Distributed Interference Alignment for Multi-Antenna Cellular Networks With Dynamic Time Division Duplex

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***Abstract*— In this letter, we propose a distributed interference alignment (DIA) technique in a two-cell multiple-input multiple-output (MIMO) network with dynamic time division duplex (TDD) mode under local channel state information assumption. The dynamic TDD operation introduces new types of interference, such as downlink-to-uplink [base station to base station (BS–BS)] and uplink-to-downlink [mobile station to mobile station (MS–MS)] interferences. Under the assumption of rank-deficient BS–BS MIMO interference channel, we mathematically characterize the achievable degrees-of-freedom of the proposed DIA technique for a given number of antennas at BS/MS. Through extensive computer simulations, it is shown that the proposed DIA technique outperforms the conventional techniques in terms of sum-rate at the cost of signaling overheads for the BS–BS and MS–MS channel overhearing.**

***Index Terms*— Dynamic TDD, traffic adaptation, interference alignment, degrees-of-freedom (DoFs), duplexing flexibility.**

I. Introduction

DYNAMIC time-division duplexing (TDD) has been considered as a promising technique for 5th generation (5G) mobile communication systems since it enables each base station (BS) to efficiently adapt to its own traffic load [1], [2]. One of the most challenging technical issues for the dynamic TDD is to manage *cross-interference* between UL and DL transmissions in neighbouring cells [2].

Recently, several interference management techniques have been proposed in literatures [3]–[8]. In [3], a transmit power control technique was proposed, where the DL transmission power decreases for reducing the BS–BS interference and the UL transmission power increases for improving uplink signal quality. In [4], a joint user scheduling, precoder design, and transmit direction (i.e., DL or UL) selection technique was investigated for a *cluster-based* MIMO cellular networks which operates with dynamic TDD. However, the proposed technique in [4] requires for the cluster controller to know *global* channel state information (CSI) of all mobile stations (MSs) in the cluster both in DL and UL, which may not be feasible in practice. In [5], an interference alignment (IA) algorithm was proposed for the dynamic TDD small cell MIMO networks which consisting of three cells. Na *et al.* [5] discarded the MS–MS interference and assumed global CSI among all BSs and MSs. In [6], the feasibility condition of the linear IA technique with constant channel coefficients was characterized for MIMO interfering braodcast–multiple-access channels (IBMACs) which is a mathematical model describing the dynamic TDD network in which one cell operates as DL and the other cell operates as UL. In [7], a necessary condition for the feasibility of IA was also obtained in MIMO reverse TDD multicell networks. Like other studies, the global CSI is assumed to be available at all users and BSs in [6] and [7]. A cyclic IA scheme was proposed for full-duplex MIMO cellular networks, where a closed-form IA beamforming (BF) solution is obtained for UL MSs, DL MSs, and a full-duplex BS in turn [8]. However, the cyclic IA also requires global CSI in determining the transmit BF vector at UL MSs.

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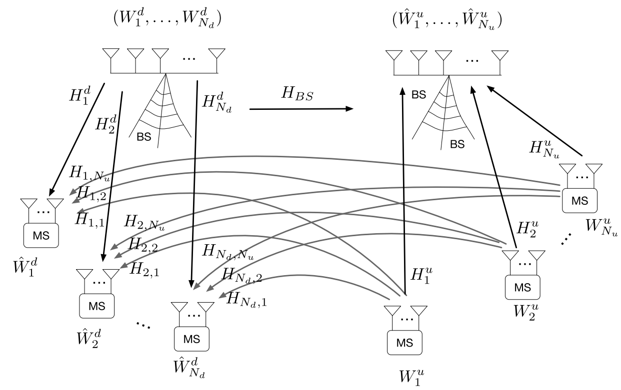

Fig. 1. System model of two-cell MIMO network with dynamic TDD.

In this letter, we first propose a novel *distributed* IA technique that operates with local CSI at all users and BSs for dynamic TDD MIMO cellular networks. We also investigate the achievable degree-of-freedom (DoF) of the proposed IA technique as a main result. Note that the proposed IA technique does not require information exchange between BSs and utilizes only linear BF technique in all BSs and MSs, but it requires for downlink MSs and uplink BS to overhear reference signal of the downlink BS and transmitted signals of the uplink MSs, respectively.

II. System Model

Consider a two-cell MIMO network as described in Fig. 1, where one cell operates as DL and the other cell operates as UL.[1] The DL cell consists of a single BS and N_d MSs, while the UL cell consists of a single BS with M antennas and N_u MSs. In general, there exist more MSs in cellular networks

[1]We focus on this case in this letter since the conventional IA techniques can be used when two cells operate with the same direction.

than the number antennas, and thus N_d and N_u are assumed to be chosen for maximizing DoFs of the network. We assume that both DL and UL BSs are equipped with M antennas, while both DL and UL MSs are equipped with L antennas due to a symmetric property of the dynamic TDD. The DL and UL BSs wish to send a set of independent messages $(W_1^d, \ldots, W_{N_d}^d)$ to the DL MSs and receive a set of independent messages $(W_1^u, \ldots, W_{N_u}^u)$ from the UL MSs, respectively. We assume that each UL and DL user sends and receives *a single* spatial stream to the UL BS and from the DL BS, respectively. The signals from the UL MSs can interfere the DL MSs, which is also called UL-DL interference (UDI). In addition, the signal from the DL BS can interfere the UL BS. The channel matrix from the DL BS to the i-th DL MS is denoted by $\mathbf{H}_i^d \in \mathbb{C}^{L\times M}$, where $i \in \mathcal{N}_d \triangleq \{1, \ldots, N_d\}$. The channel matrix from the j-th UL MS to the UL BS is denoted by $\mathbf{H}_j^u \in \mathbb{C}^{M\times L}$, where $j \in \mathcal{N}_u \triangleq \{1, \ldots, N_u\}$. The channel matrix from the j-th UL MS to the i-th DL MS is denoted by $\mathbf{H}_{i,j} \in \mathbb{C}^{L\times L}$, where $j \in \mathcal{N}_u$ and $i \in \mathcal{N}_d$. The channel matrix from the DL BS to the UL BS is denoted by $\mathbf{H}_{\mathsf{BS}} \in \mathbb{C}^{M\times M}$. Each element of $\mathbf{H}_i^d$, $\mathbf{H}_j^u$, and $\mathbf{H}_{i,j}$ is assumed to be independent and identically distributed (i.i.d) according to $\mathcal{CN}(0, 1)$.

Let the rank of $\mathbf{H}_{\mathsf{BS}}$ be D, and then $\mathbf{H}_{\mathsf{BS}}$ can be written by

$$\mathbf{H}_{\mathsf{BS}} = \sum_{k=1}^{D} \mathbf{a}_k \mathbf{b}_k^T, \tag{1}$$

where both $\mathbf{a}_k$ and $\mathbf{b}_k$ are $M \times 1$ vectors and coefficients in $\mathbf{a}_k$ and $\mathbf{b}_k$ can be drawn from a continuous distribution or can be generated by an angle of arrival (AoA) and an angle of departure (AoD) for each path between a certain transmit antenna and receiver antennas. We assume that the MIMO channel between two BSs is *rank-deficient* [9] due to strong possibility of line-of-sight (LOS) paths between BSs as noted in [5], i.e., $D \le M$. In addition, we assume the local CSI because it is much more feasible than the global CSI assumption in practical wireless networks [10]. Under the local CSI assumption, the i-th DL MS obtains $\mathbf{H}_{j,i}$ for all j and the UL BS obtains $\mathbf{H}_{\mathsf{BS}}$. For $i \in \mathcal{N}_d$, the receive signal at the i-th DL MS, $\mathbf{y}_i^d \in \mathbb{C}^{L\times 1}$, is given by

$$\mathbf{y}_i^d = \mathbf{H}_i^d \mathbf{V}_{\mathsf{BS}}^d \mathbf{x}_{\mathsf{BS}}^d + \sum_{j=1}^{N_u} \mathbf{H}_{i,j} \mathbf{v}_j^u x_j^u + \mathbf{z}_i^d, \tag{2}$$

and the received signal vector at the UL BS, $\mathbf{y}_{\mathsf{BS}}^u \in \mathbb{C}^{M\times 1}$, is given by

$$\mathbf{y}_{\mathsf{BS}}^u = \sum_{j=1}^{N_u} \mathbf{H}_j^u \mathbf{v}_j^u x_j^u + \mathbf{H}_{\mathsf{BS}} \mathbf{V}_{\mathsf{BS}}^d \mathbf{x}_{\mathsf{BS}}^d + \mathbf{z}_{\mathsf{BS}}^u, \tag{3}$$

where $\mathbf{x}_{\mathsf{BS}}^d \in \mathbb{C}^{N_d\times 1}$ indicates the transmit signal vector of the DL BS and $x_j^u \in \mathbb{C}$ indicates the transmit signal of the j-th UL MS. $\mathbf{V}_{\mathsf{BS}}^d \in \mathbb{C}^{M\times N_d}$ indicates the transmit BF (or precoding) matrix of the DL BS, where $N_d \le M$, and $\mathbf{v}_j^u \in \mathbb{C}^{L\times 1}$ indicates the transmit BF matrix of the j-th UL MS. The additive noise vectors, $\mathbf{z}_i^d \in \mathbb{C}^{L\times 1}$ and $\mathbf{z}_{\mathsf{BS}}^u \in \mathbb{C}^{M\times 1}$ are assumed to be i.i.d. according to $\mathbf{z}_i^d \sim \mathcal{CN}(\mathbf{0}_L, \mathbf{I}_L)$ for all $i \in N_d$ and $\mathbf{z}_{\mathsf{BS}}^u \sim \mathcal{CN}(\mathbf{0}_M, \mathbf{I}_M)$, respectively. The DL BS and all UL MSs are assumed to satisfy an average transmit power constraint, i.e., $\mathbb{E}[||\mathbf{x}_{\mathsf{BS}}^d||^2] \le P_{\mathsf{BS}}$ and $\mathbb{E}[||x_j^u||^2] \le P_{\mathsf{MS}}$ for all $j \in \mathcal{N}_u$.

III. Distributed Interference Alignment

In this section, we first summarize the achievable DoFs of the two-cell MIMO network with dynamic TDD, and then prove the achievable DoFs by describing the overall procedure of the proposed DIA technique.

A. Main Results

Theorem 1: When two cells operate with different directions, the following sum DoFs of the two-cell MIMO network is achievable via the DIA technique[2]

$$\mathsf{d}_{\mathsf{sum}} = \begin{cases} 2M - D & \text{if } L > M - D \\ M + L - 1 & \text{if } L \le M - D. \end{cases} \tag{4}$$

Proof: We refer to Section III-B for the proof of (4).

B. Overall Procedure of Distributed IA

In this subsection, we propose an achievable scheme for achieving the sum DoFs of the two-cell MIMO network with dynamic TDD. We assume that $N_u = M - D$ if $L > M - D$ and $N_u = L - 1$ if $L \le M - D$. In addition, we assume that $N_d = M$. Thus, the achievable DoFs for UL is equal to $M - D$ or $L - 1$, and the achievable DoFs for DL is equal to M since we assume a single spatial stream for each MS in both DL and UL. Note that all MSs and BSs utilizes their local CSI as well. The overall procedure of the achievable scheme is given as follows.

1) Broadcast of Reference Signals From DL BS: The DL BS broadcasts reference signals (pilot signals) for DL MSs to obtain the wireless channels between themselves and the UL BS, $\mathbf{H}_i^d$. In addition, the UL BS obtains $\mathbf{H}_{\mathsf{BS}}$ through the reference signal from the DL BS.

2) Broadcast of Reference Signals From UL BS: After obtaining $\mathbf{H}_{\mathsf{BS}}$, the UL BS computes its signal subspace by nulling the interference subspace from the DL BS, which is given by

$$\mathbf{U}_{\mathsf{Null}}^u = [\mathbf{u}_1, \ldots, \mathbf{u}_{M-D}], \tag{5}$$

where $\mathbf{u}_k \in \mathbb{C}^{M\times 1}$ denotes the orthogonal basis[3] of the left null space of $\mathbf{H}_{\mathsf{BS}}$. Hence, $(\mathbf{U}_{\mathsf{Null}}^u)^H \cdot \mathbf{H}_{\mathsf{BS}} = \mathbf{0}$. Then, the UL BS broadcasts reference signals (pilot signals) for the UL MSs to obtain the wireless channels between themselves and the DL BS, $\mathbf{H}_i^u$. The UL BS also broadcasts the signal subspace, $\mathbf{U}_{\mathsf{Null}}^u$, to the UL MSs.

3) Transmit BF at UL MSs: In the UL, N_u MSs send a single spatial stream to the UL BS. $\mathbf{v}_j^u \in \mathbb{C}^{L\times 1}$ denotes the unit-norm transmit BF vector at the j-th UL MS, i.e., $||\mathbf{v}_j^u||^2 = 1$, and it is chosen as:

$$\mathbf{v}_j^u = \arg\max_{\mathbf{v}} \parallel (\mathbf{U}_{\mathsf{Null}}^u)^H \mathbf{H}_j^u \cdot \mathbf{v} \parallel^2, \tag{6}$$

[2]We leave the optimality issue of Theorem 1 as a further study since it is beyond the scope of this letter.

[3]$\mathbf{u}_k$ is not necessarily orthogonal, but many studies on IA have adopted orthogonal basis to represent signal or interference space.

which maximizes the desired signal strength of the j-th UL MS. Then, the transmit BF vector becomes the eigenvector corresponding to the maximum eigenvalue of $(\mathbf{U}^u_{\mathsf{null}})^H\mathbf{H}^u_j$.

4) Transmit BF Vector Feedback From UL MSs: After obtaining the transmit BF vector, each UL MS sends its transmit BF vector, $\mathbf{v}^u_j$, to the UL BS. Considering the BS–BS interference nulling at the UL BS in the previous step, the effective channel vector of the j-th UL MS, $\mathbf{f}^u_j \in \mathbb{C}^{(M-D)\times 1}$, is given by

$$\mathbf{f}^u_j = (\mathbf{U}^u_{\mathsf{null}})^H\mathbf{H}^u_j\mathbf{v}^u_j. \tag{7}$$

Each DL MS also obtains $\mathbf{v}^u_i$ by *overhearing* the feedback.

5) Receive BF at DL MSs: Let $\mathbf{u}^d_i \in \mathbb{C}^{L_d\times 1}$ denote the unit-norm receive BF vector at the i-th DL MS, i.e., $||\mathbf{u}^d_i||^2 = 1$, and it is chosen as:

$$\mathbf{u}^d_i = \mathbf{u} \in \mathsf{Null}([\mathbf{H}^{\mathsf{UDI}}_i]^T), \tag{8}$$

where $\mathbf{u} \neq \mathbf{0}$ and $\mathbf{H}^{\mathsf{UDI}}_i \triangleq [\mathbf{H}_{i,1}\mathbf{v}^u_1, \ldots, \mathbf{H}_{i,N_u}\mathbf{v}^u_{N_u}] \in \mathbb{C}^{L\times N_u}$ denotes the interference channel matrix from N_u UL MSs to the i-th DL MS. Note that such a vector $\mathbf{u}^d_i$ in (8) always exists since $\mathbf{H}^{\mathsf{UDI}}_i \in \mathbb{C}^{L\times N_u}$ and $N_u < L$ by the assumption. The i-th DL MS is assumed to know $\mathbf{H}^{\mathsf{UDI}}_i$ based on the local CSI assumption and by overhearing the transmit BF vector feedback from the UL MSs to the UL BS as noted in the previous step.

6) Receive BF Vector Feedback From DL MSs: After obtaining the receive BF vector, each DL MS sends its receive BF vector, $\mathbf{u}^d_i$, to the DL BS[4]. Then, the effective channel vector of the i-th DL MS, $\mathbf{f}^d_i \in \mathbb{C}^{1\times M}$, is given by

$$\mathbf{f}^d_i = (\mathbf{u}^d_i)^H\mathbf{H}^d_i. \tag{9}$$

7) Data Transmission & Reception at Both DL and UL: In this step, both DL and UL data are sent simultaneously. For the DL transmission, we explain the pre-coding matrix at the DL BS shown in (2), $\mathbf{V}^d_{\mathsf{BS}} \in \mathbb{C}^{M\times N_d}$, which is given by

$$\begin{aligned}\mathbf{V}^d_{\mathsf{BS}} &= [\mathbf{v}^d_1, \mathbf{v}^d_2, \ldots, \mathbf{v}^d_{N_d}]\\ &= \begin{bmatrix} (\mathbf{u}^d_1)^H\mathbf{H}^d_1 \\ (\mathbf{u}^d_2)^H\mathbf{H}^d_2 \\ \vdots \\ (\mathbf{u}^d_{N_d})^H\mathbf{H}^d_{N_d} \end{bmatrix}^{\dagger} \begin{bmatrix} \sqrt{\gamma_1} & 0 & \cdots & 0 \\ 0 & \sqrt{\gamma_2} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \sqrt{\gamma_{N_d}} \end{bmatrix},\end{aligned} \tag{10}$$

where $\mathbf{A}^\dagger$ denotes the pseudo-inverse of matrix $\mathbf{A}$ and $\sqrt{\gamma_i}$ denotes a normalization factor for satisfying the unit-transmit power constraint for each spatial stream. Applying the receive BF (8) at the i-th DL MS and utilizing (10), (2) can be rewritten as:

$$\tilde{\mathbf{y}}^d_i = (\mathbf{u}^d_i)^H\mathbf{y}^d_i \tag{11}$$

$$= \sqrt{\gamma_i}x^d_{\mathsf{BS,i}} + \underbrace{\sum_{j=1}^{N_u}(\mathbf{u}^d_i)^H\mathbf{H}_{i,j}\cdot\mathbf{v}^u_j x^u_j}_{\text{cross-interference}} + \tilde{z}^d_i \tag{12}$$

$$= \sqrt{\gamma_i}x^d_{\mathsf{BS,i}} + \tilde{z}^d_i, \tag{13}$$

where $x^d_{\mathsf{BS,i}} \in \mathbb{C}$ denotes the transmit symbol of the DL BS to the i-th DL MS and $\tilde{z}^d_i \in \mathbb{C}$ denotes the additive noise after the receive BF, i.e., $\tilde{z}^d_i = (\mathbf{u}^d_i)^H\mathbf{z}^d_i$. Hence, $\tilde{z}^d_i \sim \mathcal{CN}(0,1)$ since $||\mathbf{u}^d_i||^2 = 1$. Note that the cross-interference term in (12) becomes *zero* because the receive BF vector at the DL MS is chosen so that the cross-interference from all UL MSs is removed as noted in (8).[5] Thus, each DL MS can achieve a single DoF and the achievable DoFs of DL is equal to $N_d = M$.

We now investigate the UL data transmission and reception. As noted before, it is assumed that $N_u = M-D$ if $L > M-D$ and $N_u = L-1$ if $L \leq M-D$. First, the UL BS multiplies the nulling matrix, $\mathbf{U}^u_{\mathsf{Null}} \in \mathbb{C}^{M\times(M-D)}$ defined in (5), to the received vector, $\mathbf{y}^u_{\mathsf{BS}}$ in (3), for removing the interference from the DL BS. Then, the projected vector of the received signal with *reduced* dimension, $\tilde{\mathbf{y}}^u_{\mathsf{BS}} \in \mathbb{C}^{(M-D)\times 1}$, is given by

$$\begin{aligned}\tilde{\mathbf{y}}^u_{\mathsf{BS}} &= (\mathbf{U}^u_{\mathsf{Null}})^H\cdot\mathbf{y}^u_{\mathsf{BS}}\\ &= \sum_{j=1}^{N_u}(\mathbf{U}^u_{\mathsf{Null}})^H\mathbf{H}^u_j\mathbf{v}^u_j x^u_j + \underbrace{(\mathbf{U}^u_{\mathsf{Null}})^H\mathbf{H}_{\mathsf{BS}}\mathbf{V}^d_{\mathsf{BS}}\mathbf{x}^d_{\mathsf{BS}}}_{\text{BS–BS interference}} + \tilde{\mathbf{z}}^u_{\mathsf{BS}}\end{aligned} \tag{14}$$

$$= \sum_{j=1}^{N_u}(\mathbf{U}^u_{\mathsf{Null}})^H\mathbf{H}^u_j\mathbf{v}^u_j x^u_j + \tilde{\mathbf{z}}^u_{\mathsf{BS}}, \tag{15}$$

where $\tilde{\mathbf{z}}^u_{\mathsf{BS}} \triangleq (\mathbf{U}^u_{\mathsf{Null}})^H\mathbf{z}^u_{\mathsf{BS}}$ and $\tilde{\mathbf{z}}^u_{\mathsf{BS}} \in \mathbb{C}^{(M-D)\times 1} \sim \mathcal{CN}(\mathbf{0}, \mathbf{I}_{M-D})$ since $\mathbf{U}^u_{\mathsf{Null}}$ consists of orthogonal columns as noted before. The UL BS multiplies the nulling matrix, $\mathbf{U}^u_{\mathsf{Null}} \in \mathbb{C}^{M\times(M-D)}$ defined in (5), to the received vector, $\mathbf{y}^u_{\mathsf{BS}}$ in (3), for removing the interference from the DL BS. Then, the BS–BS interference in (14) becomes *zero* due to the definition of $\mathbf{U}^u_{\mathsf{Null}}$ in (5). Then, the UL BS utilizes another post-coding matrix for decorrelating multiple spatial streams from the UL MSs, which is given by

$$\mathbf{U}^u_{\mathsf{BS}} = \left([\mathbf{f}^u_1, \ldots, \mathbf{f}^u_{N_u}]^\dagger\right)^H, \tag{16}$$

where $\mathbf{f}^u_1, \ldots, \mathbf{f}^u_{N_u}$ denotes the effective channel vectors from N_u UL MSs to the UL BS as defined in (7). After the post-coding at the UL BS, (2) is rewritten as:

$$\hat{\mathbf{y}}^u_{\mathsf{BS}} = (\mathbf{U}^u_{\mathsf{BS}})^H\tilde{\mathbf{y}}^u_{\mathsf{BS}} = [x^u_1, \ldots, x^u_{N_u}]^T + \hat{\mathbf{z}}^u_{\mathsf{BS}}, \tag{17}$$

where $\hat{\mathbf{z}}^u_{\mathsf{BS}} \triangleq (\mathbf{U}^u_{\mathsf{BS}})^H\tilde{\mathbf{z}}^u_{\mathsf{BS}}$. Then, $\hat{\mathbf{z}}^u_{\mathsf{BS}} \sim \mathcal{CN}(\mathbf{0}_{N_u}, \mathbf{U}^u_{\mathsf{BS}}(\mathbf{U}^u_{\mathsf{BS}})^H)$. Thus, the achievable DoFs of UL is equal to N_u and (4) is proved.

IV. Numerical Results & Discussions

In this section, we show the sum-rate performance of the proposed DIA technique via extensive computer simulations. For comparison with the proposed DIA technique, we consider four conventional schemes such as DL-IA [12], UL-IA [13], a single-cell multi-user DL/UL MIMO techniques [11].[6] We assume that total power of two cells is the same among all schemes. Fig. 2 shows the sum-rate of the two-cell MIMO

[4]It is worth noting that the codebook-based limited feedback strategy [10] can be used to reduce the feedback overhead when MSs send (7) or (9) to the BS.

[5]The proposed DIA aligns the cross-interferences from UL MSs and the inter-stream interferences to other DL MSs. Refer to [12, Fig. 2] for geometric interpretation.

[6]If there exists no UL MSs or no DL MSs, then the proposed IA technique operates as the single-cell multi-user DL or UL MIMO technique. Furthermore, if two cells operate in the same direction, uplink or downlink, then the UL-IA or DL-IA can be used.

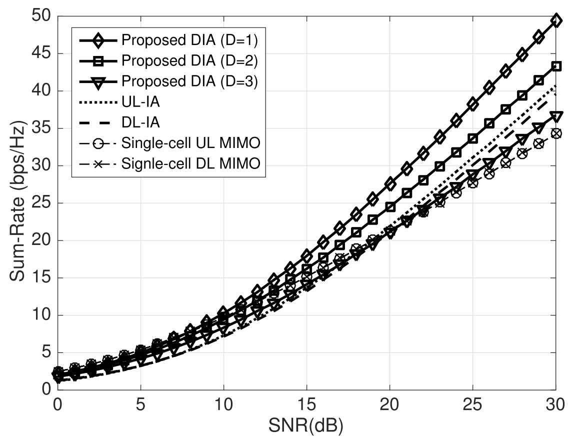

Fig. 2. Achievable sum-rate of the proposed DIA technique for varying SNR when $M = L = 4$ and $D = 1, 2, 3$.

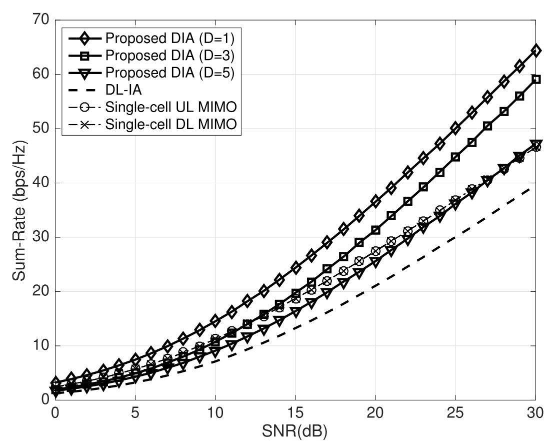

Fig. 3. Achievable sum-rate of the proposed DIA technique for varying SNR when $M = 6$, $L = 4$, and $D = 1, 3, 5$.

network for varying SNR when $M = L = 4$ and $D = 1, 2, 3$. In this case, both UL-IA and DL-IA schemes are known to achieve the DoF of 6 [12], [13], while the single-cell multi-user DL/UL MIMO schemes achieve the DoF of 4 [11]. In the proposed IA technique, however, the achievable DoF varies according to the rank of BS–BS interference channel matrix. The achievable DoF of the proposed DIA technique increases as D decreases. For example, when $D = 1$, the proposed DIA technique achieves the DoF of 7. As shown in Fig 2, the proposed technique outperforms the conventional schemes in terms of sum-rate when the SNR is larger than 15dB and $D \leq 2$. For example, when the SNR is equal to 30dB, the proposed DIA with $D = 1$ yields 20% increase in sum-rate compared with the UL-IA or DL-IA techniques. Fig. 3 shows the sum-rate of the two-cell MIMO network for varying SNR when $M = 6$, $L = 4$, and $D = 1, 3, 5$. Note that the UL-IA scheme can not be used in this setting. The proposed DIA technique achieves the DoFs of 9 when $D \leq 3$, while the single-cell DL/UL MIIMO schemes and the DL-IA achieve the same DoFs of 6. Thus, in high SNR regime, the proposed DIA achieves higher DoFs than the conventional schemes when $D \leq 4$. For example, when the SNR is equal to 30dB, the proposed DIA achieves the sum-rate of 65bps/Hz with $D = 1$, while the DL-IA and the single-cell multi-user MIMO techniques achieve 47bps/Hz and 40bps/Hz, respectively.

TABLE I
COMPARISON OF SIGNALING OVERHEAD

	UL-IA	DL-IA	**Proposed**
Reference signal broadcast	$2M$	$2M$	$2M$
Signal space broadcast	$2M$	$2MN_d$	MN_u
Beamforming vector feedback	$2N_uL$	$2N_dL$	$(N_d + N_u)L$

Table I compares the signaling overhead of the proposed DIA technique with the conventional IA techniques in terms of the required number of complex coefficients. The proposed DIA technique requires a comparable signaling overhead with the conventional IA techniques.

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