Efficient Coordinated Multi-cell Processing (CoMP) Scheme Selection and Radio Resource Management

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***Abstract*—In this paper, we propose a 6-step scheme for efficient CoMP scheme selection and radio resource management. Simulations show that the proposed 6-step scheme can greatly improve user average throughput compared to a conventional 4-step scheme.**

***Index Terms*—CoMP Scheme Selection, Joint Processing**

I. Introduction

To meet growing demand for wireless services, small cells are expected to be deployed [1]. One of the main issues in such a system is to manage inter-cell interference. CoMP has been considered as a promising candidate for mitigating interference [2][3]. CoMP can be categorized into Joint Processing (JP) [2] and coordinated beamforming (C-BF) [3]. JP requires channel state information (CSI) and data to be shared among cooperating base stations (BSs) through limited-capacity backhaul whereas C-BF only requires CSI. In case of perfect CSI, performance of C-BF is not as good as that of JP. However, in practical systems, the number of feedback bits is limited so that C-BF or a non-cooperation (NC) scheme may outperform JP. Thus, to maximize system performance such as proportional fairness, a proper CoMP scheme should be selected.

In [4], backhaul constraint is considered for CoMP operation. However, in the small cell networks, the backhaul constraint can be largely alleviated by various methods such as a wireless backhaul [1]. In [5], cell-edge users are selected and served by JP according to training overhead. However, various CoMP schemes are not considered with the same training overhead. For a very large number of users, pre-determined precoding vectors can be sent to users by a reference signal and users can calculate an exact channel quality information (CQI) value according to a 4-step scheme in [6]. By doing so, a proper set of users and CoMP scheme can be selected. However, this works only for a very large number of users. For a not-so-large number of users where a full CSIT-based precoding works much better, the 4-step scheme can be adjusted such that the full CSIT-based precoding can be performed by using a precoding matrix indicator (PMI). This modified 4-step scheme can be viewed as a general procedure for closed-loop control. However, according to this '4-step' scheme, the reported CSIs are considered to be perfect so that JP is likely to be selected since its estimated CQI is highest with perfect CSI. Meanwhile, with limited feedback, the number of feedback bits is limited, which leads to difficulty in fully utilizing frequency selectivity and poor performance of JP.

In this paper, we consider an efficient CoMP scheme selection and radio resource management for cooperative small cell networks. We propose a 6-step scheme using a multi-level codebook to reduce the feedback overhead, by which a user set and a CoMP scheme are properly selected. Simulations show that the proposed 6-step scheme can greatly improve user average throughput compared to the conventional 4-step scheme.

II. System Model

A downlink cellular network with N_C cooperating cells with a radius of D_b is considered. In the ith cell, $N_{u,i}$ users are randomly distributed. All the BSs and users are equipped with N_T and N_R antennas, respectively. A user served by CoMP schemes is called a CoMP user. Otherwise, a user is called a Non-CoMP user. There are a total of N_{sub} subchannels among which N_{sub}^{CoMP} subchannels are reserved for CoMP users. Using limited feedback, a CoMP user and a Non-CoMP user can report CSIs for M_{CoMP} best subchannels and $M_{Non-CoMP}$ best subchannels, respectively. For the CoMP scheme selection, there are JP, C-BF, and NC schemes available. We assume that each BS selects one user per subchannel. Letting $\pi(i)$ denote the selected user for the ith cell, a channel matrix between the user $\pi(i)$ and the ith BS on the nth subchannel is denoted as $\mathbf{H}^i_{\pi(i),n}$ whose elements consist of a pathloss term with pathloss exponent η and a Rayleigh fading term. An aggregated channel matrix for the user $\pi(i)$ on the nth subchannel is denoted as $\mathbf{H}_{\pi(i),n}$. The transmit power is E_s and the average noise power is N_0.

The rate of a user selected for the ith cell is given as

$$r_{\pi(i),n} = \log_2 \det \left(\mathbf{I}_{N_R} + \mathbf{S}_{\pi(i),n} \left(\mathbf{D}_{\pi(i),n} \right)^{-1} \right), \quad (1)$$

where $\mathbf{S}_{\pi(i),n}$ denotes a signal term, $\mathbf{D}_{\pi(i),n}$ denotes an interference plus noise term. For JP,

$$\mathbf{S}_{\pi(i),n} = p \left(\mathbf{H}_{\pi(i),n} \mathbf{W}_{\pi(i),n} \right) \left(\mathbf{H}_{\pi(i),n} \mathbf{W}_{\pi(i),n} \right)^H, \quad (2)$$

$$\mathbf{D}_{\pi(i),n} = N_0 \mathbf{I}_{N_R} + \sum_{j \neq i} p \left(\mathbf{H}_{\pi(i),n} \mathbf{W}_{\pi(j),n} \right) \left(\mathbf{H}_{\pi(i),n} \mathbf{W}_{\pi(j),n} \right)^H, \quad (3)$$

where $\mathbf{W}_{\pi(i),n}$ is a precoding matrix for JP [2] and $p = E_s / \max_l \left(\sum_{k=(N_T-1)l+1}^{N_T l} \left[\mathbf{W}_{\pi(i),n} \mathbf{W}_{\pi(i),n}{}^H \right]_{(k,k)} \right)$. For C-BF,

$$\mathbf{S}_{\pi(i),n} = E_s / N_R \left(\mathbf{H}^i_{\pi(i),n} \mathbf{W}^{C-BF}_{\pi(i),n} \right) \left(\mathbf{H}^i_{\pi(i),n} \mathbf{W}^{C-BF}_{\pi(i),n} \right)^H, \quad (4)$$

$$\mathbf{D}_{\pi(i),n} = N_0 \mathbf{I}_{N_R} + \sum_{j \neq i} \frac{E_s}{N_R} \left(\mathbf{H}^j_{\pi(i),n} \mathbf{W}^{C-BF}_{\pi(j),n} \right) \left(\mathbf{H}^j_{\pi(i),n} \mathbf{W}^{C-BF}_{\pi(j),n} \right)^H, \quad (5)$$

where $\mathbf{W}^{C-BF}_{\pi(i),n}$ is a precoding matrix for C-BF [3]. For the NC scheme, we use $\mathbf{W}^{NC}_{\pi(i),n} = \left(\mathbf{H}^i_{\pi(i),n} \right)^H$ instead of $\mathbf{W}^{C-BF}_{\pi(i),n}$ in (4) and (5).

III. Proposed 6-step scheme

The proposed scheme can be organized as follows:

- Step 1: Each BS sends a reference signal.
- Step 2: Users report CQI/PMI of M_{CoMP} best subchannels with the low-level codebook for JP CoMP. Here, we use $\mathbf{D}_{\pi(i),n} = N_0 \mathbf{I}_{N_R} + \frac{E_s(N_C-1)}{N_C N_T} \mathbf{E}_{\pi(i),n} \mathbf{E}^H_{\pi(i),n} \sum_{\pi(i),n}^2$ in (2) where $\mathbf{E}_{\pi(i),n}$ is an error between a true CSI and a quantized CSI and $\sum_{\pi(i),n}$ is a singular value matrix for $\mathbf{H}_{\pi(i),n}$.
- Step 3: Initial users are selected and then the BSs broadcast PMIs of the selected users.
- Step 4: The scheduled users report CQI/PMI using the high-level codebook for JP.
- Step 5: After calculating CQIs for C-BF and NC, the proper CoMP scheme and users are selected.
- Step 6: The served users send ACK/NACK signals.

Note that two additional steps are needed compared to the 4-step scheme, but they prevent the BSs from being misled by the ill-conditioned CSI feedback and allow more efficient use of frequency resources. Non-CoMP users are served by the 4-step scheme.

IV. Simulation Results

We consider 3 sectors (cells) facing each other with $D_b = 1000m$. We set $N_T = 2$ and $N_R = 1$. In each cell, 10 users are randomly distributed. Here, we consider 5 users located near the cell edge as the CoMP user and the rest of 5 users as the Non-CoMP user in each cell. Also, we set $N_{sub} = 10$ and 5 subchannels are reserved for CoMP users. For the 4-step scheme, each user sends 3 best subchannels with 4 feedback bits. For the proposed 6-step scheme, the CoMP users send 4 best subchannels with 3 feedback bits using the low-level codebook. In addition, 3 feedback bits are also used for the high-level codebook. We set $E_s/N_0/{D_b}^{\eta} = 20dB$ where $\eta = 4$. A CoMP scheme and users are selected to maximize proportional fairness among users.

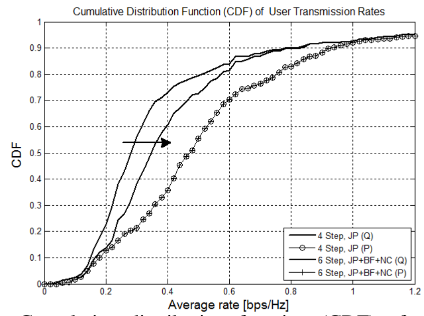

Fig. 1. Cumulative distribution function (CDF) of user average throughput

The Fig. 1 shows that user average throughput can be greatly improved by the proposed scheme compared to the conventional one since the proposed 6-step scheme can adequately select a CoMP scheme for given situations while the conventional 4-step scheme almost selects the JP CoMP scheme due to the misguidance caused by the limited feedback.

V. Conclusion

In this paper, the 6-step scheme was proposed for the efficient CoMP scheme selection and radio resource management and it was shown that the proposed 6-step scheme can greatly improve the user average throughput compared to the conventional 4-step scheme.

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