Distributed Pricing Power Control for Downlink Co-tier Interference Coordination in Two-Tier Heterogeneous Networks

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ABSTRACT

In this paper, we consider distributed power control schemes for downlink co-tier interference coordination in a two-tier heterogeneous network consisting of multiple femtocells under the coverage of a macrocell. We formulate a non cooperative game in order to solve this problem. First we propose an algorithm in which all femto access point simultaneously update their transmit power to maximize their individual payoff function according to a dynamic best response function. Numerical results show that in this non-cooperative game, all femtocells' transmit power converges quickly to Nash equilibrium points. Second, we develop a novel dynamic pricing power control scheme by using the update mechanism named gradient play to update the transmission powers of all femtocells. Numerical results show that the second proposal can attain lower transmission power but higher throughput in comparison with our first proposal, and both proposals outperform the conventional power control schemes.

Categories and Subject Descriptors

[**Networking/Telecommunications**]: Power control

Keywords

Heterogeneous Networks, Interference Coordination, Power Control, Game Theory.

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1. INTRODUCTION

Wireless data traffic has seen significant growth in volume in recent years due to development of the infrastructure of mobile market (e.g., new generation of wireless network and mobile devices in 4G and 5G) [1]. This considerable increase leads to new serious challenges for the mobile network operators (MNOs) who have to enhance and maintain their network infrastructure accordingly. One of the approach used by the MNOs is to install smallcells (i.e., femtocells) to enhance the capacity of cellular networks which is termed as heterogeneous networks (HetNets) [1]. However, there are still some technical challenges to be addressed for widespread deployment of femtocells.

A two-tier HetNets is usually implemented by sharing spectrum rather than splitting spectrum between tiers. However, this sharing can cause severe interference for both uplink and downlink communications in the same tier (co-tier interference) or other tier (cross-tier interference). Hence, the cross-tier and co-tier interference mitigation fall among the key issues in two-tier HetNets which can degrade the performance significantly if not addressed accordingly. A typical two-tier HetNet with femto and macro access nodes is shown in Fig. 1, downlink transmission between AP 2 and its users could easily be interfered by downlink transmission of the other APs and MBS. In this paper, we focus on the downlink co-tier interference problem of a two-tier orthogonal frequency-division multiple-access (OFDMA) system and propose power control schemes to resolve the interference issues.

In order to limit or mitigate interference one of the most successful and efficient mechanism used in HetNets is power control where each interfering station minimize its transmission power to avoid strong interference. The main goal of power control is to mitigate interference and maximize the system throughput, which has been extensively investigated in the literature [2]-[10]. Foschini and Miljianic [8] proposed a distributed target signal-to-interference-plus-noise ratio (SINR) tracking power control (TPC) algorithm that can support predetermined target SINRs for all users with minimum powers. However, with the increase in number of users and HetNet setting of modern cellular systems, this approach will cause strong interference (limited throughput and performance) and would have a higher convergence time. In contrast, Sung and Leung [6][7] proposed an opportunistic power control (OPC) algorithm that aims at exploiting channel fluctuation in order to improve the system throughput. The basic idea of OPC is that it instructs a transmitter to increase its power when the channel is in good condition and to decrease its power when the channel condition is bad. The transmission rate is adjusted according to the received signal-to-interference ratio. However, this approach cannot guarantee interference protection while increasing the power levels. In addition, various PC algorithms have been developed by employing the game theory approach [2],[5],[10]. In most cases, proposed PC algorithms have proven to converge to the Nash equilibrium (NE) of the underlying game. In particular, a pricing-based approach has been taken to design a PC algorithm in [10] to maximize users surplus in wireless ad hoc networks, in which each user announces a price that reflects compensation paid by other users for their interference.

In this paper, we address the problem of co-tier interference in a two-tier heterogeneous networks by proposing two distributed power control schemes for downlink using co-tier interference coordination among femtocells. Our main contributions can be summarized as follows:

- We develop a distributed algorithm based on game theory, in which all femto APs simultaneously update their transmit powers to maximize their individual payoff functions according to a best response function in a non-cooperative game. Numerical results show that all femtocells' transmit powers converge quickly to Nash equilibrium points.

- In order to further improve performance by reducing power achieved by the first proposed algorithm, we propose a second distributed dynamic pricing power control scheme. This scheme takes into account the target SINR constraint and considers the effective interference as the price of the femto APs. In this scheme, the update mechanism named gradient play is used to update the transmission powers of the femto APs. Numerical results show that the second proposal can attain lower transmission power and higher throughput compared to our first proposal, and both proposals outperform the conventional works on power control namely TPC and OPC algorithms.

This paper is organized as follows: Section 2 describes the two-tier HetNet system model. Game theoretic formulation for power control is carefully analyzed in Section 3. Following that, we analyze the non-cooperative power control game and propose the first algorithm in Section 4. In Section 5, we propose our second algorithm namely dynamic pricing power control scheme for femtocell APs. We provide numerical results to demonstrate the performance of our algorithms in Section 6 and finally conclude this paper in Section 7.

2. SYSTEM MODEL

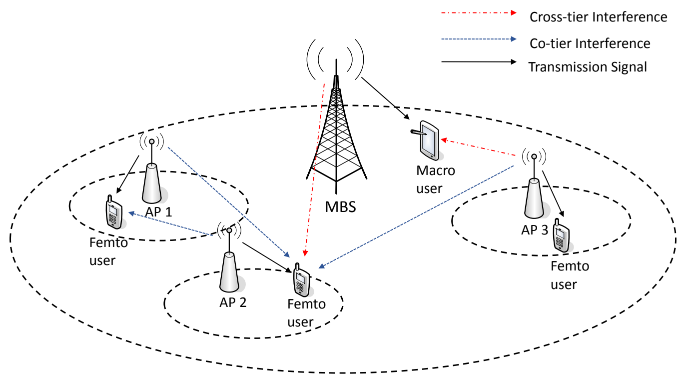

Figure 1: Network model with two-tier macrocell-femtocell

We consider a HetNet which consist of a MBS with a coverage area of $\mathcal{L} \subset \mathbb{R}^2$ and a set $\mathcal{M}$ of APs $|\mathcal{M}|= M$, where each AP m is located randomly at location $k_m \in \mathcal{L}$. As its known that femtocells have a small coverage area, the distances between femto users (FUs) in a femtocell to the femto AP are relatively much shorter than distances between femto APs in a macrocell coverage. Therefore, from neighboring femto APs' perspective, we can assume that the FUs in the femtocell are spatially located at the same point, which can be considered same location $k_m \in \mathcal{L}$ with the femto AP m. Therefore, the downlink SINR received by FUs at location k_m for the signal from femto AP m is thus given as follows:

$$\Gamma_m(\mathbf{p}) \triangleq SINR_m(\mathbf{p}) = \frac{g_m^{(k_m)} p_m}{\sum_{n\in\mathcal{M},n\neq m} g_n^{(k_m)} p_n + \sigma^2}, \quad (1)$$

where $g_m^{(k_m)}$ and p_m are representing the total channel gain from the femto AP m to the FUs at location k_m or in its coverage location and the transmit power of femto AP m during ABS period, respectively. $g_n^{(k_m)}$ is the total channel gain from femto AP n to the FUs at location k_m of femto AP m and σ^2 denotes the noise power level at location k_m. We assume that the MBS transmission power does not change over the time slot. Then, the additional cross-tier interference from the MBS (red line in Fig 1.) can be absorbed into the background noise. These channel gains include path loss only and no fast fading because the timescale for measuring these channel gains in the time slot is considered much larger than a time slot. Therefore, we can define the effective interference $R_m(\mathbf{p}_{-m})$ [6] to AP m at location k_m as follows:

$$R_m(\mathbf{p}_{-m}) \triangleq \frac{p_m}{\Gamma_m(\mathbf{p})} = \frac{\sum_{n\in\mathcal{M},n\neq m} g_n^{(k_m)} p_n + \sigma^2}{g_m^{(k_m)}}. \quad (2)$$

We assume that each femto AP m has a maximum transmit power P_m^{max}, and requires minimum QoS in term of target SINR $\hat{\gamma}_m \quad \forall m \in \mathcal{M}$ to be in service which can be represented by the following:

$$\Gamma_m(\mathbf{p}) \geq \hat{\gamma}_m, \quad m \in \mathcal{M}. \quad (3)$$

$$p_m \leq p_m^{max}, \quad m \in \mathcal{M}. \quad (4)$$

Femto AP m can estimate $R_m(\mathbf{p}_{-m})$ if it has information about the total interference, noise power and the channel power gain $g_m^{(k_m)}$ according to the SINR expression in (1). The channel power gain $g_m^{(k_m)}$ can be estimated by FUs at location k_m and sent back to AP m by using the pilot signal or any standard channel estimation technique [4]. The total interference and noise power for each femto AP can be estimated as follows. All FUs at location k_m estimate the total received power and send this value to their associated femto AP m. femto AP m can then calculate the total interference and noise power by subtracting its transmit signal power (e.g., $g_m^{(k_m)} p_m$) from the total receiving power sent by FUs. Therefore, calculation of the effective interference only requires the standard channel estimation of $g_m^{(k_m)} p_m$ and estimation of total receiving power at the FUs. In addition, signaling is only involved in sending these values from the FUs to its associated femto AP, which is relatively mild and can be conducted over the air.

3. GAME-THEORETIC FORMULATION

Each femto AP aims to maximize its throughput by maximizing its individual SINR, however, transmitting with very high power will create unacceptable co-tier interference. Consequently, it is natural to encourage femto APs from reducing co-tier interference [5]. We develop a distributed power control algorithm by using the game theory approach.

Definition 1. A power control game $\mathcal{G}$ is defined by a triple $\mathcal{G} \triangleq \{\mathcal{M}, (S_m)_{m\in\mathcal{M}}, (\mathcal{P}_m)_{m\in\mathcal{M}}\}$, where $\mathcal{M}$ is the player set (set of all femto APs), $(S_m)_{m\in\mathcal{M}}$ is the stratergy set (transmit power set) of players $S_m \triangleq \{p_m | 0 \le p_m \le p_m^{max}\}$, and $(\mathcal{P}_m)_{m\in\mathcal{M}}$ is the payoff function set.

In power control game, each femto AP determines its own transmit power in order to maximize its payoff function $\mathcal{P}_m(\mathbf{p})$ given the femto AP knows the chosen power levels from other femto APs. There are several choices of payoff function set. For example, if all femto APs adjust their transmit powers so as to hit their corresponding targets, then the payoff function can be formulated as the traditional target tracking problem as

$$\mathcal{P}_m^{(1)}(\mathbf{p}) = -(\Gamma_m(\mathbf{p}) - \hat{\gamma}_m)^2. \tag{5}$$

Given $\mathbf{p}_{-m}$, the best response of femto AP m for this payoff function is $p_m = \hat{\gamma}_m R_m(\mathbf{p}_{-m})$. This is precisely the standard Foschini-Milijanic algorithm [8].

On the other hand, Leung and Sung proposed an opportunistic power control (OPC) algorithm in [6] and [7], aims to enhance the system throughput. The payoff function of the OPC algorithm is given as follows.

$$\mathcal{P}_m^{(2)}(\mathbf{p}) = -(p_m R_m(\mathbf{p}_{-m}) - \xi_m)^2. \tag{6}$$

The goal of this design is to keep the product of the transmit power and the effective interference to a constant ξ_m called the target *signal-interference product* (SIP) of femto AP m. The corresponding best response of femto AP m is $p_m = \frac{\xi_m}{R_m(\mathbf{p}_{-m})}$. The transmit power is inversely proportional to the effective interference. When the channel condition is bad (high interference), femto AP transmits with low power and vice versa. Therefore, the proposed algorithm in [6] and [7] is opportunistic.

A hybrid power control (HPC) algorithm was proposed by Ha and Le in [4], with a payoff function from which femto AP m adaptively balance between achieving the SINR target $\hat{\gamma}_m$ and exploiting its potential favorable channel condition to increase its SINR.

$$\mathcal{P}_m^{(3)}(\mathbf{p}) = -(\Gamma_m(\mathbf{p}) - \hat{\gamma}_m)^2 - \theta_m (p_m R_m(\mathbf{p}_{-m}) - \xi_m)^2, \tag{7}$$

Best response corresponding for the the HPC algorithm is given as

$$p_m^* = \min\left\{ \frac{\hat{\gamma}_m R_m(\mathbf{p}_{-m}) + \frac{\theta_m \xi_m}{R_m(\mathbf{p}_{-m})}}{\theta_m + 1}, p_m^{max} \right\}, \quad \forall m \in \mathcal{M}. \tag{8}$$

The parameter θ_m can be used to control the desirable performance of the proposed power control algorithm. Specifically, by setting $\theta_m = 0$ femto AP m actually employs the standard Forchini-Milijanic algorithm to achieve its target SINR $\hat{\gamma}_m$ with the best respone $p_m^* = \min\{\hat{\gamma}_m R_m(\mathbf{p}_{-m}), p_m^{max}\}$, whereas if $\theta_m \to \infty$, femto AP m attempts to achieve a adaptive SINR which is the OPC algorithm proposed in [6]-[7] with the best response $p_m^* = \min\left\{\frac{\xi_m}{R_m(\mathbf{p}_{-m})}, p_m^{max}\right\}$.

4. NON-COOPERATIVE POWER CONTROL GAME (NPG)

In this paper, we consider the payoff function of femto AP m as follows

$$\mathcal{P}_m(\mathbf{p}) = U_m(\Gamma_m(p_m, \mathbf{p}_{-m})) - p_m R_m(\mathbf{p}_{-m}), \tag{9}$$

where $U_m(\Gamma_m(p_m, \mathbf{p}_{-m}))$ is the utility function. We assume utility function $U_m(p_m, \mathbf{p}_{-m})$ is a continuous, nondecreasing and strictly concave function. We consider the second term in payoff function as the linear cost function of the femto AP m and the effective interference $R_m(\mathbf{p}_{-m})$ which is the interference price of the femto AP m. The intuition of the interference price is when the channel is experiencing high interference, the femto AP reduces its transmit power to decrease the cost, and when the channel has a low interference, then the femto AP can increase its transmit power to obtain higher utility.

In general it is difficult to point out that how the interaction among players could converge to a Nash equilibrium in a non-cooperative game (NPG). In non-cooperative power control game, where femto APs do not exchange any information and simple choose transmission powers to maximize their individual payoff functions, therefore femto APs can observe the outcome of the actions of the others (e.g., via interference), but do not have explicit knowledge of other femto APs' actions and their payoffs. The best response of each femto AP m corresponding to the payoff function $\mathcal{P}_m(\mathbf{p})$ is given by the following

$$\mathcal{B}_m(\mathbf{p}_{-m}) = \arg\max_{p_m} (U_m(\Gamma_m(p_m, \mathbf{p}_{-m})) - p_m R_m(\mathbf{p}_{-m})) \tag{10}$$

i.e., the p_m that maximizes payoff function $P_m(\mathbf{p})$ given a fixed $\mathbf{p}_{-m}$. In this section we consider the distributed power control algorithm in which players repeatedly adjust their strategies in response to observations of other player actions so as to achieve the Nash equilibrium by the dynamic best response update mechanism.

Remark. The DPD algorithm can be implemented without any messages exchange among femto APs.

Theorem 1. If the **Algorithm 1** converges to a steady state, then this state is a Nash equilibrium of the NPG game.

Algorithm 1 Distributed Power Control Algorithm

Step 1: Initialization
Set $\mathbf{p}^{(\mathbf{0})}$ be any feasible point in strategy space $(S_m)_{m\in\mathcal{M}}$.
Set $t = 0$
Step 2: Dynamic power control iterations
Update power: femto AP m, $\forall m \in \mathcal{M}$, simultaneously update their transmit power according to

$$p_m^{(t+1)} = \left[\mathcal{B}_m(\mathbf{p}_{-m}^{(t)})\right]_0^{p_m^{max}} \tag{11}$$

5. PRICING BASED DYNAMIC POWER CONTROL

In this section we consider the problem which maximizes the total payoff functions of all femto APs subject to the target SINR constraint of all femto APs and maximum transmission power constraint.

$$\begin{aligned}(\mathbf{P1})\ \max_{\mathbf{p}}.\ &\widetilde{\mathcal{P}}(\mathbf{p}) = \sum_{m\in\mathcal{P}} (U_m(\Gamma_m(\mathbf{p}) - p_m R_m(\mathbf{p}_{-m}))\\ \text{s.t.}\quad &\Gamma_m(\mathbf{p}) \geq \hat{\gamma}_m, \quad m \in \mathcal{M}\\ &p_m \leq p_m^{max}, \quad m \in \mathcal{M}.\end{aligned} \tag{12}$$

Although $P_m(\mathbf{p})$ is a concave function of p_m, the objective in **P1** problem $\widetilde{P}(\mathbf{p})$ may be a nonlinear nonconcave function of $\mathbf{p}$, it can be converted into a nonlinear concave function through a log transformation [10][12], leading to a critical convexity property that establishes the global optimality of the proposed algorithm.

The Lagrangian of **P1**

$$\begin{aligned}L(\mathbf{p}, \boldsymbol{\lambda}) = &\sum_{m\in\mathcal{P}} (U_m(\Gamma_m(\mathbf{p}) - p_m R_m(\mathbf{p}_{-m}))\\ &+ \sum_{m\in\mathcal{P}} \lambda_m(\Gamma_m(\mathbf{p}) - \hat{\gamma}_m)\end{aligned} \tag{13}$$

$$\begin{aligned}\nabla L(\mathbf{p}, \boldsymbol{\lambda}) = &\frac{\partial}{\partial p_m} (U_m(\Gamma_m(\mathbf{p}) + \lambda_m \Gamma_m(\mathbf{p}) - p_m R_m(\mathbf{p}_{-m}))\\ &+ \sum_{n\neq m} \frac{\partial}{\partial p_m} (U_n(\Gamma_n(\mathbf{p}) + \lambda_n \Gamma_n(\mathbf{p}) - p_n R_n(\mathbf{p}_{-n}))\end{aligned} \tag{14}$$

Let

$$\begin{aligned}\pi_n \triangleq \mathcal{C}_n(\mathbf{p}) = -\frac{\partial}{\partial I_n(\mathbf{p}_{-n})} &(U_n(\Gamma_n(\mathbf{p}) + \lambda_n \Gamma_n(\mathbf{p})\\ &- p_n R_n(\mathbf{p}_{-n}))\end{aligned} \tag{15}$$

where $I_n(\mathbf{p}_{-n}) = \sum_{j\in\mathcal{P}, j\neq n} g_{j,n} p_j$, (hereafter for simple notation, we use $g_{j,n}$ instead of $g_j^{(k_n)}$ to denote the channel gain between femto AP j and users in femtocell n). Consider π_n as a price charged to other femto APs for generating downlink interference to user in femtocell n [10].
Denoting

$$\Delta p_m = \frac{\partial}{\partial p_m} (U_m(\Gamma_m(\mathbf{p}) + \lambda_m \Gamma_m(\mathbf{p}) - p_m R_m(\mathbf{p}_{-m})) \tag{16}$$

The gradient of Lagrangian can rewritten as follows

$$\nabla L(\mathbf{p}, \boldsymbol{\lambda}) = \Delta p_m - \sum_{n\neq m} \pi_n g_{m,n} \tag{17}$$

Our distributed co-tier interference coordination power control scheme is described in Algorithm 2. For any local optimal $\mathbf{p}^*$ of **P1** problem, it must satisfy the KKT condition in which the gradient of the Lagrangian with respect to $\mathbf{p}$ vanishes at $\mathbf{p}^*$. From the stationarity condition of the KKT condition [11], in this proposed algorithm we consider a strategy update mechanism called gradient play [3], since the power control problem is decouple into local problems for each femto AP m, and each femto AP update its transmit power in a gradient direction. Each femto AP m calculates the interference price π_m and announces the interference price to all other femto APs by wireline backhaul. All femto APs set their transmit powers based on locally measurable quantities and the received prices. Prices and powers are asynchronously updated.

Algorithm 2 Distributed Pricing Dynamic Power Control

Step 1: Initialization
Set $\mathbf{p}^{(\mathbf{0})}$ be any feasible point in strategy space $(S_m)_{m\in\mathcal{M}}$.
Set $\boldsymbol{\lambda}^{(0)}$ be any positive value, $\boldsymbol{\pi}^{(0)} = 0$ and $t = 0$
Step 2: Dynamic power control iterations
1. Update target SINR price: Each femto AP m update $\lambda_m^{(t+1)}$ according to

$$\lambda_m^{(t+1)} = \left[\lambda_m^{(t)} + \rho^{(t)} \left(\hat{\gamma}_m - \frac{p_m^{(t)}}{R_m(\mathbf{p}_{-m}^{(t)})}\right)\right]^+ \tag{18}$$

2. Update interference price: Each femto AP m update $\pi_m^{(t+1)}$ according to

$$\pi_m^{(t+1)} = \pi_m^{(t)} + \rho^{(t)} \left(\pi_m^{(t)} - \mathcal{C}_m(\mathbf{p}^{(t)})\right) \tag{19}$$

3. Each femto AP broadcasts its interference price $\pi_m^{(t+1)}$ to other femto APs.
4. Update power: femto AP m, $\forall m \in \mathcal{M}$, simultaneously update their transmit power according to

$$p_m^{(t+1)} = \left[p_m^{(t)} + \rho^{(t)} \left(\Delta p_m^{(t)} - \sum_{n\neq m} \pi_n^{(t)} g_{m,n}\right)\right]_0^{p_m^{max}} \tag{20}$$

Remark. The interference price π_m is computed based on utility function $U_m(\Gamma_m(\mathbf{p}))$, SINR $\Gamma_m(\mathbf{p})$ and effective interference $R_m(\mathbf{p}_{-m})$ which can be directly measured by femto AP m locally. Each interference price is a real number, hence, the messages exchanged are mild. Measuring the channel gain $g_{m,n}$ for $n \in \mathcal{M}$ can be accomplished by having users in each femtocell periodically feedback to femto APs and femto APs can then measure these channel gains.

Theorem 2. For any initial transmit power $\mathbf{p}^{(0)}$, **Algorithm 2** converges to the unique equilibrium.

Proof. The proof is similar as in [10] and [12].

An example of the utility function is a logarithmic utility function $U_m(\Gamma_m(\mathbf{p})) = \log(1+\Gamma_m(\mathbf{p}))$ which corresponds to the femto AP's capacity. In the high SINR regime (SINR is much larger than 1), the logarithmic utility function can be approximated as $\log(\Gamma_m(\mathbf{p}))$. In this case we have

$$\Delta p_m = \frac{1}{p_m} + \lambda_m \frac{g_{m,m}}{\sum\limits_{k\neq m} g_{k,m}p_k + \sigma^2} - \frac{\sum\limits_{k\neq m} g_{k,m}p_k + \sigma^2}{g_{m,m}}$$
$$= \frac{1}{p_m} + \frac{\lambda_m}{R_m(\mathbf{p}_{-m})} - R_m(\mathbf{p}_{-m}) \quad (21)$$

and

$$\pi_j = \frac{1}{\sum\limits_{k\neq j} g_{k,j}p_k + \sigma^2} + \frac{\lambda_j g_{j,j} p_j}{\left(\sum\limits_{k\neq j} g_{k,j}p_k + \sigma^2\right)^2} + \frac{p_j}{g_{j,j}} \quad (22)$$

6. SIMULATION RESULTS

In order to validate our proposals we provide some simulation results demonstrating the effectiveness of the Distributed Power Control (DPC) and Distributed Pricing Dynamic Power Control (DPDPC) algorithms. The network topology for our simulations is shown in Fig. 2, where femto APs and FUs are randomly located inside cirles of radius of $r_1 = 1000$ m and the radius of each femtocell is $r_2 = 100$ m.

First, we consider a network with $M = 10$ femtocells and each femto APs with utility $U_m(\Gamma_m(\mathbf{p})) = \log(\Gamma_m(\mathbf{p}))$. The channel gains $g_{m,n} = 10^{(-PL(d_{m,n}))/10}$ (no fading), where function $PL(d_{m,n})$ represents path loss (in decibels) and $d_{m,n}$ (in meters) is the distance between femto AP m and FU of femto AP n. For modeling the propagation environment we use $PL(d_{m,n}) = 16.62 + 37.6\log_{10}(d_{m,n})$ for interference path loss and $PL(d_{m,n}) = 37 + 32\log_{10}(d_{m,n})$ for indoor path loss. The femto APs transmit with power vary in range from 500 mW (27 dBm) to 4 W (36 dBm). The step sizes of DPDPC algorithm is chosen to be $\rho^{(t)} = 0.01/t$. All results are obtained by averaging over a large number of independent simulation runs, each of which realizes random locations of femto APs, femto users, and channel power gains.

In Fig. 3, we show the convergence of the algorithms to the Nash equilibrium points, the x-axis represent the iterations required whereas the y-axis represent the average power for each femto AP. First, it can be observed that both algorithm converge to the equilibrium points in very less number of iterations, i.e., less than 10 iterations with the DPC algorithm and less than 20 for DPDPC algorithm in a network consisting of 10 femto APs. This higher number of iteration for convergence of DPDPC as compared to DPC can be explained by the updating of the target SINR price and interference price in DPDPC whereas in DPC we only update the power without target SINR price and interference price. Second, it can be seen that the DPDPC algorithm with target SINR constraint has lower average transmission power in comparison to the DPC algorithm without SINR constraint.

Fig. 4 shows the SINR of each femto AP after convergence for both DPC and DPDPC algorithms. First, it can be seen that using DPDPC algorithm, the SINR is adjusted according to the predefined target SINR which allows other femto APs to meet the their respective targets. Second, it can be observed that both algorithms adaptively adjust to the network conditions which means they have higher SINR under good channel conditions and vice-versa i.e, femto AP 2,6, and 7 are located such that they have a low co-tier interference which allows to have better SINR whereas the some suffer from co-tier interference due to close location i.e, 4,5, and 9 and other femto APs are very close to the target SINR i.e., 10 dB.

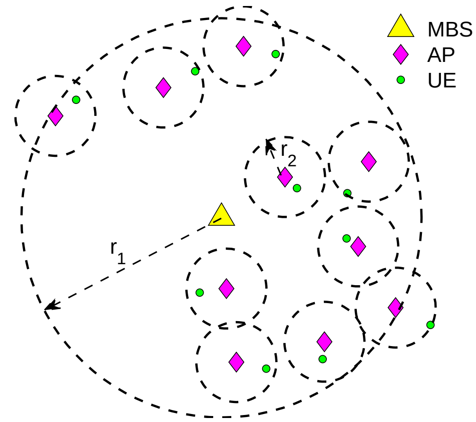

Figure 2: Network topology with two-tier macrocell-femtocell, where r_1 and r_2 are the radius of the macrocell and femtocells respectively.

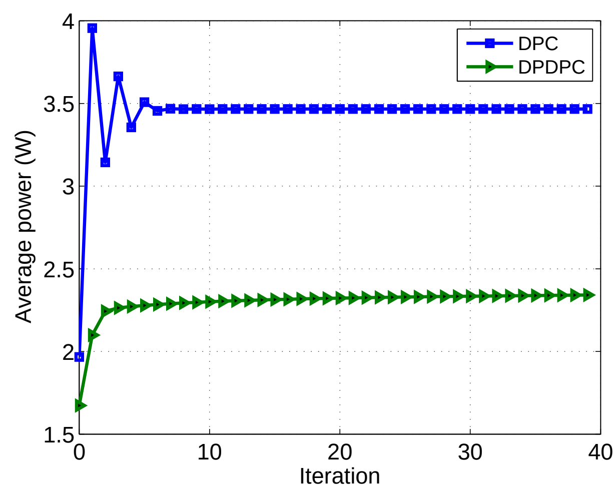

Figure 3: Average transmission power for the DPC and DPDPC algorithm for target SINR of 10 dB

In order to evaluate the performance in terms of average throughput of our proposed DPC and DPDPC algorithms, we provide some simulations by comparing them by two well known benchmark power control algorithms namely target-SINR-tracking power control (TPC) or Foschini-Miljanic algorithm [8], and opportunistic power control (OPC) [6],[7]. Fig. 5 shows the comparison of average throughput for the proposed and benchmark algorithms. It can be seen that the DPC scheme outperforms the TPC and OPC schemes and can achieve 25.5% and 5.3% higher throughput than that of TPC and OPC, respectively. Furthermore, the second algorithm DPDPC outperforms the TPC and OPC schemes and

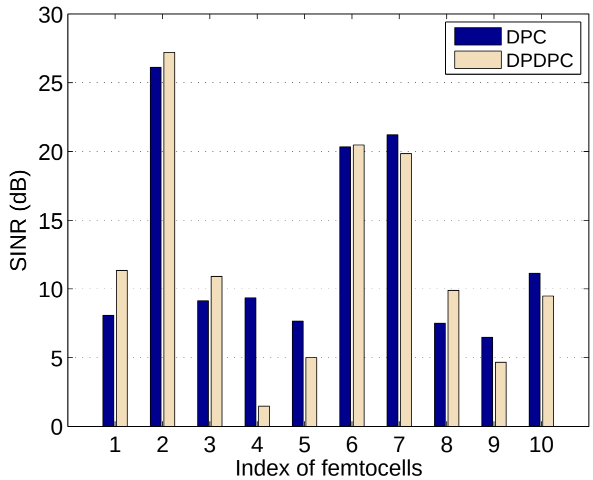

Figure 4: SINR for the DPC and DPDPC algorithm for target SINR of 10 dB

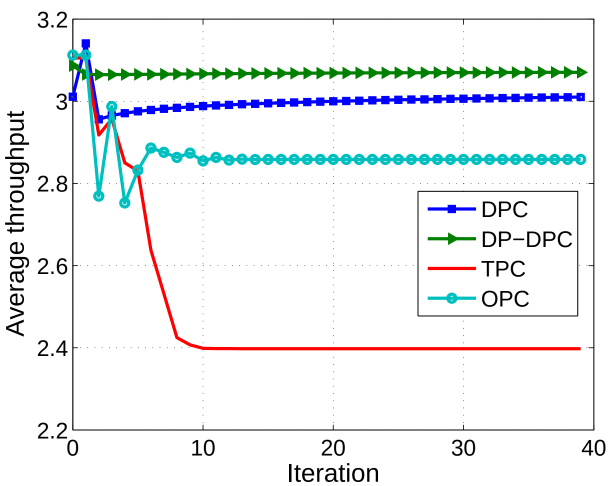

Figure 5: Comparison algorithms for target SINR of 10 dB

can achieve 28% and 7.4% higher throughput than that of TPC and OPC, respectively. This proves the effectiveness of our proposals in dynamic power control. This improvement is due to the fact that in the TPC scheme, all femto APs reach their target SINRs without optimizing their respective transmission power. In contrast, the OPC scheme results in a very different SINRs at the equilibrium where the strongest femto AP (low interference) attains high SINR while the weak ones (high interference) achieve low SINRs. Therefore, the OPC scheme tends to allocate more power to strong users to achieve high overall throughput in comparison with TPC.

7. CONCLUSIONS

We have designed two distributed power control schemes for co-tier interference coordination in two-tier heterogeneous networks consisting of a macrocell and multiple femtocells. The first scheme is designed based on game theory where we use a dynamic best response function in a non-cooperative game to achieve the Nash equilibrium. The second algorithm is designed based on a gradient play update mechanism. Additionally, we take into account the target SINR constraint. The second algorithm has high computation in compare with the first proposed algorithm, however, it can attain lower transmission power but higher throughput for all femtocell access points. Simulation results demonstrate the effectiveness of our proposed dynamic power control schemes and it has been observed that both of our proposals outperform the conventional works.

8. ACKNOWLEDGMENTS

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