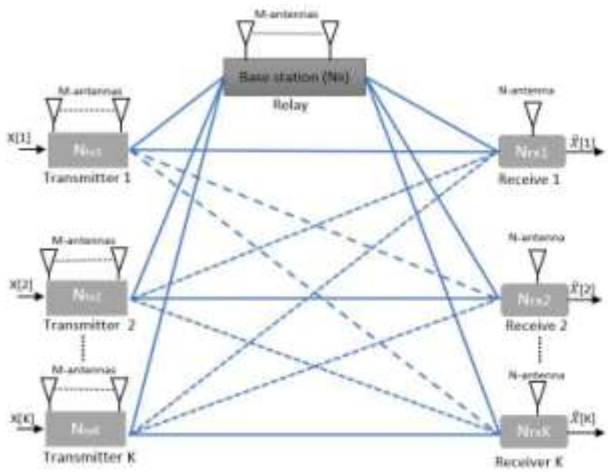

Fig. 1. Example of a K-user MIMO interference channel model with a relay.

The input-output relationship can represented as follows:

$$\mathrm{Y}_j^k(n) = \mathbf{h}_{j,j}^{[k,k]^T}\mathbf{x}_j^k(n) + \mathbf{h}_{j,j}^{[k,R]^T}\mathbf{x}_j^R(n) + \sum_{j=1, j\neq k}^{K}\mathbf{h}_{j,i}^{[k,j]^T}\mathbf{x}_i^j(n) + Z_j^{[k]}(n), \quad (1)$$

$$\mathrm{Y}_j^R(n) = \mathbf{h}_j^{[R,k]}\mathbf{x}_j^k(n) + Z_j^{[R]}, \quad (2)$$

where $\mathrm{Y}_j^k(n)$ and $\mathrm{Y}_j^R(n)$ are the k^{th} received and relay signals, respectively, from the n^th channel use, and $Z_j^{[k]}(n), Z_j^{[R]}$ are the respective k^{th} receiver and relay additive Gaussian noise signals.

The above listed decoding order is designed to achieve interference cancellation. The achievable sum-rate for the proposed K-user MIMO relay interference channel model [21], [22] is as follows:

$$R_K \leq \log(1 + \frac{\| H_{j,j} \|^2 P + \| H_{R_j} \|^2 (\frac{P_R}{2})}{\| H_{j,i} \|^2 P + 1} + \frac{2\alpha \| H_{j,j} \| \| H_{R_j} \| \sqrt{P(\frac{P_R}{2})}}{\| H_{j,i} \|^2 P + 1}). \quad (3)$$

Journal of Engineering Technology

Volume 6, Special Issue (Emerging Trends in Engineering Technology) March. 2018, PP. 31-49

RESEARCH ARTICLE -ENGINEERNG TECHNOLOGY

The achievable rate for the transmitter and receiver pairs defined for K[th] user is:

$$r^{[k]} = \limsup_{P\to\infty} \frac{R_K(P)}{\log(P)}, \tag{4}$$

where $P = SINR\times\sigma^2$ and $R_K(P)$ signal-to-interference plus noise ratio (SINR) indicates the achievable rate of $W^{[k]}$ under the average power constraint P.

Next, the transmitter $E(\|X^{[K]}[n]\|^2) \leq P$ and relay signals $E(\|X^{[R]}[n]\|^2) \leq P_R^2$ that are subject to the average power constraint are briefly described. The fraction of interference power for the desired signal is:

$$q^{avg} = \frac{1}{k}\sum_{k=1}^{k} \sigma_k, \tag{5}$$

Definition: (Chordal distance scheduling algorithm). A cycle is a set of vertices and the distance metric between subspaces, and the Grassmannian space $G(m,n)$ is the set of all dimensional subspace elements. The Chordal distance between planes A and B is given by [14], where $_F$ represents Frobenius norm:

$$d_{\mathrm{Chordal}}(A,B) = \frac{1}{\sqrt{2}} \parallel A_0 A_0^T - B_0 B_0{}^T \parallel_F. \tag{6}$$

III. Relay-Aided Three User MIMO Channel

In this section, we propose a simple three user network topology with a shared relay, as shown in Fig. 2, 3, 4. In our proposed scheme, the special case for K = 3 users is considered, where the transmitter N_{tx} and relay N_R have multiple antennas, and the number of antennas at the receiver is $N_{rx} = 1$.

$$\hat{\mathbf{X}}^{[\mathbf{K}]}[n] = \sum_{k=1}^{3} \mathbf{h}_n^{[k]}[k]\mathbf{u}_n^{[k]}. \tag{7}$$

By applying the space time relay beamforming method, the shared relay forwards the received signals while all three transmitters remain silent. The beamforming matrix can carry only two symbols for receiver $k \in \{1,2,3\}$, which is denoted

$\mathbf{V}^{[k]} = [\mathbf{V}_k^{[1]}, \mathbf{V}_k^{[2]}, \mathbf{V}_k^{[3]}] \in \mathbb{C}^{N_{tx}\times N_{tx}}$, and the transmitter signal vector at the relay is given by:

$$\begin{aligned}\hat{\mathbf{X}}^{[R]}[n] =& \gamma\,(\mathbf{V}_1^{[1]}\hat{\mathbf{u}}_1^{[1]} + \mathbf{V}_2^{[1]}\hat{\mathbf{u}}_2^{[1]}) \\ &+\gamma(\mathbf{V}_1^{[2]}\hat{\mathbf{u}}_1^{[2]}+\mathbf{V}_2^{[2]}\hat{\mathbf{u}}_2^{[2]})+\gamma(\mathbf{V}_1^{[3]}\hat{\mathbf{u}}_1^{[3]}+\mathbf{V}_2^{[3]}\hat{\mathbf{u}}_2^{[3]}), \\ =& \gamma\mathbf{V}_1^{[1]}\mathbf{u}_1^{[1]} + \gamma\mathbf{V}_2^{[1]}\mathbf{s}_2^{[1]} + \gamma\mathbf{V}_1^{[2]}\mathbf{u}_1^{[2]} + \gamma\mathbf{V}_2^{[2]}\mathbf{u}_2^{[2]} \\ &+\gamma\mathbf{V}_1^{[3]}\mathbf{u}_1^{[3]}+\gamma\mathbf{V}_2^{[3]}\mathbf{u}_2^{[3]}+\gamma\hat{\mathbf{z}}^{[R]},\end{aligned} \tag{8}$$

where $\mathbf{x}^{\sim[k]}[n]$ and $\mathbf{x}^{\sim[R]}[n]$ are the original symbol vectors for the transmitter and relay, respectively. The pre-equalization can be characterized by a pre-equalizer weight matrix $W \in C^{Ntx\times Ntx}$, and the precoding symbol vector x in terms of W can be defined as $x = W\hat{x}$. In this case, the corresponding weight matrix is described for MMSE pre-equalization in [6], [7].

The total power constraint after pre-equalization can be expressed as:

$$E[tr(\mathbf{x}^{[R]}(n)\mathbf{x}^{[R]\dagger}(n))] \leq P, \tag{9}$$

where

$$\gamma = \sqrt{\frac{P}{E\{Tr(\mathbf{H}\hat{u}\hat{u}^{\dagger}\mathbf{H}^{-1})\}}}, \tag{10}$$

and γ is a power normalization factor.

The weight matrix for the MMSE pre-equalization is as follows:

$$\begin{aligned} W_{MMSE} &= \gamma \times argmin E\left[\| \gamma^{-1}(HW\hat{x} + z) - \hat{x} \|^2\right], \\ &= \gamma \times H^H \left(HH^H + \frac{\sigma_z^2}{\sigma_x^2} I\right)^{-1}. \end{aligned} \tag{11}$$

IV. **Precoding For The Spatial-Multiplexing MIMO Channel**

In the spatial-multiplexing system, the common relay shares limited CSIR information with the receivers, as shown in Fig.(2). In this section, we consider three cases in which each user uses two antennas to send two independent intentional symbols $u_1^{(K)}$ and $u_2^{(K)}$.

Journal of Engineering Technology

Volume 6, Special Issue (Emerging Trends in Engineering Technology) March. 2018, PP. 31-49

RESEARCH ARTICLE -ENGINEERNG TECHNOLOGY

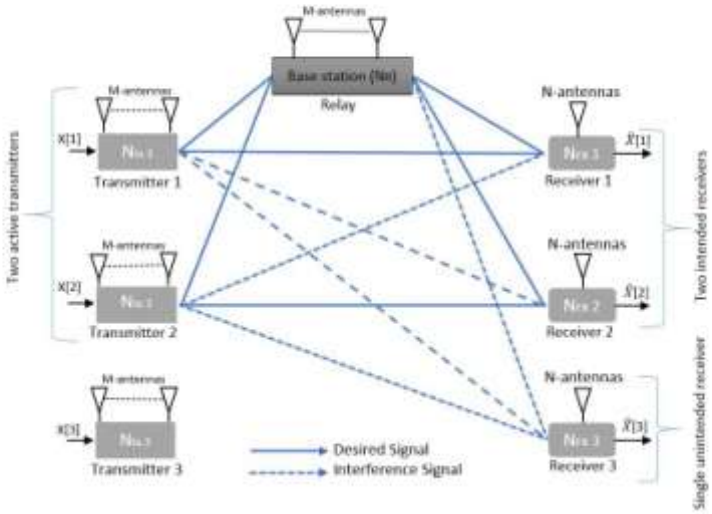

Fig. 2. Topological interference alignment: Case 1 transmission scheme.

In Case 1, the transmitted signal from User 1 is $\mathbf{X}^{[1]}[1] = [u_1^{(1)}, u_2^{(1)}]^T$, where $u_1^{(1)}$ and $u_2^{(1)}$ are the intended symbols. In Case 2, the transmitted signal from User 2 is $\mathbf{X}^{[2]}[2] = [u_1^{(2)}, u_2^{(2)}]^T$, where $u_1^{(2)}$ and $u_2^{(2)}$ are the intended symbols. In Case 3, the transmitted signal from User 3 is $\mathbf{X}^{[3]}[3] = [u_1^{(3)}, u_2^{(3)}]^T$, where $u^{(3)}_1$ and $u^{(3)}_2$ are the corresponding intended symbols.

The corresponding transmitter in each of the above mentioned cases $K = 1,2,3$ sends two independent symbols to its intended receiver [1]. In other words, the three transmitters in the three cases send a total of six independent symbols. The intended symbols are expressed in terms of $F^{[k,i]}[n]$, which indicates a linear combination of transmitted signals from User k. The use of these linear combinations of desired signal information helps to reconstruct interference signals from unintended receivers. In Algorithm 1, it is essential that the basic initialization sequence be performed before recovering the interference signals.

Case 1: In this case, Transmitters 1 and 2 are active while Transmitter 3 is silent as shown in Figure 2. In such conditions, Receiver 1 $L^{[1,1]}[1]$ and Receiver 2 $L^{[2,2]}[1]$ can acquire a superposition of two desired symbols. Nevertheless, Receiver 3 can overhear a linear combination of unintended interference signals from the active transmitters.

$$\begin{aligned}\mathbb{L}^{[1,1]}[1] &= \mathbf{h}_1^{[1,1]}[1]\mathbf{u}_1^{[1]} + \mathbf{h}_2^{[1,1]}[1]\mathbf{u}_2^{[1]},\\ \mathbb{L}^{[2,2]}[1] &= \mathbf{h}_1^{[2,2]}[1]\mathbf{u}_1^{[1]} + \mathbf{h}_2^{[2,2]}[1]\mathbf{u}_2^{[1]}.\end{aligned} \qquad (12)$$

The principal idea of the proposed beamforming scheme is in the selection of beamforming matrix from Transmitters 1 and 2 with a shared relay.

Journal of Engineering Technology

Volume 6, Special Issue (Emerging Trends in Engineering Technology) March. 2018, PP. 31-49

RESEARCH ARTICLE -ENGINEERNG TECHNOLOGY

$$\begin{bmatrix} \gamma \mathbf{h}^{(1,R)T}[n] \\ \gamma \mathbf{h}^{(2,R)T}[n] \end{bmatrix} \mathbf{V}^{(3)}[n] = \begin{bmatrix} \mathbf{h}^{(1,1)T}[n] \\ \mathbf{h}^{(2,2)T}[n] \end{bmatrix}. \tag{13}$$

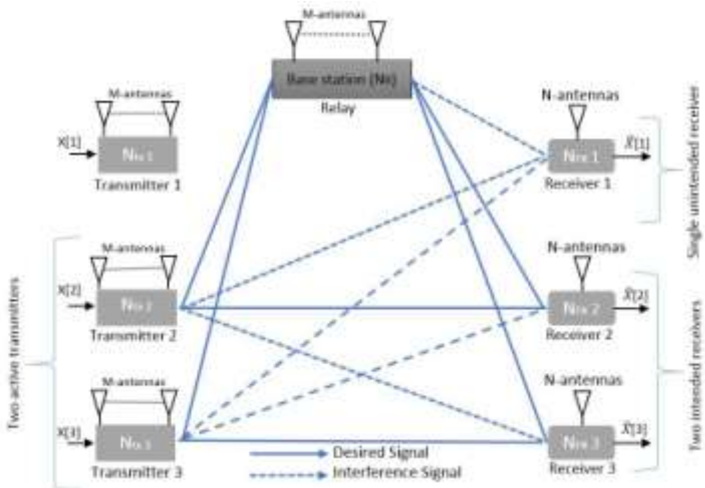

Fig. 3. Topological interference alignment for the transmission scheme in Case 2.

Case 2: In this case, Transmitters 2 and 3 are active while Transmitter 3 is silent as shown in Figure 3. Similar to Case 1, only Receiver 2 $L^{[2,2]}[2]$ and Receiver 3 $L^{[3,3]}[2]$ can acquire a superposition of two desired symbols, whereas Receiver 1 can overhear a linear combination of unintended interference signals from the active transmitters.

$$\begin{aligned} \mathbb{L}^{[2,2]}[2] &= \mathbf{h}_1^{[2,2]}[2]\mathrm{u}_1^{[2]} + \mathbf{h}_2^{[2,2]}[2]\mathrm{u}_2^{[2]}, \\ \mathbb{L}^{[3,3]}[2] &= \mathbf{h}_1^{[3,3]}[2]\mathrm{u}_1^{[2]} + \mathbf{h}_2^{[3,3]}[2]\mathrm{u}_2^{[2]}. \end{aligned} \tag{14}$$

In order to deliver the same linear combination of undesired signals from Receiver 1, the beamforming matrix is selected from Transmitters 2 and 3 with a shared relay.

$$\begin{bmatrix} \gamma \mathbf{h}^{(2,R)T}[n] \\ \gamma \mathbf{h}^{(3,R)T}[n] \end{bmatrix} \mathbf{V}^{(1)}[n] = \begin{bmatrix} \mathbf{h}^{(2,2)T}[n] \\ \mathbf{h}^{(3,3)T}[n] \end{bmatrix} \tag{15}$$

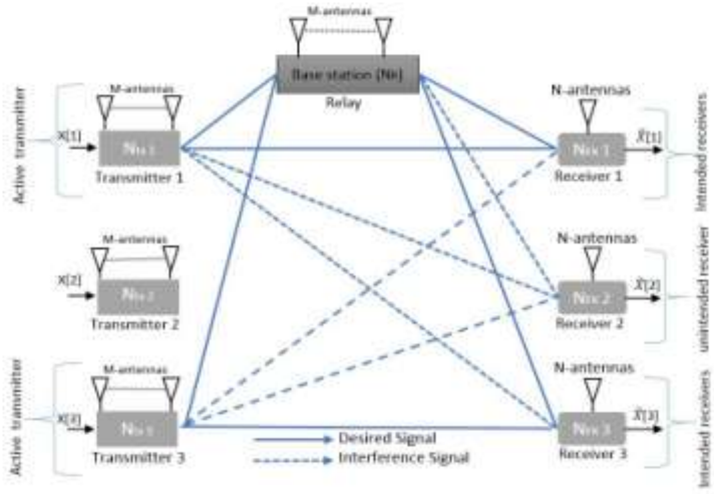

Fig. 4. Topological interference alignment: for the transmission scheme in Case 3.

Case 3: In this case, Transmitters 3 and 1 remain active, while Transmitter 2 remains silent as shown in Figure 4. At the time of transmission, only Receiver 3 $L^{[3,3]}[3]$ and Receiver 1 $L^{[1,1]}[3]$ acquire a superposition of two desired symbols whereas Receiver 2 can overhear a linear combination of the unintended interference signals from the active transmitters.

$$\mathbb{L}^{[3,3]}[3] = \mathbf{h}_1^{[3,3]}[3]\mathbf{u}_1^{[3]} + \mathbf{h}_2^{[3,3]}[3]\mathbf{u}_2^{[3]}, \\ \mathbb{L}^{[1,1]}[3] = \mathbf{h}_1^{[1,1]}[3]\mathbf{u}_1^{[3]} + \mathbf{h}_2^{[1,1]}[3]\mathbf{u}_2^{[3]}. \tag{16}$$

Consequently, to deliver the same linear combination of undesired signals from Receiver 2, a beamforming matrix is selected from Transmitters 3 and 1 with a shared relay.

$$\begin{bmatrix} \gamma \mathbf{h}^{(3,R)T}[n] \\ \gamma \mathbf{h}^{(1,R)T}[n] \end{bmatrix} \mathbf{V}^{(2)}[n] = \begin{bmatrix} \mathbf{h}^{(3,3)T}[n] \\ \mathbf{h}^{(1,1)T}[n] \end{bmatrix}. \tag{17}$$

In all three cases, the relay approximates the received symbols from the transmitters by multiplying the receiver beamforming matrix with the two received symbols [2],

$$\begin{aligned} \hat{U}^{[k]} &= \begin{bmatrix} \hat{u}_1^{[k]} \\ \hat{u}_2^{[k]} \end{bmatrix} = \left(\mathbf{H}^{[R,k]}(k)\right)^{-1} y^{[R]}(k), \\ &= u^{[k]} + \left(\mathbf{H}^{[R,k]}(k)\right)^{-1} z^{[R]}(k), k \in 1,2,3. \end{aligned} \tag{18}$$

In Algorithm 1 (Multiuser MIMO scheduling), performing the basic initialization sequence is essential before recovering the interference signals. For each of the K = 1,2,3 users, a linear combination of desired signal

Journal of Engineering Technology

Volume 6, Special Issue (Emerging Trends in Engineering Technology) March. 2018, PP. 31-49

RESEARCH ARTICLE -ENGINEERNG TECHNOLOGY

information is reconstructed by the unintended receiver. Furthermore, we evaluate the achievable sum-rate for the $K = 1,2,3$ user cases in the presence of interference in the MIMO relay channel scheme as follows:

$$\mathbf{R}_1 \leq \log\left(1+\frac{\| \mathbf{H}_{1,1} \|^2 \psi(P) + \| \mathbf{H}_{R_1} \|^2 (\frac{P_R}{2})}{\| \mathbf{H}_{2,1} \|^2 \chi(P) + \| \mathbf{H}_{3,1} \|^2 \chi(P) + 1}\right) + \left(\frac{2\alpha \| \mathbf{H}_{1,1} \| \| \mathbf{H}_{R_1} \| \sqrt{\psi(P)(\frac{P_R}{2})}}{\| \mathbf{H}_{2,1} \|^2 \chi(P) + \| \mathbf{H}_{3,1} \|^2 \chi(P) + 1}\right). \tag{19}$$

In the above equation, $H_{1,1}$ and H_{R1} are the direct signals from the transmitter and relay, respectively, whereas $H_{2,1}$ and $H_{3,1}$ are the interference signals from the two remaining users. A similar approach is applied when evaluating the sum-rate for the remaining $K = 2,3$ users.

V. Aligning Interference: Relay Space-Time Transmission

In the above cases of space-time relay transmissions, all of the receivers use Alamouti space-time relay transmission technique to decode the interference signals. When the Alamouti space-time relay transmission technique is applied to (12) and (13) of

Algorithm 1 Scheduling in Multiuser MIMO Systems

Step : 1. Input:
$\mathrm{K} \in \{1, 2, ..., k\}$; $\mathbf{V}^{[k]} = [\mathbf{V}_k^{[1]}, \mathbf{V}_k^{[2]}, ..., \mathbf{V}_k^{[k]}]$;
Initialize the transmitter & relay signals:
$\hat{\mathbf{X}}^{[K]}[n] = \sum_{k=1}^{k} \mathbf{h}_n^{[k]}[k]\mathbf{u}_n^{[k]}$; $\hat{\mathbf{X}}^{[\mathrm{R}]}[n] = \gamma(\mathbf{V}_k^{[1]}\hat{\mathrm{u}}_1^{[k]} + \mathbf{V}_k^{[1]}\hat{\mathrm{u}}_2^{[k]})$; $\gamma = \sqrt{\frac{P}{\mathrm{E}\{Tr(\mathbf{H}\hat{\mathrm{u}}\hat{\mathrm{u}}^\dagger \mathbf{H}^{-1})\}}}$.
Step : 2. Repeat:
for $k = 1, 2, 3$ **do**
Construct the received signal from the transmitter & relay:

$$\begin{bmatrix} \mathbb{L}^{[1,1]}[3] & = & \mathbf{h}_1^{[3]}[k]\mathrm{u}_1^{[k]} + \mathbf{h}_1^{[k]}[k]\mathrm{u}_2^{[k]}, \\ \mathbb{L}^{[1,1]}[2] & = & \mathbf{h}_1^{[2]}[k]\mathrm{u}_1^{[k]} + \mathbf{h}_1^{[k]}[k]\mathrm{u}_2^{[k]}, \end{bmatrix}; \begin{bmatrix} \gamma\mathbf{h}^{(3,R)T}[1] \\ \gamma\mathbf{h}^{(2,R)T}[1] \end{bmatrix} \mathbf{V}^{(k)}[n];$$

Reconstruct the desired {transmitter and relay} signal for User 1: $\mathbf{Y}_{(1)}^{[1]} = \mathbf{Y}_{(1)}^{[1,1]} + \mathbf{Y}_{(1)}^{[1,R]}$.
Calculate User 1 Chordal decomposition:

$$\begin{aligned} \mathbf{d}_{\mathbf{Chordal}}(\mathbf{Y}_1) &= \frac{1}{\sqrt{2}} \| \mathrm{Q}(\mathbf{Y}_1^1) - \mathrm{Q}(\mathbf{Y}_2^2) - \mathrm{Q}(\mathbf{Y}_3^3) \|_{\mathrm{F}}. \\ &= \sqrt{\frac{\mathrm{n}_1 + \mathrm{n}_2 + \mathrm{n}_3}{3} - \| \mathrm{Q}(\mathbf{Y}_1^1)^{\mathrm{H}} \mathrm{Q}(\mathbf{Y}_2^2) \mathrm{Q}(\mathbf{Y}_3^3) \|_{\mathrm{F}}^2}, \\ \mathbf{W}_{\mathbf{Chordal}_1} &= \mathrm{argmin} \| (\mathbf{Y}_1^{11}, \mathbf{Y}_1^{1R})^{\mathrm{T}} (\mathbf{Y}_2^{11}, \mathbf{Y}_2^{1R}) (\mathbf{Y}_3^{11}, Y_3^{1R}) \|_{\mathrm{F}}^2 \end{aligned}$$

end for.
For a fixed $\hat{\mathbf{X}}^{[K],[R]}, \gamma$ compute User 2 & 3 until the {transmitter and relay} signal has been recovered.

Case 1, the interference signal from the relay and transmitters can be expressed as:

$$\mathbf{V}^{[3]} = \frac{1}{\gamma} \begin{bmatrix} \mathbf{h}_1^{[1,R]}[3] & \mathbf{h}_2^{[1,R]}[3] \\ \mathbf{h}_1^{[2,R]}[3] & \mathbf{h}_2^{[2,R]}[3] \end{bmatrix}^{-1} \begin{bmatrix} -\mathbf{h}_2^{[1,1]^*}[2] & \mathbf{h}_1^{[1,1]^*}[1] \\ \mathbf{h}_1^{[2,2]}[1] & \mathbf{h}_2^{[2,2]}[2] \end{bmatrix}. \tag{19}$$

The signals that are transmitted to the corresponding receiver by the relay and are overheard by Receiver 3 can be expressed as:

Journal of Engineering Technology

Volume 6, Special Issue (Emerging Trends in Engineering Technology) March. 2018, PP. 31-49

RESEARCH ARTICLE -ENGINEERNG TECHNOLOGY

$$\mathbf{Y}_{(3)}^{[1,R]} = (\mathbf{h}_1^{[1,R]^T}(3) + \mathbf{h}_2^{[1,R]^T}(3))X^{[R]}[3] + Z^{[1]}(3), \quad (20)$$
$$\mathbf{Y}_{(3)}^{[2,R]} = (\mathbf{h}_1^{[2,R]^T}(3) + \mathbf{h}_2^{[2,R]^T}(3))X^{[R]}[3] + Z^{[2]}(3). \quad (21)$$

The transmitted signal, which can be recovered from the signal overheard by Receiver 3, can be expressed as:

$$\mathbf{Y}_{(3)}^{[1,1]} = -\mathbf{h}_2^{[1,1]^*}(2)\mathbf{u}_1^{[1]} + \mathbf{h}_1^{[1,1]^*}(1)\mathbf{u}_2^{[1]} + Z^{[1]}(3), \quad (22)$$
$$\mathbf{Y}_{(3)}^{[2,2]} = \mathbf{h}_1^{[2,2]}(1)\mathbf{u}_1^{[2]} + \mathbf{h}_2^{[2,2]}(2)\mathbf{u}_2^{[2]} + Z^{[2]}(3). \quad (23)$$

Similarly, for Case 2, (14) and (15) can be written as follows:

$$\mathbf{V}^{[1]} = \frac{1}{\gamma}\begin{bmatrix}\mathbf{h}_2^{[2,R]}[1] & \mathbf{h}_3^{[2,R]}[1] \\ \mathbf{h}_2^{[3,R]}[1] & \mathbf{h}_3^{[3,R]}[1]\end{bmatrix}^{-1}\begin{bmatrix}-\mathbf{h}_3^{[2,2]^*}[3] & \mathbf{h}_2^{[2,2]^*}[2] \\ \mathbf{h}_2^{[3,3]}[2] & \mathbf{h}_3^{[3,3]}[3]\end{bmatrix}, \quad (24)$$

and the corresponding received signal from the relay can be represented as:

$$\mathbf{Y}_{(1)}^{[2,R]} = (\mathbf{h}_2^{[2,R]^T}(1) + \mathbf{h}_3^{[2,R]^T}(1))X^{[R]}[1] + Z^{[2]}(1), \quad (25)$$
$$\mathbf{Y}_{(1)}^{[3,R]} = (\mathbf{h}_2^{[3,R]^T}(1) + \mathbf{h}_3^{[3,R]^T}(1))X^{[R]}[1] + Z^{[3]}(1). \quad (26)$$

The received signal from the transmitter can be represented as:

$$\mathbf{Y}_{(1)}^{[2,2]} = -\mathbf{h}_3^{[2,2]^*}(3)\mathbf{u}_1^{[2]} + \mathbf{h}_2^{[2,2]^*}(2)\mathbf{u}_2^{[2]} + Z^{[2]}(1), \quad (27)$$
$$\mathbf{Y}_{(1)}^{[3,3]} = \mathbf{h}_2^{[3,3]}(2)\mathbf{u}_1^{[3]} + \mathbf{h}_3^{[3,3]}(3)\mathbf{u}_3^{[2]} + Z^{[3]}(1). \quad (28)$$

Similarly, (16) and (17) represent Case 3, as follows:

$$\mathbf{V}^{[2]} = \frac{1}{\gamma}\begin{bmatrix}\mathbf{h}_3^{[3,R]}[2] & \mathbf{h}_1^{[3,R]}[2] \\ \mathbf{h}_3^{[1,R]}[2] & \mathbf{h}_1^{[1,R]}[2]\end{bmatrix}^{-1}\begin{bmatrix}-\mathbf{h}_1^{[3,3]^*}[1] & \mathbf{h}_3^{[3,3]^*}[3] \\ \mathbf{h}_3^{[1,1]}[3] & \mathbf{h}_1^{[1,1]}[1]\end{bmatrix}, \quad (29)$$

and the corresponding received signal from relay are as follows:

$$\mathbf{Y}_{(2)}^{[3,R]} = (\mathbf{h}_3^{[3,R]^T}(2) + \mathbf{h}_1^{[3,R]^T}(2))X^{[R]}[2] + Z^{[3]}(2), \quad (30)$$
$$\mathbf{Y}_{(2)}^{[1,R]} = (\mathbf{h}_3^{[1,R]^T}(2) + \mathbf{h}_1^{[1,R]^T}(2))X^{[R]}[2] + Z^{[1]}(2), \quad (31)$$

The received signal from transmitter as follows,

$$\mathbf{Y}_{(2)}^{[3,3]} = -\mathbf{h}_1^{[3,3]^*}(1)\mathbf{u}_1^{[3]} + \mathbf{h}_3^{[3,3]^*}(3)\mathbf{u}_2^{[3]} + Z^{[3]}(2), \quad (32)$$
$$\mathbf{Y}_{(2)}^{[1,1]} = \mathbf{h}_3^{[1,1]}(3)\mathbf{u}_1^{[1]} + \mathbf{h}_1^{[1,1]}(1)\mathbf{u}_2^{[1]} + Z^{[1]}(2). \quad (33)$$

Journal of Engineering Technology

Volume 6, Special Issue (Emerging Trends in Engineering Technology) March. 2018, PP. 31-49

RESEARCH ARTICLE -ENGINEERNG TECHNOLOGY

After separating the user interference signals based on CSIR knowledge, the effective channel input-output relationship for the User 1 relay $\mathbf{Y}_{(1)}^{[1,R]}$ and transmitter $\mathbf{Y}_{(1)}^{[1,1]}$ signals can be reconstructed. Finally, the Case 1 $\mathbf{Y}_{(1)}^{[1,R]}$ relay signal, which can be recovered from $\mathbf{Y}_{(3)}^{[1,R]}$, $\mathbf{Y}_{(2)}^{[1,R]}$, (31), and (20), respectively. Therefore, to recover the signal from $\mathbf{Y}_{(1)}^{[1,R]}$, we can neglect the other co-interference signals in order to evaluate the signal intended for

$$\begin{aligned}\mathbf{Y}_{(1)}^{[1,R]} &= \mathbf{Y}_{(3)}^{[1,R]} + \mathbf{Y}_{(2)}^{[1,R]}, \\ &= (\mathbf{h}_1^{[1,R]^T}(3) + \mathbf{h}_2^{[1,R]^T}(3))X^{[R]}[3] + (\mathbf{h}_3^{[1,R]^T}(2) + \mathbf{h}_1^{[1,R]^T}(2))X^{[R]}[2] + Z^{[1]}(1). \\ &= \underbrace{\mathbf{h}_1^{[1,R]^T}(3)X^{[R]}[3] + \mathbf{h}_1^{[1,R]^T}X^{[R]}[2](2) + Z^{[1]}(1)}_{\text{Recovered Relay Signal}}.\end{aligned} \tag{34}$$

User 1 that was received from the relay is as follows:

Similarly, we can recover relay signal $\mathbf{Y}_{(2)}^{[2,R]}$ from (21) and (25) for Case 2, and relay signal $\mathbf{Y}_{(3)}^{[3,R]}$ from (26) and (30) for Case 3. Finally, for Case 1, the transmitter signal $\mathbf{Y}_{(1)}^{[1,1]}$ can be recovered from the receiver signals given in (22) and (33) respectively. Therefore, when recovering the signal from $\mathbf{Y}_{(1)}^{[1,1]}$, we can neglect the other co-interference signals in order to evaluate the signal intended for User 1 that was received from the transmitter can

$$\begin{aligned}\mathbf{Y}_{(1)}^{[1,1]} &= \mathbf{Y}_{(3)}^{[1,1]} + \mathbf{Y}_{(2)}^{[1,1]}, \\ &= -\mathbf{h}_2^{[1,1]^*}(2)\mathbf{u}_1^{[1]} + \mathbf{h}_1^{[1,1]^*}(1)\mathbf{u}_2^{[1]} + \mathbf{h}_3^{[1,1]}(3)\mathbf{u}_1^{[1]} + \mathbf{h}_1^{[1,1]}(1)\mathbf{u}_2^{[1]} + Z^{[1]}(1). \\ &= \underbrace{\mathbf{h}_1^{[1,1]^*}(1)\mathbf{u}_2^{[1]} + \mathbf{h}_1^{[1,1]}(1)\mathbf{u}_2^{[1]} + Z^{[1]}(1)}_{\text{Recovered Transmitter Signal}}.\end{aligned} \tag{35}$$

be written as follows:

During Phase 1, the received $Y_{(1)}^{[1,1]}$ and relay $Y_{(1)}^{[1,R]}$ signals for Case 1 are recovered from the interference signals $Y_{(3)}^{[1,1]}$, $Y_{(2)}^{[1,1]}$, and $Y_{(3)}^{[1,R]}$, $Y_{(2)}^{[1,R]}$, respectively. By using multiple data streams and relay signals, the reconstructed signal at Receiver 1 can be expressed as $Y_{(1)}^{[1]} = Y_{(1)}^{[1,1]} + Y_{(1)}^{[1,R]}$, which improves the signal strength of Receiver 1 . We can compute the transmitted signal $\mathbf{Y}_{(2)}^{[2,2]}$ from the received signals (23) and (27) for Case 2. For Case 3, the received signals (28) and (32) can be used to compute the transmitted signal $\mathbf{Y}_{(3)}^{[3,3]}$. Likewise, the received signals for the other two cases, i.e., $Y_{(2)}^{[2]}$ for Case 2 and $Y_{(3)}^{[3]}$ for Case 3, can also be recovered from the interference signals. The differential scheme proposed in [4], [5] required only one interference signal to recover the desired signal information. However, the proposed scheme incorporates a combination of two unknown receiver signals, which helps to more efficiently recover the desired signal information. Overall, the algorithm proposed in this paper improves the reconstructed signal strength by incorporating two unknown receiver signals from the transmitter and relay for different alignment schemes. To analyze and simplify the complexity of the interference signals, we employed the Chordal distance scheduling algorithm described in (34) and (35), which can be used to efficiently determine the orthogonality between different users [10]. Therefore, the desired signals for User 1, i.e., $(\mathbf{Y}_1^{11}, \mathbf{Y}_1^{1R})$, acquired from the relay and transmitters are subtracted from the observed signals of Users 2 (Y_2^{22}, Y_2^{2R}) and 3, i.e., $(\mathbf{Y}_3^{33}, \mathbf{Y}_3^{3R})$, which results in $\mathbf{d}_{\mathbf{Chordal}}$.

Case 1: Chordal distance scheduling algorithm $\mathbf{d}_{\mathbf{Chordal}}(\mathbf{Y}_1^1)$ for Transmitters 1 and 2 are active while Transmitter 3 is silent as shown in Figure 2.

$$\mathbf{d}_{\mathbf{Chordal}}(\mathbf{Y}_1^1) = \frac{1}{\sqrt{2}} \parallel \mathrm{Q}(\mathbf{Y}_1^{11}, \mathbf{Y}_1^{1\mathrm{R}}) - \mathrm{Q}(\mathbf{Y}_2^{22}, \mathrm{Y}_2^{2\mathrm{R}}) \|_F, \tag{36}$$

Case 2: Chordal distance scheduling algorithm $\mathbf{d}_{\mathbf{Chordal}}(\mathbf{Y}_2^2)$ forTransmitters 2 and 3 are active while Transmitter 3 is silent as shown in Figure 3.

$$\mathbf{d}_{\mathbf{Chordal}}(\mathbf{Y}_2^2) = \frac{1}{\sqrt{2}} \parallel \mathrm{Q}(\mathbf{Y}_2^{22}, \mathrm{Y}_2^{2\mathrm{R}}) - Q(\mathbf{Y}_3^{33}, \mathbf{Y}_3^{3R}) \parallel_F, \tag{37}$$

Case 3: Chordal distance scheduling algorithm $\mathbf{d}_{\mathbf{Chordal}}(\mathbf{Y}_3^3)$ for Transmitters 3 and 1 remain active, while Transmitter 2 remains silent as shown in Figure 4.

$$\mathbf{d}_{\mathbf{Chordal}}(\mathbf{Y}_3^3) = \frac{1}{\sqrt{2}} \parallel \mathrm{Q}(\mathbf{Y}_3^{33}, \mathbf{Y}_3^{3\mathrm{R}}) - \mathrm{Q}(\mathbf{Y}_1^{11}, \mathbf{Y}_1^{1\mathrm{R}}) \|_F, \tag{38}$$

$$\mathbf{d}_{\mathbf{Chordal}}(\mathbf{Y}_1^1, \mathbf{Y}_2^2, \mathbf{Y}_3^3) = \sqrt{\left(\frac{\mathrm{n}_1 + \mathrm{n}_2 + \mathrm{n}_3}{3}\right) - \|\mathrm{Q}(\mathbf{Y}_1^1)^{\mathrm{H}}\mathrm{Q}(\mathbf{Y}_2^2)\mathrm{Q}(\mathbf{Y}_3^3)\|_{\mathrm{F}}^2}. \tag{39}$$

where $Q(\mathbf{Y}_1^{11}$ and $\mathbf{Y}_1^{1R})$ define a matrix that consists of the orthonormal basis vectors of Y_1^1, which helps to align the span, column, and space of the interference signal vectors $(\mathbf{Y}_2^{11}, \mathbf{Y}_2^{1R})(\mathbf{Y}_3^{11}, \mathbf{Y}_3^{1R})$. Similarly, $\mathbf{Y}_2{}^2$ and $\mathbf{Y}_3{}^3$ are orthonormal basis vectors of $Q(\mathbf{Y}_2^{22}, \mathbf{Y}_2^{2R})$ and $Q(\mathbf{Y}_3^{33}, \mathbf{Y}_3^{3R})$, and can be calculated from the corresponding interference signals.

$$\begin{aligned}\mathbf{w}_{\mathbf{Chordal}} = \operatorname{argmin}\{&\|(\mathbf{Y}_1^{11},\mathbf{Y}_1^{1R})^{\mathrm{T}}(\mathbf{Y}_2^{11},\mathbf{Y}_2^{1R})(\mathbf{Y}_3^{11},Y_3^{1R})\|_{\mathrm{F}}^2 \\ &+ \| (\mathbf{Y}_2^{22},\mathbf{Y}_2^{2R})^{\mathrm{T}}(\mathbf{Y}_3^{22},\mathbf{Y}_3^{2R})(\mathbf{Y}_1^{22}, \mathbf{Y}_1^{2R}) \|_{\mathrm{F}}^2 \\ &+ \| (\mathbf{Y}_3^{33},\mathbf{Y}_3^{3R})^{\mathrm{T}}(\mathbf{Y}_2^{33},\mathbf{Y}_2^{3R})(\mathbf{Y}_1^{33},\mathbf{Y}_1^{3R}) \|_{\mathrm{F}}^2\}.\end{aligned} \tag{40}$$

Moreover, the interference signals detected by the additional receiver are aligned, and the Chordal distance algorithm is used at the destination to minimize the error probability. The pair-wise error probability can be determined by the distance between two symbol vectors for a given channel realization. The minimum distance for channel realization should be maximized in order to realize the optimum performance at the receiver [14].

Journal of Engineering Technology

Volume 6, Special Issue (Emerging Trends in Engineering Technology) March. 2018, PP. 31-49

RESEARCH ARTICLE -ENGINEERNG TECHNOLOGY

VI. Computational Complexity Analysis

The computational complexity is described based on number of flops. In general the complexity (flops) is calculated based on total number of real addition, subtraction, multiplication, and a division are counted as flop is denoted by ξ. Where M,N are the used antenna setups for transmitter and receiver for the (k^{th}) user $H_k(k = 1,...,K)$ channel entries are independent identical distributed (i.i.d) complex with zero mean and unit variance.

Frobenius norm: $\| H_F^2 \|$ has $2MN$ real multiplication and $2MN$ real addition in total 4MN flops. The Gram-Schmidt orthogonalization has $4MN^2 - 2MN$ real multiplication, $4MN^2 - 2MN$ real additions and $2MN$ real divisions in total $8MN^2 - 2MN$ flops. The computational complexity for Frobenius norm based algorithm is expressed as $\xi_{Frobenius} \approx O\left(\frac{K}{M^2}\ln\frac{K}{M^2}\right)$.

Water-filling: considering over n eigenmodes has $\frac{1}{2}(n^2+3n)$ real multiplications, $(n^2 + 3n)$ real additions and $\frac{1}{2}(n^2+3n)$ real divisions in total $2n^2 + 6n$ flops. In singular value decomposition (SVD) in total $24MN^2 + 48M^2N + 54M^3$ real multiplication, additions and divisions flops. The computational complexity for water filling algorithm is expressed as $\xi_{Water-}filling \approx O(N + n\log(N))$.

A. Optimal Scheduling and Suboptimal Scheduling Algorithm

Optimal Scheduling: In general the base stations execute comprehensive search to find the optimal users,

$$\begin{aligned} \xi_{Opt} &\geq \begin{bmatrix} \mathrm{K} \\ \mathrm{k} \end{bmatrix} \cdot k \cdot [(48(k-1)^2+8)N^2M + 24(k-1)NM^2 + (54(K-1)^3 + 2K^2 + 126)N3 + 8kN] \\ \xi_{Opt} &\approx O\begin{bmatrix} \mathrm{K} \\ \mathrm{k} \end{bmatrix} \cdot k \cdot M^3 \end{aligned} \tag{41}$$

we know that K ∈ {1,2,...,k}, k =$\lceil \frac{M}{N} \rceil$, $N \leq$M and for an N × M complex valued matrix H.

Suboptimal Scheduling: The computational complexity of capacity based algorithm is expressed as follows,

$$\xi_{Sub-opt} \geq \sum_{i=2}^{K} [48i(i-1)^2 + 48i]N^2M + [24i(i-1) + 32i]NM^2 + (54i(i-1)^3 + 54i)N^3 \tag{42}$$

$$+2i^2N^2 + 8iN \times (k(48N^2M + 24NM^2 + 54N^3 + 2N^2 + 8N) \tag{43}$$

$$\xi_{Sub-opt} \approx O(k.K^2.M^3). \tag{44}$$

B. Chordal Distance Scheduling Algorithm

In general, we use the Chordal distance scheduling algorithm to select the users to maximize the channel matrix distance between desired and undesired (interference) users. we know that orthogonality among the desired and undesired users is very important for Chordal scheduling algorithm, if the users are close to the orthogonal the common subspace is reliably small.

Journal of Engineering Technology

Volume 6, Special Issue (Emerging Trends in Engineering Technology) March. 2018, PP. 31-49

RESEARCH ARTICLE -ENGINEERNG TECHNOLOGY

The proposed Chordal distance scheduling algorithm is expressed as follows,

$$\xi_{Chordal} \approx \left(\sum_{i=1}^{K}[8(i-1)^2N^2M{-}2(i-1)NM{+}7(i-1)Nm^2]{+}[8N^2M-2NM+7NM^2+3M^2]\right) \quad (45)$$

$$\times k - i + 1 + 4kNM \quad (46)$$

$$\xi_{Chordal} \approx O(k.M^3). \quad (47)$$

from the above computational complexity, we can conclude that proposed Chordal distance scheduling algorithm has the lowest computational complexity among other scheduling algorithms. Table 1. Computational Complexity Performance Comparison describes the flop ratio and the complexity compression between different approaches

TABLE I

COMPUTATIONAL COMPLEXITY PERFORMANCE COMPARISON

Computational Complexity Analysis		
Approaches	**Flop Ratio**	**Complexity**
Frobenius norm	$8MN^2 - 2MN$	$\xi_{Frobenius} \approx O\left(\frac{K}{M^2}\ln\frac{K}{M^2}\right)$
Water-filling	$24MN^2 + 48M^2N + 54M^3$	ξ_{Water}*–filling* $\approx O(N + n\log(N))$
Optimal Scheduling	$[(48(k-1)^2+8)N^2M + 24(k-1)NM^2 + (54(K-1)^3 + 2K^2 + 126)N3 + 8kN]$	$\xi_{Opt} \approx O\begin{bmatrix}\mathrm{K}\\ \mathrm{k}\end{bmatrix} \cdot k \cdot M^3$
Suboptimal Scheduling	$[48i(i-1)^2 + 48i]N^2M + [24i(i-1) + 32i]NM^2 + (54i(i-1)^3 + 54i)N^3 + 2i^2N^2 + 8iN$	ξ_{Sub}*–opt* $\approx O(k.K^2.M^3)$
Chordal Distance	$[8(i-1)^2N^2M{-}2(i-1)NM{+}7(i-1)Nm^2]{+}[8N^2M - 2NM + 7NM^2 + 3M^2]$	$\xi Chordal \approx O\ (k.M3)$

VII. **Numerical Results**

We obtained numerical results by analyzing the K-user MIMO interference relay channel using the R-STIA technique. The following setup was used for the simulation: the transmitters and relay antennas were N_{tx} and N_R = 8,10, and the receiver data stream was $N_{rx} = 1$. The total power constraint for the transmitter was P, the relay power constraint was P_R, and the noise variance of all nodes was $\sigma^2 = 1$. The channel coefficients for the desired signals were $H_{11}^{[1]}$ and $H_{22}^{[2]} = 2$. For the interference signals, they were $H_{12}^{[1]}$ and $H_{21}^{[2]} = 0.75$, and the relay channel coefficients were $H_1^{[R_1]} = [2\ 1]$ and $H_2^{[R_2]} = [1.2\ 1]$. The received signals were decoded under space-time relay transmission constraints using the R-STIA technique decoding strategy described in Section 5. We compared the proposed R-STIA (interference MIMO relay channel) technique with the existing relay transmission and the sum-rate multi antenna Gaussian broadcast channel schemes. We also compared the interference MIMO relay channel schemes proposed, which employ an amplify-and-forward two-hop broadcast channel strategy (assuming a direct link from the source to the destination), with the proposed R-STIA technique. Similarly, we compared the

Journal of Engineering Technology

Volume 6, Special Issue (Emerging Trends in Engineering Technology) March. 2018, PP. 31-49

RESEARCH ARTICLE -ENGINEERNG TECHNOLOGY

proposed R-STIA (assuming a direct link from the source to the relay, and from the relay to the destination) technique with ideal cooperation to the MIMO broadcast channel scheme described in [22] and the interference channel scheme in [23].

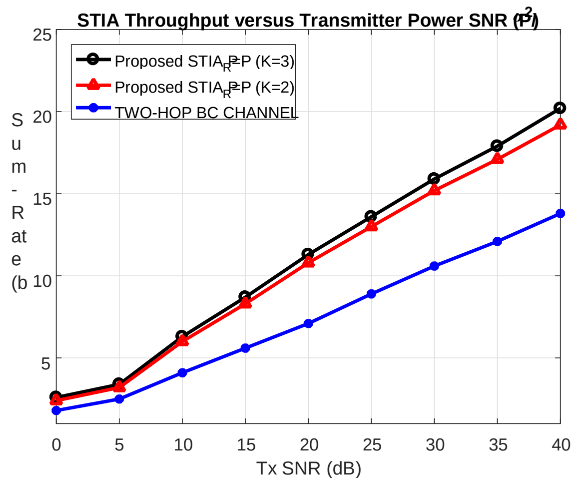

Fig. 5. Power allocation versus the Sum-rate strategy for transmitter.

Fig. 5 represents the power allocation strategy versus the achievable sum-rate, and compares the sum-rate of the STIA under the average transmitted power constraint. In the comparison, we focused on three major schemes. The fraction of signal power for transmitter $P_R = P$ versus the sum-rate was computed for $K = 2$ and 3 users. Furthermore, we illustrated the sum-rate with the two-hop broadcast channel scheme when no relay was present in the desired system model. At $SNR = 20dB$ and $SNR = 40dB$, the results for the proposed STIA technique for the case of $K = 2$ users showed that the sum-rate increased significantly from 11 to 19 bps/Hz, whereas the two-hop broadcast channel scheme achieved 7.5 to 13.5 bps/Hz. This large increase in the sum-rate was predictable because in each case the proposed scheme did not activate more than two transmitters, so the throughput power for the transmitters was reduced and the achievable sum-rate significantly increased significantly.

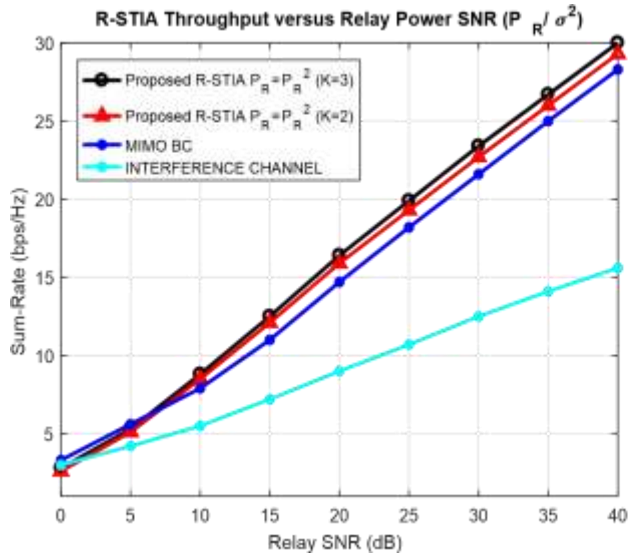

Fig. 6. Network throughput versus the Power allocation for $P_R = P$ and $P_R = P^2$.

Fig. 6 depicts the optimal power allocation strategy versus the achievable sum-rate. We focused on four major schemes, and first compared the sum-rate of the R-STIA under the average relay power constraint. In addition, the fraction of signal power for relay $P_R = P^2$ versus the sum-rate was computed for the K = 2,3 user cases. We also explained the sum-rate with the MIMO broadcast and interference channel schemes when there was no relay present in the desired system model. At $SNR = 20dB$ and $SNR = 40dB$, the proposed R-STIA technique for the K = 2 user case the sum-rate increased drastically from 16.5 to 29 bps/Hz, whereas the MIMO broadcast channel achieved a rate of 15.5 to 27 bps/Hz, while the interference channel scheme achieved 8.5 to 15.5 bps/Hz, respectively. These extreme variations in the sum-rate were expected, since the proposed scheme (i.e., no more than two active transmitters), which included a relay, helped to increase the sum-rate compared to the STIA, MIMO broadcast channel, and interference channel schemes. These results clearly demonstrate that the R-STIA technique has a greater impact on the sum-rate regime. Although the relay cannot improve the DoF, it can facilitate an approach to efficiently recover and align the interference signals.

Fig. 7 depicts the number of users (K) versus the run-time in milliseconds. The performance of the proposed Chordal based algorithm in terms of the CPU runtime (ms) is better than the Frobenius norm and capacity based algorithms for a large number of users. For the K = 35 user case, the proposed Chordal distance based scheduling algorithm runtime was predictably reduced to $10^{0.5}$ *ms*; however, the Frobenius norm run time was $10^{0.7}$ *ms* and the capacity based user case run time was $10^{1.2}$ *ms*. The simulation results show that the Chordal distance based scheduling algorithm enhanced the performance of the projected system model compared to those of the Frobenius norm and capacity based schemes, and the proposed Chordal based scheduling algorithm exhibited linear behavior with respect to the users when evaluating the CPU runtime performance between different algorithms, as described in [14], [20].

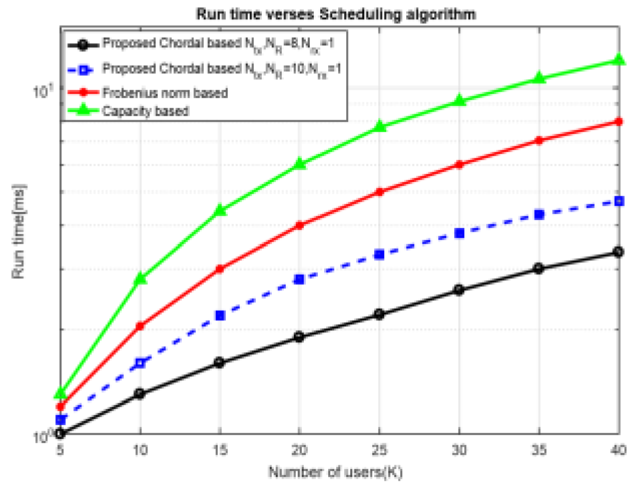

Fig. 7. Comparison of the run times for the different algorithms.

VIII. Conclusion

A new transmission method R-STIA beamforming technique was proposed for three user MIMO interference channels with a shared relay. We tested the proposed scheme for three cases in which the transmitter and relay information were recovered by an additional receiver with the help of limited local CSIR knowledge and the R-STIA technique, which leveraged the recovered information. An MMSE based signal detection technique was proposed that employed multiple antennas at the base station and relay to maximize the worst-case post-detection (SINR) criterion. We achieved the maximum diversity and highest possible throughput by employing the Alamouti space-time relay transmission technique. With this method, we were able to recover the interference signals in various conditions, such as without cooperation between the transmitters and assuming limited CSIR knowledge for the $M \times 2$ MIMO broadcast active relay channels. The proposed scheme efficiently align and reconstruct the interference signals at the unintended receiver. Computational complexity analysis for proposed Chordal distance scheduling algorithm $\xi_{Chord} \approx O(K_T.M^3)$ is lower than the existing scheduling algorithms and the proposed algorithm user selection is promising for practical multiuser MIMO relay channels as it can be used to minimize the distance between the source and relay precoders. The numerical results prove that the proposed R-STIA transmission techniques and Chordal distance scheduling algorithm achieve higher sum-rates compared to those of existing MIMO broadcast channel schemes.

Acknowledgement

This research was supported by the Brain Research Program through the National Research Foundation of Korea (NRF) funded by the ministry of science, CT and Future Planning (NRF-2017M3C7A1044815) and Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science and ICT (2015R1A2A1A05000977), Republic of Korea.

References

[1] Selvaprabhu, P.; Chinnadurai, S.; Li, J.; Lee, M.H. Topological Interference Management for K-User Downlink Massive MIMO Relay Network Channel. *Sensors*. 2017, 17, 1896, doi:10.3390/s17081896.

[2] Lee, N.; Heath, R.W.; Jr. Space-time interference alignment and degree-of-freedom regions for the MISO broadcast channel with periodic CSI feedback. *IEEE Trans.Inf.Theory*. 2014, 60, 515-528, doi:10.1109/TIT.2013.2285216.

[3] Shin, W.; Lee, N.; Lee, J.; Poor, H.V. Guiding blind transmitters for K-user MISO interference relay channels with imperfect channel knowledge. *IEEE International Symposium on Information Theory conference*. 2016, 545-549, doi:10.1109/ISIT.2016.7541358.

[4] Li, J.; Wen, M.; Cheng, X.; Yan, Y.; Song, S.; Lee, M.H. Generalized Precoding-Aided Quadrature Spatial Modulation. *IEEE Trans. Veh. Technol*. 2017, 66, . doi:10.1109/TVT.2016.2565618

[5] Chinnadurai, S.; Selvaprabhu, P.; Jeong, Y.; Jiang, X.; Lee, M.H. Worst-Case Energy Efficiency Maximization in a 5G Massive MIMO-NOMA System. *Sensors*, 2017, 17, 2139, doi: 10.3390/s17092139

[6] Soo Cho, Y.; Kim, J.; Yang, W.Y; Kang, C.G. MIMO-OFDM wireless communications with MATLAB. *IEEE press, John Wiley & Sons (Asia) Pte Ltd*, Singapore, 2010, 12, 294-297, 381-382, ISBN978-0-470-82561-7.

[7] Poongundran Selvaprabhu**,** S. Chinnadurai, Md.Abdul, and M.H.Lee: "Joint Interference Alignment and Power Allocation for K-User Multicell MIMO Channel Through Staggered Antenna Switching," Sensors, MDPI, Vol.18, (2018).

[8] Li, Z.; G, K.; Xia. A simple Alamouti space time transmission scheme for asynchronous cooperative systems. *IEEE signal processing letters*,2007, 14, 804-807, doi:10.1109/LSP.2007.900224.

[9] Maleki, H.; Jafar, A.S; Shamai,S. Retrospective interference alignment over interference networks. *IEEE journal of selected topics in signal processing*, 2012, 6, 228-240, doi:10.1109/JSTSP.2011.2181155.

[10] Lee, J.H.; Park, D. Antenna selection and unitary precoding for interference alignment with ML receiver. *IEEE communications letters*, 2012, 16, 1216-1219, doi:10.1109/LCOMM.2012.060112.120568.

[11] Hai, H.; Jiang, X.; Lee, M.H.; Jeong, Y. Efficient Transmission and Detection Based on RNS for Generalized Space Shift Keying. *IEEE Wirel. Commun. Lett.* **2017**, *6*, 486–489.

[12] Shu, Y.; Q. Wang, Q.; J. Zhang, J.; Sun, T. Relay-aided interference alignment and neutralization for 3-cellular interference channels *IEEE/CIC Int.Conf on ICCC Commun in China*, 2014, 637-641, doi:10.1109/isit.2011.6034051.

[13] Han,H.; Jiang,X.; Wen,M.; Lee,M.H; and Jeong,Y. Efficient Transmission and Detection Based on RNS for Generalized Space Shift Keying. *IEEE Wireless Communications Letters*, 2017, 6,486-489, doi:10.1109/LWC.2017.2707088.

[14] Ko,K.;Lee,J. Multiuser MIMO user selection based on chordal distance. *IEEE Trans. Communications*, 2012, 60, 649-654, doi:10.1109/TCOMM.2012.020912.110060.

[15] Lee, K.-J.; Sung, H.; Park, E.; Lee, I. Joint optimization for one and two-way MIMO AF multiple-relay systems.*IEEE Trans. Wireless Commun.*, 2010, 9, 3671-3681, doi:10.1109/TWC.2010.102210.091021.

[16] Chinnadurai, S.; Selvaprabhu, P.; Lee, M.H. User clustering and Robust Beamforming Design for 5G Communication Systems. *International Journal of Electronics and communication*, 2017.doi:10.1016/j.aeue.2017.05.021

[17] Selvaprabhu, P.; Chinnadurai, S.; Song. S.; Lee, M.H. Interference alignment for K-user MIMO interference channel using multiple relays. *International conference on Information and Communication Technology Convergence (ICTC)*, 2015, doi:10.1109/iscit.2014.7011860.

[18] Selvaprabhu, P.; Chinnadurai, S.; Song. S.; Lee, M.H. Topological interference alignment for MIMO interference broadcast channel. *International Conference on Information and Communication Technology Convergence(ICTC)*,2016,doi:10.1109/ictc.2016.7763370.

[19] Yi, X.; Sun, H.; Jafar, S.A.; Gesbert, D. TDMA is Optimal for All-unicast DoF Region of TIM if and only if Topology is Chordal Bipartite. *arXiv:1501.07870 [cs.IT]*, 2017, doi:abs/1501.07870.

[20] Shen, Z.; Chen, R.; Andrews, J.G.; Heath, R.W.; Jr; Evans, B.L. Low complexity user selection algorithms for multiuser MIMO systems with block diagonalization. *IEEE Trans.Signal Process*, 2006, 54, 3658-3663, doi:10.1109/TSP.2006.879269.

[21] Gherekhloo, S.;Chaaban, A.; Di, C.; Sezgin, A. (Sub)-optimality of treating interference as noise in the cellular uplink with weak interference. *IEEE Trans.Inf.Theory*,2016, 62, 322-356,doi:10.1109/TIT.2015.2499189.

[22] Geng,C.; Naderializadesh, N.; Avestimehr, A. S.; Jafar, S. A. On the optimality of treating interference as noise. *IEEE Trans.Inf.Theory.*,bf 2015, 61, 1753-1767, doi:10.1109/TIT.2015.2408342.

[23] Ying, T.; Feng, W.; Su, W.; Jiang, W. On the degrees of freedom of MIMO X networks with non-cooperation transmitters. *IEEE Trans. Wireless Commun.*,2017, 16, 2490-2504, doi:10.1109/TWC.2017.2665544.

[24] Han,H.; Jiang,X.; Jeong,Y.; Lee,M.H; and Jeong,Y. Low complexity precoding codebook design based on DFRST for limited feedback precoded OSTBC systems. *EURASIP Journal on Wireless Communications and Networking*, 2017, 103, doi:10.1186/s13638-017-0891-6.

[25] Jindal, N.; Rhee, W.; Vishwanath,S.; Jafar,S. A.; Goldsmith, A. Sum power iterative water-filling for multi-antenna Gaussian broadcast channels. *IEEE Trans. Inf. Theory*, 2005, 51, 1570-1580, doi:10.1109/TIT.2005.844082.

[26] Etkin, R.; Ordentlich, E. On the degrees-of-freedom of the K-user Gaussian interference channel. em in Proc. IEEE Int. Symp. Inf. Theory, bf 2009, 1919-1923, doi:10.1109/isit.2009.5205564.

[27] Shen, C.; Fitz, M.P. MIMO-OFDM Beamforming for Improved Channel Estimation. *IEEE Journal on Selected Areas in Communications*,2008, 26, 948-959, doi:10.1109/JSAC.2008.080811.