Multi-Cell Pseudo-Random Beamforming: Opportunistic Feedback and Beam Selection

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***Abstract*—In this paper, we propose a novel *pseudo-random* beamforming (BF) technique in multi-cell downlink networks consisting of multiple base stations (BSs) and one BS coordinator. In the proposed technique, each BS first generates M BF matrices with a pseudo-random manner and each mobile station (MS) *opportunistically* feeds back the received signal-to-interference-and-noise (SINR) ratio for each random beam to its home-cell BS. Then, each BS selects MSs for each beam based on the feedback information, and it also feeds back the achievable sum-rate for M BF matrices to a BS coordinator via wired backhaul links. Finally, the BS coordinator determines the optimal BF matrix that maximizes the sum-rate over the network, and sends the index of the optimal BF matrix to BSs. Each BS sends data to MSs by using the optimal BF matrix among M BF matrices. Main results indicate that there exists a trade-off between the feedback overhead and the achievable sum-rate, but the sum-rate of the proposed technique with opportunistic feedback approaches to that with full feedback as the number of MSs in each cell increases.**

***Index Terms*—Beam selection, opportunistic feedback, pseudo-random beamforming, user scheduling, cloud radio access network (C-RAN).**

I. INTRODUCTION

Interference management for mitigating the level of both inter-cell and intra-cell interference has been considered as one of the most important techniques in cellular networks in order to improve the achievable sum-rate performance [1]. Recently, a joint design of transmit/receive beamforming (BF) and user scheduling has been proposed as a promising interference management technique for multi-cell uplink [2], [3] and multi-cell downlink [4], [5]. In particular, the schemes in [2]–[5] operate in a distributed manner that does not require any coordination among base stations (BSs) and mobile stations (MSs), and thus they are known to be easily implementable in practice.

On the other hand, in a single-cell downlink network, a random BF technique with beam selection was proposed in [6], where a BS randomly generates multiple BF matrices, which is then shared with MSs, during the training period. In [6], each MS feeds back the index of the best BF vector for each BF matrix in terms of maximizing the signal-to-interference-noise ratio (SINR) and the corresponding SINR value. Then, the BS choose the optimal BF matrix among multiple candidates that maximizes the sum-rate. The performance becomes improved as the number of BF matrices or the number of MSs in the cell increases at the expense of the signaling overhead for both downlink and uplink.

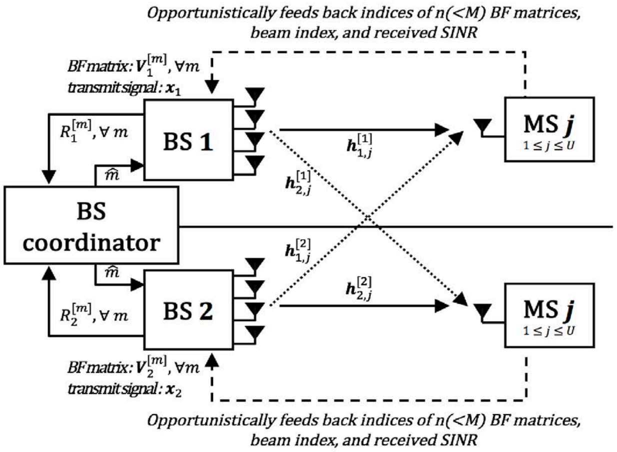

Fig. 1. System model of multi-cell downlink networks when $K = 2$ and $N_t = 4$

In this paper, we propose a novel multi-cell *pseudo-random* BF (MC-PRBF) technique that not only improves the sum-rate performance of *multi-cell* downlink networks, consisting of multiple BSs and one BS coordinator, but also reduces signaling overhead for both downlink and uplink. In the proposed MC-PRBF technique, each BS pseudo-randomly generates multiple BF matrices according to a pre-defined pattern, which is assumed to be known at each MS. Thus, additional training period caused by multiple BF matrices is not needed. Each MS opportunistically feeds back the best beam index in terms of maximizing the SINR and the corresponding SINR value, and the signaling overhead for uplink is decreased accordingly [7]. This paper is organized as follows. Section II describes the system and channel models. The proposed MC-PRBF technique is explained in Section III. Simulation results are shown in Section IV. Finally, conclusions are drawn in Section V.

II. SYSTEM MODEL

We consider a K-cell downlink network equipped with one BS coordinator as illustrated in Fig. 1. Each cell consists of

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a BS with N_t antennas and U MSs with a single antenna. All BSs are assumed to share the same frequency band and to be connected with the BS coordinator through the wired backhaul link. The channel vector from the k-th BS to the j-th MS in the i-th cell is denoted by $\mathbf{h}_{i,j}^{[k]} \in \mathbb{C}^{1\times N_t}$, where i,$k \in \{1, ..., K\}$ and $j \in \{1, ..., U\}$. Each element of $\mathbf{h}_{i,j}^{[k]}$ is assumed to be an i.i.d. complex Gaussian random variable, i.e., $\mathbf{h}_{i,j}^{[k]} \sim \mathcal{CN}(\mathbf{0}, \mathbf{I}_{N_t})$. The channel coefficient is assumed to be remain constant during each data transmission time. We assume that each BS generates M BF matrices, $\mathbf{V}_i^{[m]} \in \mathbb{C}^{N_t\times B}$, with a pseudo-random manner, where $i \in \{1, 2, \ldots, K\}$, $m \in \{1, 2, \ldots, M\}$, and $1 \leq B \leq N_t$. Then, it follows that $\mathbf{V}_i^{[m]} \triangleq [\mathbf{v}_i^{[m,1]}, ...\mathbf{v}_i^{[m,b]}, \mathbf{v}_i^{[m,B]}]$, where $\mathbf{v}_i^{[m,b]} \in \mathbb{C}^{N_t\times 1}$. When BSs transmit data with the m-th BF matrix, the received signal at the j-th MS in the i-th cell is given by

$$y_{i,j}^{[m]} = \sum_{b=1}^{B} \mathbf{h}_{i,j}^{[i]} \mathbf{v}_i^{[m,b]} x_i^{[b]} + \sum_{k=1,k\neq i}^{K} \sum_{b=1}^{B} \mathbf{h}_{i,j}^{[k]} \mathbf{v}_k^{[m,b]} x_k^{[b]} + z_{i,j}, \tag{1}$$

where $x_i^{[b]} \in \mathbb{C}$ denotes the symbol sent via the b-th beam of the i-th BS and $\mathbf{x}_i \triangleq [x_i^{[1]}, ..., x_i^{[B]}]^T \in \mathbb{C}^{B\times 1}$. In addition, we define the transmit power of each BS as $P \triangleq \|\mathbf{x}_i\|_2^2$ for all i, and thus $|x_i^{[b]}|^2 = P/B$. Here, $z_{i,j}$ represents the thermal noise at the j-th MS in the i-th cell, where $z_{i,j} \sim \mathcal{CN}(0, N_0)$.

III. MULTI-CELL PSEUDO-RANDOM BEAMFORMING TECHNIQUE

In this section, we first explain the overall procedure of the proposed MC-PRBF technique. Then, we analyze the achievable sum-rate of the proposed technique.

A. Overall Procedure

1) Reference Signal Broadcast from BSs: Each BS broadcasts the reference signal so that all MSs acquire the downlink channel vector from the BS.

2) SINR feedback from MSs: After receiving the reference signal from BSs, each MS calculates the received SINR values for all $m \in \{1, \cdots, M\}$ and $b \in \{1, \cdots, B\}$. The received SINR for the b-th beam of the m-th BF matrix is given by

$$\mathsf{SINR}_{i,j}^{[m,b]} = \frac{|\mathbf{h}_{i,j}^{[i]} \mathbf{v}_i^{[m,b]}|^2}{\sum_{l=1,l\neq b}^{B} |\mathbf{h}_{i,j}^{[i]} \mathbf{v}_i^{[m,l]}|^2 + \sum_{k=1,k\neq i}^{K} \sum_{b=1}^{B} |\mathbf{h}_{i,j}^{[k]} \mathbf{v}_k^{[m,b]}|^2 + \frac{B}{\rho}}, \tag{2}$$

where $\rho = P/N_0$.

In this paper, we introduce two different feedback strategies: the conventional feedback and *opportunistic feedback*.

- In the conventional feedback strategy [6], each MS feeds back the beam index leading to the maximum SINR values for all m. Hence, the number of bits required for feedback in each MS is given by

$$F_{\text{conv}} = M(\log_2 B + Q), \tag{3}$$

where Q denotes the number of bits required for quantizing the SINR value.
- In the *opportunistic feedback* strategy, each MS feeds back the $n(\leq M)$ beam indices leading to the maximum SINR values among MB beams and the corresponding n SINR values. Hence, the number of bits required for feedback in each MS is given by

$$F_{\text{max-n-SINR}} = n(\log_2 MB + Q). \tag{4}$$

3) User Scheduling at BSs: Based on the feedback information from MSs, each BS selects the MS with the maximum SINR value for each beam, where the total number of beams is equal to MB. Then, with the m-th BF matrix, the achievable sum-rate of the i-th cell is given by

$$R_i^{[m]} = \sum_{b=1}^{B} \left[\log\left(1 + \max_{1\leq j\leq U} \mathsf{SINR}_{i,j}^{[m,b]}\right)\right]. \tag{5}$$

Each BS calculates the achievable sum-rate for all m, which is then sent to the BS coordinator $R_i^{[m]}$ for all m via the wired backhaul link.

4) Optimal BF Matrix Selection at the BS Coordinator: The BS coordinator selects the optimal BF matrix among M candidates in terms of maximizing the sum-rate of K cells, which is expressed as

$$\widehat{m} = \arg\max_{1\leq m\leq M} \sum_{k=1}^{K} R_k^{[m]}. \tag{6}$$

5) Data Transmission: If the optimal BF matrix is selected, then each BS transmits data with the optimal pseudo-random BF matrix. Let $\widehat{m}$ be the index of the optimal BF matrix. Then, the received signal at the j-th MS in the i-th cell is given by

$$y_{i,j}^{[\widehat{m}]} = \sum_{b=1}^{B} \mathbf{h}_{i,j}^{[i]} \mathbf{v}_i^{[\widehat{m},b]} x_i^{[b]} + \sum_{k=1,k\neq i}^{K} \sum_{b=1}^{B} \mathbf{h}_{i,j}^{[k]} \mathbf{v}_k^{[\widehat{m},b]} x_k^{[b]} + z_{i,j}. \tag{7}$$

B. Achievable Sum-Rate

In the proposed technique, the achievable sum-rate of the K-cell downlink network is expressed as

$$R_{\mathsf{sum}} = \sum_{k=1}^{K} \sum_{b=1}^{B} \left[\log\left(1 + \max_{1\leq j\leq U} \mathsf{SINR}_{k,j}^{[\widehat{m},b]}\right)\right]. \tag{8}$$

IV. SIMULATION RESULTS

In this section, we show simulation results of the proposed technique along with various system parameters. Figs. 2 and 3 show that the sum-rate performance of the proposed technique with the conventional feedback and opportunistic feedback strategies according to the number of MSs in a cell. In both figures, we assume $\rho = 0$dB. For example, when $n = 2$, each MS feeds back the maximum two SINR values among MB candidates. It is obvious to see that the sum-rate performance of the proposed technique improves as M increases. It is also observed that when the number of MSs is small, the sum-rate performance achieved by opportunistic feedback strategy

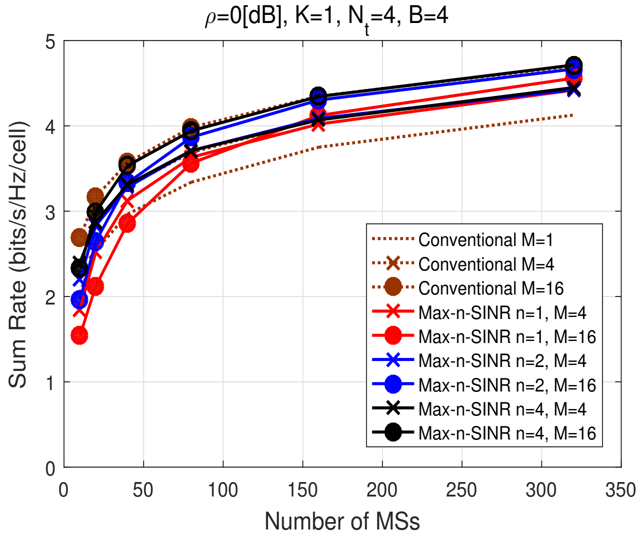

Fig. 2. Sum-rate of the proposed technique according to the number of MSs in a cell when $K = 1$, $N_t = 4$, and $\rho = 0\text{dB}$

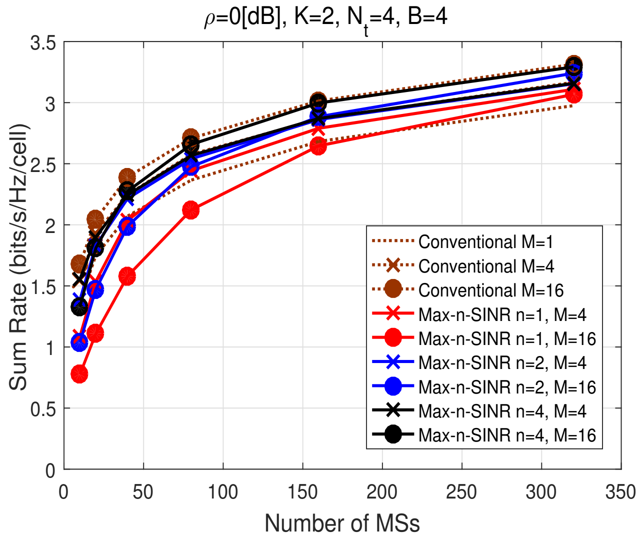

Fig. 3. Sum-rate of the proposed technique according to the number of MSs in a cell when $K = 2$, $N_t = 4$, and $\rho = 0\text{dB}$

is slightly lower than the conventional feedback case, but the performance gap between two strategies becomes negligible as the number of MSs in a cell increases. In addition, the sum-rate performance of the proposed technique with opportunistic feedback becomes improved as n increases even though the feedback overhead also increases. Fig. 4 shows the number of feedback bits per MS for the proposed opportunistic feedback strategy according to M. The required number of feedback bits per MS for the conventional feedback strategy linearly increases as M increases, while the required number of feedback bits per MS for the opportunistic feedback strategy much slowly increases according to M.

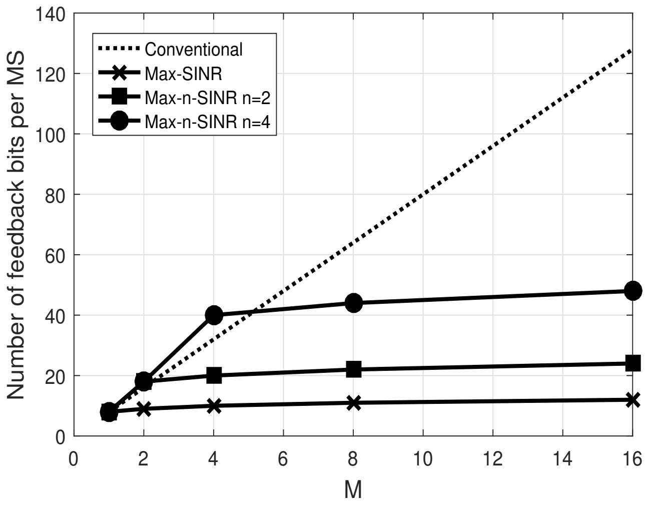

Fig. 4. The required feedback bits per MS of the opportunistic feedback scheme according to M.

V. CONCLUSION

In this paper, we proposed a MC-PRBF technique with opportunistic feedback, where each BS generates multiple BF matrices in a pseudo-random manner and each MS computes the received SINR values for each beam of the multiple BF matrices, and each MS opportunistically feeds back the beam indices and the corresponding SINR values to the BS. The sum-rate performance of the proposed technique increases as the number of candidate BF matrices, but the signaling overhead also increases. It was shown that the signaling overhead can be significantly reduced by using the opportunistic feedback strategy, while the sum-rate performance of the MC-PRBF technique is comparably maintained.

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