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# MIMO relay channel signal transmission in transformed signal subspace

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ABSTRACT

We design a new improved signal space alignment scheme in MIMO Y channel where one of $K$ source nodes sends $K-1$ independent messages to the other nodes and each message achieves the degrees of freedom (DoF) of $d$. The key is to let the messages to be exchanged by applying improved signal space alignment for network coding and interference cancellation when antennas configuration extends to $N > 2M$, where $N$ and $M$ denote the number of antennas at the relay and each source respectively. It is not feasible for the traditional signal space alignment to achieve the same DoF under this antenna number configuration. Moreover, we discuss the ill-conditioned channel to improve the system performance for Zero Forcing decoder. The simulations show that our proposed scheme achieves DoF of $dK(K-1)$ and improves system performance reliability.



## 1. Introduction

Wireless communication is one of the fastest growing industries over the last decades. The number of cellular and wireless network users worldwide indicates rapid growth of business in wireless systems. Nowadays, wireless users require more applications, such as peer-to-peer (P2P) file sharing, online gaming, and multimedia. At the same time, there exists increasing users demand for more bandwidth, broader coverage, and better mobility support, which establishes a trend of significant increase in traffic volume in wireless networks [1,2]. To support the tremendous wireless traffic volume with high reliability and broader coverage, cooperative diversity schemes, using relays between the source and destination, have been widely investigated because of their spatial diversity and extensive coverage with reduced power consumption [3,4].

In practical wireless systems, co-channel interference arises inevitably due to frequency reuse, and has been shown to be a key limiting factor for many future MIMO applications. Thus, it is important to design effective signals processing algorithms to eliminate the co-channel interference [5,6]. It is likely that several users simultaneously initiate a service request at the instant. Exploiting spatial-multiplexing capability of multiple transmitting antennas to efficiently serve multiple users simultaneously is a much more powerful method than the maximizing the capacity of a single user link.

Interference alignment (IA) [7] is one of the attractive ideas that has emerged to overlap interference signals at each receiver to minimize the dimension of the signal space occupied by interference signals. Then, it is extended to MIMO multi-user relay channel first by Lee et al. in [8]. The authors consider a three-user MIMO Y channel where each user sends two independent messages to other users and receives two messages via a relay. The key idea of signal space alignment (SSA) is to align the receiving vectors of paired signals from two users communicating with each other at the relay. Since signals can be aligned unless two users have an intersection space at the relay, the SSA cannot be applied to the case when two users do not project a common subspace at the relay. Many researchers have been investigating different signaling schemes for two-way relay channels (TWRC) and multi-way relay channels (MWRC). The authors in [9] take into account example for four-user MIMO Y channel. Because of the SSA constraint, the interference nulling beamforming vector should generally not be constructed. Thus, the authors consider antenna selection schemes to solve this dimensionality constraint problem which leads to achieving the trivial cut-set outer bound impossibly. Wang et al. [10] extend interference nulling beamforming to $K$-user with $d$ interference-free streams by mitigating selective interference signals. Then, the SSA scheme applies to the generalized $K$-user Y channel in [11] and the X relay channel [12]. Recently, Wang et al. [13] proposed a novel scheme where users combine bi-directional multi-pair messages exchange with multi-directional multi-pair exchange with SSA and successive network code. It is proved that the SSA significantly increases this network throughput. The authors in [14] analyze the feasibility condition

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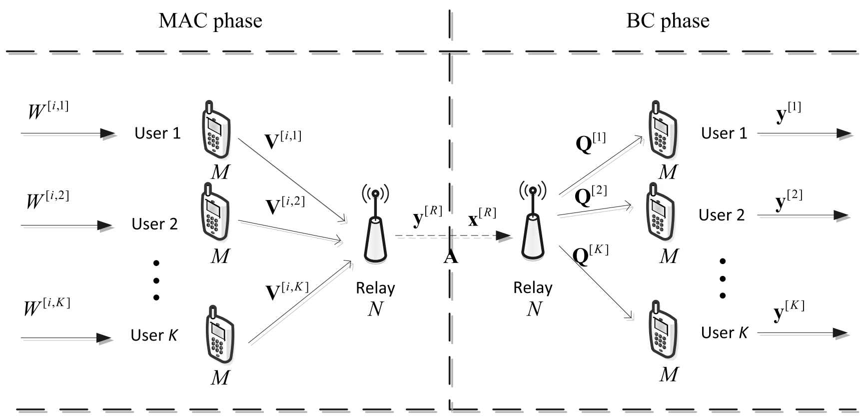


**Fig. 1.** System model for MIMO multi-way relay network.

for SSA and show that the degrees of freedom (DoF) of $K(K-1)$ is achieved if $M \geq K-1$, $N \geq K(K-1)$ and $N < 2M$ where $M$ is the number of users' antennas and $N$ is relay antennas. It is accomplished by adopting the SSA for network coding during both multiple access channel (MAC) and broadcast channel (BC).

The authors in [15] consider the new case $N > 2M$ which has a broader range of dimension constraint compared to the existing SSA schemes [8–14]. Recently, the authors in [16] proposed a generalized signal alignment (GSA) based transmission scheme for MIMO two-way X relay channels. The key is to let the signals to be exchanged between every source node align in a transformed subspace, rather than the direct subspace, at the relay so as to form network-coded signals. This is realized by jointly designing the precoding matrices at all source nodes and the processing matrix at the relay.

In this paper, we extend the result of [16] into the case of a general number of users as $K$-user MIMO Y channel when $N > 2M$. It is worth mentioning that SSA is not feasible under the antenna configuration $N \geq 2M$. We want to improve the GSA scheme so that the scheme is performed not only at the MAC phase but also in the BC phase on MIMO Y channel, named *improved signal space alignment* (ISSA). We will investigate the antenna configuration condition of the ISSA for the $K$-user in order to obtain the DoF of $dK(K-1)$ when each source node sends $K-1$ independent messages to the other nodes and each message achieves the DoF of $d$. We can find many applications of the proposed signaling scenario in wireless networks. For example, information exchange happens among all users in a wireless mesh or ad-hoc system where nodes are connected by sharing a single relay as tree or star topology. Also in a cellular system, where a base station is communicated with some users via a relay (multiuser MIMO relaying system), the relay locally forwards the data for exchanging among users without sending to the base station. In addition, the other case models situation where it is easier to mount antennas at the users than at the relay node, such as when the relay is a satellite node. The users and relay can be flexible enough to set antennas by using SSA or ISSA.

This paper is organized as follows: Section 2 describes the system model of $K$-user MIMO Y channel. In Section 3, we introduce the idea of the ISSA transmission scheme to $K$-user MIMO Y channel. Firstly, we give an illustrative example for 3-user MIMO Y channel. Then we extend the scheme to general $K$-user case. We have tried to clarify the transmission strategy in the extension of the interference alignment algorithm into more general scenarios as described in section 4. In Section 5, we improve the performance of the proposed scheme under ill-conditioned channels by using zero-forcing (ZF) decoder. Section 6 verifies the derived results through numerical simulations. Finally, this paper is concluded in section 7.

Throughout this paper, the bold upper and lower case letters are used for the matrix and the column vector. $(\bullet)^T$ and $(\bullet)^H$ demonstrate the transpose and the conjugate transpose, respectively. The nullspaces is implied by NULL($\bullet$). The rank value of the matrix is demonstrated by rank($\bullet$). E($\bullet$) and Tr($\bullet$) denote the expectation and the trace operator of a matrix.

## 2. System model

We consider a MIMO Gaussian $K$-user MIMO Y channel in this section shown as Fig. 1. In this channel, each user equipped with $M$ antennas wants to convey $K-1$ independent messages for $K-1$ different users and wants to decode independent messages from other users via the intermediate relay with $N$ antennas during two time slots. We assume that users and relay have perfect channel state information (CSI) of all links. Furthermore, we assume that there is no direct link between user pairs. User $i$ sends the message $W^{[j,i]}$ to user $j \in \{1, 2, \ldots, K\}/\{i\}$ and it is dependent for different $i$ and $j$. All users want to transmit $d$ independent data streams for each message. That is $d \leq \lfloor \frac{M}{K-1} \rfloor$.

In the first time slot, which is called a multiple access phase (MAC). In the MAC phase, each node transmits its signal to relay and the signal of user $i$ is precoded as $\mathbf{x}^{[i]} = \sum_{j=1, j\neq i}^{K} \mathbf{V}^{[j,i]}\mathbf{s}^{[j,i]}$, where $\mathbf{V}^{[j,i]}$ is the $M \times d$ precoding matrix $\mathbf{V}^{[j,i]} = [\mathbf{v}_1^{[j,i]}\ \mathbf{v}_2^{[j,i]}\ \ldots\ \mathbf{v}_d^{[j,i]}]$ and $\mathbf{s}^{[j,i]}$ is vector $\mathbf{s}^{[j,i]} = [s_1^{[j,i]}\ s_2^{[j,i]}\ \ldots\ s_d^{[j,i]}]^T$.

Then, the received signal vector at the relay becomes:

$$\mathbf{y}^{[R]} = \sum_{i=1}^{K} \mathbf{H}^{[R,i]}\mathbf{x}^{[i]} + \mathbf{n}^{[R]} \tag{1}$$

where $\mathbf{H}^{[R,i]}$ represents the $N \times M$ channel matrix from user $i$ to the relay, $\mathbf{x}^{[i]} \in \mathbb{C}^M$ denotes transmit vector at user $i$, and $\mathbf{n}^{[R]} \in \mathbb{C}^N$ denotes an additive white Gaussian noise (AWGN) vector. The user has an average power constraint, $\mathrm{E}[\mathrm{Tr}(\mathbf{x}^{[i]}\mathbf{x}^{[i]^H})] \leq \mathrm{SNR}$. The channel is assumed to be quasi-static and each entry of the channel matrix is an independently and identically distributed (i.i.d.) zero means complex Gaussian random variable with unit variance, i.e., $NC(0, 1)$. After receiving the signal $\mathbf{y}^{[R]}$, the relay deal with it to get a new signal $\mathbf{x}^{[R]} = \mu\mathbf{P}\mathbf{y}^{[R]}$. Where $\mathbf{P}$ is precoding matrix and $\mu$is power normalizing factor to satisfy the power constraint of $\mathrm{E}[\mathrm{Tr}(\mathbf{x}^{[R]}\mathbf{x}^{[R]^H})] \leq \mathrm{SNR}$.

During broadcast channel (BC) phase, the relay broadcasts $\mathbf{x}^{[R]}$ to all users. The received signal vector at user $i$ is given by:

$$\mathbf{y}^{[i]} = \mathbf{Q}^{[i]}\mathbf{H}^{[i,R]}\mathbf{x}^{[R]} + \mathbf{Q}^{[i]}\mathbf{n}^{[i]} \tag{2}$$

where $\mathbf{Q}^{[i]}$ denotes the receiving precoding matrix, $\mathbf{H}^{[i,R]}$ denotes the $M \times N$ channel matrix from the relay to user $i$, $\mathbf{x}^{[R]} \in \mathbb{C}^N$ is