Shadowing Time-Scale Admission and Power Control for Small Cell Networks

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Abstract—**Small cell networks are widely considered as an efficient low-cost solution to enhance the coverage and capacity of cellular layers on top of being environmentally friendly due to their low energy consumption. However, due to their aggressive spectrum reuse, it is important to properly control interference in such networks before deploying them on a large-scale basis. In this paper, we investigate the joint admission and power control problem in two-tier small cell networks. We aim to maximize the number of small cell users that can be admitted at their desired quality-of-service (QoS) without violating the macrocell users' QoS. However, it can be computationally challenging to perform adaptation at the fast fading time-scale. It also requires substantial signaling overhead due to feedback of channel state information. Therefore, we propose a joint admission and power control method where the QoS metric used is outage constraint so that the algorithm can adapt at a much slower log-normal shadowing time-scale. Even though this joint admission and power control problem is NP-hard, convex relaxation can be used to obtain high quality approximate solutions that demonstrate near optimal performance.**

I. INTRODUCTION

The surging demand for internet-enabled wireless devices and bandwidth-hungry multimedia services have necessitated the need to exploit spectral resources as optimally as possible. Furthermore, the ever-increasing number of wireless users, the relentless demand for higher data rates, and the widespread usage of complex, spectrum efficient techniques to support high data volumes have led to rapidly increasing power consumption [1]. In order to ensure the sustainability of our world, future communication infrastructures need to tackle the energy consumption and electromagnetic pollution problems which draw attention to the need for green cellular networks.

One approach to green cellular network design is to overlay a macrocell network with many small cells [2]. An example of a small cell is the femtocell which is generating a lot of interest in the cellular network industry. A small cell is enabled by a small cell access point (SAP) which is a short range, low cost, and low power user-deployed base station. The SAP is connected to the cellular network by a backhaul, e.g., digital subscriber line, cable modem, or an available radio frequency channel. With the use of small cells, users can receive better indoor reception and decrease power consumption due to the low transmit powers. From the point of view of network operators, besides the very little upfront cost, SAPs can help to offload data traffic from the expensive macrocell network via backhaul links and hence, enhance the overall network coverage and capacity. However, one of the major challenges that impedes the massive deployment of small cells is the incursion of inter-tier interference due to aggressive frequency reuse, which can deteriorate the effectiveness of two-tier small cell networks.

Thus, there has been a lot of research on inter-tier and intra-tier interference management for two-tier small cell networks [3]–[13]. In [3], the authors proposed a spectrum partitioning approach to avoid the inter-tier interference between the macrocell and small cell tiers using orthogonal spectrum allocation. Evidently, under a sparse small cell deployment setting, this method is inefficient and much higher area spectrum efficiency can be achieved by spectrum sharing [4]. However, for spectrum sharing in two-tier small cell networks, it becomes important to properly manage the inter-tier interference by using techniques such as access control [4], [5], power control [6]–[8], multiple antennas [9], [10], or cognitive radio [11]–[13]. Since all these interference management schemes require certain amount of processing and signaling overhead, if the set of active small cells changes at the fast fading time-scale, there will be very frequent signaling and updating between the macrocell base station (MBS) and the SAPs which can lead to excessive power consumption. Hence, this motivates us to design an interference management method with admission control that tracks at a much slower shadowing time-scale.

An essential traffic management mechanism is admission control whereby new users are admitted only when there are adequate spectrum resources and that quality-of-service (QoS) constraints of existing users are not violated. There are many works that incorporate admission control with interference management where multiple users share the wireless communication medium [14]–[16]. A two phase algorithm is proposed for a single-tier network in [14] which alternates between admission control and power control until the users attain their desired signal-to-interference-plus-noise ratios (SINRs). In particular, [15], [16] proposes an elegant one-stage joint admission and power control framework, where the QoS constraints of the users are instantaneous SINR constraints. The limitation of these works are that they assume that perfect channel state information (CSI) is always available at the network controller and/or the admission and interference management algorithms can update at the fast fading time-scale. However, the computational and signalling load of these algorithms which follow at fast-fading time-scale can be very

high.

In this paper, we consider a two-tier small cell network, where small cell users share the same spectrum with the macrocell user. We assume that the macrocell user has a higher priority than the small cell users in accessing the spectrum and its QoS requirement must not be compromised. The small cell users can share the residual spectrum as long as their minimum QoS can be met. This motivates us to investigate the joint admission and power control problem that aims to maximize the number of small cells admitted at their desired QoS and simultaneously minimize their total transmission power, while guaranteeing the QoS of the macrocell user. Different from conventional works, the QoS constraints chosen for the macrocell and small cell users are outage constraints, which take into account the statistical fluctuations in their SINRs due to Rayleigh fading. Such outage constraints allow the admission and power updating to be performed on a much slower time-scale of log-normal shadowing instead of the time-scale of Rayleigh fading. As this formulation is NP-hard, convex relaxation is applied to obtain high quality approximate solutions that exhibit near optimal performance. Extensive simulation results show the effectiveness of our proposed algorithm to determine high quality approximate solutions.
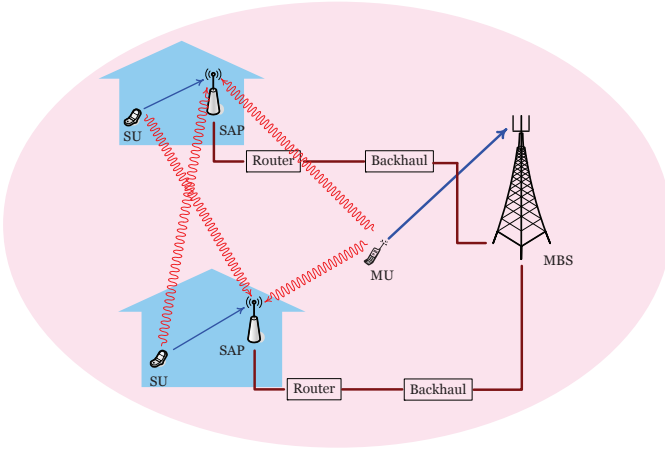
II. SYSTEM MODEL AND PROBLEM FORMULATION

Fig. 1. Two-tier network where a macrocell network is overlaid with small cells. The blue lines indicate the desired links while the red wavy lines indicates inter-tier and intra-tier interfering links.

As shown in Fig. 1, we consider an uplink two-tier network where a macrocell network is overlaid with N small cells. We consider a closed-access scheme. The MBS and the SAPs are operating in a common frequency band with one macrocell user[1] (MU) and N small cell users (SUs). We assume that there is one SU in each small cell requesting to share the spectrum with the MU in order to communicate with its SAP.

[1] A single MU is considered for brevity of exposition. More QoS constraints can be added to include multiple MUs; the structure of the proposed problem is not changed.

Therefore, the received SINR of the ith SU can be written as

$$\mathsf{SINR}_i^\mathrm{s} = \frac{G_{ii}^\mathrm{ss} F_{ii}^\mathrm{ss} P_i^\mathrm{s}}{\sum_{l=1,l\neq i}^N G_{il}^\mathrm{ss} F_{il}^\mathrm{ss} P_l^\mathrm{s} + G_{i0}^\mathrm{sm} F_{i0}^\mathrm{sm} P^\mathrm{m} + N_o} \quad (1)$$

where G_{il}^ss and F_{il}^ss denote the slow and fast fading gains from the lth SU to the ith SAP, respectively. In the following, we consider the slow fading gain to include the effect of propagation path loss and shadowing, and the fast fading gain is modeled as exponential power fading which corresponds to Rayleigh fading assumption. Similarly, G_{i0}^sm and F_{i0}^sm refers to the slow and fast fading gains from the MU (assigned index "0") to the ith SAP, respectively. The transmit power of the lth SU is P_l^s, the transmit power of the MU is P^m, which is assumed to be fixed as the MU does not cooperate with the SUs, and the noise power is N_o. With the Rayleigh fading assumption on the fast fading gains, F_{ij}^kl are independent exponentially distributed random variables with unit mean. Thus, the outage constraint of the ith SU is given by [8]

$$\Pr(\mathsf{SINR}_i^\mathrm{s} \leq \gamma_i^\mathrm{s,th}) \leq \rho_i^\mathrm{s,th}$$

$$\Rightarrow 1 - \exp(-\frac{\gamma_i^\mathrm{s,th} N_o}{G_{ii}^\mathrm{ss} P_i^\mathrm{s}})$$

$$\prod_{l\neq i}^N \left(1 + \frac{\gamma_i^\mathrm{s,th} G_{il}^\mathrm{ss} P_l^\mathrm{s}}{G_{ii}^\mathrm{ss} P_i^\mathrm{s}}\right)^{-1} \left(1 + \frac{\gamma_i^\mathrm{s,th} G_{i0}^\mathrm{sm} P^\mathrm{m}}{G_{ii}^\mathrm{ss} P_i^\mathrm{s}}\right)^{-1} \leq \rho_i^\mathrm{s,th}$$

$$\Rightarrow \frac{\gamma_i^\mathrm{s,th} N_o}{G_{ii}^\mathrm{ss} P_i^\mathrm{s}} + \sum_{l=1,l\neq i}^N \ln(1 + \frac{\gamma_i^\mathrm{s,th} G_{il}^\mathrm{ss} P_l^\mathrm{s}}{G_{ii}^\mathrm{ss} P_i^\mathrm{s}})$$

$$+ \ln(1 + \frac{\gamma_i^\mathrm{s,th} G_{i0}^\mathrm{sm} P^\mathrm{m}}{G_{ii}^\mathrm{ss} P_i^\mathrm{s}}) \leq -\ln(1 - \rho_i^\mathrm{s,th})$$

$$\Rightarrow \frac{b_i^\mathrm{s} N_o}{P_i^\mathrm{s}} + \sum_{l=1,l\neq i}^N \ln(1 + \frac{b_i^\mathrm{s} G_{il}^\mathrm{ss} P_l^\mathrm{s}}{P_i^\mathrm{s}})$$

$$+ \ln(1 + \frac{b_i^\mathrm{s} G_{i0}^\mathrm{sm} P^\mathrm{m}}{P_i^\mathrm{s}}) \leq -\ln(1 - \rho_i^\mathrm{s,th}) \quad (2)$$

where $\gamma_i^\mathrm{s,th}$ and $\rho_i^\mathrm{s,th}$ denote the pre-specified SINR threshold and outage probability threshold of the ith SU, respectively, and for notational convenience, $b_i^\mathrm{s} \triangleq \gamma_i^\mathrm{s,th}/G_{ii}^\mathrm{ss}$.

When SUs are operating, the received SINR of the MU is

$$\mathsf{SINR}^\mathrm{m} = \frac{G_{M0}^\mathrm{mm} F_{M0}^\mathrm{mm} P^\mathrm{m}}{\sum_{i=1}^N G_{Mi}^\mathrm{ms} F_{Mi}^\mathrm{ms} P_i^\mathrm{s} + N_o} \quad (3)$$

where G_{M0}^mm and F_{M0}^mm are the slow and fast fading gains from the MU to the MBS and G_{Mi}^ms and F_{Mi}^ms are the slow and fast fading gains from the ith SU to the MBS. The outage constraint of the MU is then given by

$$\Pr(\mathsf{SINR}^\mathrm{m} \leq \gamma^\mathrm{m,th}) \leq \rho^\mathrm{m,th}$$

$$\Rightarrow 1 - \exp(-\frac{\gamma^\mathrm{m,th} N_o}{G_{M0}^\mathrm{mm} P^\mathrm{m}}) \prod_{i=1}^N \left(1 + \frac{\gamma^\mathrm{m,th} G_{Mi}^\mathrm{ms} P_i^\mathrm{s}}{G_{M0}^\mathrm{mm} P^\mathrm{m}}\right)^{-1} \leq \rho^\mathrm{m,th}$$

$$\Rightarrow \sum_{i=1}^N \ln(1 + b_{Mi}^\mathrm{ms} P_i^\mathrm{s}) \leq \ln \mu^\mathrm{m} \quad (4)$$

where $\rho^{\mathrm{m,th}}$ is the pre-specified outage probability threshold of the MU, $\mu^{\mathrm{m}} = (1 - \bar{\rho}^{\mathrm{m}})/(1 - \rho^{\mathrm{m,th}})$, $\bar{\rho}^{\mathrm{m}}$ is the outage probability of the MU in the absence of SUs, and for notational convenience, $b_{\mathrm{M}i}^{\mathrm{ms}} \triangleq (\gamma^{\mathrm{m,th}} G_{\mathrm{M}i}^{\mathrm{ms}})/(G_{\mathrm{M0}}^{\mathrm{mm}} P^{\mathrm{m}})$.

The objective of this work is to maximize the number of SUs that can be admitted with a guaranteed QoS while guaranteeing the QoS of the MU and simultaneously minimize their total transmission power. In this paper, the QoS provided to the MU as well as the SUs is outage probability constraint. The problem of interest can be separated into two stages. In the first stage, we want to maximize the number of admitted SUs such that their QoS and that of the MU can be ensured. Mathematically, this problem can be formulated as follows:

$$\max_{\mathcal{S} \subseteq \{1,\cdots,N\}} \quad |\mathcal{S}| \tag{5}$$

$$\text{s.t.} \quad 0 \le P_i^{\mathrm{s}} \le P^{\mathrm{s,max}}, \qquad \forall i \in \mathcal{S}$$

$$\frac{b_i^{\mathrm{s}} N_o}{P_i^{\mathrm{s}}} + \sum_{l \ne i, l \in \mathcal{S}} \ln(1 + \frac{b_i^{\mathrm{s}} G_{il}^{\mathrm{ss}} P_l^{\mathrm{s}}}{P_i^{\mathrm{s}}})$$

$$+ \ln(1 + \frac{b_i^{\mathrm{s}} G_{i0}^{\mathrm{sm}} P^{\mathrm{m}}}{P_i^{\mathrm{s}}}) \le -\ln(1 - \rho_i^{\mathrm{s,th}}), \ \forall i \in \mathcal{S}$$

$$\sum_{i \in \mathcal{S}} \ln(1 + b_{\mathrm{M}i}^{\mathrm{ms}} P_i^{\mathrm{s}}) \le \ln \mu^{\mathrm{m}}$$

where $|\cdot|$ denotes the cardinality, $\mathcal{S} \subseteq \{1, \cdots, N\}$ is the set of the total number of requesting SUs, and $P^{\mathrm{s,max}}$ is the maximum transmit power of each SU. In the second stage, we want to minimize the total transmit power of the SUs in $\tilde{\mathcal{S}}$ that are admitted in the first stage, where $\tilde{\mathcal{S}}$ is the solution of (5), while maintaining the QoS of the MU and the admitted SUs. This problem can be cast as follows:

$$\min_{P_i^{\mathrm{s}}} \quad \sum_{i \in \tilde{\mathcal{S}}} P_i^{\mathrm{s}} \tag{6}$$

$$\text{s.t.} \quad 0 \le P_i^{\mathrm{s}} \le P^{\mathrm{s,max}}, \qquad \forall i \in \tilde{\mathcal{S}}$$

$$\frac{b_i^{\mathrm{s}} N_o}{P_i^{\mathrm{s}}} + \sum_{l \ne i, l \in \tilde{\mathcal{S}}} \ln(1 + \frac{b_i^{\mathrm{s}} G_{il}^{\mathrm{ss}} P_l^{\mathrm{s}}}{P_i^{\mathrm{s}}})$$

$$+ \ln(1 + \frac{b_i^{\mathrm{s}} G_{i0}^{\mathrm{sm}} P^{\mathrm{m}}}{P_i^{\mathrm{s}}}) \le -\ln(1 - \rho_i^{\mathrm{s,th}}), \ \forall i \in \tilde{\mathcal{S}}$$

$$\sum_{i \in \tilde{\mathcal{S}}} \ln(1 + b_{\mathrm{M}i}^{\mathrm{ms}} P_i^{\mathrm{s}}) \le \ln \mu^{\mathrm{m}}$$

where the optimization problem in (6) can be reformulated into a geometric program (GP) in convex form, hence it can be solved globally and efficiently using interior point method. However, the combinatorial problem (5) is NP-hard to solve.

Following the approach in [15], we can provide a compact and elegant single-stage framework that is equivalent to the two-stage formulation (5)-(6). The advantages of a single-stage reformulation are that it helps to reveal the non-convexity components of the problem and it allows convenient convex relaxation which can produce high quality approximate solutions efficiently as we will show in Section IV. Different from [15] which constrains the instantaneous SINRs of the SUs, the proposed formulation constrains the outage probabilities of the MU and SUs. Consequently, the objective function, weighing parameter ϵ, and the effect that the scheduling variables s_i exert on the constraints in our proposed formulation are entirely different from those in [15]. To this end, we introduce auxiliary scheduling variables $s_i \in [0, 1]$ and the single-stage

reformulation is given by

$$\min_{P_i^{\mathrm{s}}, s_i} \quad \epsilon \sum_{i=1}^{N} P_i^{\mathrm{s}} + (1 - \epsilon) \sum_{i=1}^{N} \frac{1}{s_i + 1} \tag{7a}$$

$$\text{s.t.} \quad 0 \le P_i^{\mathrm{s}} \le P^{\mathrm{s,max}}, \qquad \forall i \tag{7b}$$

$$s_i \in [0, 1], \qquad \forall i \tag{7c}$$

$$\frac{s_i b_i^{\mathrm{s}} N_o}{P_i^{\mathrm{s}}} + \sum_{l=1, l \ne i}^{N} \ln(1 + \frac{s_i b_i^{\mathrm{s}} G_{il}^{\mathrm{ss}} P_l^{\mathrm{s}}}{P_i^{\mathrm{s}}})$$

$$+ \ln(1 + \frac{s_i b_i^{\mathrm{s}} G_{i0}^{\mathrm{sm}} P^{\mathrm{m}}}{P_i^{\mathrm{s}}}) \le -\ln(1 - \rho_i^{\mathrm{s,th}}), \ \forall i \tag{7d}$$

$$\sum_{i=1}^{N} \ln(1 + b_{\mathrm{M}i}^{\mathrm{ms}} P_i^{\mathrm{s}}) \le \ln \mu^{\mathrm{m}} \tag{7e}$$

where the value of s_i determines the admissibility of the ith SU and if the outage constraint of the ith SU is taken into consideration in the power control part of the joint admission and power control problem. If $s_i = 0$, the ith SU is rejected and (7d) reduces to the trivial inequality $\ln(1 - \rho_i^{\mathrm{s,th}}) \le 0$; if $s_i = 1$, the ith SU is scheduled for admission and (7d) becomes an active constraint. The cost function consists of the weighted sum of transmit powers which is bounded and the admission cost which is discrete-valued. Intuitively, the weighing parameter $\epsilon < \epsilon^*$ has to be small enough in order to ensure that admission control is always prioritized before power control. The choice of ϵ can be understood by visualizing the objective function (7a) as a ruler where the decimal tickers correspond to the discrete admission cost and the intervals between the tickers are covered (partially) by the continuous power cost. The interpretation is that dropping any user costs more than can possibly be saved by total power minimization [15]. Thus, it is important to determine the optimal ϵ^* as provided in the following theorem.

Theorem 1: By choosing $\epsilon < \epsilon^* = 1/(2NP^{\mathrm{s,max}} + 1)$, the one-stage reformulation (7) is equivalent to the two-stage formulation (5)-(6).

Proof: Due to space constraint, the proof is omitted. $\square$

Remark 1: From Theorem 1, given that $\epsilon < \epsilon^*$, the solution of (7) admits the same (maximum) number of SUs as that of (5) and the total transmit power of the admitted SUs is the minimum (same as (6)) while maintaining the outage constraints of the MU and admitted SUs. There are several interesting features of the one-stage reformulation. First, the single-stage reformulation (7) is always feasible since $s_i = 0$ which implies $P_i^s = 0, \forall i$ is always admissible. Next, as the constraints in (7c) are binary and the second term in the objective function $1/(s_i + 1)$ is neither a posynomial nor a monomial, this single-stage formulation is non-convex and NP-hard to solve. In order to find the globally optimal solution, an exhaustive search is required. However, the compact framework of (7) is helpful in isolating the non-convex components which then facilitates the use of convex relaxation techniques on (7) in order to obtain a convex but approximate formulation. Although the resulting formulation can only give sub-optimal solutions, its performance is remarkably close to that of the globally optimal solution (obtained from (5)-(6) via exhaustive search).

III. CONVEX RELAXATION

The single-stage reformulation in (7) is non-convex due to the binary constraints (7c) and the term $1/(s_i + 1)$ in the objec-

tive function being neither a posynomial nor a monomial. To circumvent this problem, we first relax the binary constraints to allow s_i to take on any real value within the interval $[0, 1]$. Next, we approximate $f(s_i) = 1/(s_i + 1)$ with a monomial, i.e., $\hat{f}(s_i) = cs_i^\alpha$ where c and α are carefully chosen such that the entire optimization problem can be cast as a GP. We choose $cs_i^\alpha = 0.5s_i^{-\frac{1}{2}}$ by monomial approximation (details are skipped for brevity) and we compare it with a straightforward choice $cs_i^\alpha = s_i^{-1}$ in Section IV to show the effect of different approximations on the quality of the approximate solutions of the relaxed formulation. In the sequel, we retain the use of cs_i^α instead of $0.5s_i^{-\frac{1}{2}}$ for clarity of presentation. Finally, we obtain our new convex single-stage formulation as follows:

$$\min_{P_i^s, s_i} \quad \epsilon \sum_{i=1}^N P_i^s + c(1-\epsilon) \sum_{i=1}^N s_i^{-\alpha} \tag{8a}$$

$$\text{s.t.} \quad 0 \le P_i^s \le P^{s,\max}, \qquad \forall i \tag{8b}$$

$$0 \le s_i \le 1, \qquad \forall i \tag{8c}$$

$$\frac{s_i b_i^s N_o}{P_i^s} + \sum_{l=1,l\neq i}^N \ln\left(1 + \frac{s_i b_i^s G_{il}^{ss} P_l^s}{P_i^s}\right)$$
$$+ \ln\left(1 + \frac{s_i b_i^s G_{i0}^{sm} P^m}{P_i^s}\right) \le -\ln(1 - \rho_i^{s,th}), \ \forall i \tag{8d}$$

$$\sum_{i=1}^N \ln(1 + b_{Mi}^{ms} P_i^s) \le \ln \mu^m \tag{8e}$$

which is clearly a GP and it can be solved globally and efficiently. After (8) is solved, if all $s_i = 1$, it means that all the MU and SUs can be served while satisfying their outage constraints. Otherwise, the problem of removal of SUs comes into play in order to admit the maximum number of SUs with their outage constraints and that of the MU met. Two removal algorithms are used; (i) iterative removal algorithm removes the SU with the minimal $s_{i|s_i\neq 1}$ at each iteration and (ii) one-step removal algorithm removes all SUs with $s_i \neq 1$ after the first iteration and terminates at the second iteration.

IV. SIMULATION RESULTS

The performance of our proposed joint admission and power control algorithm is investigated for a code division multiple access system. The MBS is located in the centre of a square area of length 2000m. The small cells are randomly located in the same area excluding a square area of length 100m centred at the MBS. The SAP is located at the centre of each small cell (square area) and the SU is randomly located at either one of the four corners of the cell at a distance of 40m. The small cells are separated from each other by at least 1m. The MU is randomly located outside the small cells by at least 1m. The noise power at the MBS and SAPs is $N_o = 10^{-10}$W. The transmit power and SINR threshold of the MU are $P^m = 1$W and $\gamma^{m,th} = 0$dB, respectively. The maximum transmit power of the SUs is $P^{s,\max} = 1$W. The processing gains of the MBS and SAPs are $PG^m = 10$ and $PG^s = 1$, respectively. The MU and SUs have an outage probability threshold $\rho^{p,th} = 10\%$ and $\rho_i^{s,th} = 10\%$. The slow fading gain between transmitter j and receiver i is modeled as $G_{ij} = K_0 \times 10^{\beta_{ij}/10} \times d_{ij}^{-\eta}$ where d_{ij} is the distance between them, $K_0 = 10^3$ is a factor to include the effects of antenna gain and carrier frequency, β_{ij} is a Gaussian random variable
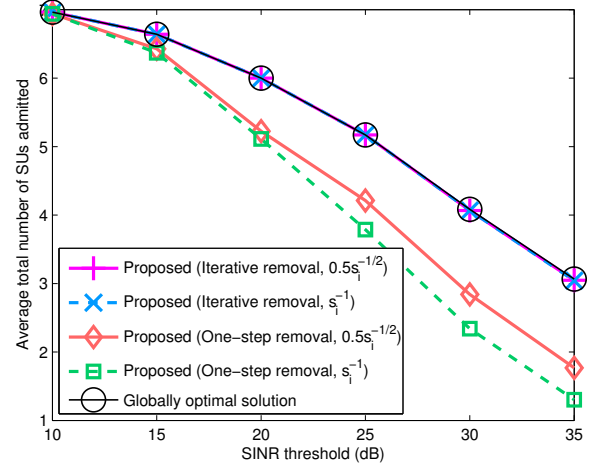

Fig. 2. Average total number of SUs admitted by the proposed algorithm and the globally optimal solution versus SUs' SINR threshold.

with zero mean and standard deviation of 4dB to account for log-normal shadowing effects, and the path loss exponent is $\eta = 4$. In the following, the globally optimal solution refers to that of the two-stage formulation (5)-(6). The simulation results are obtained by averaging over 200 independent runs.

First, we compare the use of (i) $0.5s_i^{-1/2}$ and (ii) s_i^{-1} in the objective function of our proposed algorithm to show the importance of a good approximation of $\frac{1}{s_i+1}$. From Fig. 2, there is no difference in the number of SUs admitted when $0.5s_i^{-1/2}$ or s_i^{-1} is used for the proposed formulation with iterative removal scheme. In the one-step removal case, the proposed algorithm with $0.5s_i^{-1/2}$ admits more SUs than that with s_i^{-1} as s_i^{-1} introduces excessive penalty into the objective function of (8). For fair comparison, in Fig. 3, we compare the total transmit power of the admitted SUs for the proposed formulation with iterative removal and that of the globally optimal solution. The total transmit power of the SUs is nearer to the globally optimal solution when $0.5s_i^{-1/2}$ is used instead of s_i^{-1}. Hence, $0.5s_i^{-1/2}$ is used for the next example.

We study the performance of the proposed algorithm when the number of requesting SUs is increased. The threshold SINR of the SUs is $\gamma_i^{s,th} = 25$dB. Fig. 4 shows that the proposed formulation with iterative removal scheme admits as many SUs as the globally optimal solution. Although the proposed formulation with one-step removal scheme is fast with at most two iterations, it admits fewer SUs than that with the iterative removal scheme. We then compare the total transmit power of the admitted SUs obtained by the proposed formulation with iterative removal scheme and that of the globally optimal solution. The proposed formulation with iterative removal scheme only incurs a slightly higher total power than the globally optimal solution.

V. CONCLUSION

In this paper, we investigated a shadowing time-scale joint admission and power control algorithm in two-tier small cell
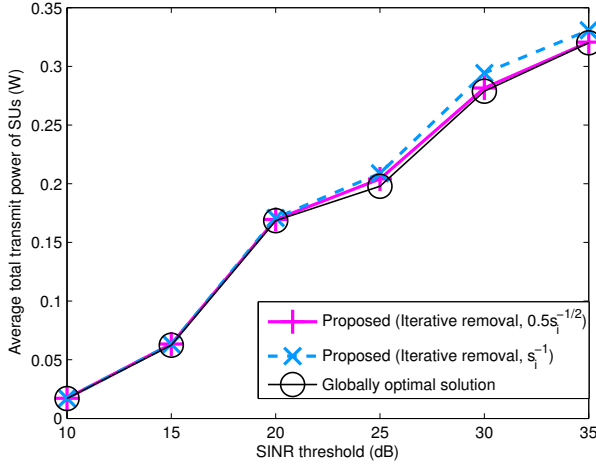
Fig. 3. Average total transmit power of SUs obtained by the proposed algorithm and the globally optimal solution versus SUs' SINR threshold.
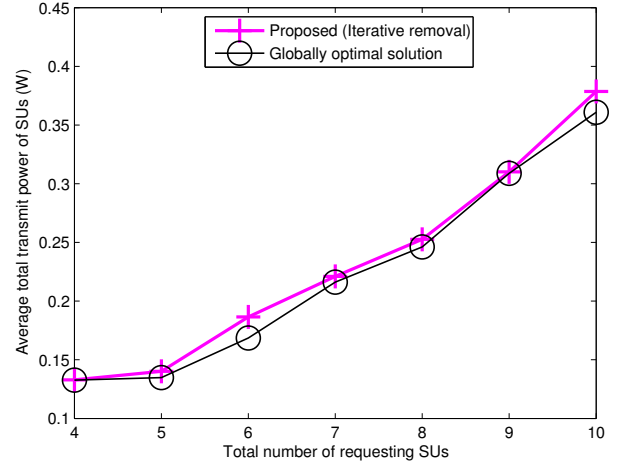

Fig. 5. Average total transmit power of SUs obtained by the proposed algorithm and the globally optimal solution versus total number of requesting SUs.
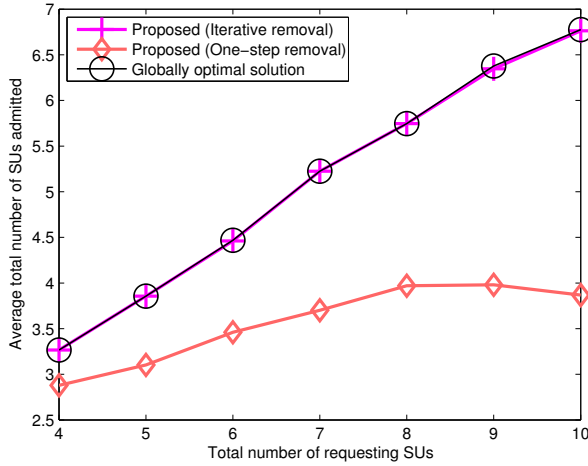

Fig. 4. Average total number of SUs admitted by the proposed algorithm and the globally optimal solution versus total number of requesting SUs.

networks. In particular, we proposed to maximize the number of small cell users that can be admitted at their desired outage specifications and minimize their total transmit powers while guaranteeing that the outage specification of the macrocell user is not compromised. Although this joint admission and power control problem is NP-hard, convex relaxation is applied to obtain high quality approximate solutions which demonstrate near optimal performance.

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