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Beamforming and Interference Alignment Transmission Mechanism Based on Optimal Relay Selection

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Abstract — **In this paper, we consider the two-hop MIMO interference network, where T source-destination pairs communicate via $T \times K$ relays selected from G alternative relays. Based on optimal relay selection, each source-destination pair selected K relays to transmit data streams. In the first time slot, the source node transmits data steams to the selected relays by adaptive beamforming .In the second time slot, the selected relays forward the data streams by interference alignment technique. Compared the beamforming and interference alignment transmission mechanism based on fairness relay selection, our scheme can achieve higher system capacity.**

***Keywords*— optimal relay selection; beamforming; interference alignment; MIMO**

I. INTRODUCTION

Interference is the main bottleneck to enhance the capacity of the wireless communication system. In past work, study of interference management in centralized network is relatively mature. Compared to a centralized network, the distributed interference channel (IC) where multiple source nodes that communicate with their paired destination nodes over a shared physical channel still needs further study.

In the recent years, some researchers applied relay and interference alignment technique into the distributed interference channel. In [1, 2], Bolcskei took the approach named distributed interference cancellation by placing multiple relay nodes between the source and destination nodes to orthogonalize the IC. By simple backward and forward zero-forcing or matched filtering at the relay nodes, they improved the degrees of freedom of interference networks. The earliest application of interference alignment appears in Example 7 of the 1998 INFOCOM paper of Birk and Kol [3,4] in the context of the Informed Source Coding on Demand (ISCOD) problem. In [5], Chen S and Cheng R S introduced the interference alignment algorithm in K-user MIMO interference channel with a MIMO relay. In [6], Torabi and Frigon imported numbers of relays into the distributed IC. By decomposition of the channel matrix, they divided the system into a plurality of non-interference relay channels, then they took interference alignment. The scheme in [6] has higher complexity and the interference alignment scheme did not consider the symbol extension. In [7], LEI Wei-jia proposed a transmission mechanism based on beamforming and interference alignment, the transmission mechanism outperforms the distributed interference cancellation technique, but the relay selection scheme in the transmission mechanism is not optimal.

In this paper, we introduce a transmission mechanism involving beamforming and interference based on optimal relay selection. Relay selection based on two-hop channel gain Harmonic mean function, adaptive beamforming and interference alignment are discussed in this paper. We jointly apply these three technologies and achieve better performance. Simulation results show that our transmission mechanism can achieve higher system capacity especially when the amount of alternative relays is small.

The rest of this paper is organized as follows: in section II we present the system model and capacity formulation. In section III we show the optimal relay selection scheme based
on two-hop channel gain Harmonic mean function and

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the interference alignment. In section IV we present the simulation results and finally we conclude in section V.

Notions: $(.)^H$ and J represents conjugate transpose and trace of a matrix, respectively. I_N is a $N \times N$ identity matrix. $span\{.\}$ and $null\{.\}$ denotes the column space and null space of a matrix, respectively.

II. SYSTEM MODEL

We consider that there are T source nodes (denoted by $S_1, S_2, ..., S_T$), T destination nodes (denoted by $D_1, D_2, ..., D_T$) and G alternative relays uniformly distributed between the source and destination. Based on certain relay selection strategy, each user chooses K relays to transmit K independent data streams. Throughout this paper, we consider all the relays transmit the data streams by means of half-duplex amplify-and forward **(AF)**. There are two channel hops and two non-overlapping time slots. During the first time slot, the source nodes transmit several pre-coded data streams to the selected relays. We assume that for the reason of large scale fading, the destination nodes can't receive any information directly from the source nodes. During the second time slot, while all the source nodes stop transmitting data streams to the relays, the relays transmit data with pre-coding vectors designed by interference alignment technology, the destination nodes receive the pre-coded data with corresponding interference elimination vectors to remove the aligned interference.

In our system model, all the relays' position is fixed and all the relays know their local backward and forward CSI. Through a feedback link, the relays transmit the direction of arrival (DOA) and CSI to the source nodes. During the first time slot, the source node $S_i\left(i=1,2,...,T\right)$ designs beamforming weight vector $w_{ij}\left(j=1,2,...,K\right)$ by adaptive beamforming algorithm for the selected relay R_{ij}. Transmitted by the adaptive beamforming weight vector, the interference of relay R_{ij} is close to zero. The signal of relay R_{ij} can be expressed by (1).

$$y_{R_{ij}} = H^H_{S_iR_{ij}} w_{ij} x_{ij} + Z^R_{ij} \tag{1}$$

Where $H_{S_iR_{ij}}$ and Z^R_{ij} respectively denotes the channel gain and white zero-mean circularly symmetric complex Gaussian noise between source node S_i and relay R_{ij}, x_{ij} denotes the data stream. During the second time slot, relay R_{ij} transmits the data stream with the pre-coding vectors V_{ij}, which make the interference from other users aligned. The destination node D_i decodes the signal with homologous interference elimination vectors U_{ij}. The signal of D_i can be expressed by (2).

$$\begin{aligned} y_{D_i} = & \underbrace{\sum_{j=1}^{K} U^H_{ij} H_{D_iR_{ij}} V_{ij} y_{R_{ij}}}_{Signal} + \\ & \underbrace{\sum_{j=1}^{K} \sum_{t=1, t\neq i}^{T} U^H_{ij} H_{D_iR_{ij}} V_{tj} y_{R_{tj}}}_{Interference} + \\ & \underbrace{\sum_{j=1}^{K} U^H_{ij} H_{D_iR_{ij}} V_{ij} Z^R_{ij} + \sum_{j=1}^{K} Z^D_{ij}}_{Noise} \end{aligned} \tag{2}$$

Where $H_{D_iR_{ij}}$ and Z^D_{ij} respectively denotes the channel gain and white zero-mean circularly symmetric complex Gaussian noise between relay R_{ij} and destination node D_i .There are T source-destination pairs and each pair has K independent sub-channels, we may write the sum capacity[6] as (3).

$$C_{sum} = \frac{1}{2} \sum_{i=1}^{T} \sum_{j=1}^{K} \log\left(1+\eta_{i,j}\right) \tag{3}$$

Where $\eta_{i,j}$ denotes the signal to interference plus noise ratio **(SINR)** of the j -th data stream transmitted by source node S_i

III. OPTIMAL RELAY SELECTION AND INTERFERENCE ALIGNMENT

As is mentioned above, each source-destination pair will select K relays from an alternative relay set including G alternative relays. In our work, we suppose a relay selection strategy based on Harmonic mean function of two-hop channel gain [7]. The channel gain can be expressed by trace of the channel gain matrix. The Harmonic mean function of two-hop channel gain between source-destination pair S_i - D_i can be expressed as (4).

$$\beta\left(H_{S_iR_g}, H_{D_iR_g}\right) = \frac{2J\left(H_{S_iR_g} H^H_{S_iR_g}\right) J\left(H_{D_iR_g} H^H_{D_iR_g}\right)}{J\left(H_{S_iR_g} H^H_{S_iR_g}\right) + J\left(H_{D_iR_g} H^H_{D_iR_g}\right)} \tag{4}$$

Where $g \in \left(1,2,...,G\right)$ is the index of alternative relay.

Our relay selection strategy is expressed as follows.

1) Each source-destination pair calculates the Harmonic mean function of two-hop channel gain $\beta\left(H_{S_iR_g}, H_{D_iR_g}\right)$, and forms Harmonic mean function matrix $B \in \mathbb{C}^{T\times G}$.

2) Examine the source-destination pair whether has already selected K relays, if yes, then the source-destination pair exits the relay selection.

3) Find the maximal $\beta\left(H_{S_iR_g}, H_{D_iR_g}\right)$, then source-destination pair S_iD_i selects relay R_g as its relay. And delete R_g from the alternative relay set.

4) Repeat step 2) 3) until all the source-destination pair have already selected K relays.

Thus, we finish the process of relay selection. Different from the relay selection strategy in [7], our relay selection strategy allows source-destination pair who has the maximal $\beta\left(H_{S_iR_g}, H_{D_iR_g}\right)$ to have priority to select relay, thus the source-destination pair will achieve higher channel gain.

After the process of relay selection, all the source-destination pairs have already selected enough relays. In the first step, all the source-destination pairs perform beamforming as explained in [7]. In the second step, the selected relays amplify and forward data streams to the corresponding destination node by the application of interference alignment. The interference alignment algorithm is as follows.

As is mentioned above, there are T source-destination pairs in the network, and each pair has selected K relays to transmit data streams. By designing pre-coding vectors at all the selected relays, the interference arrived at destination node D_i from other $T-1$ source-destination pairs will be aligned to $T-1$ independent directions. In particular, K interference data streams from any other source-destination pair are aligned to a single direction. The formula for destination node D_i can be expressed as follow.

$$\begin{aligned} span\left\{H_{D_iR_{s,1}}V_{s,1}\right\} = span\left\{H_{D_iR_{s,2}}V_{s,2}\right\} = \\ \ldots = span\left\{H_{D_iR_{s,K}}V_{s,K}\right\} = C_{si} \end{aligned} \quad (5)$$

Where $R_{s,1}$ represents the first selected relay of source-destination pair S_sD_s and $s \neq i, s \in (1,2,\ldots T)$, $V_{s,1}$ is the pre-coding vector at the first selected relay of source-destination pair S_sD_s. $C_{si}\,(s=1,2,\ldots,T; i=1,2,\ldots,T; s\neq i)$ represents equivalent interference direction from source-destination pair S_sD_s to S_iD_i.

Change formula (5) into matrix pattern as follow.

$$\underbrace{\left[\begin{array}{cccccc|ccc}
I_N & & & & & & -H_{D_1R_{i,1}} & & \\
\vdots & & & & & & & \ddots & \\
I_N & & & & & & & & -H_{D_1R_{i,K}} \\
& \vdots & & & & & \vdots & \vdots & \vdots \\
& & I_N & & & & -H_{D_{i-1}R_{i,1}} & & \\
& & \vdots & & & & & \ddots & \\
& & I_N & & & & & & -H_{D_{i-1}R_{i,K}} \\
& & & I_N & & & -H_{D_{i+1}R_{i,1}} & & \\
& & & \vdots & & & & \ddots & \\
& & & I_N & & & & & -H_{D_{i+1}R_{i,K}} \\
& & & & \vdots & & \vdots & \vdots & \vdots \\
& & & & & I_N & -H_{D_TR_{i,1}} & & \\
& & & & & \vdots & & \ddots & \\
& & & & & I_N & & & -H_{D_TR_{i,1}}
\end{array}\right]}_{[(T-1)NK][(T-1)N+KM]}
\begin{bmatrix} C_{i1} \\ \vdots \\ C_{i(i-1)} \\ C_{i(i+1)} \\ \vdots \\ C_{iT} \\ V_{i1} \\ \vdots \\ V_{ii} \\ \vdots \\ V_{iK} \end{bmatrix} = 0$$

(6)

Where N , M respectively represents the antenna amount of each relay node and destination node.

By solving the homogeneous equations, we can get the equivalent interference direction from source-destination pair S_iD_i to other pairs. In addition to this, we can also get the pre-coding vectors V_{ij} of the selected relay R_{ij} .In order to ensure homogeneous equations solvable, the number of rows must be less than the number of columns in the coefficient matrix of homogeneous equations, scilicet:

$$(T-1)N + KM - (T-1)NK \geq 1 \quad (7)$$

In order to receive the data stream without interference, we need to design the interference elimination vectors to remove the interference. The interference can be divided into two parts, one is the aligned interference from other source-destination pairs, another one is the interference from the other $K-1$ data streams in the same source-destination pair. We call the former as external interference and the latter as internal interference. In order to remove the external interference, we design the interference elimination vectors $U_i\left(i=1,2,...,T\right)$, and U_i can be expressed as follow:

$$U_i = null\left\{\begin{matrix}\left(H_{D_iR_{1,1}}V_{1,1}\right),\left(H_{D_iR_{2,1}}V_{2,1}\right),\cdots; \\ \left(H_{D_iR_{(i-1),1}}V_{(i-1),1}\right),\left(H_{D_iR_{(i+1),1}}V_{(i+1),1}\right),\cdots; \\ \left(H_{D_iR_{T,1}}V_{T,1}\right)\end{matrix}\right\} \quad (8)$$

Change formula (8) into homogeneous equations and suppose that $U_i \in \mathbb{C}^{N\times L}$, in order to ensure homogeneous equations solvable, we need:

$$N-\left(T-1\right)\geq L \quad (9)$$

To eliminate the internal interference, we need to design interference elimination vectors $U_{ij}\left(i=1,2,...,T;j=1,2,...,K\right)$ for every independent data stream in every destination node. U_{ij} can be expressed as follow:

$$U_{ij} = null\left\{\begin{matrix}\left(H_{D_iR_{i,1}}V_{i,1}\right),\left(H_{D_iR_{i,2}}V_{i,2}\right),\cdots; \\ \left(H_{D_iR_{i,(j-1)}}V_{i,(j-1)}\right),\left(H_{D_iR_{i,j+1}}V_{i,j+1}\right),\cdots; \\ \left(H_{D_iR_{i,K}}V_{i,K}\right)\end{matrix}\right\} \quad (10)$$

In a similar way, we change it into homogeneous equations. To ensure the homogeneous equations solvable, we need to satisfy the inequality $L \geq K$, suppose that $L = K$ and take it into formula (7) (9), we get:

$$M \geq \frac{1+N\left(T-1\right)\left(K-1\right)}{K} \quad (11)$$

IV. Simulation Result

In this section, numerical results of the proposed algorithms are presented. All channels are assumed to be zero-mean unit covariance Rayleigh fading channel while the effect of large-scale fading is neglected. Each source node sends the data stream by the same power.

In Fig. 1, we plotted the system capacity of the network where $T=3,K=2,G=6$ with fairness relay selection in [7] and optimal relay selection. From Fig. 1, we can get that transmission mechanism of beamforming and interference alignment based on optimal relay selection can achieve higher system capacity under different SNR.

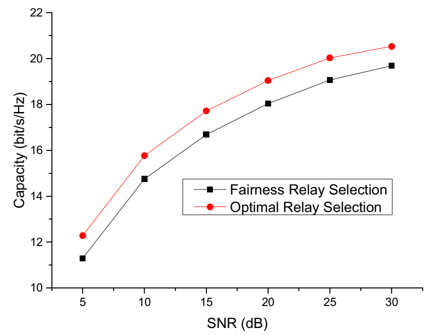

Fig. 1. Ergodic capacity as a function of SNR for $T=3,K=2,G=6$

In Fig. 2, we analysis the system capacity in the network where $T=3,K=2$ under different amount of alternative relays $G\in\{6,10,15,20,25\}$.

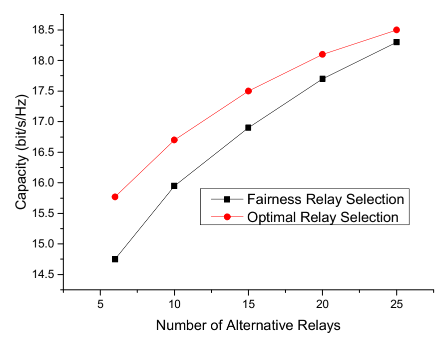

Fig. 2. Ergodic capacity as a function of number of alternative relays for $T=3,K=2,SNR=10dB$

As we can see from Fig. 2, with the growth of G, the system capacity grows with different rate. When the amount of alternative relays is relatively small, the transmission mechanism based on optimal selection performs much better. When the amount of alternative relays is relatively big, the performance of two transmission mechanism is approaching the same.

V. Conclusions

In this paper, we considered about a transmission mechanism involving relay selection beamforming and interference alignment in MIMO interference relay network. The transmission mechanism makes full use of the channel state information, and it outperforms the conventional distributed interference cancellation. By using optimal relay selection algorithm in the transmission mechanism we can achieve much higher system capacity especially when there are small amount of alternative relays in the network. In general, rational utilization of these three techniques can enhance the system capacity of the MIMO interference relay network.

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REFERENCES

[1] H. Bölcskei, R. Nabar, O. Oyman, and A. J. Paulraj, "Capacity scaling laws in MIMO relay networks," IEEE Trans. Wireless Commun.,vol.5, no. 6, pp. 1433-1444, Jun. 2006.

[2] R.U.Nabar,O.Oyman,H.Bolcskei, and A. J. Paulraj, "Capacity scaling laws in MIMO wireless networks," in Proc. Allerton Conf. Commun., Control, and Computing, Oct. 2003, pp. 378-389.

[3] Y. Birk and T. Kol, ‘‘Informed-source coding-on-demand (ISCOD) over broad-cast channels,’’ in Proceedings of the Seventeenth Annual Joint Conference of the IEEE Computer and Communications Societies, IEEE INFOCOM’98, pp. 1257–1264, 1998.

[4] Y. Birk and T. Kol, ‘‘Coding on demand by an informed source (ISCOD) for efficient broadcast of different supplemental data to caching clients,’’ IEEE Transactions on Information Theory , vol. 52, no. 6, pp. 2825–2830, June 2006.

[5] Sujie Chen; Cheng, R.S., "Achieve the Degrees of Freedom of K-User MIMO Interference Channel with a MIMO Relay," Global Telecommunications Conference (GLOBECOM 2010), 2010 IEEE , vol., no., pp.1,5, 6-10 Dec. 2010

[6] Torabi, M.A.; Frigon, J.-F., "A Decomposition Approach to MIMO Interference Relay Networks," Global Telecommunications Conference, 2008. IEEE GLOBECOM 2008. IEEE , vol., no., pp.1,6, Nov. 30 2008-Dec. 4 2008

[7] LEI Wei-jia, SHI Zhao-yuan, XIE Xian-zhong and LU Hua-bing, ‘‘Multi-Relay Transmission Mechanism Based on Interference Alignment and Beamforming,’’ Journal of Beijing University of Posts and Telecommunications, 2013,03:49-53.

[8] M. A. Torabi and J. F. Frigon, "Semi-orthogonal relay selection and beaforming for amplify-and-forward MIMO relay channels," in Proc. IEEE WCNC'08, Las Vegas, USA, Mar. 2008.

[9] Hammerstroem and A. Wittneben, "Power allocation schemes for amplify-and-forward MIMO-OFDM relay links," IEEE Trans. Wireless Commun., vol. 6, no. 8, pp. 2798 - 2802, Jun. 2007.

[10] M. A. Maddah-Ali, A. S. Motahari, and A. K. Khandani, "Communication over MIMO X channels: Interference alignment, decomposition, and performance analysis," IEEE Trans. Inf. Theory, vol. 54, no. 8, pp. 3457-3470, 2008.

[11] B. Nourani, A. S. Motahari, and A. K. Khandani, "Relay-Aided Interference Alignment for the Quasi-Static Interference Channel," in Information Theory, 2010. ISIT 2010. IEEE International Symposium on, pp. 405-409, 2010.

[12] Ghasemi, A. S. Motahari, and A. K. Khandani, "Interference Alignment for the K User MIMO Interference Channel," http://arxiv.org/abs/ 0909.4604. pp. 5534-5562, 2007.

[13] Xuesong Wang; Yong-Ping Zhang; Zhang, P.; Xiaotao Ren, "Relay-aided interference alignment for MIMO cellular networks," Information Theory Proceedings (ISIT), 2012 IEEE International Symposium on , vol., no., pp.2641,2645, 1-6 July 2012.