Distributed Power Control for Downlink Co-tier Interference Coordination in Two-Tier LTE HetNets

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Abstract

In LTE heterogeneous networks, cross-tier interference between macrocell and smallcells i.e., picocells, can be eliminated by reserving certain periods termed as Almost Blank Subframes (ABS periods) for smallcells transmission. However, co-tier interference among smallcells during ABS periods remains a significant problem which reduces the network performance. In this paper, we consider a distributed power control scheme for downlink co-tier interference coordination in two-tier LTE heterogeneous networks. In our proposed distributed algorithm, all pico access points simultaneously update their transmit power to maximize their individual payoff functions according to a best response function in a non-cooperative game. Our numerical simulation results show that all picocells' transmit powers converge quickly towards Nash equilibrium points.

I. 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). 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 to enhance the capacity of cellular networks which is termed as heterogeneous networks (HetNets) [1].

However, in LTE, since picocells typically share the same frequency band as macrocells, the performance of low-power pico access point (AP) could be severely impaired by cross-tier interference from high-power macrocell base station (MBS). In order to assist pico downlink transmission, the MBS can mute all downlink transmissions to its users in certain subframes termed ABS[2]. However, co-tier interference among smallcells during ABS periods remains a significant problem which reduces network performance. Address this problem, we proposed a distributed power control scheme for downlink co-tier interference coordination among picocells. Our proposal is based on a non-cooperative game, in which all pico AP simultaneously update their transmit power to maximize their individual payoff functions according to a best response function. Our numerical results show that all picocells' transmit powers converge quickly to Nash equilibrium points.

II. System model

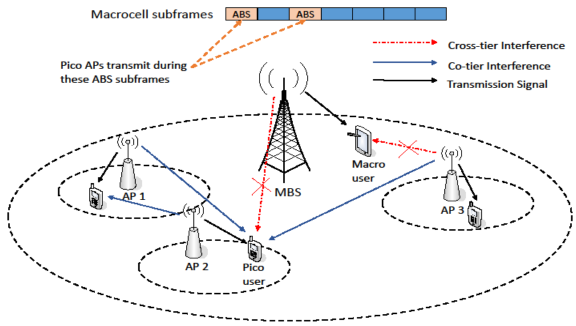

Fig.1 System model

We consider the coverage area of MBS $\mathcal{L} \subset \mathbb{R}^2$. Each AP m is located randomly at location $k_m \in \mathcal{L}$. Because of the small coverage of picocells, the distances between mobile users (MUs) in a picocell to its pico AP are relatively much shorter than distances between pico APs in macrocell coverage. From neighboring pico APs' perspective, we can assume that the MUs in the picocell are spatially located at the same point [3] which can be considered as same location $k_m \in \mathcal{L}$ with the pico AP m. The downlink SINR received by MUs at location k_m from pico AP m is thus given by

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

where $g_m^{(k_m)}$ and p_m representing the total channel gain from the pico AP m to the MUs at location k_m or in its coverage location and the transmit power of pico AP m during ABS period, respectively. $g_n^{(k_m)}$ is the total channel gain from pico AP n to the MUs at location k_m of pico AP m and σ^2 denotes the noise power level at location k_m. These channel gains include path loss only and no fast fading because the timescale for measuring these channel gains is the ABS period is considered much larger than a time slot. We define the effective interference $R_m(\mathbf{p}_{-m})$ [3] to AP m at location k_m as follows

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

We assume that each pico AP m has a maximum transmit power P_m^{max} and requires minimum QoS in term of target SINR $\hat{\gamma}_m$ $\forall m \in \mathcal{P}$ to be in service

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

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

Pico 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 MUs at location k_m and sent back to AP m by using the pilot signal or by any standard channel estimation technique [3]. The total interference and noise power for each pico AP can be estimated as follows. All MUs at location k_m estimate the total received power and send this value to their associated pico AP m. Pico AP m then can 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 MUs. 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 MUs.

III. Non-cooperative Power Control Game

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

$$\mathcal{P}_m(\mathbf{p}) = U_m(\Gamma_m(p_m, \mathbf{p}_{-m})) - p_m R_m(\mathbf{p}_{-m}) \quad (5)$$

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 pico AP m and the effective interference $R_m(\mathbf{p}_{-m})$ is the interference price of the pico AP m. The intuition of the interference price is that when the channel has high interference, the pico AP reduces the transmission power to decrease the cost, and when the channel has low interference the pico AP can increase its transmission 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, pico APs do not exchange any information and choose transmission powers to maximize their individual payoff functions. Therefore pico APs can only observe the outcome of the actions of the others (e.g., interference), but do not have knowledge of other pico APs' actions (transmit power) and their payoffs. The best response of each pico AP m corresponding to the payoff function $\mathcal{P}_m(\mathbf{p})$ is

$$\mathcal{B}_m(\mathbf{p}_{-m}) = \arg\max_{p_m}(U_m(\Gamma_m(p_m, \mathbf{p}_{-m})) - p_m R_m(\mathbf{p}_{-m})) \quad (6)$$

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

Algorithm 1: The Distributed Power Control Algorithm:

Step 1: Initialization

Set $\mathbf{p}^{(0)}$ be any feasible point in strategy space $(S_m)_{m\in\mathcal{P}}$

Set $t = 0$

Step 2: Dynamic power control iterations

Update power: Pico AP $m, \forall m \in P,$ simultaneously update their transmit power according to

$$p_m^{(t+1)} = \left[\mathcal{B}_m(\mathbf{p}_{-m}^{(t)})\right]_0^{p_m^{max}} \quad (7)$$

Remark. The DPC algorithm can be implemented without any messages exchange among pico APs.

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

IV. Numerical Results.

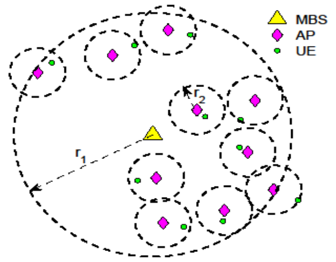

Fig. 2: Network topology

We provide some simulation results to demonstrate the performance of the DPC algorithms. The network topology for our simulations is shown in Fig. 1, where pico APs and MUs are randomly located inside cirles of radius of $r_1 = 1000m$ and the radius of each picocell is $r_2 = 100m$. We consider a network with $M = 10$ picocells and each pico 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 dB) and $d_{m,n}$ (in meters) is the distance between pico AP m and MU of pico 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 pico APs transmit with varying power range from 500 mW (27 dBm) to 4 W (36 dBm).

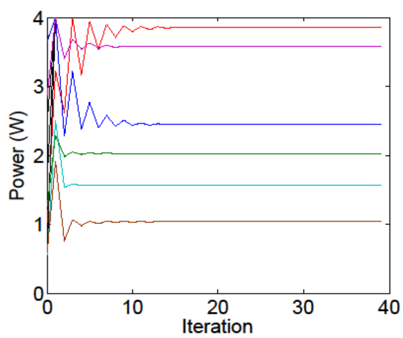

Fig 3: Power convergence of DPC algorithm.

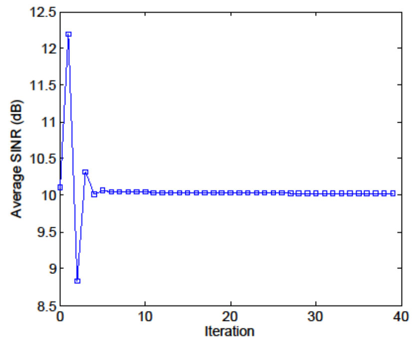

Fig 4: Average SINR of DPC algorithm

Fig. 3 shows the convergence of our proposed algorithm, each line corresponds to the power for one pico AP with a random initialization. It can be seen that all transmit powers converge to Nash equilibrium points after limited number of iterations. Fig. 4 shows convergence of the average SINR for all pico Aps. It can be observed that average SINR obtains the targeted value i.e., 10dB.

V. Conclusions

We have proposed a distributed power control algorithms for co-tier interference coordination in two-tier heterogeneous networks. Our proposal is based on a non-cooperative game, in which each pico AP simultaneously update its transmission power to maximize the individual payoff according to the best response function termed as gradient play. Our numerical results show that the algorithm converge quickly towards Nash equilibrium points, which also limits the required overhead.

Acknowledgment

This research was supported by Basic Science Research Program through National Research Foundation of Korea (NRF) funded by the Ministry of Education(NRF-2014R1A2A2A01005900). Dr. CS Hong is the corresponding author.

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