Cell-Grouping Based Distributed Beamforming and Scheduling for Multi-cell Cooperative Transmission

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***Abstract*—Base station cooperative transmission is an effective strategy to mitigate inter-cell interference. Centralized multicell transmission provides considerable performance gains but is impractical in large cellular systems, due to its prohibitive complexity and large amount of overhead. Dividing cells into small clusters enables practical channel acquisition and coordination within each cluster but still suffers from out-of-cluster interference. In this paper, we propose a dynamic cooperative framework for large cellular systems, which divides cells into groups such that neighboring cells belong to different groups. Based on the cell-grouping, a distributed scheduling strategy is proposed which can effectively coordinate the interference between cell-groups. With limited signalling among BSs and lower complexity, the cell-grouping based distributed scheduling and beamforming shows performance advantages over the fixed clustering based centralized scheduling and beamforming.**

I. Introduction

Base station (BS) cooperative transmission, which is also known as coordinated multi-point transmission (CoMP), is an effective strategy to mitigate the inter-cell interference (ICI) arising in universal frequency reuse cellular systems [1, 2].

When both data and channel state information (CSI) can be shared among all BSs via backhaul links, coherent cooperative transmission can be applied to fully exploit the cooperative gain [1]. However, coherent multicell transmission not only requires high-capacity backhaul for data and CSI sharing, but also needs accurate synchronization among BSs and increases the delay-spread [3]. To reduce the requirements on inter-BS coordination and backhaul, non-coherent coordination is widely considered [4, 5], where the transmission strategies and resource allocation schemes, rather than data signals, are coordinated across BSs.

Centralized non-coherent coordination can improve the performance significantly [5], but is infeasible in large cellular systems due to its prohibitive complexity and huge demands on the channel estimation, feedback links, and backhaul networks [6]. To avoid these problems, BSs can be divided into fixed clusters [6], which enables practical channel acquisition and coordination within each cluster. However, users located at cluster edges still suffer from out-of-cluster interference. To improve the performance of cluster-edge users, the cooperation clusters can be formed dynamically [3, 7, 8]. In the dynamic clustering framework proposed in [3], each BS forms its own cluster including itself and its own set of interference cells. Since one cell may cause interference to several cells, it can belong to several clusters and the clusters in the network are partially overlapped [8]. Under such a dynamic clustering framework, an inter-cluster confliction will occur during the coordinated scheduling. In particular, the scheduling of one cell can be performed to guarantee the performance of one cluster, but it may be not suitable for other clusters.

Centralized multicell scheduling can solve the problem of scheduling confliction by joint scheduling of user in all cells, but is infeasible in large networks. Low-complexity algorithms with limited signalling among BSs have been proposed in [9, 10], which let the transmitters sequentially select users by taking interference caused to previously selected users into account. The delay and backhaul signalling of these sequential algorithms increases rapidly with the size of the system.

Herein, we propose a cell-grouping scheme to solve the problem of scheduling confliction and exploit the scalability of cooperation in large cellular systems. The proposed cell-grouping divides the cells into groups such that neighboring cells belong to different groups.[1] Thus, the cells in the same group will cause negligible interference to each other and can therefore perform scheduling simultaneously and independently. The interference between cell-groups can however be large and will be coordinated by letting groups sequentially make scheduling decisions based on the scheduling in previously considered groups. As the number of groups depends on the cell density and not the size of the system, our algorithm is scalable to practical conditions.

The main contributions of the paper are:

- A dynamic cooperation framework is proposed for coordinated multicell transmission. It is based on cell-grouping and requires limited backhaul signalling among BSs, while still taking ICI into account.

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[1] This cell-grouping is performed off-line and has conceptual similarities to the design of frequency reuse patterns, but is exploited herein for simplified processing with universal frequency reuse.

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- A distributed scheduling algorithm is proposed based on sequential decisions for the different cell-groups. No central unit (CU) is required and the algorithm has good scalability. It can be used with any scheduling metric, but herein we consider the weighted sum rate. We consider distributed virtual SINR (DVSINR) beamforming [11], which can adjust its performance according to the location of users in different cells.

II. System Model

A. Signal and Channel Model

Consider a large cellular network with universal frequency reuse, i.e., the number of cells in the network is so large that it is impractical to do coordination for all the cells. The set of all cells in the network is denoted as $\mathcal{B}_{\text{tot}}$. Each cell contains one BS equipped with N_t antennas and K single-antenna users.

Definition 1: Cell-grouping is to divide all the cells in the network into G groups, such that the cells in the same group are located sufficiently far away that the interference among cells in the group is negligible.

The number of cell-groups, G, depends on the topology of the cellular network. Ideally, four cell-groups are sufficient to make adjacent cells with any shape belong to different groups (also known as the four color theorem [12]), but a few more groups might be necessary in practice to make the interference between cell-groups negligible. An example of the cell-grouping in a hexagonal-structured cellular system is shown in Fig. 1, where three cell-groups are enough to make adjacent cells belong to different groups.

Denote the set of cells in the gth cell-group as $\mathcal{B}_g$, and denote the BS of the bth cell in cell-group g as BS_{gb}. Let the set of interference-cells for the bth cell in cell-group g be denoted as $\mathcal{I}_{gb}$, which includes cells that are located so close to the bth cell that their BSs can cause non-negligible interference to the users served by BS_{gb}.[2] The interference generated by other cells, which are not in $\mathcal{I}_{gb}$, to users in the bth cell of cell-group g is negligible and is treated as background noise. Reciprocally, BS_{gb} generates non-negligible interference only to its interference-cells.

Denote the set of users in the bth cell of group g as $\mathcal{U}_{gb}$. At a given time slot, let the set of scheduled users in the bth cell of group g be denoted as $\mathcal{S}_{gb} \subseteq \mathcal{U}_{gb}$. The signal transmitted by BS_{gb} can be expressed as

$$\mathbf{x}_{gb} = \sum\nolimits_{s_j \in \mathcal{S}_{gb}} \sqrt{p_{s_j}} \mathbf{w}_{s_j,gb} d_{s_j}, \tag{1}$$

where $\mathbf{w}_{s_j,gb} \in \mathbb{C}^{N_t \times 1}$ and p_{s_j} are the unit-norm beamforming vector and the power allocation of BS_{gb} for user s_j respectively, and d_{s_j} is the data of user s_j, which is assumed to be zero-mean and has unit variance.

The received signal of user s_i served by BS_{gb} is denoted as

$$y_{s_i} = \mathbf{h}_{s_i,gb}^H \mathbf{x}_{gb} + \sum\nolimits_{\text{BS}_{\breve{g}\breve{b}} \in \mathcal{I}_{gb}} \mathbf{h}_{s_i,\breve{g}\breve{b}}^H \mathbf{x}_{\breve{g}\breve{b}} + n_{s_i}, \tag{2}$$

[2]In practical cellular systems, it is reasonable to take all the adjacent cells of the bth cell in cell-group g as its interference-cells set, as shown in Fig. 1.

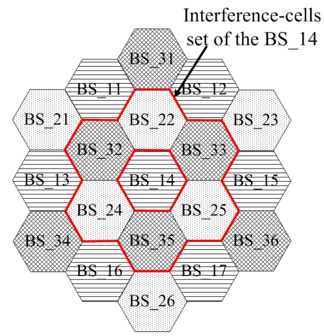

Fig. 1. An example of cell-grouping in the hexagonal-structured cellular system, where the cells marked with the same pattern are in the same group and the cells in the system are divided into three groups.

where $\mathbf{h}_{s_i,\breve{g}\breve{b}}$ is the channel vector between $\text{BS}_{\breve{g}\breve{b}}$ and user s_i, and n_{s_i} is the additive white complex Gaussian noise with zero mean and covariance $\sigma_{s_i}^2$, which contains both noise and weak interference from BSs not in the interference-cells of BS_{gb}. The channel $\mathbf{h}_{s_i,\breve{g}\breve{b}} \in \mathcal{CN}(\mathbf{0}, \mathbf{R}_{s_i,\breve{g}\breve{b}})$ includes both large scale fading and small scale fading, $\mathbf{R}_{s_i,\breve{g}\breve{b}}$ is the channel covariance matrix with $tr\{\mathbf{R}_{s_i,\breve{g}\breve{b}}\} = N_t \alpha_{s_i,\breve{g}\breve{b}}^2$, where $\alpha_{s_i,\breve{g}\breve{b}}^2$ is the large scale fading gain of the channel.

The instantaneous SINR of user s_i is

$$\text{SINR}_{s_i} = \frac{p_{s_i} |\mathbf{h}_{s_i,gb}^H \mathbf{w}_{s_i,gb}|^2}{\text{IUI}_{s_i} + \text{ICI}_{s_i} + \sigma_{s_i}^2}, \tag{3}$$

where $\text{IUI}_{s_i} = \sum_{s_j \in \mathcal{S}_{gb} \setminus \{s_i\}} p_{s_j} |\mathbf{h}_{s_i,gb}^H \mathbf{w}_{s_j,gb}|^2$ is the intra-cell inter-user interference (IUI) caused by signal transmitted from BS_{gb} to other users scheduled by the same BS, and $\text{ICI}_{s_i} = \sum_{\text{BS}_{\breve{g}\breve{b}} \in \mathcal{I}_{gb}} \sum_{s_j \in \mathcal{S}_{\breve{g}\breve{b}}} p_{s_j} |\mathbf{h}_{s_i,\breve{g}\breve{b}}^H \mathbf{w}_{s_j,\breve{g}\breve{b}}|^2$ is ICI caused by signals transmitted from the interference BSs of BS_{gb}.

The instantaneous downlink rate for user s_i is

$$R_{s_i} = \log_2(1 + \text{SINR}_{s_i}). \tag{4}$$

B. Distributed Beamforming and Power Allocation

The optimal downlink multi-cell resource allocation involves the joint optimization of multicell transmit beamforming, power allocation, and user scheduling, which is NP-hard [5]. In practice, it is therefore not possible to solve the resource allocation optimally. Herein, we propose suboptimal solutions that are practically suitable. To this end, the problem is divided into two parts: 1) Coordinated scheduling; and 2) Coordinated beamforming and power allocation.

In this paper, we consider a fixed power allocation scheme, which allocates the power of BS_{gb} equally to its scheduled users, i.e., $p_{s_i} = \frac{P_{gb}}{|\mathcal{S}_{gb}|}$. While non-optimal, the equal power allocation enables other BSs to predict how much power will be allocated to each user without additional backhaul signalling. We use DVSINR beamforming, which is known to be optimal at low and high SNR, and provides good performance at intermediate SNRs [11]. We assume that each BS has perfect CSI from itself to users served by its interference-cells, which can be achieved by exploiting the channel reciprocity between uplink and downlink in TDD systems. Then, the DVSINR beamforming of BS_{gb} for user s_i is

$$\mathbf{w}_{s_i,gb} = \arg\max_{\|\mathbf{w}\|^2=1} \frac{|\mathbf{h}_{s_i,gb}^H \mathbf{w}|^2}{\frac{\sigma_{s_i}^2}{P_{gb}} + \mathrm{IUL}_{s_i} + \mathrm{ICL}_{s_i}}, \tag{5}$$

where $\mathrm{IUL}_{s_i} = \sum_{s_j \in \mathcal{S}_{gb} \setminus \{s_i\}} |\mathbf{h}_{s_j,gb}^H \mathbf{w}|^2$ is the intra-cell inter-user leakage (IUL) of signal transmitted to user s_i, $\mathrm{ICL}_{s_i} = \sum_{\mathrm{BS}_{\check{g}\check{b}} \in \mathcal{I}_{gb}} \sum_{s_k \in \mathcal{S}_{\check{g}\check{b}}} |\mathbf{h}_{s_k,gb}^H \mathbf{w}|^2$ is the inter-cell leakage (ICL) of the signal for user s_i to users served by the interference BSs set of BS_{gb}. The expression to be optimized in (5) is a Rayleigh quotient which can be solved by standard eigenvalue techniques. One solution is [11]

$$\mathbf{w}_{s_i,gb} = \frac{\mathbf{\Omega}_{s_i}^{-1} \mathbf{h}_{s_i,gb}}{\|\mathbf{\Omega}_{s_i}^{-1} \mathbf{h}_{s_i,gb}\|}, \tag{6}$$

where $\mathbf{\Omega}_{s_i} = \sigma_{s_i}^2 / P_{gb} + \sum_{s_j \in \mathcal{S}_{gb} \setminus \{s_i\}} \mathbf{h}_{s_j,gb} \mathbf{h}_{s_j,gb}^H + \sum_{\mathrm{BS}_{\check{g}\check{b}} \in \mathcal{I}_{gb}} \sum_{s_k \in \mathcal{S}_{\check{g}\check{b}}} \mathbf{h}_{s_k,gb} \mathbf{h}_{s_k,gb}^H$, which comes from denominator of (5) and includes the channels of both IUL and ICL.

Remark 1. The DVSINR can adjust its performance according to the location of users served in its interference-cells. For example, if user s_k, which is served by $\mathrm{BS}_{\check{g}\check{b}} \in \mathcal{I}_{gb}$, is located sufficiently far away from BS_{gb}, the channel $\mathbf{h}_{s_k,gb}$ will be so weak that its impact on the beamformer in (6) is negligible.

III. Multicell Coordinated Scheduling

Optimal multicell coordinated scheduling aims at finding the set of users for each cell, which maximize a certain performance metric of the whole network. In this paper, we consider the weighted sum-rate of the users in all cells as the scheduling criterion, which is expressed as

$$R_{\Sigma(\mathcal{S}_{\mathrm{tot}})} = \sum_{\mathrm{BS}_{gb} \in \mathcal{B}_{\mathrm{tot}}} \sum_{s_j \in \mathcal{S}_{gb}} \beta_{s_j} R_{s_j}, \tag{7}$$

where $\mathcal{S}_{\mathrm{tot}}$ denotes the scheduled user sets in all cells and β_{s_j} is the positive weighting coefficient of user s_j.

To achieve the optimal multicell coordinated scheduling, the CSI of all links in the network and the weighting coefficients of all users should be obtained by a CU for evaluating all the possible sets of users in the whole cellular system. The problem is NP-hard and many suboptimal approaches are also infeasible in large systems, due to their complexity and large amounts of backhaul signalling between CU and all BSs.

In large cellular systems, BSs that are located sufficiently far away will not have any influence on each other. Thus it is unnecessary to jointly select users served by them. One solution is to let adjacent cells form fixed clusters and perform joint scheduling and beamforming within the cluster [6]. However, such fixed clustering cannot handle inter-cluster interference properly. Under a dynamic clustering framework, where each BS has its own set of interference-cells, the scheduling among overlapped clusters will conflict. In the following, we solve this problem by a distributed scheduling algorithm based on the proposed cell-grouping scheme.

A. Distributed Scheduling

The intuition behind the distributed scheduling is that, with the cell-grouping defined in Section II, the BSs in the same group will not cause interference to each other and can therefore perform scheduling simultaneously and independently. The interference between cell-groups is coordinated by letting groups sequentially make scheduling decisions based on the scheduling in previously considered groups.[3] Although the concept of sequentially scheduling among BSs are widely considered [9, 10], the novelty of the proposed distributed scheduling is on the coordination among cell-groups rather than individual BSs.

We assume that the scheduling order of all the groups is predetermined and is known to all the groups. During each scheduling slot, all the BSs in the same group update their scheduling simultaneously. Without loss of generality, we take the scheduling of BS_{gb} as an example to describe.

In order to exploit the benefit of coordination, the scheduling of BS_{gb} should be done by taking into account the interference caused to the previously scheduled groups. Since BS_{gb} does not know the scheduling results of groups which make scheduling decisions after it, the beamforming of all BSs can not be perfectly known. Thus, the scheduling metric of BS_{gb} can only be maximizing an estimated weighted sum rate, rather than the actual expression in (7).

By incorporating both the performance of BS_{gb} and its interference to the previously scheduled groups, we propose the following metric for the scheduling of BS_{gb}

$$\mathcal{S}_{gb} = \arg\max_{\hat{\mathcal{S}}_{gb} \in \mathcal{U}_{gb}} \hat{R}_{\Sigma(\hat{\mathcal{S}}_{gb})}, \tag{8}$$

where $\hat{R}_{\Sigma(\hat{\mathcal{S}}_{gb})} = \sum_{s_j \in \hat{\mathcal{S}}_{gb}} \beta_{s_j} \hat{R}_{s_j}$ is the estimated weighted sum rate of users set $\hat{\mathcal{S}}_{gb}$ in the bth cell of group g.

In the following, we will analyze how to estimate the weighted sum rate in (8) with limited signalling among BSs for efficient ICI coordination.

The rate of user s_i, which is a potentially scheduled user of BS_{gb}, is estimated as $\hat{R}_{s_i} = \log_2(1 + \widehat{\mathrm{SINR}}_{s_i})$, with the $\widehat{\mathrm{SINR}}_{s_i}$ given by

$$\widehat{\mathrm{SINR}}_{s_i} = \frac{\frac{P_{gb}}{|\hat{\mathcal{S}}_{gb}|} |\mathbf{h}_{s_i,gb}^H \hat{\mathbf{w}}_{s_i,gb}|^2}{\widehat{\mathrm{IUI}}_{s_i} + \widehat{\mathrm{ICI}}_{s_i} + \sigma_{s_i}^2}, \tag{9}$$

where $\widehat{\mathrm{IUI}}_{s_i} = \frac{P_{gb}}{|\hat{\mathcal{S}}_{gb}|} \sum_{s_j \in \hat{\mathcal{S}}_{gb} \setminus \{s_i\}} |\mathbf{h}_{s_i,gb}^H \hat{\mathbf{w}}_{s_j,gb}|^2$, $\widehat{\mathrm{ICI}}_{s_i} = \sum_{\mathrm{BS}_{\check{g}\check{b}} \in \mathcal{I}_{gb}} \sum_{s_k \in \mathcal{S}_{\check{g}\check{b}}} \frac{P_{\check{g}\check{b}}}{|\hat{\mathcal{S}}_{\check{g}\check{b}}|} |\mathbf{h}_{s_i,\check{g}\check{b}}^H \hat{\mathbf{w}}_{s_k,\check{g}\check{b}}|^2$, and $\hat{\mathbf{w}}_{s_k,\check{g}\check{b}}$ is the beamforming of $\mathrm{BS}_{\check{g}\check{b}}$, which is predicted by BS_{gb} for its scheduling.

A good estimate of the SINR for user s_i includes the prediction of beamforming used for transmission by both BS_{gb} and BSs of its interference-cells. The beamforming for BS_{gb}, i.e., $\hat{\mathbf{w}}_{s_i,gb}$, $s_i \in \hat{\mathcal{S}}_{gb}$, is required for evaluation of both signal power and IUI, and that of its interference BSs, i.e., $\hat{\mathbf{w}}_{s_k,\check{g}\check{b}}$, $s_k \in \mathcal{S}_{\check{g}\check{b}}$, $\mathrm{BS}_{\check{g}\check{b}} \in \mathcal{I}_{gb}$, is used for ICI estimation.

[3]More iterations can be performed when all cell-groups has performed scheduling once, but at the expense of a long scheduling period and heavy backhaul overhead. In this paper, we consider only one iteration of scheduling.

Considering that BS_{gb} does not know the scheduling results of cell-groups which make scheduling decisions after it, the beamforming of BS_{gb} used for scheduling can be computed only based on the scheduling results of previously scheduled groups. Under this assumption, the beamforming of BS_{gb} used for scheduling, i.e., $\hat{\mathbf{w}}_{s_j,gb}$, $s_j \in \hat{\mathcal{S}}_{gb}$, is computed according to (6) with $\hat{\mathbf{\Omega}}_{s_i}$ formulated as

$$\hat{\mathbf{\Omega}}_{s_i} = \frac{\sigma_{s_i}^2}{P_{gb}} + \sum\nolimits_{s_j \in \hat{\mathcal{S}}_{gb} \setminus \{s_i\}} \mathbf{h}_{s_j,gb} \mathbf{h}_{s_j,gb}^H + \sum\nolimits_{\mathrm{BS}_{\breve{g}\breve{b}} \in \mathcal{I}_{gb}, \breve{g} < g} \sum\nolimits_{s_k \in \mathcal{S}_{\breve{g}\breve{b}}} \mathbf{h}_{s_k,gb} \mathbf{h}_{s_k,gb}^H, \tag{10}$$

where the third term only includes the leakage from BS_{gb} to users in those groups, which perform scheduling prior to BS_{gb}.

The ICI of user s_i can be divided into two parts, which are the ICI from cell-groups which perform scheduling prior to BS_{gb}, i.e., $\mathrm{ICI}_{s_i}^{\breve{g}<g}$, and the ICI from cell-groups performing scheduling after BS_{gb}, i.e., $\mathrm{ICI}_{s_i}^{\breve{g}>g}$. For those cell-groups which have not yet performed scheduling, it is impossible to predict their beamforming by BS_{gb}. In order to be more robust to the ICI, herein we consider a pessimistic estimate of ICI from those cell-groups by assuming that they will not coordinate their interference to users served by BS_{gb}. Thus, by averaging over the small scale fading channels, an estimate of $\mathrm{ICI}_{s_i}^{\breve{g}>g}$ can be obtained as

$$\begin{aligned}\widehat{\mathrm{ICI}}_{s_i}^{\breve{g}>g} &\approx \mathbb{E}\{\mathrm{ICI}_{s_i}^{\breve{g}>g}\} \\ &= \mathbb{E}\{\sum\nolimits_{\mathrm{BS}_{\breve{g}\breve{b}} \in \mathcal{I}_{gb}, \breve{g}>g} \sum\nolimits_{s_k \in \mathcal{S}_{\breve{g}\breve{b}}} \frac{P_{\breve{g}\breve{b}}}{|\hat{\mathcal{S}}_{\breve{g}\breve{b}}|} |\mathbf{h}_{s_i,\breve{g}\breve{b}}^H \hat{\mathbf{w}}_{s_k,\breve{g}\breve{b}}|^2\} \\ &= \sum\nolimits_{\mathrm{BS}_{\breve{g}\breve{b}} \in \mathcal{I}_{gb}, \breve{g}>g} P_{\breve{g}\breve{b}} \alpha_{s_i,\breve{g}\breve{b}}^2, \end{aligned} \tag{11}$$

where the last equation comes by the pessimistic assumption, which results in that the beamforming of $\mathrm{BS}_{\breve{g}\breve{b}}$ and the channel between $\mathrm{BS}_{\breve{g}\breve{b}}$ and user s_i served by BS_{gb} are uncorrelated.

We assume that additional information can be transmitted from the interference BSs of BS_{gb} in previously scheduled groups, so as to let BS_{gb} obtain a closer estimate of $\mathrm{ICI}_{s_i}^{\breve{g}<g}$. To estimate $\mathrm{ICI}_{s_i}^{\breve{g}<g}$, BS_{gb} should first predict the beamforming of its interference-cells which have performed scheduling, i.e., $\hat{\mathbf{w}}_{s_k,\breve{g}\breve{b}}$, $\mathrm{BS}_{\breve{g}\breve{b}} \in \mathcal{I}_{gb}, \breve{g} < g$. Then, using the CSI of interference channels, which are the channels between the interference BSs of BS_{gb} and users in the bth cell of group g, BS_{gb} can estimate the $\mathrm{ICI}_{s_i}^{\breve{g}<g}$. According to (6), if BS_{gb} wants to predict the beamforming of its interference BSs, i.e., $\mathrm{BS}_{\breve{g}\breve{b}}$, both the channel from $\mathrm{BS}_{\breve{g}\breve{b}}$ to the users it scheduled, and the channel from $\mathrm{BS}_{\breve{g}\breve{b}}$ to the users scheduled by its interference BSs are all required, which demands large amount of signalling through backhaul. In order to reduce the signalling, we let BS_{gb} estimate the beamforming of $\mathrm{BS}_{\breve{g}\breve{b}}$, i.e., $\hat{\mathbf{w}}_{s_k,\breve{g}\breve{b}}$, $s_k \in \mathcal{S}_{\breve{g}\breve{b}}$, according to (6) with $\hat{\mathbf{\Omega}}_{s_k}$ given as

$$\hat{\mathbf{\Omega}}_{s_k} = \frac{\sigma_{s_m}^2}{P_{\breve{g}\breve{b}}} + \sum\nolimits_{s_m \in \mathcal{S}_{\breve{g}\breve{b}} \setminus \{s_k\}} \mathbf{h}_{s_m,\breve{g}\breve{b}} \mathbf{h}_{s_m,\breve{g}\breve{b}}^H + \sum\nolimits_{s_j \in \hat{\mathcal{S}}_{gb}} \mathbf{h}_{s_j,\breve{g}\breve{b}} \mathbf{h}_{s_j,\breve{g}\breve{b}}^H, \tag{12}$$

where in the third term, only the leakage from $\mathrm{BS}_{\breve{g}\breve{b}}$ to users in the bth cell of group g are accounted for.

B. CSI Requirements for Distributed Scheduling

According to the above analysis, the CSI required by the proposed distributed scheduling is summarized as follows.

In order to obtain an estimate of both signal power and IUI, the CSI from BS_{gb} to users located in its interference cells are required for computing of the beamforming according to (6) and (10). In TDD systems, this part the of CSI can be achieved by exploiting the channel reciprocity.

Regarding to the estimate of $\mathrm{ICI}_{s_i}^{\breve{g}>g}$ in (11), the long term information $\alpha_{s_i,\breve{g}\breve{b}}^2$ is needed, which can be first estimated by user s_i and then fed back. Since the long term information changes slowly, it can be obtained with negligible overhead.

For the estimate of $\mathrm{ICI}_{s_i}^{\breve{g}<g}$, the CSI between users located in the bth cell of group g and their interference BSs in previously scheduled groups is required. In TDD systems, this part of CSI can be first achieved by the interference BSs of BS_{gb} exploiting the channel reciprocity. Then, those interference BSs in previously scheduled groups send these CSI to BS_{gb} over the backhaul. At the same time, the CSI between $\mathrm{BS}_{\breve{g}\breve{b}}$ and its scheduled users should also be transferred to BS_{gb} for the computing of beamforming in (12).

With these CSI, BS_{gb} first computes the predicted beamforming of itself and that of it interference BSs according to (6), (10) and (12). Then, based on the estimated beamforming and the approximate ICI in (11), it evaluates the estimated sum rate in (8) and finds out the users set according to (8).

Remark 2. Finding the optimal user group to schedule according to (8) typically involves evaluating the performance for all conceivable user groupings, which becomes computationally prohibitive even for a modest number of users. To reduce the scheduling complexity, the sub-optimal greedy user scheduling scheme in [13] can be directly extended here.

IV. Simulation Results

A. Simulation Set-up

A cellular system with 19 hexagonal cells is considered; see Fig. 1. We use a wrap-around topology to mitigate the edge effect of the layout. The radius of each cell is 500 m and the cell-edge SNR is 10 dB. Each BS is equipped with $N_t = 4$ antennas. To highlight the performance improvement for cell-edge users, we let 10 users be uniformly distributed in a cell-edge region, in which the distance between users and its serving BS is larger than 250 m. The pathloss model in 3GPP Long Term Evolution (LTE) is used as $\mathrm{PL}^{\mathrm{dB}} = 36.3 + 37.6 \log_{10}(d)$, where d is the distance between BS and user. The shadowing follows a log-normal distribution with 8 dB standard deviation. Users are randomly distributed 100 times. During each user distribution, 500 time slots are simulated. The small scale fading channel is modeled as block Rayleigh fading and spatial uncorrelated. In each block, the weighting coefficients of users are updated according to the proportional fairness criteria [14], with the depth of the throughput integrating window as 100.

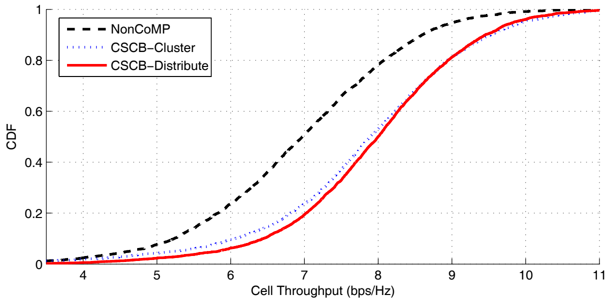

Fig. 2. The CDF of cell throughput, in which the cell throughput of the 'CSCB-Distribute' and 'CSCB-Cluster' are almost overlapping.

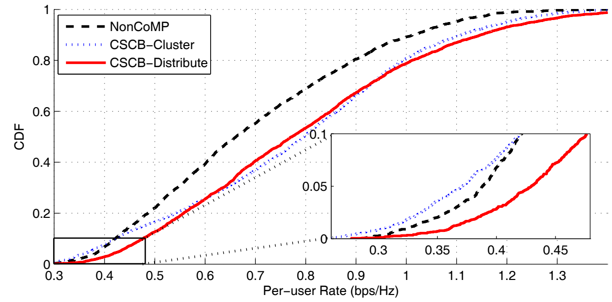

Fig. 3. The CDF of per-user rate.

B. Simulation Results

The proposed cell-grouping based distributed scheduling and beamforming (CSCB-Distribute) is compared with both non-cooperative transmission (NonCoMP) and fixed clustering cooperative transmission (CSCB-Cluster). In the simulation of the cell-grouping based distributed scheduling and beamforming, three cell-groups shown in Fig. 1 are considered. For the fixed clustering cooperative transmission, we let three adjacent cells form a cluster. Each cluster is controlled by a CU, which can collect both the CSI of all links and the weighting coefficients of all users in the cluster to perform centralized scheduling and beamforming. The centralized scheduling is the direct extension of the sub-optimal multi-user scheduling scheme in [13]. The beamforming is based on the DVSINR by considering the leakage only in the cluster.

The cumulative distribution function (CDF) of cell throughput of the three schemes are shown in Fig. 2. From the simulation results we can observe that the cell throughput of the cell-grouping based distributed scheduling and beamforming is almost the same as for the fixed clustering cooperative transmission. However, our proposed scheme requires much less backhaul signalling among BSs compared with the fixed clustering cooperative transmission. Furthermore, the cell-grouping based distributed scheduling and beamforming can be performed distributely without any CU.

The CDF of the per-user rates of the three schemes are shown in Fig. 3. It is clear that, the fixed clustering cooperative transmission cannot improve the throughput of cell-edge user compared with the NonCoMP transmission, because the users located near the cluster edge still suffer from severe inter-cluster interference. Our cell-grouping based distributed scheduling and beamforming shows performance enhancement for the cell-edge users. That is because in the cell-grouping based distributed scheduling and beamforming scheme, each BS can coordinate its interference to all the victim users in other cells.

V. Conclusion

In this paper, a dynamic cooperative framework for large cellular system is proposed, where cells are divided into groups such that neighboring cells belong to different groups. Based on the cell-grouping, a distributed scheduling is proposed which lets different cell-groups make scheduling decisions sequentially. The cell-grouping based scheduling and beamforming can be performed distributely with limited signalling among BSs. Simulation results show that it provides considerable performance gains compared with the non-cooperative transmission. It also provides better cell-edge user performance than the fixed clustering based centralized scheduling and beamforming without decreasing the cell throughput.

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