Chapter 11

Game Theory and Femtocell Communications:

Making Network Deployment Feasible

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ABSTRACT

Game Theory (GT) is a natural paradigm to study and analyze wireless networks where players compete for the same resources. The importance of studying the coexistence between macro- and femtocells from a game theoretical perspective is multi-fold: First, by modeling the dynamic spectrum sharing among network players as games, the behaviors and actions of players can be analyzed in a formalized structure, by which the theoretical achievements in GT can be fully utilized. Second, GT equips us with various optimality criteria for the spectrum sharing problems, which are of key importance when it comes to analyzing the equilibrium of the game. Third, the application of GT enables us to derive efficient distributed algorithms for femtocell networks relying only on partial information. Without a doubt, the theory of learning in games is instrumental in allowing players to choose the right strategies and gradually learn from their environment until convergence.

1. INTRODUCTION

The provision of high data rate services imposes stringent requirements on cellular communication systems. Particularly, indoor users or those trying to communicate at cell border are severely affected by poor coverage and uneven guarantee of Quality of Service (QoS). In this context, the femtocell concept constitutes an inexpensive alternative to increase capacity, while coping with the scarcity of resources, providing better spectral efficiency and improving spatial reuse. However, the deployment of femtocell sites faces challenging obstacles: resource allocation, timing and synchronization, reliable IP backhaul, interference management,

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mobility control, self-organization and security issues. Among all the technical challenges, the Co-Channel Interference (CCI) arising from uncoordinated transmissions generated by other femtocells and the overlay macrocell is the most demanding (Chandrasekhar 2009; Claussen 2008 among others).

The expected contribution is this chapter is as follows: In the first section of the chapter, we show that the deployment of femtocell networks is cast into a dynamic spectrum sharing (Bennis 2009; Bennis 2010; Perlaza 2008) problem with different interference scenarios such as femtocell-to-femtocell and femtocell-to-macrocell interference. Femto Base Stations (FBSs) and their associated Femtocell User Equipments (FUEs) need to to autonomously determine their transmission strategies in order to maximize their own performance metrics. Often, this configuration is described by the power allocation scheme, channel/carrier selection, modulation scheme, etc. However, the transmission configuration of one femto-base station affects the performance of other FBS and all their associated FUEs. Hence, this scenario is clearly a competition of selfish autonomous devices for radio resources. Under these conditions, GT appears as one of the paradigms to study these types of networks. Finally, in this section, we provide the fundamental concepts of game theory required to understand the results presented in the rest of this chapter. The second section tackles one of the most important issues in self organized networks, namely learning. Due to their non-coordinated nature, femtocells opportunistically share the spectrum with the macrocell network while mitigating interference among each others. In order to do so, femtocells need to self-organize and optimize their strategies/actions (power level, carrier allocation etc) taking into account their side information. Learning is an inherent part of self-organization paradigms and is crucial for developing and adapting multi-agent strategies based on their perceived reward. The problem boils down as to how femtocells gradually learn from their environment (through trials-and-errors) while at the same time not interfering with the overlay macrocell network. Furthermore, learning is adamantly driven by the type of information available at every agent where the possibility of exchanging their local information drives the learning efficiency (and convergence) and thereby their respective pay-offs. For this purpose, we will investigate both private and public information exchange among femtocells. The third section looks into the QoS provisioning of femtocell networks, in which femtocells mitigate their interference towards the overlay macrocell network. Tools from game theory and Stochastic geometry are used to come up with decentralized algorithms to achieve the equilibrium (Lasaulce 2009) of the game. The fourth section investigates the spectral efficiency of femtocell networks using the framework of potential games. Here, typical problems such as power allocation and channel selection are tackled in detail. Finally, we discuss several decentralized algorithms which allow self-configuring femtocell networks to achieve the equilibrium.

Finally, all possible interference scenarios related to femtocell communications coexisting with one overlay macrocell network are outlined in Figure 1 where (1) refers to FUE-MBS UL interference, (2) refers to MBS- FUE DL interference, (3) refers to FUE-FAP UL interference, (4) refers to FBS-FUE DL interference, (5) refers to FBS-MUE DL interference and finally (6) refers to MUE-FBS UL interference.

1.1 System Model

We assume that there exists a set $N = \{1,\ldots,N\}$ of N frequency bands over which a Macrocell Base Station (MBS) can operate. Let $\Gamma_0^{(m)}, m \in M$, denote the minimum time-average SINR offered by MBS m over its corresponding fixed frequency band. Consider now a set $K = \{1,\ldots,K\}$ of K femtocells under-laying the M-cell N-frequency band macrocell system. Each femtocell can use

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