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INTERFERENCE ALIGNMENT TECHNIQUES FOR MIMO MULTICELL BASED ON RELAY INTERFERENCE BROADCAST CHANNEL

Mr.S.V.Manikanthan, Assistant Professor, Department of Information and Communication, Dr.Paul's Engineering College, Villupuram Dist.

Mrs.D.Sugandhi, Student, Department of Information and Communication, Dr.Paul's Engineering College, Villupuram Dist.

Abstract- ***In wireless communication system, a multiuser multiple input multiple output (MIMO) Gaussian broadcast channel (BC), where the transmitter and receivers have multiple antennas. The interference alignment is a promising technique to efficiently mitigate interference and to enhance capacity of a wireless communication networks [1]. This proposes an interference alignment scheme for a network with multiple cells and multiple multiple-input and multiple-output (MIMO) users under a Gaussian interference broadcast channel (IFBC) scenario. The novel approach using the principle of multiple access channel (MAC) - broadcast channel (BC) duality to perform interference alignment while maximizing capacity of users in each cell .The algorithm in its dual form is solved using interior point methods[5]. We show that the proposed approach outperforms the extension of the grouping method in terms of capacity and base station complexity.***

I. INTRODUCTION

Interference Alignment scheme for a network with multiple cells and MIMO users under a Gaussian interference broadcast channel with extended the grouping method in the multi-cell scenario to jointly design the transmitter and receiver beam forming vectors using a closed form expression without a need for iterative computation, ensure no ICI and IUI at each user's receiver while reducing both the number of antennas and the complexity at the base station as compared to the conventional zero-forcing beam forming scheme.

We propose an interference alignment algorithm for a multi-cell multi-user MIMO-IFBC based on a hybrid interference alignment[6] and MAC-BC duality based beam former design. The receiver beam forming vector design for effective ICI channel alignment, and the transmit beam forming vector design for removing ICI and IUI. Specifically, all the users in the same cell cooperatively construct the receiver beam forming vectors so as to align the effective ICI channel. Based[11] on this ICI channel alignment, each BS is able to treat these ICI channels as one ICI channel. Therefore, each BS can remove ICI and IUI by making the transmit beam forming vectors orthogonal to the subspace spanned by the effective ICI channel and IUI channel vectors[9]. Hence, the cost in terms of number of transmitting antennas is reduced by employing the extension of grouping algorithm .In particular, degrees of freedom (DoF) is used as a tool to characterize the asymptotic behavior of network capacity in high signal-to-noise ratio (SNR). For a K-user multiple-input-multiple-output (MIMO) interference channel with M antennas at every transmitter (Tx) and receiver (Rx)[7], that if channel coefficients are time-varying/frequency-selective and form non-degenerate matrices, the sum capacity can be characterized as

$$C(\mathrm{SNR}) = KM/2 \log(\mathrm{SNR}) + o(\log(\mathrm{SNR})). \quad (1)$$

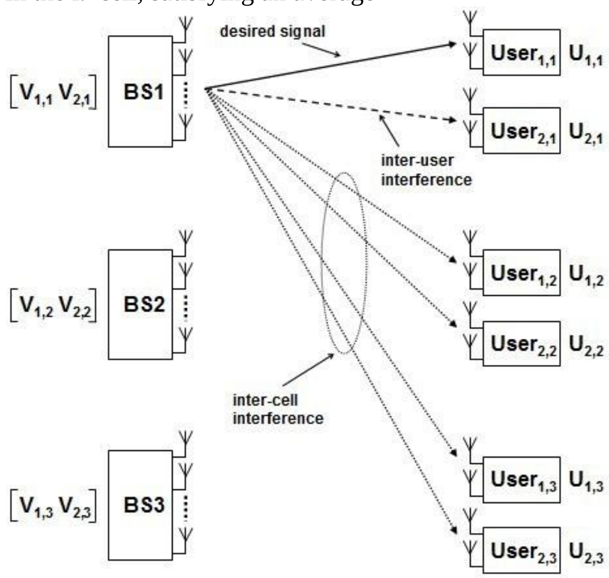
The pre-log factor "KM/2" is defined as the DoF of the K user $M \times M$ interference channel. Here SNR represents the transmission power over the noise power at each node. The DoF achievable scheme is based on the idea of interference alignment[3]. Each Tx constructs its recoding vector such that at every Rx, interference signals lie within a "wasted" space that does not intersect with the space spanned by the desired signals. we consider a K-user $M \times N$ MIMO interference channel with a MIMO relay, where global CSI is only available at the relay, while Rxs only have partial CSI and Txs have no CSI. Since characterizing the DoF region of this channel is still an open problem, we focus on the symmetric DoF which is defined as the maximum DoF that can be achieved simultaneously at all Tx-Rx pairs. We want to obtain the symmetric DoF and find out how it can be achieved by utilizing a MIMO relay[8]. We start from the case where all Txs and Rxs have the same number of antennas, i.e., $M = N$. We propose a two-time-slot transmission scheme based on the idea of interference alignment. In our scheme, the relay applies a linear transformation on its received signals instead of decode-and-forward (DF)

II. PREVIOUS WORK

The MIMO-IFBC model consists of a cellular network with L cells, each cell consists of K users. We assume that each user is equipped with N_r antennas and each cell has one BS consisting of N_t antennas. The channel in each cell can be regarded as MIMO-IFBC. An example for the case of L = 3 and K = 2 is illustrated in Fig. 1. As shown in Fig. 1, the BS 1 sends data to user 1 while introducing both inter-user interference and inter-cell interference. Similarly, BS 2 and BS 3 introduce interference to other users. We assume each BS aims to convey d_s data streams to its corresponding user, where $d_s \leq \min(N_t, N_r) = N_r$, we assumed $N_r < N_t$. We refer to the k_{th} user in the l_{th} cell as user [k, l]. The signal intended for the k_{th} user in the l_{th} cell is written as

$$\mathbf{x}^{[k,l]} = \sum \mathbf{v}^{[k,l]}_i s^{[k,l]}_i = \mathbf{V}^{[k,l]} \mathbf{s}^{[k,l]}, \quad (1)$$

where $s^{[k,l]}_i$ denotes the i_{th} transmitted symbol for the k_{th} user in the l_{th} cell, satisfying an average



$E[||\mathbf{x}^{[k,l]}||^2] \leq P^{[k,l]}$, and $\mathbf{v}^{[k,l]}_i \in C^{N_t \times 1}$ is the linear transmit beam forming vector corresponding to the symbol, $s^{[k,l]}_i$, with a unity norm constraint, i.e., $||\mathbf{v}^{[k,l]}_I|| = 1$. The transmitter beam forming matrix for the user [k, l] is written as $\mathbf{V}^{[k,l]} = [\mathbf{v}^{[k,l]}_1 \; \mathbf{v}^{[k,l]}_2 \; \mathbf{v}^{[k,l]}_{d_s}] \in C^{N_t \times d_s}$, and its corresponding data signal vector is denoted by $\mathbf{s}^{[k,l]} = [s^{[k,l]}_1 \; s^{[k,l]}_2 \; s^{[k,l]}_{d_s}]^T \in C^{d_s \times 1}$. Herefore , the received signal of the k_{th} user in the l_{th} cell $\mathbf{y}^{[k,l]} \in C^{N_r \times 1}$ can be written as

$$\mathbf{y}^{[k,l]} = \sum_{i=1}^{L} \mathbf{H}^{[k,l]}_i \sum_{j=1}^{K} \mathbf{x}^{[j,i]} + \mathbf{n}^{[k,l]} = \mathbf{H}^{[k,l]}_l \mathbf{V}^{[k,l]} \mathbf{s}^{[k,l]} + \sum_{j=1, j \neq k}^{K} \mathbf{H}^{[k,l]}_l \mathbf{V}^{[j,l]} \mathbf{s}^{[j,l]} + \sum_{i=1, i \neq l}^{L} \sum_{j=1}^{K} \mathbf{H}^{[k,l]}_i \mathbf{V}^{[j,i]} \mathbf{s}^{[j,i]} + \mathbf{n}^{[k,l]}$$

INTERFERENCE ALIGNMENT SCHEME USING MAC-BC DUALITY AND DATA RATE BALANCING

1) Group the users and design the receiver beam forming matrices $\mathbf{U}^{[k,l]}$, $k \in 1, 2, \ldots K$, $l \in 1, 2, \ldots L$;
2) Design the base matrices for the transmit beam forming using equation , $k \in 1, 2, \ldots K$, $l \in 1, 2, \ldots L$;
3) Define the effective channel from BS l to user [k, l] using equation for $k \in 1, 2, \ldots K$, $l \in 1, 2, \ldots L$;
4) **For** l = 1, 2, … , L, do the following:
5) Initialize: $\mu_{d1} \ldots \mu_{dK}$ to positive values, d = 1;
6) **repeat**
7) Determine the optimal solution $\mathbf{Q}^{[k,l]}_m$ for MAC problem as in Subsection A, $\mathbf{Q}^{[k,l]}_m$ is mapped to $\mathbf{Q}^{[k,l]}_b$ using MAC-BC duality;
8) Update the Lagrangian coefficient μ_{dk} ,d = d + 1;
9) **Stop** when $|R^{[k,l]}_b - R^{[k-1,l]}_b| \leq \_$ for k = 2, ,K;
10) **End For**.

III. PROPOSED REGISTRATION FRAMEWORK

(a) DOF ACHIEVABLE SCHEME FOR K-USER M × M INTERFERENCE CHANNEL

When M = N, it has been shown [7] that the DoF is upper bounded by $\frac{KM}{2}$. This bound is general in the sense that it is valid regardless of the availability of global CSI at Txs or the number of antennas at the relay. Note that when global CSI is only available at the relay, this bound can be achieved by a two-time-slot transmission scheme where the relay first decodes all Txs' signals and then broadcasts to all Rxs, provided that the relay has at least KM antennas for decoding[3]. However, decoding operation induces high processing complexity. Here we are looking for a lower complexity processing such as linear operation t the relay to achieve the same DoF. we address this issue by proposing a two-time-slot interference alignment scheme.

(b) Two-time-slot Interference Alignment Scheme

In the first time slot, all Txs transmit and the signals received at Rx j and at the relay can be respectively expressed as

$$y_j(1) = \sum_{i=1}^{K} H_{j,i} x_i + z_j \quad \text{and}$$

$$y_R = \sum_{i=1}^{K} F_i x_i + z_R$$

Here $x_i \in C^{M\times 1}$ is the vector transmitted by Tx i in the first time slot. $z_j(1)$ and $z_R(1)$ denote the noise vectors at Rx j and at the relay, respectively. All noise elements are assumed to be i.i.d. circular symmetric Gaussian random variables with unit variance, i.e., $\mathcal{CN}(0, 1)$.In the second time slot, the relay transmits to all Rxs and the transmitted signal is generated through a linear transformation on

y_R, i.e., $x_R = \Gamma y_R$, where $\Gamma \in C^{R\times R}$ is referred to as the beam forming matrix. The signal received by Rx *j* can be
expressed as

$y_j(2) = G_j x_R + z_j(2) = \_{K i=1}\ G_j \Gamma F_i x_i + \bar{z}_j$

where $\bar{z}_j(2) = G_j \Gamma z_R(1) + z_j(2)$ represents the equivalent
noise. Thus, at Rx *j*, the received signals in the two time slots form a $2M \times 1$ column vector

$y_j = y_j(1) y_j(2) = H_{j,j} G_j \Gamma F_{j\_j} + _{K i=1, i\_=j\_} H_{j,i} G_j \Gamma F_{i\_} x_i$

$+\_z_j(1)\bar{}z_j(2)$

The available signal space at each Rx has $2M$ dimensions since the two-time-slot transmission is applied, while the desired signal that an Rx needs to recover has *M* *d*imensions .If the interference signals can be projected onto an *M* dimensional space that does not intersect with the space spanned by the desired signal, simple zero-forcing can null out all the interference. This condition is called the interference alignment condition. On the other hand, at each Rx, its desired signal should fully span an *M*-dimensional space after zero forcing, and we call this the decidability condition. A valid beam forming matrix should satisfy both conditions simultaneously for all Tx-Rx pairs.

IV. EXPERIMENTAL SET-UP AND RESULTS

To evaluate We next evaluate the achievable DoF by computing the achievable sum rate versus SNR in a K-user M $\times$M MIMO interference channel with a relay. We assume that the channel elements are generated i.i.d. according to $\mathcal{CN}(0, 1)$. The result when the number of antennas is given by $R = (K - 1)M$. For fixed number of users, e.g., $K = 3$, the asymptotic slopes of sum rates (solid lines) increase linearly with M. Similarly, for fixed number of antennas, e.g., $M = 3$, the asymptotic slopes of sum rates (dashed lines) increase linearly with K. Furthermore, we can see that for systems having the same KM product, the asymptotic slopes of their sum rate curves are the same. All the slopes approach $KM/2$ asymptotically as SNR tends to infinity, which verifies that the DoF of $KM/2$ is indeed achievable.

When $R < (K - 1)M$, theoretical analysis shows that it is almost surely impossible to construct a beamforming matrix to satisfy both conditions (6) and (7). Now we use numerical results to show the effect of insufficient antennas at the relay on the achievable DoF. In constructing the beamforming matrix Γ, we just choose solutions randomly from the solution space of (11), given by $\hat{s} = I_{R^2+KM^2}\ W^\dagger W\ \_\ r$,

where r is a randomly generated vector. Hence, the derived beam forming matrix Γ. We found that these randomly generated Γ, when substituted into the matrix , result in a rank less than $2M$. The achievable DoF for $K = 3, M = 5$ and $K = 5, M = 3$, respectively. The achievable DoF decreases as the number of antennas at the relay reduces, and the decrease in DoF can be significant even when R is reduced by just 1.In particular, when $K = 5$, $M = 3$, we found that reducing R, the rank of the matrix) using the derived beam forming matrix is only M and hence the achievable DoFis equal to 0.

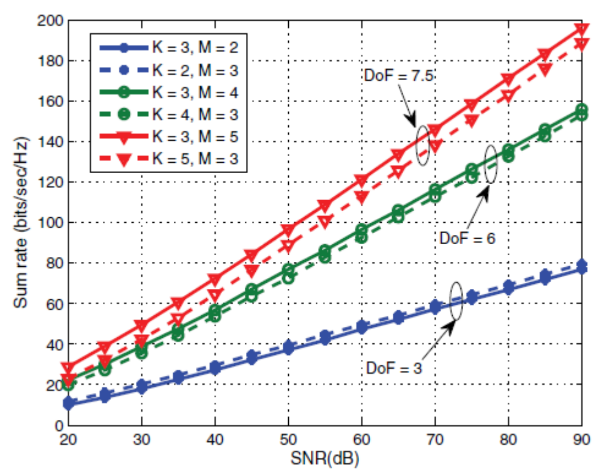


Fig.1 Achievable sum rates versus SNR for K-user $M \times M$ interference channel with a MIMO relay. The number of antennas at the relay is given by$R = (K - 1)M$.z

This result shows the limitation of the proposed beam forming construction method that all users suffer from when the number of antennas at the relay is not enough to handle the excessive interference streams. Therefore, in this scenario, more conservative methods such as allowing only a fraction of users to transmit may achieve higher DoF. The achievable DoF decreases as the number of antennas at the relay reduces, and the decrease in DoF can be significant even when R is reduced by just 1. In particular, when $K = 5, M = 3$, we found that reducing R from 12 to 11, the rank of the matrix in (7) using the derived beamforming matrix is only M and hence the achievable DoF is equal to 0.

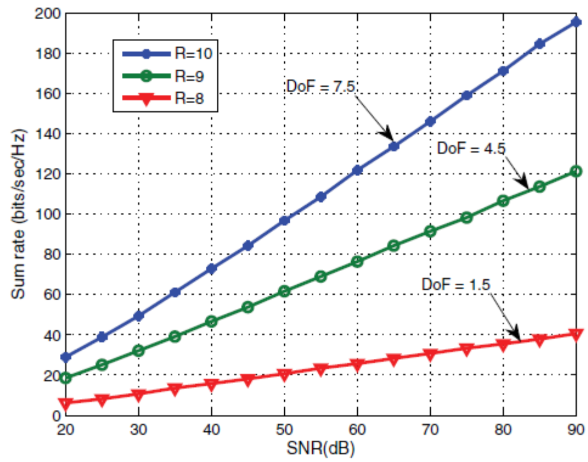


Fig. 2 . Achievable sum rate versus SNR for 3-user 5×5 interference channel with different number of antennas at the relay.

(a) Results Discussion

In this section, the scheme proposed in for a K-user M $\times$ M interference channel without relays achieves the DoF of $KM/2$ only when the channel coefficients are timevarying/ frequency-selective, and when the Txs and Rxs have global CSI. One advantage of adding a global-CSI-acquired relay is that the signaling complexity can be greatly reduced. For each Rx that feeds back channel information, it only needs to transmit the feedback information reliably to the relay. Moreover, the channels do not need to be timevarying/ frequency-selective. Actually, since our scheme aligns the interference by adjusting the direction of the beams instead of relying on the channel fluctuations , it can work in slow varying or constant channels, where Rxs do not have to spend too much effort estimating and feeding back the CSI. Now we draw a comparison between our proposed scheme and two well-known transmission schemes: 1) Amplify-and forward (AF) transmission where relay inverts the aggregated channel from K Txs to itself in the first time slot, and then broadcasts to Rxs; 2) DF transmission where K transmitted messages are decoded by the relay in the first time slot before being re-encoded and transmitted to Rxs in the second time slot. In both cases, the channel is a multiple access channel (MAC) in the first time slot and a broadcast channel (BC) in the second time slot.

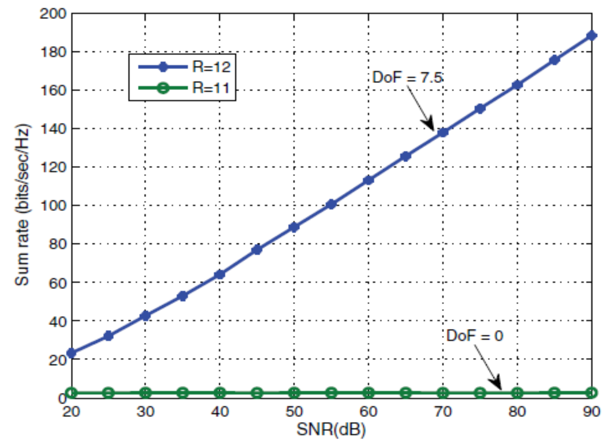


Fig. 3. Achievable sum rate versus SNR for 5-user 3×3 interference channel with different number of antennas at the relay.

Our proposed scheme is able to achieve the same DoF with $(K-1)M$ antennas. The saving in terms of percentage of antennas can be significant when K is relatively small, e.g., 33% and 25% when $K = 3$ and $K = 4$, respectively. Moreover, from the perspective of processing complexity, the MIMO relay in our proposed scheme only processes its received signal with a linear transformation, which has similar complexity to the DFMAC-BC scheme but lower than that of the DF-MAC-BC scheme.

V. Conclusion

This paper studies the achievable DoF of a K-user MIMO interference channel with a MIMO relay. We focus on a more realistic scenario that Txs have no CSIT and global CSI is only available at the relay. We first consider a special case that all Txs and Rxs have the same number of antennas. A two-timeslot transmission scheme based on the idea of interference alignment is proposed. It can be shown that if and only if there are $R \geq (K-1)M$ antennas at the relay, our proposed scheme can achieve the symmetric DoF $\frac{M}{2}$, or equivalently the sum DoF $\frac{KM}{2}$ in the system. Since the CSI requirement at the Txs can be completely eliminated by the proposed scheme

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D.Sugandhi, M.E student ,Discipline in computer and communication Engineering, Dr.Paul's Engineering college,villupuram district and received the B.E degree in Electronics and communication Engineering from the Madras University, Chennai, in 2002.She is working at present as Lecturer in Motilal Nehru Government polytechnic college,Lawspet ,puducherry -08.

S.V.Manikanthan, was born in Chennai, Indiain . He received his Diploma of Engineering in Electronics and Communication Engineering, from DOTE, Chennai and Bachelor of Engineering degree in Electronics and Communication from University of Madras, Chennai, India. Master of Engineering in Communication Systems from University of Vels, Chennai, Currently he is working as Assit.Professor in Dr. Pauls Engineering College, Villupuram and affiliated to Anna University Chennai, Tamil Nadu, India. His area of interest includes Wireless Sensor and Computer Networks.