On the Joint Design of Beamforming and User Scheduling in Multi-Cell MIMO Uplink Networks

Bang Chul Jung[1], Su Min Kim[2], Hyun Jong Yang[3], and Won-Yong Shin[4]
[1]Dept. of ICE, Gyeongsang National Univ., Tongyeong, Korea, E-mail: bcjung@gnu.ac.kr
[2]ACCESS Linneaus Centre, School of EE, KTH, Stockholm, Sweden, E-mail: sumin@kth.se
[3]School of ECE, UNIST, Ulsan, Korea, E-mail: hjyang@unist.ac.kr
[4]Dept. of CSE, Dankook Univ., Yongin, Korea, E-mail: wyshin@dankook.ac.kr

***Abstract*—Due to the difficulty of coordination in cellular *uplink* networks, it is a practical challenge to achieve better throughput with a distributed scheduling. Futhermore, multiple antennas at mobile stations (MSs) can be utilized for reducing interference or for improving the desired signal strength. In this paper, we investigate a joint design of beamforming and user scheduling for multi-cell multiple input multiple output (MIMO) uplink networks. In the proposed scheme, each BS with M antennas adopts M random beamforming techniques and each MS with L antennas utilizes a single beamforming vector which minimizes the sum power of generating interferences to home cell as well as other cells. In each cell, then, the BS selects M MSs such that both sufficiently large desired signal power and sufficiently small generating interference are guaranteed. Numerical results show that the proposed scheme outperforms the existing distributed schemes in terms of sum-rate in practical environments.**

***Index Terms*—MIMO interfering multiple access channel, multiuser diversity, beamforming, user scheduling**

I. Introduction

Interference management is one of the most challenging issues to provide better services in cellular networks. In general, each mobile station (MS) (or each base station (BS)) suffers from intra-cell interference as well as inter-cell interference in the cellular downlink (or in the cellular uplink). Interference alignment (IA) was recently proposed by Cadambe and Jafar for fundamentally solving the interference problem [1]. It was shown that the IA achieves the optimal degrees-of-freedom in the K-user interference channel with time-varying channel coefficients. Subsequent work has shown that the IA can be applicable to other wireless networks including multiple-input multiple-output (MIMO) interference channels [2], [3] and cellular networks [4]–[9].

On the other hand, there have been remarkable techniques that exploit usefulness of fading in a single cell network, thus resulting in a *multiuser diversity (MUD)* gain: opportunistic scheduling [10], opportunistic beamforming [11], and random beamforming [12]. Moreover, scenarios obtaining the MUD gain have been studied in ad hoc networks [13], in cognitive radio networks [14], and multi-cell downlink and uplink networks [15], [16]. In particular, the authors of [16] proved that the optimal MUD gain can be achieved with a distributed user scheduling even in the presence of inter-cell interference when both MS and BS have a signle antenna. When both MS and BS have multiple antennas, however, it remains open how to design a joint user scheduling and beamforming at both MS and BS, which efficiently exploits the MUD gain in multi-cell uplink networks.

In this paper, we propose a joint beamforming and user scheduling technique which efficiently exploits the MUD gain in time-division duplexing (TDD) K-cell MIMO uplink networks, where there exist N MSs with L antennas and one BS with M antennas in each cell. As for the beamforming, each BS employs M random receive beamforming vectors and each MS adopts a single beamforming vector which minimizes the sum of generating interference to home cell and other cells. In each cell, the BS selects M MSs such that both sufficiently large desired signal power and sufficiently small generating interference are guaranteed. Note that the proposed scheme operates with a *distributed* manner and requires only local channel state information (CSI) at each MS as in [2]. Simulation results show that the proposed scheme outperforms the conventional distributed scheduling algorithms in practical environments.

II. System Model

We consider a TDD K-cell MIMO IMAC model where each cell consists of a single BS with M antennas and N MSs, each of which has L antennas. An example for $K = 3$, $N = 6$, $L = 2$, and $M = 3$ is illustrated in Fig. 1.

We assume a block fading model where the channel matrices are constant during a transmission block (e.g., frame) and independently change for every transmission block. Then, the received signal vector at the i-th BS, $\mathbf{y}_i$, is given by

$$\mathbf{y}_i = \sum_{j=1}^{M} \sqrt{\beta_i^{[i,j]}} \mathbf{H}_i^{[i,j]} \mathbf{w}^{[i,j]} x^{[i,j]} + \sum_{k=1,k\neq i}^{K} \sum_{j=1}^{M} \sqrt{\beta_i^{[k,j]}} \mathbf{H}_i^{[k,j]} \mathbf{w}^{[k,j]} x^{[k,j]} + \mathbf{z}_i, \quad (1)$$

where $\beta_k^{[i,j]}$ denotes the large-scale path-loss from the j-th user in the i-th cell to the k-th BS, $0 < \beta_k^{[i,j]} \triangleq {d_k^{[i,j]}}^{-\alpha} \leq 1$ where $d_k^{[i,j]} \geq 1$ represents the distance from the j-th MS in the i-th cell to the k-th BS and α denotes the path-loss exponent. $\mathbf{H}_k^{[i,j]} \in \mathbb{C}^{M\times L}$ denotes the small-scale fading channel matrix

Authorized licensed use limited to: AJOU UNIVERSITY. Downloaded on March 05,2025 at 08:23:12 UTC from IEEE Xplore. Restrictions apply.
978-1-4799-4912-0/14/$31.00 ©2014 IEEE

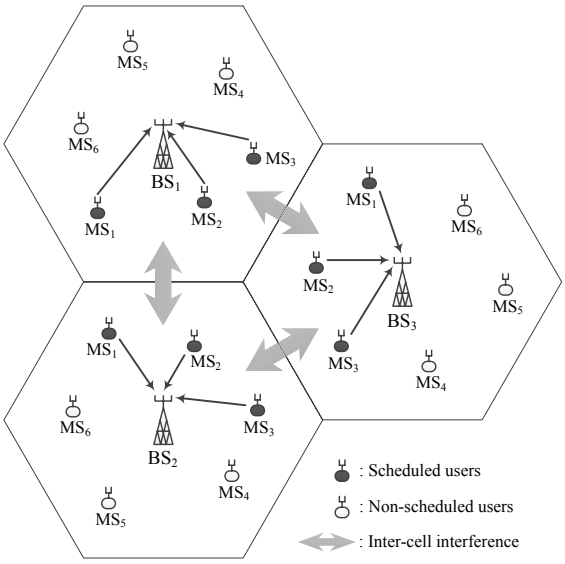

Fig. 1. MIMO IMAC model where $K = 3$, $N = 6$, $L = 2$, and $M = 3$.

from the j-th user in the i-th cell to the k-th BS and each element of the channel matrix is assumed to follow a complex Gaussian distribution with zero mean and unit variance, and to be independent across different i, j, and k. $\mathbf{w}^{[i,j]} \in \mathbb{C}^{L\times 1}$ denotes the transmit beamforming vector of the j-th MS in the i-th cell and $x^{[i,j]}$ represents the transmitted data symbol of the j-th MS in the i-th cell. In this paper, we assume that each BS selects M MSs at a time slot and the selected M MSs send their messages simultaneously through a *single* spatial stream by using L antennas. $\mathbf{z}_i \in \mathbb{C}^{M\times 1}$ denotes the circular symmetric complex additive white Gaussian noise vector with zero mean and covariance matrix $N_0\mathbf{I}_M$, $\mathbf{z}_i \sim \mathcal{CN}(0, N_0\mathbf{I}_M)$ where N_0 represents the noise spectral density. We also assume that each MS has an average transmit power constraint $\mathbb{E}\left[\left|x^{[i,j]}\right|^2\right] \le P$, $\forall i, j$ and then $\mathrm{SNR} = P/N_0$.

III. Receive Beamforming & User Scheduling

In this section, we first propose a distributed and opportunistic scheduling (DOS) which exploits two threshold values for desired signal power and generating interference power, respectively. In this section, we assume that the transmit beamforming vectors are already determined at each MS, and we will show how to design the transmit beamforming vectors in the next section. Each BS generates M *random* receive beamforming vectors orthogonal to each other for each time slot and matches each beamforming vector to a single MS in the corresponding cell[1]. The beamforming matrix for the i-th BS, $\mathbf{U}_i \in \mathbb{C}^{M\times M}$, is defined as

$$\mathbf{U}_i \triangleq [\mathbf{u}_{i,1}, \mathbf{u}_{i,2}, \ldots, \mathbf{u}_{i,M}],$$

where $\mathbf{u}_{i,m} \in \mathbb{C}^{M\times 1}$ denotes the orthonormal vector for the m-th received signal. Here, $\mathbf{u}_{i,m}$'s are generated in accordance with an isotropic distribution. These randomly generated beamforming matrices are broadcasted by BSs to all users in the network before scheduling[2]. After receive beamforming, the received signal vector at the i-th BS is expressed as:

$$\begin{aligned}\mathbf{r}_i = &\sum_{m=1}^{M} \sqrt{\beta_i^{[i,\pi_{i,m}]}}\mathbf{U}_i{}^H\mathbf{H}_i^{[i,\pi_{i,m}]}\mathbf{w}^{[i,\pi_{i,m}]}x^{[i,\pi_{i,m}]} \\ &+ \sum_{k=1,k\neq i}^{K}\sum_{m=1}^{M} \sqrt{\beta_i^{[k,\pi_{k,m}]}}\mathbf{U}_i{}^H\mathbf{H}_i^{[k,\pi_{k,m}]}\mathbf{w}^{[k,\pi_{k,m}]}x^{[k,\pi_{k,m}]} \\ &+ \tilde{\mathbf{z}}_i, \end{aligned} \tag{2}$$

where $\pi_{i,m}$ denotes the index of the scheduled MS for the m-th receive beamforming vector in the i-th cell and $\tilde{\mathbf{z}}_i = \mathbf{U}_i{}^H\mathbf{z}_i \sim \mathcal{CN}(0, N_0\mathbf{I}_M)$. Then, the received signal for m^*-th receive beamforming vector of i-th BS is expressed as:

$$\begin{aligned} r_{i,m^*} = &\underbrace{\sqrt{\beta_i^{[i,\pi_{i,m^*}]}}\mathbf{u}_{i,m^*}{}^H\mathbf{H}_i^{[i,\pi_{i,m^*}]}\mathbf{w}^{[i,\pi_{i,m^*}]}x^{[i,\pi_{i,m^*}]}}_{\text{desired signal}} \\ &+ \underbrace{\sum_{m=1,m\neq m^*}^{M} \sqrt{\beta_i^{[i,\pi_{i,m}]}}\mathbf{u}_{i,m^*}{}^H\mathbf{H}_i^{[i,\pi_{i,m}]}\mathbf{w}^{[i,\pi_{i,m}]}x^{[i,\pi_{i,m}]}}_{\text{intra-cell interference}} \\ &+ \underbrace{\sum_{k=1,k\neq i}^{K}\sum_{m=1}^{M} \sqrt{\beta_i^{[k,\pi_{k,m}]}}\mathbf{u}_{i,m^*}{}^H\mathbf{H}_i^{[k,\pi_{k,m}]}\mathbf{w}^{[k,\pi_{k,m}]}x^{[k,\pi_{k,m}]}}_{\text{inter-cell interference}} \\ &+ \tilde{z}_i, \end{aligned} \tag{3}$$

where $\tilde{z}_i = \mathbf{u}_{i,m^*}{}^H\mathbf{z}_i \sim \mathcal{CN}(0, N_0)$.

Assuming the channel reciprocity of TDD system, it is possible to obtain all the received channel matrices $\mathbf{H}_k^{[i,j]}$ for the j-th user in the i-th cell by using a pilot signaling from BSs in downlink, where $j \in \{1, \ldots, N\}$ and $i, k \in \{1, \ldots, K\}$ [7]. In the proposed DOS protocol, at each scheduling instance, the j-th user in the i-th cell finds $m^* \in \{1, \ldots, M\}$ satisfying the following criteria by using both receive beamforming matrices, $\{\mathbf{U}_1, \ldots, \mathbf{U}_K\}$, and channel matrices, $\sqrt{\beta_k^{[i,j]}}\mathbf{H}_k^{[i,j]}$, which are obtained by BSs' broadcast and pilot signaling, respectively.

$$\text{(C1)} \qquad \beta_i^{[i,j]}\left|\mathbf{u}_{i,m^*}{}^H\mathbf{H}_i^{[i,j]}\mathbf{w}^{[i,j]}\right|^2 \ge \eta_{tr}, \tag{4}$$

$$\begin{aligned}\text{(C2)} \qquad &\sum_{m=1,m\neq m^*}^{M} \beta_i^{[i,j]}\left|\mathbf{u}_{i,m}{}^H\mathbf{H}_i^{[i,j]}\mathbf{w}^{[i,j]}\right|^2 \\ &+ \sum_{k=1,k\neq i}^{K}\sum_{m=1}^{M} \beta_k^{[i,j]}\left|\mathbf{u}_{k,m}{}^H\mathbf{H}_k^{[i,j]}\mathbf{w}^{[i,j]}\right|^2 \le \eta_I, \end{aligned} \tag{5}$$

where η_{tr} and η_I denote the pre-determined positive threshold values. The transmit beamforming vector $\mathbf{w}^{[i,j]}$ of the i-th

[1]It can be regarded as an uplink version of the conventional random beamforming technique which was originally proposed for downilnk [12].

[2]By using pseudo-random pattern, $\mathbf{U}_i$ can be informed to users without any signaling process as in [7].

Authorized licensed use limited to: AJOU UNIVERSITY. Downloaded on March 05,2025 at 08:23:12 UTC from IEEE Xplore. Restrictions apply.

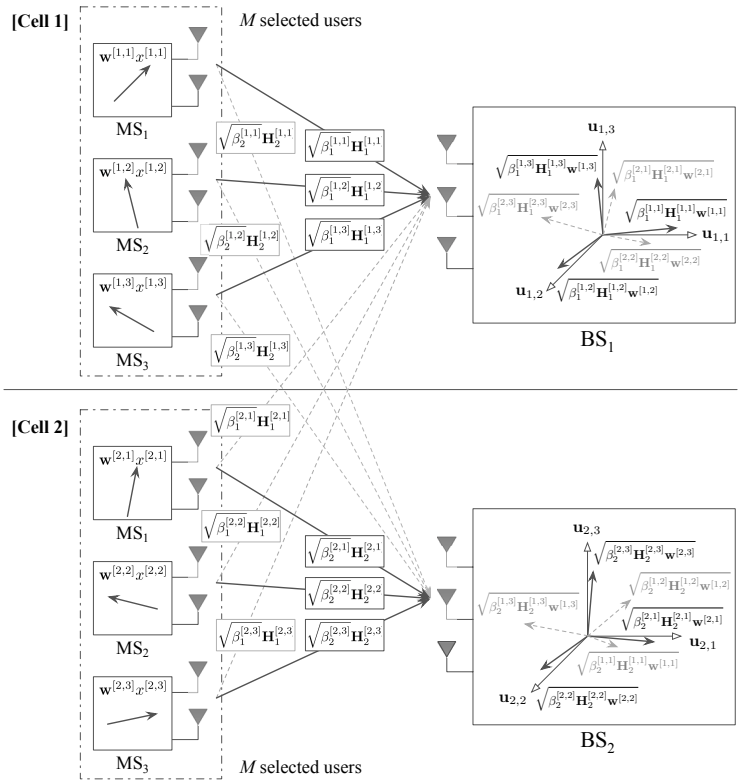

Fig. 2. Geometric interpretation of the received signals at BSs in the proposed DOS where $K = 2$, $L = 2$, and $M = 3$ ($\pi_{1,1} = \pi_{2,1} = 1$, $\pi_{1,2} = \pi_{2,2} = 2$, $\pi_{1,3} = \pi_{2,3} = 3$).

user in the j-th cell is assumed to be optimally determined according to transmission strategy, which are explained in next section. Criterion $(\mathrm{C1})$ is satisfied if the desired signal power strength is greater than or equal to η_{tr}, which is determined in such a way that the users' desired signal power received at the corresponding BS is sufficiently large to obtain MUD gain. On the other hand, criterion $(\mathrm{C2})$ is satisfied if the sum power of $(MK-1)$ interference signals generated by the MS to its own BS (i.e., intra-cell interference) and other BSs (i.e., inter-cell interference) is less than or equal to η_I, which is determined to a sufficiently small value to assure that the cross-channels of the selected MS are in deep-fade, while not preventing the system from obtaining MUD gain. The left-hand side of (5) denotes the sum power of intra- and inter-cell interferences generated by the j-th user to other BSs. In this paper, we call this *leakage of interference (LIF)*. Therefore, the LIF of the j-th user in the i-th cell for the m^*-th receive beamforming vector is defined as:

$$\mathcal{L}(i,j,m^*) \triangleq \sum_{m=1,m\neq m^*}^{M} \beta_i^{[i,j]} \left| \mathbf{u}_{i,m}{}^H \mathbf{H}_i^{[i,j]} \mathbf{w}^{[i,j]} \right|^2 + \sum_{k=1,k\neq i}^{K} \sum_{m=1}^{M} \beta_k^{[i,j]} \left| \mathbf{u}_{k,m}{}^H \mathbf{H}_k^{[i,j]} \mathbf{w}^{[i,j]} \right|^2. \quad (6)$$

When an MS has at least one index m^* satisfying the both criteria $(\mathrm{C1})$ and $(\mathrm{C2})$, it feeds back the indices and their corresponding scheduling metrics in (4) and (5) to the corresponding BS. Otherwise, it feeds back nothing. This feedback strategy implies that the MSs whose the criteria are satisfied request a packet transmission to their corresponding BS. Thereafter, each BS randomly selects one MS among the MSs that feed back the same beamforming vector index $m^* \in \{1,\ldots,M\}$. If there exists a beamforming vector index that was not fed back from any users, the beamforming vector is not used for signal decoding. This may cause some performance degradation, but we can reduce the probability of the event if the two threshold values are set appropriately and the number of users in a cell increases. Finally, the selected MSs in each cell transmit their packets. Then, each BS decodes the MSs' signals by using the corresponding receive beamforming vectors, while treating all the interference as noise. Fig. 2 shows a geometric interpretation of the proposed scheme.

IV. Tranasmit Beamforming & Achievable Sum-Rate

In this section, we first analyze the achievable sum-rate of the proposed scheme and propose the transmit beamforming technqiue at MSs. The achievable sum-rate of the proposed scheme is expressed as:

$$R(\mathrm{SNR}) = \sum_{k=1}^{K} \sum_{m^*=1}^{M} R_{k,m^*}(\mathrm{SNR}), \quad (7)$$

Authorized licensed use limited to: AJOU UNIVERSITY. Downloaded on March 05,2025 at 08:23:12 UTC from IEEE Xplore. Restrictions apply.

where $R_{k,m^*}(\text{SNR})$ denotes the achievable rate of the π_{k,m^*}-th MS (i.e., for the selected MS using the m^*-th receive beamforming vector in the k-th cell). Assuming the sum of intra- and inter-cell interference to follow Gaussian distribution, the achievable rate of the π_{i,m^*}-th MS is lower-bounded as:

$$\begin{aligned} R_{i,m^*}(\text{SNR}) &\geq \log\left(1+\text{SINR}_{i,m^*}\right) \\ &\geq P_{i,m^*}\cdot\log\left(1+\text{SINR}_{i,m^*}\right), \end{aligned} \tag{8}$$

where P_{i,m^*} denotes the probability that at least one MS satisfying both the criteria (C1) and (C2) exists for the m^*-th receive beamforming vector of the i-th BS.

In accordance with Eq. (3), the signal-to-interference-plus-noise-ratio (SINR) of the π_{i,m^*}-th MS is written as:

$$\text{SINR}_{i,m^*} = \frac{\beta_i^{[i,\pi_{i,m^*}]}\left|\mathbf{u}_{i,m^*}{}^H\mathbf{H}_i^{[i,\pi_{i,m^*}]}\mathbf{w}^{[i,\pi_{i,m^*}]}\right|^2}{1/\text{SNR}+\mathcal{I}(i,\pi_{i,m^*},m^*)}, \tag{9}$$

where

$$\begin{aligned} \mathcal{I}(i,\pi_{i,m^*},m^*) &\triangleq \sum_{m=1,m\neq m^*}^{M}\beta_i^{[i,\pi_{i,m}]}\left|\mathbf{u}_{i,m^*}{}^H\mathbf{H}_i^{[i,\pi_{i,m}]}\mathbf{w}^{[i,\pi_{i,m}]}\right|^2 \\ &+\sum_{k=1,k\neq i}^{K}\sum_{m=1}^{M}\beta_i^{[k,\pi_{k,m}]}\left|\mathbf{u}_{i,m^*}{}^H\mathbf{H}_i^{[k,\pi_{k,m}]}\mathbf{w}^{[k,\pi_{k,m}]}\right|^2, \end{aligned} \tag{10}$$

which implies the sum power of intra- and inter-cell interference for the scheduled MS π_{i,m^*} using the m^*-th receive beamforming vector in the i-th cell.

In the proposed scheme, each MS finds the transmit beamforming vector that *minimizes its LIF* by using well-known singular value decomposition (SVD). The LIF of the j-th user in the i-th cell for a given receive beamforming vector $m^*\in\{1,\ldots,M\}$ is expressed as:

$$\begin{aligned} \mathcal{L}_{\text{SVD}}(i,j,m^*) &= \sum_{m=1,m\neq m^*}^{M}\beta_i^{[i,j]}\left|\mathbf{u}_{i,m}{}^H\mathbf{H}_i^{[i,j]}\mathbf{w}^{[i,j]}\right|^2 \\ &+\sum_{k=1,k\neq i}^{K}\sum_{m=1}^{M}\beta_k^{[i,j]}\left|\mathbf{u}_{k,m}{}^H\mathbf{H}_k^{[i,j]}\mathbf{w}^{[i,j]}\right|^2 \\ &\leq \sum_{m=1,m\neq m^*}^{M}\left|\mathbf{u}_{i,m}{}^H\mathbf{H}_i^{[i,j]}\mathbf{w}^{[i,j]}\right|^2 \\ &+\sum_{k=1,k\neq i}^{K}\sum_{m=1}^{M}\left|\mathbf{u}_{k,m}{}^H\mathbf{H}_k^{[i,j]}\mathbf{w}^{[i,j]}\right|^2 \\ &= \left\|\mathbf{G}^{[i,j,m^*]}\mathbf{w}^{[i,j]}\right\|^2 \triangleq \tilde{\mathcal{L}}_{\text{SVD}}(i,j,m^*), \end{aligned} \tag{11}$$

where $\mathbf{G}^{[i,j,m^*]}\in\mathbb{C}^{(KM-1)\times L}$ is defined as (12) at the top of the next page, where $\tilde{\mathbf{U}}_i^{[m^*]}\in\mathbb{C}^{M\times(M-1)}$ is defined by

$$\tilde{\mathbf{U}}_i^{[m^*]} \triangleq [\mathbf{u}_{i,1},\ldots,\mathbf{u}_{i,m^*-1},\mathbf{u}_{i,m^*+1},\ldots,\mathbf{u}_{i,M}]. \tag{13}$$

Let the SVD of $\mathbf{G}^{[i,j,m^*]}$ be denoted by

$$\mathbf{G}^{[i,j,m^*]} = \mathbf{\Omega}^{[i,j,m^*]}\mathbf{\Sigma}^{[i,j,m^*]}\mathbf{V}^{[i,j,m^*]H}, \tag{14}$$

where $\mathbf{\Omega}^{[i,j,m^*]}\in\mathbb{C}^{(KM-1)\times L}$, $\mathbf{V}^{[i,j,m^*]}\in\mathbb{C}^{L\times L}$ consists of L orthonormal columns, and $\mathbf{\Sigma}^{[i,j,m^*]} = \text{diag}\left(\sigma_1^{[i,j,m^*]},\ldots,\sigma_L^{[i,j,m^*]}\right)$ in which $\sigma_1^{[i,j,m^*]}\geq\cdots\geq\sigma_L^{[i,j,m^*]}$. Then, the optimal weight vector $\mathbf{w}_{\text{SVD}}^{[i,j]*}$ of the j-th user using the m^*-th receive beamforming vector in the i-th cell is determined as

$$\mathbf{w}_{\text{SVD}}^{[i,j]*} = \arg\min_{\mathbf{v}}\left\|\mathbf{G}^{[i,j,m^*]}\mathbf{v}\right\|^2 = \mathbf{v}_L^{[i,j,m^*]}, \tag{15}$$

where $\mathbf{v}_L^{[i,j,m^*]}$ denotes the L-th column of $\mathbf{V}^{[i,j,m^*]}$.

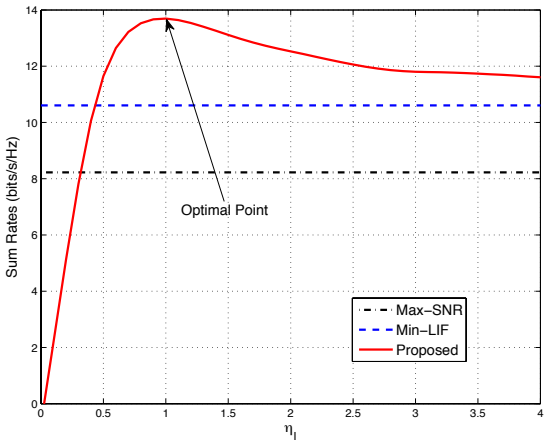

Fig. 3. Sum-rate versus η_I for $K=2$, $N=20$, $M=L=3$, and $\text{SNR}=20$ dB.

V. Numerical Results

For performance comparison, two baseline schemes are considered: max-SNR and min-LIF schemes. In the max-SNR scheme, the transmit beamforming vector $\mathbf{w}^{[i,j]}$ is designed as $\mathbf{w}^{[i,j]} = \left(\mathbf{u}_{i,m^*}^H\mathbf{H}_i^{[i,j]}\right)^H$ to maximize desired channel gain. In addition, the users with higher gains of the desired channels are selected. In the min-LIF scheme [8], the design of $\mathbf{w}^{[i,j]}$ as well as the user scheduling is performed only to minimize the LIF in (6).

Fig. 3 shows sum-rates versus η_I for $K=2$, $N=20$, $M=L=3$, and $\text{SNR}=20$ dB. Note that the condition (4) was replaced in the simulations by choosing M users with the highest $\beta_i^{[i,j]}\left|\mathbf{u}_{i,m^*}{}^H\mathbf{H}_i^{[i,j]}\mathbf{w}^{[i,j]}\right|^2$ among the users satisfying the condition (5), which only improves the sum-rate of the proposed scheme. It is shown from the figure that optimal η_I can be found by the numerical evaluation of sum-rates for given N and SNR, with which the proposed scheme outperforms the baseline schemes.

Fig. 4 depicts sum-rates versus SNR for $K=2$, $N=20$, and $M=L=3$. For the proposed scheme, η_I was optimized for each N and SNR. The sum-rate of the max-SNR shows only marginal improvement with respect to SNR due to constant interference level. The proposed scheme effectively suppresses the interference level and improves the desired channel gains simultaneously. The proposed scheme yields higher sum-rates in all SNR regime than the baseline schemes,

Authorized licensed use limited to: AJOU UNIVERSITY. Downloaded on March 05,2025 at 08:23:12 UTC from IEEE Xplore. Restrictions apply.

$$\mathbf{G}^{[i,j,m^*]} \triangleq \Bigg[\underbrace{\left(\tilde{\mathbf{U}}_i^{[m^*]H}\mathbf{H}_i^{[i,j]}\right)^T}_{\text{intra-cell interference}}, \underbrace{\left(\mathbf{U}_1{}^H\mathbf{H}_1^{[i,j]}\right)^T, \ldots, \left(\mathbf{U}_{i-1}{}^H\mathbf{H}_{i-1}^{[i,j]}\right)^T, \left(\mathbf{U}_{i+1}{}^H\mathbf{H}_{i+1}^{[i,j]}\right)^T, \ldots, \left(\mathbf{U}_K{}^H\mathbf{H}_K^{[i,j]}\right)^T}_{\text{inter-cell interference}} \Bigg]^T, \quad (12)$$

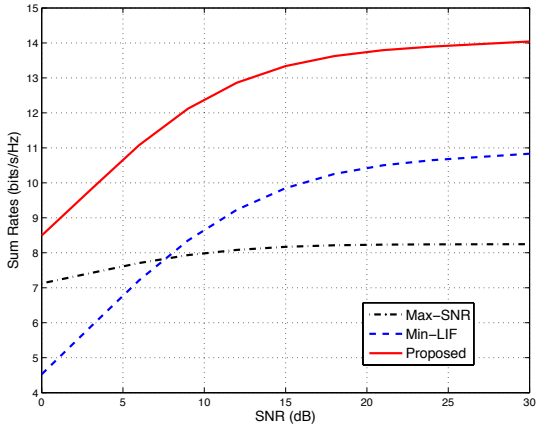

Fig. 4. Sum-rate versus SNR for $K = 2$, $N = 20$, and $M = L = 3$.

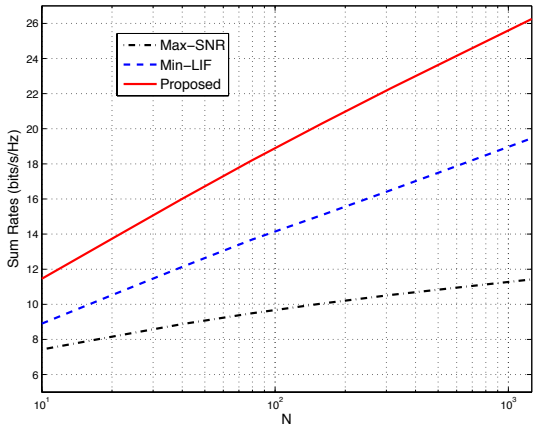

Fig. 5. Sum-rate versus N for $K = 2$, $M = L = 3$, and SNR=20dB.

whereas the min-LIF scheme is inferior to the max-SNR scheme in the low SNR regime.

Fig. 5 shows sum-rates versus N for $K = 2$, $M = L = 3$, and $\mathrm{SNR} = 20$ dB. It is seen that the proposed scheme exhibits the highest sum-rate with respect to N.

VI. Conclusion

In this paper, we proposed a joint design of beamforming and user scheduling for multi-cell multiple input multiple output (MIMO) uplink networks, which efficiently exploits multiuser diversity gain even though both the user scheduling at the BS and beamforming at each MS are performed with a distributed manner in each cell. Numerical results show that in a practical setting of the multi-cell network, the proposed scheme outperforms the existing distributed schemes in terms of sum-rate. However, the thresholds should be carefully chosen for better throughput and we leave the issue on the optimal thresholds for future work.

Acknowledgement

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (2013R1A1A2A10004905).

References

[1] V. R. Cadambe and S. A. Jafar, "Interference alignment and degrees of freedom of the K-user interference channel," *IEEE Trans. Inf. Theory*, vol. 54, no. 8, pp. 3425–3441, Aug. 2008.

[2] K. Gomadam, V. R. Cadambe, and S. A. Jafar, "A distributed numerical approach to interference alignment and applications to wireless interference networks," *IEEE Trans. Inf. Theory*, vol. 57, no. 6, pp. 3309–3322, Jun. 2011.

[3] T. Gou and S. A. Jafar, "Degrees of freedom of the K-user $M \times N$ MIMO interference channel," *IEEE Trans. Inf. Theory*, vol. 56, no. 12, pp. 6040–6057, Dec. 2010.

[4] C. Suh, M. Ho, and D. Tse, "Downlink interference alignment," *IEEE Trans. Commun.*, vol. 59, no. 9, pp. 2616–2626, Sep. 2011.

[5] C. Suh and D. Tse, "Interference alignment for celluar networks," in *Proc. 46th Annual Allerton Conf. on Commun., Control, and Computing*, Monticello, IL, Sep. 2008.

[6] B. C. Jung and W.-Y. Shin, "Opportunistic interference alignment for interference-limited cellular TDD uplink," *IEEE Commun. Lett.*, vol. 15, no. 2, pp. 148–150, Feb. 2011.

[7] B. C. Jung, D. Park, and W.-Y. Shin, "Opportunistic interference mitigation achieves optimal degrees-of-freedom in wireless multi-cell uplink networks," *IEEE Trans. Commun.*, vol. 60, no. 7, pp. 1935–1944, Jul. 2012.

[8] H. J. Yang, W. -Y. Shin, B. C. Jung, and A. Paulraj, "Opportunistic interference alignment for MIMO interfering multiple-access channels," *IEEE Trans. Wireless Commun.*, vol. 12, no. 5, pp. 2180–2192, May 2013.

[9] H. J. Yang, W. -Y. Shin, B. C. Jung, C. Suh, and A. Paulraj, "Opportunistic downlink interference alignment," *Preprint*, [Online] Available: http://arxiv.org/abs/1312.7198.

[10] R. Knopp and P. Humblet, "Information capacity and power control in single cell multiuser communications," in *Proc. IEEE Int. Conf. Commun. (ICC)*, Seattle, WA, Jun. 1995, pp. 331–335.

[11] P. Viswanath, D. N. C. Tse, and R. Laroia, "Opportunistic beamforming using dumb antennas," *IEEE Trans. Inf. Theory*, vol. 48, no. 6, pp. 1277–1294, Aug. 2002.

[12] M. Sharif and B. Hassibi, "On the capacity of MIMO broadcast channels with partial side information," *IEEE Trans. Inf. Theory*, vol. 51, no. 2, pp. 506–522, Feb. 2005.

[13] W.-Y. Shin, S.-Y. Chung, and Y. H. Lee, "Parallel opportunistic routing in wireless networks," *IEEE Trans. Inf. Theory*, to appear.

[14] T. W. Ban, W. Choi, B. C. Jung, and D. K. Sung, "Multi-user diversity in a spectrum sharing system," *IEEE Trans. Wireless Commun.*, vol. 8, no. 1, pp. 102-106, Jan. 2009.

[15] W.-Y. Shin and and B. C. Jung, "Network coordinated opportunistic beamforming in downlink cellular networks," *IEICE Trans. Commun.*, vol. E95-B, no. 4, pp. 1393–1396, Apr. 2012.

[16] W. -Y. Sin, D. Park, and B. C. Jung, "Can one achieve multiuser diversity in uplink multi-cell networks?," *IEEE Trans. Commun.*, vol. 60, no. 12, pp. 3535-3540, Dec. 2012.

Authorized licensed use limited to: AJOU UNIVERSITY. Downloaded on March 05,2025 at 08:23:12 UTC from IEEE Xplore. Restrictions apply.