Fractional Dynamic Clustering in Downlink Cellular network

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***Abstract*—In modern cellular systems, to improve the spectral efficiency and the system capacity we use multiple base station (BS) cooperation in downlink cellular networks. This method can highly improve the transmission rate when the user is a cell-edge user. But when the user is a cell-center user, it has minimal improvement on the user capacity, and increases the complexity of the network. As the whole system BS cooperation is hardly achieved, grouping BSs into clusters can realize BSs cooperation. But it still suffers from inter-cluster interference especially for the cluster-edge users. In this paper we consider fractional base station cooperation to deal with the problem.The clusters are formed dynamically for the cell-edge users from the users' perspective to reduce the inter-cluster interference, and are allowed to be overlapped. Accordingly, coordinated precoding scheme is adopted to reduce the intra-cluster interference. Simulations show that the proposed scheme provides impressive average capacity and the user fairness is improved significantly.**

***Index Terms*—BS Cooperation, interference, precoding, power allocation**

I. Introduction

Next generation mobile systems such as IMT-Advanced [1] and LTE-Advanced [2] are going to achieve high-rate communication by using MIMO (Multiple-Input Multiple-Ouput) technology [3]. Multiple Base station (BS) cooperation also known as network MIMO in the cellular networks, has received a lot of attention because of its potential to achieve significant throughput gains [3][4]. However for the cell-edge users, the throughput is not efficient by using single BS MIMO because of low SNR, co-channel interference, and high antenna correlation. So the cell-edge problem is the one of the difficulties faced by current MIMO cellular system.

In the past, we use FR (Frequency reuse) to solve the cell-edge problem. Fractional Frequency Reuse (FFR), and Terminal Adaptive Array (TAA) are the specific methods of frequency reuse. FR is a scheme a base station using different frequency to serve different users. In this way, it can efficiently minimize the interference from other users. However, using different frequency causes decreasing of system throughput. So another scheme called multiple base station cooperation has been adopted.

Non-clustering processing in the conventional networks leads to severe co-channel interference. Multiple base station transmit data cooperatively from multiple BSs to multiple users can be an effective way to mitigate the inter-cell interference. By using proper precoding vectors intra-cell interference can be also greatly descreased.

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As the whole network cooperation is hardly achieved because of the difficulty of acquiring global channel station information, limited cooperation among a small set of BSs, named clustering [5]-[8], is a feasible way to realize the network MIMO. However in [9] we know that for the cell-center users the SVD-MIMO processing outperform the network MIMO transmission, and also it reduces the complexity of the system. Unfortunately the cluster-edge users still suffer from strong inter-cluster interference. In [5] a static clustering algorithm is proposed to form the clusters. In [6] and [7] a centralized and a decentralized algorithms are proposed respectively. In these algorithms not only a large amount of CSI and signaling overhead is required but also the cluster-edge users still suffer from inter-cluster interference. But the cell-edge users can be "moved" to the interior of each cluster, so its user fairness is enhanced.

In [6]-[8], the same cluster-edge user problem is not solved properly. So the authors in [9] considered a clustering way which is clustered from the user's perspective which allowed the clusters to be overlapped. This method improved the throughput of the cluster-edge users greatly. Based on this intuition, in [10], a dynamic clustering which allows to be overlapped is proposed, where the cluster size is not necessarily identical for all users.

In this paper, fractional dynamic clustering is proposed to solve these problems. We adopt simple SVD-MIMO transmission method for the cell-center users, while for the cell-edge users we choose three BSs with the largest channel strength as its serving cluster. In the proposed dynamic clustering cellular system, a distributed cooperation controller is located at each BS to cooperate with surrounding BSs autonomously and distributedly. In this algorithm, two geographyic regions are formed, namely cooperative region and non-cooperative region. Therefore, according to the user locations, BSs are able to select the most suitable transmission schemes to users. And the numerical results show that the proposed method has better estimation performance.

Through out this paper, $|\cdot|$ denotes the cardinality of a set. $\|\cdot\|$ denotes the Euclidean norm of a vector (or absolute value of a scalar). $(\cdot)^T$ and $(\cdot)^H$ denote the transpose and conjugate transpose of a matrix or a vector. $\mathbb{E}$ represents the expectation operation.

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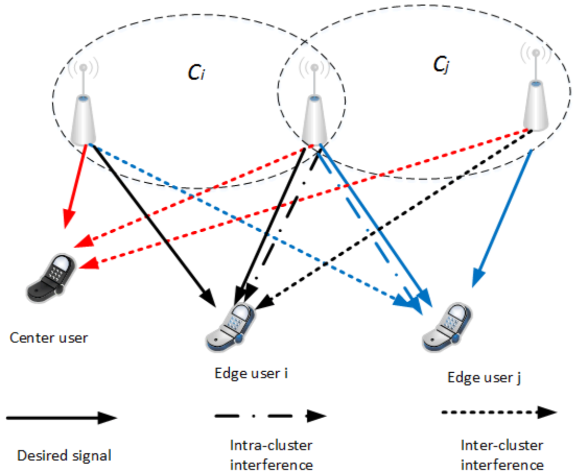

Fig. 1. An example of fractional clustering and interference illustration with a identical size $C_i = C_j = 2$.

II. System Model and Problem Formulation

In this section, we consider the downlink system consisting of M BSs using universal frequency reuse. Each BS has N_t transmit antennas and each user has N_r receive antennas. Denote the set of users as $\mathcal{U}$ and the set of base stations as $\mathcal{B}$, and $|\mathcal{U}| = U$. Block fading model is assumed so that the channel is static in a interval, but changes from interval to interval. Denote $h_{im}(t)$ that is an $N_r \times N_t$ vector as the CSI (channel state information) from BS m to user i at time t. As the CSI is static during a interval, we ignore the index t for simplicity. User i will estimate and feedback the CSI of the BSs to choose its serving cluster denoted by C_i. Then the received signal of the user i is :

$$y_i = \underbrace{\sum_{m\in C_i} h_{im} w_{im} \sqrt{p_{im}} x_i +}_{\text{desired signal}} \underbrace{\sum_{j\neq i} \sum_{m'\in C_j \bigcap C_i} h_{im'} w_{im'} \sqrt{p_{jm'}} x_j +}_{\text{intra-cluste interference}} \underbrace{\sum_{j\neq i} \sum_{m'\in C_j \backslash C_i} h_{im'} w_{jm'} \sqrt{p_{jm'}} x_j}_{\text{inter-cluster interference}} + n_i, \quad (1)$$

where p_{im} is the corresponding transmission power, w_{im} is the normalized precoding vector from BS m to user i. x_i is the desired signal of user i. x_j is the desired signal of user j and n_i is the additive white Gaussian noise with zero mean and identical variance $\mathbb{E}(n_i n_i^H) = \sigma_n^2$ for all users. The intra-cluster interference can be managed through precoding, the intra-cluster interference and the inter-clustering interference are written apart for emphasis. Denote $h_i = [h_{im_1}, h_{im_2}, ..., h_{im_{C_i}}]$, $m_k \in C_i$. Accordingly denote $w_i = [\sqrt{p_{im_1}} w_{im_1}^T, \sqrt{i_{im_2}} w_{im_2}^T, ..., \sqrt{p_{im_{C_i}}} w_{im_{C_i}}^T]^T$. Similarly, the channel from C_j (the cluster of user j where $j \neq i$) to user i can be written as $h_{i,C_j} = [h_{im_1}, h_{im_2}, ..., h_{im_{C_j}}]$, $m_k \in C_j$.

Then the equation (1) can be rewritten as

$$y_i = h_i w_i x_i + \sum_{j\neq i} h_{i,C_j} w_j x_j + n_i. \quad (2)$$

Then the received SINR is:

$$\begin{aligned} \gamma_i &= \frac{|\sum_{m\in C_i} h_{im} w_{im} \sqrt{p_{im}}|^2}{\sum_{j\neq i} |\sum_{m'\in C_j} h_{im'} w_{jm'} \sqrt{p_{jm'}}|^2 + \sigma_n^2} \\ &= \frac{|h_i w_i|^2}{\sum_{j\neq i} |h_{i,C_j w_j}|^2 + \sigma_n^2}. \end{aligned} \quad (3)$$

An example of base station cooperation and interference illustration is dipicted in Fig.1. The objective of this paper is to find the better capacity and maintain the fairness between the cell-edge users and the center users. So we form our problem as below:

$$Max_{(C_i, P_i, w_i)} \sum_i \frac{1}{N} \log(1+\gamma_i).$$

$$s.t. \sum_{m\in C_i} p_{im} |w_{im}|^2 \leq P_0, m = 1, ..., M. \quad (4)$$

where N is the total number of the users. The problem is to find the max sum rate $(\sum log(1+\gamma_i))$, so the results can maintain the user fairness at certain degrees. Because if one user's rate is much smaller than the others, the sum rates will be lowed intensely, which can be mathematically proved. Remark that the optimization variables are the power allocation p_{im}, the precoding vector w_{im} and also the cluster C_i. So the problem (4) can not be solved directly. Instead we propose a heuristic algorithm to form clusters and accomplish power allocation and precoding design accordingly, which is detailed in the next section.

III. Fractional Dynamic Clustering and Precoding

A. Fractional Base station cooperation

In downlink cellular network we form the cooperation clusters from the user' perspective, i.e. user i feeds back the CSI of C_i BSs with the largest instantaneous channel strength $\| h_{im} \times h_{im}^H \|$ to form its serving cluster C_i. In this way we think the best cluster is selected and also the inter-cluster interference is minimized. Accordingly as the CSI of the intra-cluster are known we can select proper precoding vectors to minimize the intra-cluster interference. In addition the resource cost on CSI feedback can be efficiently reduced since the channels to be fed back are relatively strong which is also good for implementation in real communication systems.

Since [11] concludes that 3-cell network MIMO can effectively overcome the inter-cluster interference and relieve the burden of executing the complex multi-BS joint processing for a large number of cluster cells, in this paper we choose three as the cluster size, the following clustering algorithms are evaluated:

(1) For users in the same cell, denote the interference from other cells as σ^2. When

$$C_0 = \log\left(1 + \frac{|h_{i0} h_{i0}^H|}{\sigma^2 + \sigma_n^2}\right) > \beta. \quad (5)$$

we set user i as a cell-center user and transmit its signal using the traditional MIMO skill.

(2) On the other side when

$$C_0 = \log\left(1 + \frac{| h_{i0}h_{i0}^H |}{\sigma^2 + \sigma_n^2}\right) \leq \beta. \tag{6}$$

the user i is a cell-edge user and we choose three BSs whose $| h_{im} \times h_{im}^H |$ are bigger than the other cells to form its serving cluster. The variable β is very important for this algorithm, and the simulation results in next section will show the importance of β.

In this way we can lower the complexity of the center users compared with the dynamic clustering in [10] and improve the capacity of the cell-edge users compared with the traditional transmit ways. And also the cell-edge users can fix their serving clusters in a relatively long time to reduce the complexity. It is comfirmed in [10].

B. Power allocation and zero-forcing precoding

We describe the power allocation and precoding vector in this section. First the power allocation p_{im} is allocated as below:

$$p_{im} = \frac{| h_{im}h_{im}^H |^2}{\sum_{m\in C_j} | h_{jm}h_{jm}^H |^2}. \tag{7}$$

where the power is allocated proportionally to the channel strength of each user similar to the so called channel aware power splitting [10]. Then the received SINR is:

$$\begin{aligned}\gamma_i &= \frac{| \sum_{m\in C_i h_{im}w_{im}\sqrt{p_{im}}} |^2}{\sum_{j\neq i} | \sum_{m'\in C_j h_{im'}w_{jm'}\sqrt{p_{jm'}}} |^2 + \sigma_n^2} \\ &= \frac{| h_i w_i |^2}{\sum_{j\neq i} | h_{i,C_j w_j} |^2 + \sigma_n^2}.\end{aligned} \tag{8}$$

As the CSI of the C_i is known to the users so the precoding vector w_{im} can be the right singular matrix of h_{im}. It is the so called SVD-MIMO[9].

So the whole algorithm is:

Algorithm 1 Fractional base station cooperation

step 1: for user i, decide whether it is a cell-center user or a cell-edge user basing on Eq. (5) and Eq. (6).
step 2: if it is a cell-center user, using SVD-MIMO to calculate its' capacity. If it is a cell-edge user, using cooperation schemes to calculate its' capacity.
step 3: for user j, back to step 1.
step 4: for all the users, calculate their average capacity.

IV. Simulation Results

In this section simulation results are carried out to evaluate the performance of our proposed algorithm comparing with the other three algorithms. And we also compaired our scheme with different values of β. As we know, different β can lead to the different cell of cell-center users, and of course the cell-edges users are changed too. We use a cellular network of 19 BSs $(2tiers)$ to simulate. Each BS is located in the center of the hexagon cell with radius 1 km.In each base station, the transmit antennas $N_t = 4$, and the receive antennas $N_r = 2$. And we have 2 users randomly placed in each cell for each simulation. We set the total power of each user $P_0 = 1W$. The CSI from BS m to user i is $h_{im} = g_{im}\sqrt{G\eta_{im}/l_{im}}$, where g_{im} is the small-scale Rayleigh fading coefficient with unit variance, and $G = 9dB$ is the antenna power gain at the BS, and η_{im} is the log-normal shadowing with 8dB standard deviation.The path-loss, which is set according to the 3GPP Long Term Evolution (LTE) signal [12]is $l_{im} = 148.1 + 37.6log_{10}(d_{im}^{km})$, where $d_{im}^{km}$is the distance from BS m to user i in km.

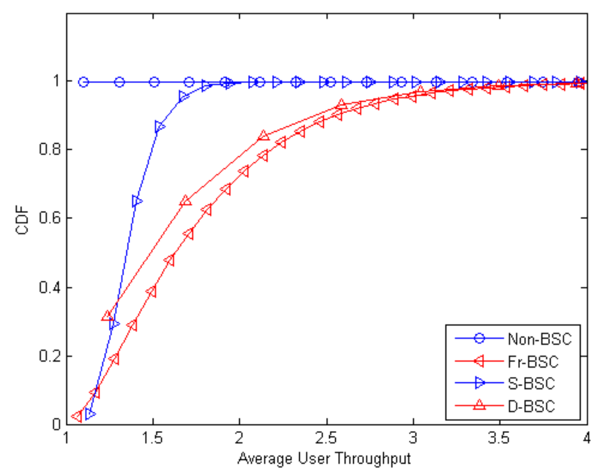

Fig. 2. Cumulative distribution function of user throughput for $N_t = 4, N_r = 2$.

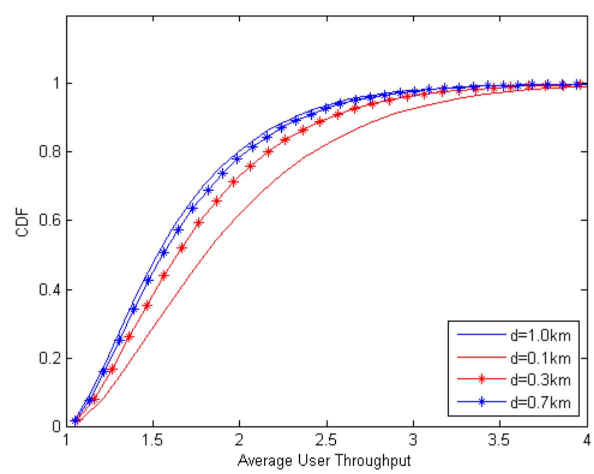

Fig. 3. Cumulative distribution function of user throughput at different locations in one cell

The following approaches are simulated for comparison:

(1) Non-clustering (traditional MIMO transmission). Each user is only served by the BS with the largest signal strength and the other 18 BSs are considered as the interference.

(2) Static clustering, i.e. the clusters serving for each user is static though the all intervals. In this approach the clusters are

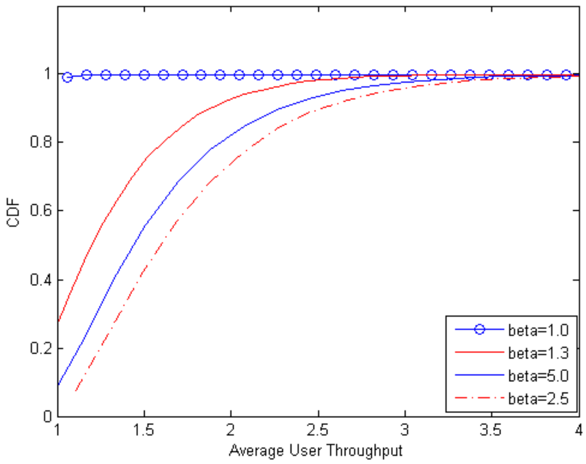

Fig. 4. Cumulative distribution function of user throughput for different values of β

formed once for all, usually we choose the nearest three BSs to form the cluster for the user. Accordingly, the set of users in each cluster is static too according to [6]. This clustering is just like a bigger cell transmission in traditional MIMO transmission.

(3) Dynamic clustering according to [10]. In this case, the clusters are formed dynamicly in each interval according to its channel conditions. So the clusters will be always the three BSs whose channel strength are the biggest.

For the fairness of comparison, the SVD-MIMMO precoding vectors is adopted for all the schemes. Denote our proposed scheme as Fraction-BSC, the scheme (1) as Non-BSC, scheme (2) as S-BSC and the scheme (3) as D-BSC.

Fig. 2 shows the cumulative distribution function (CDF) of the average user throughput for the cluster size $C_i = 3$ with $N_t = 4, N_r = 2$, and $U = 2$ in each cell. Compared with these schemes our proposed scheme does not introduce additional system overhead, because the users feedback the same amount of CSIs even though the channels maybe different and the same precoding vectors are adopted. And also our algorithm decrease the complexity of the system comparing with the dynamic clustering proposed in [10] as our algorithm only co-operate for the cell-edge users. We can see from the Fig. 2, The three cooperation schemes all outperform the non-clustering scheme, and the fractional BS cooperation outperforms the other two. Also in the system model our target is to find the maximization of the $\sum log(1+\gamma_i)$, so we can make sure that our scheme has better fairness than the other three.

The results in Fig. 3 show that the different location of the user does not change its' capacity too much. When the distance from the base station to the user is $0.1km$, the capacity the user gains is the best. When $d = 0.3km$, for β is relatively small, the user can still be seen as a center-user. For the cell-edge users($d = 0.9km, d = 1.0km$), you can see from Fig. 3. The user throughput is not as good as the cell-center users, but it is quite better than the traditional transmission.

Fig. 4 shows the cumulative distribution of the average users when β is different in our proposed scheme. It shows that when $\beta = 1.0$, the proposed scheme is not much better than the traditional scheme, of course is much worse than the dynamic clustering. And when $\beta = 1.3$, the result becomes a little better. When $\beta = 2.5$, the result becomes much better. It outperforms all the other schemes as it can show in Fig. 2. However when $\beta = 5.0$, the result becomes worse. So from this result, we can be sure that there must be a best β for our scheme and there should be a algorithm to find this β.

V. Conclusion

In this paper, a fractional base station cooperation algorithm has been proposed to form cluster according to the channel condition with fairness constraint. With the overlapped clustering and the SVD-MIMO precoding, the proposed algorithm leads to significant average throughput comparing with the existing clustering algorithms, especially for the cell edge users. Also it gets better fairness for all the users. In addition the system complexity can be reduced as our cluster size is static and we do not cooperate for the cell-center users. Our future work includes finding a proper user scheduling scheme when the users are much more than the transmit antennas in each cell to gain fairness through a relative long time for all the users. And also we need to find the best β to gain a better average throughput for all the cell-center users and the cell-edge users.

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