Adaptive Joint Multi-cell Reception with Uplink Power Control and Beamforming

Invited paper

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Abstract

Assuming that multiple base stations (BSs) are coordinated for the joint reception of each user's transmitted signal in the uplink, we study the sum power minimization (SP-MIN) problem for the cellular systems. As BSs may have multiple antennas, power control and receive beamforming are jointly optimized with the adaptive multi BS set (MBS) selection for each user. By doing optimization iteratively, an algorithm is proposed to find the minimum transmit power. Although the SP-Min problem is non-convex in general, it is proven that the proposed algorithm using the optimal MBS selection can converge to the optimal solution as long as it is feasible. To improve the computational efficiency of the algorithm, two simplified MBS selection schemes have been presented as well as the optimal scheme. Using the proposed algorithm with either the optimal or the simplified MBS selection schemes, a significant power efficiency improvement is obtained which is verified by the system level simulations.

Keywords: Power control, receive beamforming, coordinated multi base station reception.

I. Introduction

Due to the broadcast nature of wireless channels the received signal by each base station (BS) is the superposition of the signals from the users that simultaneously transmit on the same radio resource. For each user, the signals from other users are regarded as co-channel interference (CCI), which makes uplink transmission becoming interference-limited. In conventional cellular systems, CCI is usually reduced by power control (PC) with inter-cell coordination amongst BSs, which has been extensively studied for many years. For the uplink of code division multiple access (CDMA) systems, PC was utilized to combat with the near-far problem and satisfy a desired carrier-to-interference ratio [1]–[3]. Under a fixed user to BS assignment, several centralized or decentralized algorithms have been proposed by optimizing each user's transmit power iteratively.

The sum power minimization (SP-MIN) subject to minimum signal-to-interference-plus-noise ratio (SINR) constraint per user was studied by Yates and Huang in [4], where PC and the adaptive user to BS assignment were jointly considered. An iteration optimization algorithm was designed. They proved that for the feasible SINR constraints the problem can always be optimally solved by using the proposed algorithm. This work was extended to three implementation models in [5]. Considering the multiple antenna implementation of BSs, the SP-MIN was reformulated [6] under both fixed and adaptive user to BS assignment. An interesting result was that the joint optimization over PC and the receive beamforming with either fixed or adaptive BS assignment can still be optimally solved by using the similar iterative optimization algorithms as those in [4] as long as the problem is feasible. Later, for the downlink communications the joint PC and transmit beamforming problem was studied in [7]–[9], where the coordinated transmit beamformer design was considered by exploiting the downlink-uplink SINR duality and the semi-definite programming respectively.

We concentrate on the uplink communications with coordinated multi BS reception (CMBR) in this paper, where a joint reception across several BSs is performed on each user's transmitted signal. As BSs can have larger number of receive antennas, PC and receive beamforming is jointly considered with adaptive multi BS set (MBS) selection to minimize the transmit power. The simplest example of our problem is the one that BSs have only one receive antenna. In this case, it reduces to the diversity reception model described in [5]. With the optimal MBS selection, an iterative optimization algorithm is presented. Its optimality to solve the SP-MIN problem is proven by using the similar approach as [5] and [6]. Later for the complexity reduction purposes, two simplified MBS selection schemes are described. A significant improvement of the transmit power efficiency by using CMBR is then verified by system level simulations.

The remainder of this paper is organized as follows. In Section II, the system model and the SP-MIN problem formulation with adaptive MBS selection are introduced. The proposed iterative optimization algorithm is presented in Section III. Its global optimality and complexity are analyzed in Section IV, where two simplified MBS selection schemes are described as well. The simulation result is shown in Section V and the paper is summarized in Section VI.

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II. The Multicell System Model

The cellular system consisting of K users and B BSs is considered under the flat fading channel assumption. In our model, all users have one transmit antenna while BS i has N_i receive antennas, $N_i \geq 1$. The received signal $\mathbf{r}_i$ at the ith BS can be written as

$$\mathbf{r}_i = \sum_{k=1}^{K} \sqrt{p_k}\mathbf{h}_{k,i} s_k + \mathbf{n}_i, \tag{1}$$

where p_k is user k's transmit power, $\mathbf{h}_{k,i} \in \mathbb{C}^{N_i \times 1}$ is the complex channel vector between user k and BS i, s_k is the transmitted signal of user k with normalized power equal to 1, $\mathbf{n}_i \in \mathbb{C}^{N_i \times 1}$ is the additive white Gaussian noise (AWGN) vector at BS i with covariance σ_i^2 for each receive antenna.

With CMBR, joint beamforming over a set of chosen BSs is utilized to extract user k's signal, i.e.,

$$\begin{aligned}\hat{s}_k &= \sum_{i\in\pi_k} \mathbf{w}_{k,i}^* \mathbf{r}_i \\ &= \sum_{i\in\pi_k} \sqrt{p_k}\mathbf{w}_{k,i}^*\mathbf{h}_{k,i}s_k + \\ &\quad \sum_{i\in\pi_k}\left(\sum_{k'=1,k'\neq k}^{K} \sqrt{p_{k'}}\mathbf{w}_{k,i}^*\mathbf{h}_{k',i}s_{k'} + \mathbf{w}_{k,i}^*\mathbf{n}_i\right).\end{aligned} \tag{2}$$

where $\mathbf{w}_{k,i} \in \mathbb{C}^{N_i}$ is the receive beamformer for user k's received signal at BS i and π_k is the MBS associated to user k. Its elements are the indices of BSs jointly providing service to user k which are denoted by $\pi_k(\cdot)$.

III. SP-MIN Problem Formulation And Algorithm Derivation

A. SP-MIN Problem

Given $\mathbf{w}_{k,i}$ and π_k, the effective SINR of user k can be written as

$$\Gamma_{k,\pi_k} = \frac{\left|\sum_{i\in\pi_k}\mathbf{w}_{k,i}^*\mathbf{h}_{k,i}\right|^2 p_k}{\sum_{k'\neq k}\left|\sum_{i\in\pi_k}\mathbf{w}_{k,i}^*\mathbf{h}_{k',i}\right|^2 p_{k'} + \sum_{i\in\pi_k}\left\|\mathbf{w}_{k,i}\right\|^2\sigma_i^2}, \tag{3}$$

where $|\cdot|$ denotes the absolute value and $\|\cdot\|$ the standard Euclidean norm.

By using (3), the SP-MIN problem with adaptive MBS selection can be formulated as

$$\begin{aligned}\underset{\mathbf{w}_{k,i},\pi_k,p_k}{\text{minimize}} \quad & \sum_{k=1}^{K} p_k \\ \text{subject to} \quad & \Gamma_{k,\pi_k} \geq \gamma_k \\ & p_k \leq P_k\end{aligned}, \tag{4}$$

where γ_k and P_k are user k's minimum SINR requirement and maximum transmit power. Note that (4) is a non-convex problem in general.

When $|\pi_k|$, the cardinality of π_k, is equal to 1, (4) is exactly the same joint PC, beamforming and user to BS assignment problem studied in [6]. Hence, it can be optimally solved by using the iterative optimization algorithms proposed in [6]. On the other hand, when all $|\pi_k| = B$, (4) is reduced to the coherent receive beamforming amongst all BSs.

B. Algorithm Derivation

Based on the minimum SINR constraint of user k, we define a mapping function $m_k(\mathbf{p})$ as

$$m_k(\mathbf{p}) = \min_{\pi_k,\mathbf{w}_k} \frac{\sum_{k'\neq k}\left|\sum_{i\in\pi_k}\mathbf{w}_{k,i}^*\mathbf{h}_{k',i}\right|^2 p_{k'} + \sum_{i\in\pi_k}\left\|\mathbf{w}_{k,i}\right\|^2\sigma_i^2}{\left|\sum_{i\in\pi_k}\mathbf{w}_{k,i}^*\mathbf{h}_{k,i}\right|^2}\gamma_k , \tag{5}$$

where $\mathbf{p} = [p_1, p_2, \cdots, p_K]$ is the stacked power vector of all users, $\mathbf{w}_k$ is the stacked beamformers of user k, i.e. $[\mathbf{w}_{k,\pi_k(1)}^{\mathrm{T}}, \mathbf{w}_{k,\pi_k(2)}^{\mathrm{T}}, \cdots, \mathbf{w}_{k,\pi_k(|\pi_k|)}^{\mathrm{T}}]^{\mathrm{T}}$.

Then by defining $m(\mathbf{p})$ as a stacked vector $[m_1(\mathbf{p}), m_2(\mathbf{p}), \cdots, m_K(\mathbf{p})]$, we know that the optimal power vector $\mathbf{p}^\star$ of problem (4) must be a fixed point of the mapping function $m(\mathbf{p})$, i.e.,

$$\mathbf{p}^\star = \begin{bmatrix} p_1^\star \\ p_2^\star \\ \vdots \\ p_K^\star \end{bmatrix} = \begin{bmatrix} m_1(\mathbf{p}^\star) \\ m_2(\mathbf{p}^\star) \\ \vdots \\ m_K(\mathbf{p}^\star) \end{bmatrix} = m(\mathbf{p}^\star) , \tag{6}$$

as long as the problem is feasible. This is evident because the SINR constraint determines that $p_k^\star \geq m_k(\mathbf{p}^\star)$. If the equality does not hold, for example, for user 1, we can always find another feasible vector

$$\mathbf{p}^{\star\star} = \begin{bmatrix} p_1^{\star\star} \\ p_2^{\star\star} \\ \vdots \\ p_K^{\star\star} \end{bmatrix} = \begin{bmatrix} m_1(\mathbf{p}^\star) \\ p_2^\star \\ \vdots \\ p_K^\star \end{bmatrix} , \tag{7}$$

As the sum of $\mathbf{p}^{\star\star}$ is smaller than that of $\mathbf{p}^\star$, this conflicts with the assumption that $\mathbf{p}^\star$ is the optimum. Therefore the equality must hold and $\mathbf{p}^\star$ is a fixed point of $m(\cdot)$.

For the defined mapping function $m(\cdot)$, the following lemma holds.

Lemma 1: The fixed point of the mapping function $m(\cdot)$ is unique.

Proof: Following the approach in [6], we assume that there are two different fixed points $\mathbf{p}^{\star,1}$ and $\mathbf{p}^{\star,2}$. $\mathbf{p}^{\star,1}$ and $\mathbf{p}^{\star,2}$ are also positive as the SINR constraint $\gamma_k > 0$. Without loss of the generality, we also assume that $\mathbf{p}^{\star,1}$ has at least one element larger than $\mathbf{p}^{\star,2}$. Thus, we must be able to find an index

$$l = \arg\max_{k=1,\cdots,K} p_k^{\star,1}/p_k^{\star,2} \tag{8}$$

and a scalar $\alpha = p_l^{\star,1}/p_l^{\star,2} > 1$. Then, we can construct a new vector $\alpha\mathbf{p}^{\star,2}$, where $\alpha p_l^{\star,2} = p_l^{\star,1}$ and $\alpha p_k^{\star,2} \geq p_k^{\star,1}$ for $k \neq l$.

However, for $p_l^{\star,1}$ we also have

$$
\begin{aligned}
p_l^{\star,1} &= m_l(\mathbf{p}^{\star,1}) \\
&= \min_{\pi_l,\mathbf{w}_l} \frac{\sum\limits_{k'\neq l}\big|\sum\limits_{i\in\pi_l}\mathbf{w}_{l,i}^{*}\mathbf{h}_{k',i}\big|^2 p_{k'}^{\star,1} + \sum\limits_{i\in\pi_l}\big\|\mathbf{w}_{l,i}\big\|^2\sigma_i^2}{\big|\sum\limits_{i\in\pi_l}\mathbf{w}_{l,i}^{*}\mathbf{h}_{l,i}\big|^2}\gamma_l \\
&< \min_{\pi_l,\mathbf{w}_l} \frac{\sum\limits_{k'\neq l}\big|\sum\limits_{i\in\pi_l}\mathbf{w}_{l,i}^{*}\mathbf{h}_{k',i}\big|^2 \alpha p_{k'}^{\star,2} + \sum\limits_{i\in\pi_l}\big\|\mathbf{w}_{l,i}\big\|^2\alpha\sigma_i^2}{\big|\sum\limits_{i\in\pi_l}\mathbf{w}_{l,i}^{*}\mathbf{h}_{l,i}\big|^2}\gamma_l \\
&= \min_{\pi_l,\mathbf{w}_l} \alpha\frac{\sum\limits_{k'\neq l}\big|\sum\limits_{i\in\pi_l}\mathbf{w}_{l,i}^{*}\mathbf{h}_{k',i}\big|^2 p_{k'}^{\star,2} + \sum\limits_{i\in\pi_l}\big\|\mathbf{w}_{l,i}\big\|^2\sigma_i^2}{\big|\sum\limits_{i\in\pi_l}\mathbf{w}_{l,i}^{*}\mathbf{h}_{l,i}\big|^2}\gamma_l \\
&= \alpha m_l(\mathbf{p}^{\star,2}) = \alpha p_l^{\star,2}.
\end{aligned}
\tag{9}
$$

The inequality in (9) is from the fact that all coefficients are positive and $\alpha > 1$. As this comes into conflict with the fact that $p_l^{\star,1} = \alpha p_l^{\star,2}$, the fixed point must be unique. The proof completes. ■

By using the mapping function $m(\cdot)$, we can design an iterative optimization algorithm accordingly, which is summarized in *Algorithm 1.*

Algorithm 1 Joint PC and Receive Beamforming with Adaptive MBS Selection.

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1) Initialization: Set the iteration index $t = 0$. Set $\tilde{p}_k^{[0]} = 0\ \forall\ k$.
2) Set $t = t + 1$, for each MS k
   a) Calculate $\{\mathbf{w}_{k,\pi_k(1)}, \mathbf{w}_{k,\pi_k(2)}, \cdots, \mathbf{w}_{k,\pi_k(|\pi_k|)}\}$ for all possible MBS sets π_k by using (10).
   b) Given the beamforming vectors for each possible π_k, compute p_{k,π_k} under SINR constraint γ_k as

$$
p_{k,\pi_k} = \frac{\sum\limits_{k'\neq k}\big|\sum\limits_{i\in\pi_k}\mathbf{w}_{k,i}^{*}\mathbf{h}_{k',i}\big|^2 \tilde{p}_{k'}^{[t-1]} + \sum\limits_{i\in\pi_k}\big\|\mathbf{w}_{k,i}\big\|^2\sigma_i^2}{\big|\sum\limits_{i\in\pi_k}\mathbf{w}_{\mathbf{k},\mathbf{i}}^{*}\mathbf{h}_{k,i}\big|} \quad k
$$

   c) Select $\tilde{\pi}_k^{[t]}$ that requires the least transmit power

$$
\tilde{\pi}_k^{[t]} = \arg\min_{\pi_k} p_{k,\pi_k}
$$

   d) Update $\{\tilde{\mathbf{w}}_{k,\tilde{\pi}_k^{[t]}(1)}^{[t]}, \tilde{\mathbf{w}}_{k,\tilde{\pi}_k^{[t]}(2)}^{[t]}, \cdots, \tilde{\mathbf{w}}_{k,\tilde{\pi}_k^{[t]}(|\tilde{\pi}_k^{[t]}|)}\}$ and $\tilde{p}_k^{[t]}$ accordingly.

$$
\begin{aligned}
&\{\tilde{\mathbf{w}}_{k,\tilde{\pi}_k^{[t]}(1)}^{[t]}, \tilde{\mathbf{w}}_{k,\tilde{\pi}_k^{[t]}(2)}^{[t]}, \cdots, \tilde{\mathbf{w}}_{k,\tilde{\pi}_k^{[t]}(|\tilde{\pi}_k^{[t]}|)}\} = \\
&\{\mathbf{w}_{k,\tilde{\pi}_k^{[t]}(1)}, \mathbf{w}_{k,\tilde{\pi}_k^{[t]}(2)}, \cdots, \mathbf{w}_{k,\tilde{\pi}_k^{[t]}(|\tilde{\pi}_k|)}\} \\
&\tilde{p}_k^{[t]} = p_{k,\tilde{\pi}_k^{[t]}}
\end{aligned}
$$

   e) If any $\tilde{p}_k^{[t]} > P_k$, stop iterations since the SINR constraints are infeasible.
3) If the difference between $\sum_{i=1}^{K}\tilde{p}_k^{[t]}$ and $\sum_{i=1}^{K}\tilde{p}_k^{[t-1]}$ less than a threshold ϵ, e.g. $1e$-6, stop and output the result. Otherwise go to step 2).

IV. Convergence Analysis and Complexity Discussion

A. Convergence Analysis

First we define another mapping function $m_k^{\mathbf{w}_k}(\mathbf{p})$ as

$$
m_k^{\mathbf{w}_k}(\mathbf{p}) = \min_{\pi_k} \frac{\sum\limits_{k'\neq k}\big|\sum\limits_{i\in\pi_k}\mathbf{w}_{k,i}^{*}\mathbf{h}_{k',i}\big|^2 p_{k'} + \sum\limits_{i\in\pi_k}\big\|\mathbf{w}_{k,i}\big\|^2\sigma_i^2}{\big|\sum\limits_{i\in\pi_k}\mathbf{w}_{k,i}^{*}\mathbf{h}_{k,i}\big|^2}\gamma_k\ ,
\tag{11}
$$

where the stacked beamformers $\mathbf{w}_k$ of user k is fixed. Then following the approach in [6], we give another lemma as follows.

Lemma 2: If $\mathbf{p}'$ is element-wise no larger than $\mathbf{p}''$, denoted by $\mathbf{p}^1 \preceq \mathbf{p}^2$, the following inequalities hold:

$$
\begin{aligned}
&\text{(a)}\quad m_k(\mathbf{p}') &&\le m_k^{\mathbf{w}_k}(\mathbf{p}'), &&\forall\ \mathbf{w}_k, k \\
&\text{(b)}\quad m_k^{\mathbf{w}_k}(\mathbf{p}') &&\le m_k^{\mathbf{w}_k}(\mathbf{p}''), &&\forall\ \mathbf{w}_k, k \\
&\text{(c)}\quad m_k(\mathbf{p}') &&\le m_k(\mathbf{p}''), &&\forall\ k
\end{aligned}
\tag{12}
$$

Proof: (12.a) obviously holds since $m_k(\cdot)$ does the minimization over all possible π_k and $\mathbf{w}_k$ while $m_k^{\mathbf{w}_k}(\cdot)$ does minimization over π_k only. (12.b) also holds because of the fact that all the coefficients of $m_k^{\mathbf{w}_k}(\cdot)$ are positive. Define $\pi_k^\star$ and $\mathbf{w}_k^\star$ as the optimal solutions that

$$
\{\pi_k^\star, \mathbf{w}_k^\star\} = \arg\min_{\pi_k,\mathbf{w}_k} \frac{\sum\limits_{k'\neq k}\big|\sum\limits_{i\in\pi_k}\mathbf{w}_{k,i}^{*}\mathbf{h}_{k',i}\big|^2 p_{k'}'' + \sum\limits_{i\in\pi_k}\big\|\mathbf{w}_{k,i}\big\|^2\sigma_i^2}{\big|\sum\limits_{i\in\pi_k}\mathbf{w}_{k,i}^{*}\mathbf{h}_{k,i}\big|^2}\gamma_k.
$$

Obviously, $m_k(\mathbf{p}'') = m_k^{\mathbf{w}_k^\star}(\mathbf{p}'')$. Then by using (12.a) and (12.b), we have

$$
m_k(\mathbf{p}'') = m_k^{\mathbf{w}_k^\star}(\mathbf{p}'') \ge m_k^{\mathbf{w}_k^\star}(\mathbf{p}') \ge m_k(\mathbf{p}').
$$

The proof completes. ■

In fact, lemma 2 tells us the monotonicity of $m(\cdot)$. Moreover, because of the coefficients of $m(\cdot)$ being positive, the positivity and scalability properties hold also, i.e.,

$$
\begin{aligned}
&\mathbf{0} \preceq m(\mathbf{p}) \\
&m(\alpha\mathbf{p}) \preceq \alpha m(\mathbf{p}), \quad \alpha > 1
\end{aligned}
\tag{13}
$$

Therefore, $m(\cdot)$ also has the three properties of a standard interference function and the following theorem holds.

Theorem 1: For any initial power vector $\hat{\mathbf{p}}^{[0]}$, the iterative optimization algorithm based on the mapping function $m(\cdot)$ converges to the optimal solution $\mathbf{p}^\star$, as long as problem (4) is feasible.

Proof: A similar proof based on the standard interference function as [5] and [6] can be utilized, which is summarized as follows.

First, because of the monotonicity property, the algorithm will monotonically decrease to the fixed point provided the initial power vector $\hat{\mathbf{p}}^{[0]}$ is a feasible solution. On the other hand, the algorithm will monotonically increase to the fixed point if $\hat{\mathbf{p}}^{[0]}$ is zero. According to lemma 1, in both cases the algorithm will converge to $\mathbf{p}^\star$.

$$\begin{bmatrix} \mathbf{w}_{k,\pi_k(1)}^{[t]} \\ \vdots \\ \mathbf{w}_{k,\pi_k(|\pi_k|)}^{[t]} \end{bmatrix} = \arg\max_{\mathbf{w}_{k,i}} \frac{|\sum_{i\in\pi_k} \mathbf{w}_{k,i}^{*}\mathbf{h}_{k,i}|^2 \tilde{p}_k^{[t-1]}}{\sum_{k'\neq k} |\sum_{i\in\pi_k} \mathbf{w}_{k,i}^{*}\mathbf{h}_{k',i}|^2 \tilde{p}_{k'}^{[t-1]} + \sum_{i\in\pi_k} \|\mathbf{w}_{k,i}\|^2 \sigma_i^2}$$
$$= \left(\sum_{k'\neq k} p_{k'}^{[t-1]} \begin{bmatrix} \mathbf{h}_{k',\pi_k(1)} \\ \vdots \\ \mathbf{h}_{k',\pi_k(|\pi_k|)} \end{bmatrix} \left[\mathbf{h}_{k',\pi_k(1)}^{*} \cdots \mathbf{h}_{k',\pi_k(|\pi_k|)}^{*}\right] + \begin{bmatrix} \sigma_{\pi_k(1)}\mathbf{I} & & \\ & \ddots & \\ & & \sigma_{\pi_k(|\pi_k|)}\mathbf{I} \end{bmatrix} \right)^{-1} \begin{bmatrix} \mathbf{h}_{k,\pi_k(1)} \\ \vdots \\ \mathbf{h}_{k,\pi_k(|\pi_k|)} \end{bmatrix} \quad (10)$$

Second, for any $\hat{\mathbf{p}}^{[0]}$ we can always find a scalar $\alpha > 1$ satisfying $\hat{\mathbf{p}}^{[0]} \prec \alpha\mathbf{p}^{\star}$, where the operator $\prec$ denotes the element-wise smaller as well. Using the scalability property it is known that $\alpha\mathbf{p}^{\star}$ must be a feasible solution. Since $\mathbf{0} \prec \hat{\mathbf{p}}^{[0]} \prec \alpha\mathbf{p}^{\star}$, again using the monotonicity we have $m^{[t]}(\mathbf{0}) \prec m^{[t]}(\hat{\mathbf{p}}^{[0]}) \prec m^{[t]}(\alpha\mathbf{p}^{\star})$ for $t = 1, 2$, and so on. As $m^{[t]}(\mathbf{0})$ and $m^{[t]}(\alpha\mathbf{p}^{\star})$ both converge to $\mathbf{p}^{\star}$, $m^{[t]}(\hat{\mathbf{p}}^{[0]})$ must converge to $\mathbf{p}^{\star}$ as well. Our proof completes. ■

B. Complexity Discussion And Simplified MBS Selection

Obviously, a larger size π_k achieves better performance by using Algorithm 1. But for each user k the optimal MBS selection is done by an exhaustive search over all possible π_k at each iteration. The larger size π_k (when $|\pi_k| < B/2$) also implies the significant higher complexity due to the user-wise exhaustive search. In order to limit the complexity under an acceptable level, we provide two simplified MBS selection schemes to improve the computational efficiency.

Simplified MBS selection scheme 1. In this scheme, π_k is determined by a central controller based on the BSs' large scale fading factors for user k. Those factors can be obtained by feedbacking the received signal strength (RSS) values of each user and the BSs having the $|\pi_k|$ least large scale fading factors will be selected.

Simplified MBS selection scheme 2. In the second scheme, a more flexible setting can be considered. We first pre-select R BSs also based on the RSS values, $|\pi_k| \leq R \leq B$. Then, we run Algorithm 1 but limit the adaptive MBS selection over those R BSs instead of all BSs. By doing so, a better tradeoff between the complexity and the performance can be achieved.

As a result, using the simplified MBS selection schemes will degrade the performance. However the complexity can be significantly reduced.

V. Simulation Results

The proposed algorithm with different sizes of π_k is evaluated by the system level simulations. In the simulation, we consider a cellular system containing 19 BSs with 3 sectors per BS, so 57 sectors in total. As shown in Fig. 1, the central 57 sectors are the original sectors while the outer sectors are the copies of the central sectors. The edge effect is then approximated by wrapping around the network [10]. Other simulation parameters are listed in Table I.

To simplify the simulation, we set the same size $|\pi_k|$ to each user. The cumulative distribution functions (CDF) of the minimum sum transmit power of users are obtained by using the proposed algorithm with $|\pi_k|$ equal to 1, 2 and 3, respectively. Besides the optimal MBS selection, two simplified MBS selection schemes are compared as well. The results are averaged over 300 different user location drops. In all comparisons, we denote the algorithm using the optimal MBS selection by Alg2 while the others using simplified MBS selections by Alg1 and Alg3 respectively. In Alg3, we set

TABLE I
SIMULATION PARAMETERS.

Parameters	Value
Layout	19 cells, 3 sectors/cell - wrap around
Propagation scenario	Base coverage urban
Cell radius	1000 m
Maximum MS transmit power	24 dBm
Maximum antenna gain	17 dBi
Thermal noise density	−174 dBm/Hz
Number of users	30 in 19 cells
BS receiver antenna array	ULA
BS receiver antenna elements	2
UE antenna	1
Number of BSs for coordinate reception	1, 2, 3
SINR constraint per MS	4, 8 dB
MS speed	3km/h
Shadow fading	Log-Normal, 8 dB standard deviation
Shadowing correlation	independent
Down tilt angle	8 degree

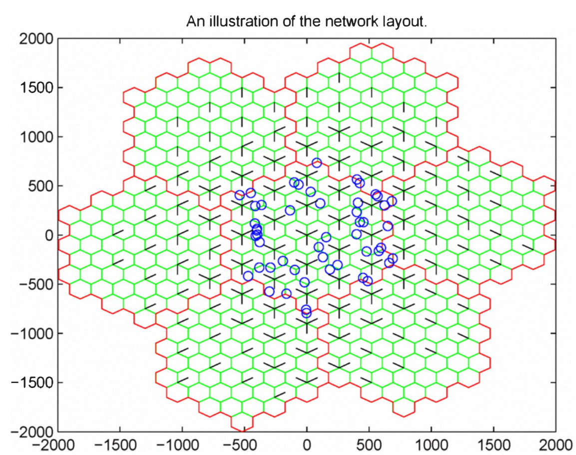

Fig. 1. An illustration of the wrap-around multicell multiuser network layout.

$R = 4$ in simulations.

Firstly, the feasibilities of the alternative schemes with different sizes of π_k are compared. Fig. 2 gives the results where the SINR constraint per user is 4 dB. When increasing the number of users from 10 to 110, Compared with the case without CMBR at all, using the adaptive CMBR obtains a significant improvement and Alg2 shows more feasibility improvement than Alg1 and Alg3. For example when $|\pi_k| = 3$, Alg2 can achieve almost 95% feasibility to support 50 users simultaneously communicating with BSs while Alg1 40% and Alg2 85%. It is also noticed that the gap between Alg1 and Alg2 is much more significant than that between Alg2 and Alg3. Hence from the viewpoint of the tradeoff between the complexity and performance, Alg3 is of great interest for practical implementations. The feasibility performance with 8 dB SINR constraint per user is shown in Fig. 3. The similar findings can be found therein.

In the second comparison, 30 users are uniformly distributed over the whole area of interest in Fig. 1. When setting the SINR constraint per user to 4 dB, the average transmit power of users are compared as shown in Fig. 4. In this comparison, only the powers obtained under the feasible channel realizations are counted. The adaptive CMBR also shows significant reduction of the sum transmit power. The larger the size of π_k the smaller user transmit powers are achieved. Due to the simplified MBS selection, both Alg1 and Alg3 suffers performance degradation but the gaps between the alternative schemes reduce when $|\pi_k|$ is increased. Compared with Alg1, Alg3 works much better. It provides very close performance to Alg2, the optimal MBS selection, while its complexity is only a little larger than Alg1, the simplest MBS selection. Conclusively, Alg3 may be a good option from the performance to complexity tradeoff viewpoint. Similar results are presented in Fig. 5 with 8 dB SINR constraint per user.

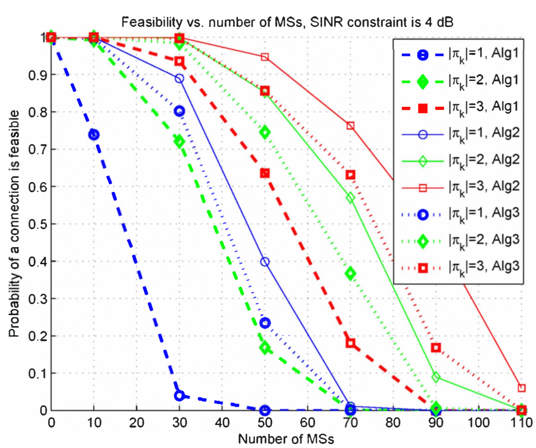

Fig. 2. Comparison of probability of feasible connections of different number of MSs with the SINR constraint of 4 dB

VI. Conclusion

Joint PC, receive beamforming with adaptive MBS selection for uplink communications is studied. An iterative optimization algorithm is provided to solve the SP-MIN problem. As long as the problem is feasible, we prove that the proposed algorithm must converge to the optimal power allocation vector. As the optimal MBS selection involves the exhaustive search over all MBS candidates per user, two simplified MBS selection schemes are presented as well. The proposed algorithm with both optimal and simplified MBS selection schemes is evaluated by the system level simulations. The results show that by using the optimal MBS selection the largest improvement can be obtained while by using the simplified versions we can tradeoff the complexity and performance for practical implementations.

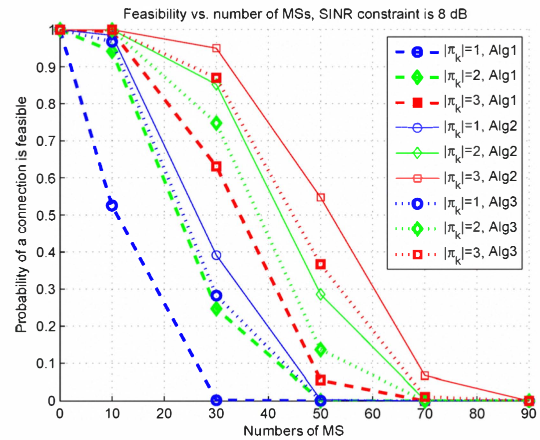

Fig. 3. Comparison of probability of feasible connections of different number of MSs with the SINR constraint of 8 dB

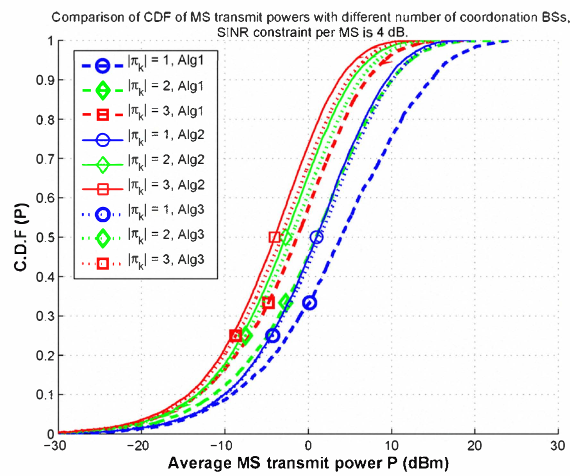

Fig. 4. Comparison of CDF of transmit power of different number of coordination BSs of fixed and CMBR algorithm with the SINR constraint of 4 dB.

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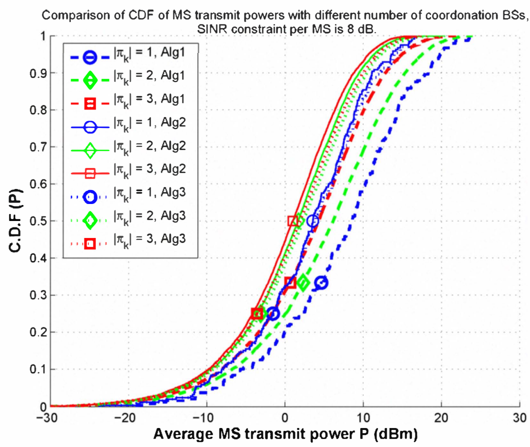

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