An Optimized Cooperative Transmission Scheme for Interference Mitigation in Heterogeneous Downlink Network

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***Abstract*—In the context of out-of-cell interference mitigation, cooperative base-station transmission strategy in homogeneous network deployment has been intensively investigated and also been demonstrated effectively. To tackle the problem of interference cancelation in a hierarchical cell structure, this paper proposes a framework for the study of cooperative base-station transmission strategy over macro and femto base stations within the heterogeneous network deployment. In particular, we consider two distinct coordinated schemes for cell median and edge users respectively. The main contribution of this paper is a network-wide optimized transmission scheme in terms of per cell sum rate maximization. Numerical results show that with the proposed cooperative transmission scheme, higher throughput is achieved by both cell median and edge users when compared to the conventional transmission strategy without coordination for inter-cell interference mitigation.**

I. Introduction

The mitigation of out-of-cell interference has become one of the most crucial tasks to improve the performance of multi-antenna system (known as MIMO) in future cellular network. One major reason is that the performance of MIMO system degrades sharply in the low signal-to noise ratio regime. Unfortunately, this phenomenon is now prevalent in cellular network where universal frequency reuse is employed for high spectrum efficiency and where supplemental infrastructures in the form of small cells are deployed for better capacity and coverage. In the cellular environment, frequency reuse benefits the overall spectrum utility however it inevitably introduces the co-channel interference for surrounding cells. When this interference dominates, it hinders MIMO system to achieve higher capacity as it operates in single cell scenario with no external interference [1]. Likewise, conventional cellular network with embedded small cells are intended to improve network capacity and provide better quality of service [2]. But it also causes cross-tier interference in a hierarchical cell structure where macro cell and small cells interfere with each other heavily on the overlapping region of their coverages [3].

Recently, cooperative base station transmission is proposed as an effective approach to suppress other cell interference (OCI) and therefore dramatically enhance the downlink capacity in the interference-limited multicell MIMO system [4]–[7]. With cooperative processing among relevant base stations, the inter-cell interference can be utilized as the desired signal hence making the performance gain of this transmission strategy enormously remarkable [5]. However, most previous works in terms of the network coordination are extensively investigated only in the scenario of homogeneous network with a macro-centric planned process, where all the user terminals anywhere inside the cell are supported by merely one transmission point. From a long-term standpoint, coordination in a heterogeneous network comprised of a central macro cell overlaid with lower power and shorter range small cells deserves much more attentions since future gains of wireless communication are more likely to obtained by such advanced network topology [2], [8]. In this paper, hereby we propose a framework for the study of joint transmission strategy over cooperative base stations in MIMO downlink system of heterogeneous network, as depicted in Fig. 1.

In a cooperative system, a deliberate user selection scheme [9], an advanced spatial precoding approach [10] and a judicious power allocation method [11] can substantially exploit the benefits of network coordination. These three strategies can be designed jointly within the optimization problem of the overall network utility, which can be defined as a objective function of transmission rate, signal quality or fairness metrics. In this paper, the optimization problem of network utility associated with the transmission scheme is adopted as the objective in terms of per-cell sum rate maximization. In some case, finding the optimal solution toward the optimization problem in global seems difficult mathematically, where the utility maximization problem is formulated into a combinatorial and nonconvex form [12]. Instead of aiming for a global optimal solution, here we propose a heuristic approach for maximizing the network utility.

II. System Model and Problem Formulation

A. Single Base Station Transmission Strategy Without Coordination

Consider a hierarchical network deployment, in which each macrocell overlaid with three femtocells, as shown in Fig. 1. We assume the macro base-station and the femto base-station is equipped with N_{t_1} and N_{t_2} antennas respectively. Due to the

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limitation of space, this paper mostly focus on the base station-side interference control strategy and the remote terminal with single antenna is adopted here for simplicity of analysis.

In the following, the system under consideration employs a spatial multiplexing scheme and therefore multiple users within each cell can be served simultaneously in each frequency or time slot via scheduling. Further, full frequency reuse is employed here for maximal spectrum efficiency, in which each macro base station shares the radio spectrum with embedded femto base stations in its coverage. In such network layout, mobile users may experience both intra-cell and inter-cell interference because of a spatial multiplexing scheme and the universal frequency reuse. In the rest of this paper, we only consider the linear spatial coding scheme in the form of beamforming.

In the conventional scenario of single base station transmission, the downlink received signal $y_{mk} \in \mathbb{C}$ at kth user in mth cell is given by

$$\begin{aligned} y_{mk} &= \sqrt{p_{mk}}\mathbf{h}_{mk}\mathbf{w}_{mk}^H x_{mk} + \sqrt{p_{ml}}\mathbf{h}_{mk}\sum_{l\neq k}\mathbf{w}_{ml}^H x_{ml} \\ &+ \sqrt{p_{m'l'}}\mathbf{h}_{m'k}\sum_{m'\neq m}\mathbf{w}_{m'l'}^H x_{m'l'} + n_{mk} \end{aligned} \tag{1}$$

where $\mathbf{h}_{mk} \in \mathbb{C}^{1\times N_{t_i}}, i = 1, 2$ denotes the downlink channel vector from mth BS to the kth users with zero-mean unit variance i.i.d complex Gaussian entries, $\mathbf{w}_{mk} \in \mathbb{C}^{1\times N_{t_i}}$ denotes its beamforming vector, $(\cdot)^H$ is the conjugate transpose operation, $x_{mk} \in \mathbb{C}$ is the transmitted signal for the targeted user, $n_{mk} \in \mathbb{C}$ is the additive white Gaussian complex noise with zero mean and variance σ^2, the term $\sqrt{p_{ml}}\mathbf{h}_{mk}\mathbf{w}_{ml}^H x_{ml}$ denotes the intra-cell interference coming from user ml to the user mk, and the term $\sqrt{p_{m'l'}}\mathbf{h}_{m'l'}\mathbf{w}_{m'l'}^H x_{m'l'}$ denotes inter-cell interference coming from the m'th cell neighboring to mth cell. Here, p_{mk} represents the transmitting power of mth BS that allocate to the kth user. Note that $\mathbf{h}_{mk} \in \mathbb{C}^{1\times N_{t_1}}$ represents the channel vector from macro base-station to the remote terminal and $\mathbf{w}_{mk} \in \mathbb{C}^{1\times N_{t_1}}$ denotes its beamforming weight vector whereas $\mathbf{h}_{mk} \in \mathbb{C}^{1\times N_{t_2}}$ represents that from femto base-station to the mobile user and $\mathbf{w}_{mk} \in \mathbb{C}^{1\times N_{t_2}}$ is its beamforming vector. The signal-to-interference plus noise ratio (SINR) of the kth user in mth cell can be expressed by equation (2).

B. Joint Signal Processing Strategy over Cooperative Base Stations

In the case of single base-station transmission, the inter-cell interference is simply treated as additive background noise. However, inter-cell interference from adjacent cells can transform into transmitting signal in the joint processing strategy among cooperative base-stations [5].

To guarantee better user experience, this paper proposes two distinct cooperative transmission schemes for both cell-median and cell-edge users. For cell-center users, we consider a coordination area consists of a central macro base-station and three corresponding femto base-stations within the macrocell coverage. In particular, we extend the coordination area for

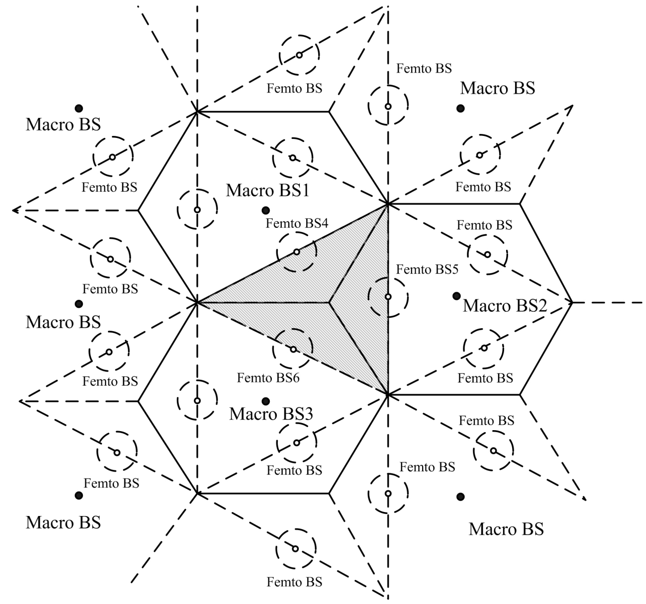


Fig. 1: The coordinated cluster for cell edge users consists of Macro BS1, Macro BS2, Macro BS3 , Femto BS4, Femto BS5 and Femto BS6. The cell edge users are dropped in the area that is highlighted.

cell-edge users where the coordination cluster is composed of three macro base stations and three femto base stations within their respective macrocell coverage boundary, as illustrated in Fig.1. In both cases, channel state information (CSI) and data streams are shared among the relevant base stations through backhaul. Here we assume the CSI to be perfect and the joint transmission to be synchronized in this paper to highlight the contribution of the joint processing scheme. In the following of the paper, we only focus on the discussion of the transmission scheme for cell edge users. The analysis and derivation procedures for cell median users are very similar with that for cell edge ones and they will be omitted for saving the space.

We define $\widehat{\mathbf{h}}_{mk} = [\mathbf{h}_{mk_1}, \mathbf{h}_{mk_2}, \mathbf{h}_{mk_3}, \widetilde{\mathbf{h}}_{mk_4}, \widetilde{\mathbf{h}}_{mk_5}, \widetilde{\mathbf{h}}_{mk_6}] \in \mathbb{C}^{1\times(3\times N_{t_1}+3\times N_{t_2})}$ as the composite downlink channel vector for the cell-edge users, where $\mathbf{h}_{mk_{1,2,3}}$ denote the channel vectors from coordinated $(1, 2, 3)$th macrocell BS to kth user, and $\widetilde{\mathbf{h}}_{mk_{4,5,6}}$ denote the channel vectors from coordinated $(4, 5, 6)$th femtocell BS to the kth user. Further, we define $\widehat{\mathbf{w}}_{mk} = [\mathbf{w}_{mk_1}, \mathbf{w}_{mk_2}, \mathbf{w}_{mk_3}, \widetilde{\mathbf{w}}_{mk_4}, \widetilde{\mathbf{w}}_{mk_5}, \widetilde{\mathbf{w}}_{mk_6}] \in \mathbb{C}^{1\times(3\times N_{t_1}+3\times N_{t_2})}$ as their respective linear precoding vector, where $\mathbf{w}_{mk_{1,2,3}} \in \mathbb{C}^{1\times N_{t_1}}$ are the beamforming vector from macro BS corresponding to $\mathbf{h}_{mk_{1,2,3}}$ and $\widetilde{\mathbf{w}}_{mk_{4,5,6}} \in \mathbb{C}^{1\times N_{t_2}}$ are that from femto BSs corresponding to $\widetilde{\mathbf{h}}_{mk_{4,5,6}}$.

Then the signal received by kth user in mth cell can be written as

$$y_{mk} = \sqrt{p_{mk}}\widehat{\mathbf{h}}_{mk}\widehat{\mathbf{w}}_{mk}^H x_{mk} + \sqrt{p_{ml}}\widehat{\mathbf{h}}_{mk}\sum_{l\neq k}\widehat{\mathbf{w}}_{ml}^H x_{ml} + n_{mk}. \tag{3}$$

From (3) we may clearly observe that the inter-cell interference has been utilized as desired signal by joint processing scheme.

$$\mathsf{SINR}_{mk} = \frac{|\mathbf{h}_{mk}\mathbf{w}_{mk}^H|^2 p_{mk}}{\sum_{l\neq k,l} |\mathbf{h}_{mk}\mathbf{w}_{ml}^H|^2 p_{ml} + \sum_{m'\neq m,m}\sum_{l'} |\mathbf{h}_{m'k}\mathbf{w}_{m'l'}^H|^2 p_{m'l'} + \sigma^2}. \tag{2}$$

With the help of joint transmission, the SINR of the kth user in mth cell is now adjusted to

$$\mathsf{SINR}_{mk} = \frac{|\widehat{\mathbf{h}}_{mk}\widehat{\mathbf{w}}_{mk}^H|^2 p_{mk}}{\sum_{l\neq k} |\widehat{\mathbf{h}}_{mk}\widehat{\mathbf{w}}_{ml}^H|^2 p_{ml} + \sigma^2}. \tag{4}$$

C. Optimization Problem Formulation

In this paper, the network utility objective is defined as the function of downlink per-cell sum rate maximization. To maximize the network-wide utility objective, the coordinated base stations should jointly schedule users and adapt the precoder vector as well as the transmit power spectra. In this way, the joint optimization problem is formulated as

$$\begin{aligned}
\max_{\mathcal{S}_m, p_{mk}, \widehat{\mathbf{w}}_{mk}} \sum_{k\in\mathcal{S}_m} R_{mk} &= \sum_{k\in\mathcal{S}_m} \log_2(1+\mathsf{SINR}_{mk}) \\
&= \sum_{k\in\mathcal{S}_m} \log_2\Big(1+\frac{|\widehat{\mathbf{h}}_{mk}\widehat{\mathbf{w}}_{mk}^H|^2 p_{mk}}{\sum_{l\neq k, l\in\mathcal{S}_m} |\widehat{\mathbf{h}}_{mk}\widehat{\mathbf{w}}_{ml}^H|^2 p_{ml} + \sigma^2}\Big) \\
\text{s.t. } & \mathcal{S}_m \subset \mathcal{U}_m \\
& \sum_{k\in\mathcal{S}_m} |\mathbf{w}_{mk_j}\mathbf{w}_{mk_j}^H| p_{mk} \le P_{\mathrm{M}}^{\max}, j=1,2,3 \\
& \sum_{k\in\mathcal{S}_m} |\widetilde{\mathbf{w}}_{mk_{j'}}\widetilde{\mathbf{w}}_{mk_{j'}}^H| p_{mk} \le P_{\mathrm{F}}^{\max}, j'=4,5,6 \\
& p_{mk} \ge 0
\end{aligned} \tag{5}$$

where $\mathcal{U}_m$ denotes the user set in mth cell and the number of its corresponding user is K, $\mathcal{S}_m$ denotes set of users severed by cooperative base stations simultaneously with a spatial multiplexing scheme in mth cell, $P_{\mathrm{M}}^{\max}$ is the maximal transmit power of macro cell BS, and $P_{\mathrm{F}}^{\max}$ is that of femto cell BS. The network utility maximization objective (5) is a well-known combinatorial and nonconvex optimization problem for which finding the global optimal solution is likely to be impractical. Toward this end, this paper proposes a heuristic approach for this optimization problem. The proposed algorithm first schedules the best users wisely in each cell assuming equal power allocation for approximation, which is widely applied in many user selection schemes [5] [13]. Then the algorithm computes the precoder vector under the given set of scheduled users and finally optimizes the power spectra subject to the per base station power constraint.

III. Proposed Algorithm

A. User Selection Scheme

Semiorthogonal user selection (SUS) algorithm is a low complexity scheduling method that does not take exhaustive searching procedure yet can still obtain a large fraction of the benefit of multiuser diversity gain [13]. With SUS algorithm, even a simple precoding method like zero-forcing beamforming (ZFBF) can still achieve the asymptotic sum rate as dirty paper coding (DPC), which is known as the capacity-achieving strategy in MIMO downlink system [13]. In the following, we extend the SUS algorithm from single cell scenario to the multiple cells scenario proposed in this paper, where all the cooperative base stations jointly schedule the targeted users within their respective coverage. The scheduling algorithm proposed here is associated with joint processing scheme and hereby we name it JP-SUS. To achieve the goal of fairness among users, we further mix JP-SUS with the proportional fairness scheduling method in this paper, which is named PF-JP-SUS.

The procedure of our PF-JP-SUS in mth cell at tth time slot is summarized as follows.

1) Initialization

$$\Gamma_{m1} = \{(m-1)K+1, (m-1)K+2, \ldots, mK\}$$
$$i' = 1, \quad \mathcal{S}_m = \emptyset$$

2) For each user k in mth cell $\in \Gamma_{m1}$, calculate $\widehat{\mathbf{h}}_{mk}$ and select a user with the maximal composite channel norm

$$\pi_1 = \arg\max_{k\in\Gamma_{m1}} \|\widehat{\mathbf{h}}_{mk}\|, \quad \mathcal{S}_m = \mathcal{S}_m \cup \{\pi_1\}$$
$$\Gamma_{m1} = \Gamma_{m1} - \mathcal{S}_m, \quad \widehat{\mathbf{h}}_1 = \widehat{\mathbf{h}}_{\pi_1}, \quad \widehat{\mathbf{g}}_1 = \mathbf{h}_{\pi_1}, \quad i' = i'+1$$

3) For each user k in mth cell $\in \Gamma_{mi'}$, calculate $\mathbf{g}_{mk}$, the projection of $\widehat{\mathbf{h}}_{mk}$ to orthogonal complement of the subspace spanned by $\{\widehat{\mathbf{g}}_1, \widehat{\mathbf{g}}_2, \ldots, \widehat{\mathbf{g}}_{i'-1}\}$

$$\widehat{\mathbf{g}}_{mk} = \widehat{\mathbf{h}}_{mk} - \widehat{\mathbf{h}}_{mk}\sum_{j=1}^{i'-1}\frac{\widehat{\mathbf{g}}_j^H\widehat{\mathbf{g}}_j}{\|\widehat{\mathbf{g}}_j\|^2}$$

4) select the user as follows.

$$\begin{aligned}
\pi_{i'} &= \arg\max_{k\in\Gamma_{mi'}} \mu_k(t)\widetilde{R}_{mk}(\mathcal{S}_m, t) \\
&= \mu_k(t)\log_2\Big(1+\frac{P_m^{\max}}{M}\|\widehat{\mathbf{g}}_{mk}\|\Big)
\end{aligned} \tag{6}$$

$$\mathcal{S}_m = \mathcal{S}_m \cup \{\pi_{i'}\}, \quad \Gamma_{mi'} = \Gamma_{mi'} - \mathcal{S}_m$$
$$\widehat{\mathbf{h}}_{i'} = \widehat{\mathbf{h}}_{\pi_{i'}}, \quad \widehat{\mathbf{g}}_{i'} = \mathbf{g}_{\pi_{i'}}, \quad i' = i'+1$$

5) If $|\mathcal{S}_m| < M$, calculate $\Gamma_{mi'}$, the set of users semiorthogonal to $\widehat{\mathbf{g}}_{i'}$

$$\Gamma_{mi'+1} = \{k \neq \pi_{i'}, k\in\Gamma_{mi'} | \frac{|\widehat{\mathbf{h}}_{mk}\widehat{\mathbf{g}}_{i'}^H|}{\|\widehat{\mathbf{h}}_{mk}\|\|\widehat{\mathbf{g}}_{i'}\|} \le \alpha\}$$

where $\mathcal{S}_m$ is the scheduling user group in mth cell, $\Gamma_{mi'}$ is the user pool at i'th iteration step and initiated by the set of total users in mth cell Γ_{m1}, α is a small positive constant that determines the performance of the scheduling algorithm, $\mu_k(t)$ is the weight factor, $\widetilde{R}_{mk}(\mathcal{S}_m, t)$ is the approximate rate of user k at time t and M is the number of users to be scheduled. We have $M = N_{t_1}$ in macrocell and $M = N_{t_2}$ in femtocell. The iterations will be stop until either $i' = M$ or $\Gamma_{mi'}$ is an empty set.

In our PF-JP-SUS, users with both relative high channel magnitudes and good spatial separations are chosen to the selected group. From step (3), it is easily to see in set $\{\widehat{\mathbf{g}}_{i'}, 1 \le i' \le |\mathcal{S}_m|\}$, the element is orthogonal to each other. Further, step (5) guarantees that users left in $\Gamma_{mi'+1}$ would be semiorthogonal to $\widehat{\mathbf{g}}_1, \widehat{\mathbf{g}}_2, \ldots, \widehat{\mathbf{g}}_{i'}$ when α is chosen appropriate, and therefore we have $\widehat{\mathbf{h}}_{mk} \approx \mathbf{g}_{mk}$ for $k \in \Gamma_{mi'+1}$. Since $\widehat{\mathbf{h}}_{i'} \approx \mathbf{g}_{i'}$ in this algorithm, the selected set $\mathcal{S}_m$ is constructed with a group of users with $\widehat{\mathbf{h}}_{i'}$ semiorthogonal to one another. In addition, users with the largest channel norm projection are selected in (6), which guarantees their effective channel gain.

In the fairness context, we select the users with largest weighted data rate rather than with largest data rate in (6). Since the exact value of data rate of user k is not available before the scheduling decision, it is approximated under the assumption of equal power allocation and $\widehat{\mathbf{g}}_{mk} = \widehat{\mathbf{h}}_{mk}$, which is reasonable since the scheduled users are nearly orthogonal to one another.

The weight factor $\mu_k(t)$ at time t is obtained by

$$\begin{aligned}\frac{1}{\mu_k(t+1)} &= (1-\frac{1}{\Delta t})\frac{1}{\mu_k(t)} \\ &\quad + \frac{1}{\Delta t}R_{mk}(\mathcal{S}_m, t), \qquad k \in \mathcal{S}_m \qquad (7)\\ \frac{1}{\mu_k(t+1)} &= (1-\frac{1}{\Delta t})\frac{1}{\mu_k(t)}, \quad k \notin \mathcal{S}_m \qquad (8)\end{aligned}$$

where Δt is the windows size and $R_{mk}(\mathcal{S}_m, t)$ is the exact transmission rate of user k over the time window $[t-\Delta t, t]$. Note that after the schedule decision at tth time slot, we can simply compute the exact rate of M scheduled users by applying the beamforming and power allocation method introduced in the following part. Hereby, $\mu_k(t+1)$ can be easily derived from (7) for the next schedule round. In this scheduling method, fairness is guaranteed in (7) and (8). When the users have already been scheduled in tth time slot, the chance of being scheduled in the next time slot decreases since its weight factor is reduced in (7).

B. Spatial Precoding Scheme

Among linear precoding methods for interference presubtration, zero-forcing beamforming (ZFBF) scheme is widely applied in cooperative transmission system because of its low complexity implementation [4], [5]. In this paper, ZFBF is adopted as the spatial precoding scheme for the joint optimization problem formulated in (5).

Let $\widehat{\mathbf{H}} = [\widehat{\mathbf{h}}_1^H, \ldots, \widehat{\mathbf{h}}_u^H, \ldots, \widehat{\mathbf{h}}_{(3\times N_{t_1}+3\times N_{t_2})}^H]^H$ denotes the channel matrix of the total scheduled users within the whole coordination area in each time slot, where each row denotes the channel vector of one corresponding active user in the selected user set $\mathcal{S}_m, m = 1, \ldots, 6$. Note that the number of rows of $\widehat{\mathbf{H}}$ denotes there are $3\times N_{t_1} + 3\times N_{t_2}$ scheduled users within the coordinated area composed of three cooperative macro and femto basestations. $\widehat{\mathbf{W}} = [\widehat{\mathbf{w}}_1, \ldots, \widehat{\mathbf{w}}_v, \ldots, \widehat{\mathbf{w}}_{(3\times N_{t_1}+3\times N_{t_2})}]$ denotes the beamforming weight matrix, where each column denotes the corresponding beamforming vector of each scheduled user in set $\mathcal{S}_m$. In ZFBF scheme, the beamforming matrix $\widehat{\mathbf{W}}$ is the pseudoinverse of $\widehat{\mathbf{H}}$, i.e.,

$$\widehat{\mathbf{W}} = \widehat{\mathbf{H}}^H(\widehat{\mathbf{H}}\widehat{\mathbf{H}}^H)^{-1}. \qquad (9)$$

where the selected beamforming vectors satisfy $\widehat{\mathbf{h}}_u \widehat{\mathbf{w}}_v^H = 0$ for $u \neq v$.

C. Power Allocation Scheme

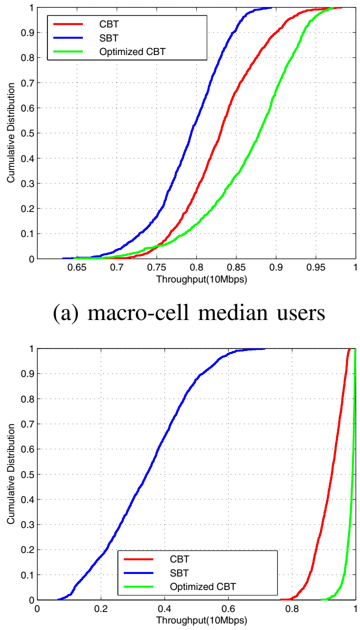
Given the fixed user set $\mathcal{S}_m$ and their respective beamforming vectors by our proposed scheme, the power constraints of each base-stations in (5) is transformed into a set of linear constraints. Further, the objective defined in terms of sum rate maximization is concave in the data symbol power $\{p_{mk}\}$, and therefore the optimization problem becomes a convex programming problem with respect to $\{p_{mk}\}$, which can be addressed effectively via standard convex optimization techniques.

IV. Simulation Results

The performance of the proposed cooperative strategy is evaluated on the three-cell macro deployment shown in Fig. 1, with a 1km macro BS-to-BS distance and with 10MHz bandwith. Interference coming out of the coordinated area is treated as background noise. Each macro base station has four antennas with an antenna gain of 14dBi and the maximal transmission power of 46dBm whereas each femto base station has two antennas with an antenna gain of 5dBi and the maximal transmission power of 30dBm. The distance-dependent path-loss model for macro base-station to terminal is $L = 128.1 + 37.6\log_{10}(d)$ and $L = 127.0 + 30\log_{10}(d)$ for femto base-station to terminal, where d is the distance in km, with 8dB and 10dB lognormal shadowing respectively. 100 users are uniformly dropped in the macrocell coverage. In similar, 10 users are randomly dropped in the femtocell coverage, where the radius is 50m. In each time or frequency slot, $N_{t_1} = 4$ macro-cell users and $N_{t_2} = 2$ femto-cell users will be scheduled respectively. The scheduling parameter α is 0.3, which is the optimal one under the number of users assumed above.

Fig. 2 compares the cumulative distribution functions (CDF) of total throughput per cell with respect to macro-cell and femto-cell median users with single base-station transmission (SBT), cooperative base-station transmission (CBT), and the optimized cooperative base-station transmission. Both SBT and CBT adopt the round-bin scheduling method and the equal power allocation scheme, where in each time slot the base station randomly selects the users and equally allocates the transmit power among them. The optimized CBT employs the algorithm proposed in Section III. As expected, CBT has much higher gain of throughput than that of SBT because the interference coming from adjacent cells is effectively mitigated. Moreover, the performance of optimized CBT outstrips CBT significantly, which indicates the effectiveness of our proposed algorithm.

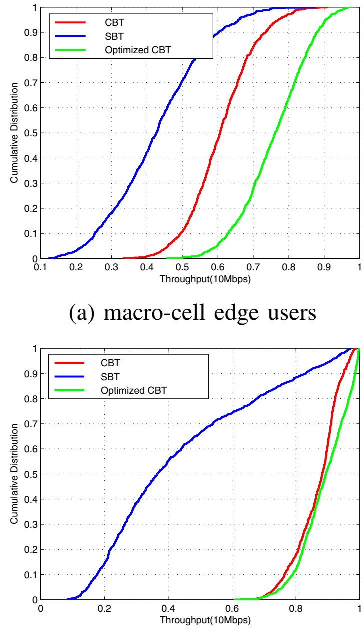
Fig. 3 compares the sum rate of cell edge users in three strategies, which shows a similar result as Fig. 2. One key observation on Fig. 3 is that the performance gaps among the



(a) macro-cell median users

(b) femto-cell median users

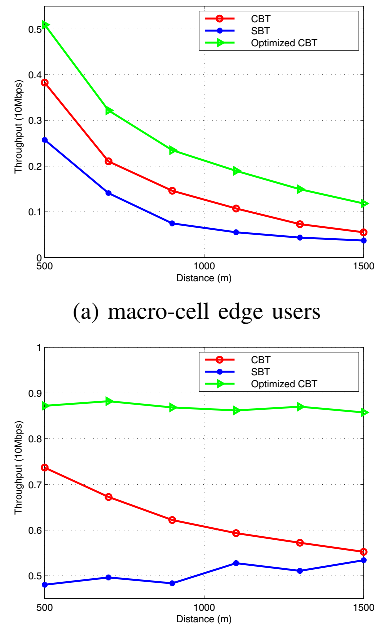
Fig. 2: CDF of downlink cell median user rate for different transmission strategy.



(a) macro-cell edge users

(b) femto-cell edge users

Fig. 3: CDF of downlink cell edge user rate for different transmission strategy.



(a) macro-cell edge users

(b) femto-cell edge users

Fig. 4: Variation of macro BS-to-BS distance.

three strategies become larger when compared to that in Fig.3. A reason is that the number of cooperative base-stations for cell edge users is more than that for cell center users. Another reason is that effectiveness of joint processing strategy is much more remarkable in the boundary region where the signal is weaker yet interference is stronger.

Fig. 4 investigates the performance of the three strategies in different sizes of macro cell, where the macro BS-to-BS distance varies from 500 to 1500 meters. Simulation result shows that total throughput of macrocell users decreases over distance in CBT, SBT and optimized CBT strategy, which results from harsh power loss of the transmission signal from macro base-stations. For femtocell users, the optimized CBT scheme performs robustness during the variation of distance. The reason is because the rate of femtocell users is mainly affected by the femto base-station other than macro base-station.

V. Conclusions

In this paper, we propose two different cooperative transmission schemes for cell center users and cell edge users in heterogeneous network. In both cases, the network utility maximization objective associated with the transmission scheme is solved by a heuristic approach. Simulation results show that the proposed optimized cooperative transmission scheme enhances the users rate effectively by reducing the other cell interference.

References

[1] S. Catreux, P. F. Driessen, and L. J. Greenstein, "Simulation results for an interference-limited multiple-input multiple-output cellular system," *IEEE Commun. Letters*, vol. 4, no. 11, pp. 334–336, Nov. 2000.

[2] V. Chandrasekhar, J. G. Andrews and A. Gatherer, "Femtocell networks: a survey," *IEEE Commun. Magazine*, pp. 59–67, Sept. 2008.

[3] Y. Bai, J. Zhou, L. Liu, L. Chen, and H. Otsuka, "Resource coordination and interference mitigation between macrocell and femtocell," in Proceedings of *IEEE Symp. Personal, Indoor and Mobile Radio Commun.*, pp. 1401–1405, Sept. 2009.

[4] H. Zhang and H. Dai, "Cochannel interference mitigation and cooperative processing in downlink multicell multiuser MIMO networks," *EURASIP J. Wirel. Commun. Netw.*, vol. 2, pp. 222–235, 2004.

[5] M. K . Karakayali, G. J. Foschini, and R. A. Valenzuela, "Network coordination for spectrally efficient communications in cellular systems," *IEEE Wireless Commun.*, pp. 56–61, Aug. 2006.

[6] D. Gesbert, S. Hanly, H. Huang, S. S. Shitz, O. Simeone and W. Yu, "Multi-cell MIMO cooperative networks: a new look at interference," *IEEE J. Select. Areas Commun.*, vol. 28, no. 9, pp. 1380–1408, Dec. 2010.

[7] J. G. Andrews, W. Choi and R. W. Heath JR., "Overcoming interference in spatial multiplexing MIMO cellular networks," *IEEE Wireless Commun.*, pp.95–104, Dec. 2007.

[8] *Qualcomm Incorporated*, "LTE advanced: heterogeneous networks," Feb. 2010.

[9] W. Choi and J. G. Andrews, "The capacity gain from intercell scheduling in multi-antenna systems," *IEEE Trans. Wireless Commun.*, vol. 7, no. 2, pp. 714–725, Feb. 2008.

[10] L. Venturino, N. Prasad, and X. Wang, "Coordinated linear beamforming in downlink multi-cell wireless networks," *IEEE Trans. Wireless Commun.*, vol. 9, no. 4, pp. 1451–1461, Apr. 2010.

[11] S. H. Ali and V. C. M. Leung, "Dynamic frequency allocation in fractional frequency reused OFDMA networks," *IEEE Trans. Wireless Commun.*, vol. 8, no. 8, pp. 4286–4295, Aug. 2009.

[12] W. Yu T. Kwon and C. Shin, "Multicell coordination via joint scheduling, beamforming and power spectrum adaptation," in Proceedings of *IEEE INFOCOM*, pp. 2570–2578, Apr. 2011.

[13] T. Yoo and A. Goldsmith, "On the optimality of multiantenna broadcast scheduling using zero-forcing beamforming," *IEEE J. Select. Areas Commun.*, vol. 24, no. 3, 528–541, Mar. 2006.