Chapter 8
Distributed Coalition Formation and Resource Allocation in Cognitive LTE Femto-Cells

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ABSTRACT

This chapter investigates resource allocation in a Universal Mobile Telecommunication System (UMTS) Long Term Evolution (LTE) network. Users form coalitions, each exploiting resources in a particular femto-cell, while occupying optimal resources in the sense that total network throughput is maximized. Users in each cell collaborate to increase network throughput and simultaneously attempt to increase their own payoffs subject to a fairness criterion. Payoffs to the users are defined as the monetary equivalent of the individual users' achievable throughput in the specified coalition structure. A distributed game-theoretic resource allocation mechanism is studied whereby users autonomously decide which sub-channel in which coalition to join. It is proved that if each user operates according to the proposed algorithm, the sum throughput of all links converges almost surely to its maximum feasible value.

8.1 INTRODUCTION

8.1.1 Game Theory

Next generation wireless communication systems are evolving towards more autonomous and distributed architectures with shorter communication links so as to provide truly mobile broadband connectivity services. The key motivation to adopt such a distributed networking approach is the possibility to substantially reduce transmission power while enhancing system capacity, e.g., through localizing (spatial offloading of) the traffic demand, exploiting cooperative diversity schemes and utilizing cognitive mechanisms.

DOI: 10.4018/978-1-4666-2005-6.ch008

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Several emerging standards manifesting such architectural paradigm shifts are currently in final preparation phases to achieve the goal of shaping the so-called 4G communications. One such candidate technology is the universal mobile telecommunication system (UMTS) long term evolution (LTE) and LTE-Advanced (LTE-A), developed in the framework of 3rd Generation Partnership Project (3GPP).

Amongst important features of the UMTS LTE standard, we emphasize the introduction of *X2* interface to facilitate direct interaction of base-stations (BSs) (3rd Generation Partnership Project, 2009). This novel architecture evolution alleviates the need for radio network controller (RNC) to centrally coordinate BSs as in previous generations of cellular technologies. 3GPP standards further support the deployment of low-power BSs, commonly known as *femto-cell BS (fBS)* (Knisely, Yoshizawa, & Favichi, 2009). Deployment of fBS sets the scene for inclusion of inexpensive reduced-scale access points with simple plug-and-play characteristic, primarily geared towards indoor applications. These developments yield a mixed wireless architecture comprised of randomly located hot-spot femto-cells within traditional macro-cells. Thus, macro-BSs and fBSs require intelligent resource allocation and sophisticated self-organizing capability in an interference-limited capacity regime.

Besides, it is now well understood that there are very few spectral ranges (particularly in the prime spectrum bands such as 300-3000 MHz) available to be dedicated to the next generation technologies. The scarcity of available frequency bands has excessively increased the cost of licensed spectrum, which mandates a considerable amount of investment from service providers. As a result, service providers are shifting towards *universal frequency reuse (UFR)* in network planning in order to maximally utilize their licensed spectrum. The choice of UFR, however, calls for adaptive scheduling methods to mitigate co-channel interference (CCI). In the LTE/LTE-A context, due to the provisioned architecture, coordination of resources among different BSs in a multi-cell scenario (as well as fBSs in an isolated cell) needs to be realized in a distributed manner. A promising tool to realize such distributed interference management solutions is *Cognitive Radio (CR)*. It is thus not surprising that several studies have investigated the potentials of cognitive fBSs in recent years (Lien, Tseng, Chen, & Su, 2010; Attar, Krishnamurthy, & Namvar Gharehshiran, 2011). In this chapter, it is assumed that fBSs are equipped with CR capability so as to avoid interfering with neighbouring cells.

As shown in Figure 1, users in both the macro-cell and femto-cells utilize resources belonging to the same service provider[1]. It is thus natural to assume that the service provider puts in place mechanisms to guide such entities to operate collaboratively so as to maximally exploit the licensed spectrum. At times, such egalitarian policy opposes individual user's desire of maximizing their own achievable throughput, hence, mandating a level of cooperation amongst users.

The main theme of this chapter is to motivate adopting collaborative strategies in LTE/LTE-A networking scenarios by illustrating superior long-term performance, as opposed to short-term greedy schemes such as opportunistic scheduling. We further embark on developing a novel distributed coalition formation and resource allocation scheme such that the *network throughput* is maximized subject to the local access constraints. Two questions that arise are: (i) what are the optimal coalition structures and resource allocations (in each coalition) to maximally utilize resources designated to the service provider? (ii) How can users, in a distributive fashion, form collaborative coalitions and be allocated optimal resources in the cells to ensure such a goal?

The above questions can be addressed within the framework of coalition formation in a cooperative game. The abstract formulation we consider is a non-superadditive cooperative game. The term non-superadditive means that the *grand* coali-

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