Chapter 7
Game Theory for Cognitive Radio

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ABSTRACT

Demands on high data rate applications are increasing and consequently demands on spectral resources are increasing as well. Although electromagnetic spectrum is recently said to be in a scarcity situation, several studies have shown that this scarcity is mainly due to the legacy command-and-control regulation rather than due to physical scarcity of spectrum. For this reason, researchers have started investigating techniques to better manage the usage of spectrum. Among these techniques there exist the methods allowing the primary/secondary usage of spectrum, or secondary market. Secondary market techniques mainly manage sensing, accessing, and aborting the spectrum usage by the secondary users. Techniques developed for secondary market context are also referred to as algorithms for Cognitive Radio (CR) networks. Regulators worldwide took measures to promote the deployment of primary/secondary context. In this chapter, the authors give an illustrative discussion on CR and on the application of game theory to overcome the spectrum scarcity problem. Game theory is a field of applied mathematics that describes and analyzes scenarios with interactive decisions. In recent years, there has been considerable interest in adopting game theoretic approaches to model many communications and networking problems such as radio resource management and routing. Nowadays, game theory is also used to model interactive situations for CR terminals.

7.1 INTRODUCTION

We start the chapter by giving a brief about the efforts carried out by regulators to introduce the primary/secondary context. We give an overview on game theory and we discuss the motivations for game theory usage in CR networks modeling. We illustrate the concept of "Nash equilibrium" and we discuss both the convergence and the efficiency of the equilibrium. We also present for the reader examples from the literature on game theory application in cognitive radio networks.

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Several studies, initiated recently by the US regulator Federal Communications Commission (FCC), have shown that the frequency spectrum is underutilized and inefficiently exploited: some bands are highly crowded, at some day hours or in dense urban areas, while others remain poorly used. Regulators worldwide are beginning to recognize that the traditional way of managing the electromagnetic spectrum, called Fixed Spectrum Access (FSA), in which the licensing method of assigning fixed portions of spectrum, for very long periods, is inefficient (Liu, 2011).

Among the efforts taken, by regulators worldwide, in order to achieve better usage of spectrum is the introduction (promotion) of secondary markets. In a secondary usage context, the spectrum owned by the license owner (also called primary user) can be shared by a non-licensee referred to as a secondary user. As an example of these efforts, FCC in USA proposes two models of spectrum leasing to promote the secondary markets. In the proposed models the constraints on the *license owner* and on the *duration of the license* are relaxed[1]. The two models are named De-facto transfer and spectrum manager. In the former model the lessee is responsible of reporting back to FCC the rules compliance with the original license terms. In the latter model, the primary owner is responsible of reporting to FCC.

Regulators in Europe have also taken measures to overcome the spectrum scarcity problem. In France, a secondary market has been recently allowed in the band 3.4−3.6 GHz, where two licenses have been awarded to deploy WiMAX based Wireless Local Loop (WLL) services. It is possible for the license owner to resell the whole license or a part of it. Reselling a part of the license may concern the geographical area, the frequency band, or the license duration. It is also possible for the license owner to keep the license while authorizing another entity to use the frequencies. In this case the primary user is responsible to fulfill the license obligations (Coupechux, Godlewski & Kumar, 2007). The British regulator, Ofcom, proposes a similar framework named spectrum trading. The main difference from the French framework is that the spectrum trading can be applied to several bands, such as cellular, Private Mobile Radio (PMR), or WLL, as given in (OFCOM, 2002).

Besides the promotion for secondary markets, we are currently experiencing rapid evolutions of Software Defined Radio (SDR) techniques. Such techniques allow reconfigurable wireless transceivers to change their transmission/reception parameters, such as the operating frequency that can be modified over a very wide band, according to the network or users' demands. The efforts taken by regulators in order to make better usage of spectrum, in particular the promotion for secondary market, together with the rapid evolution of the SDR techniques, have led to the development of opportunistic Cognitive Radio (CR) systems.

The term Cognitive Radio (CR) was first introduced by Mitola in 1999, and it was defined as: "*The point in which wireless personal digital assistants (PDAs) and the related networks are sufficiently computationally intelligent about radio resources and related computer-to-computer communications to detect user communications needs as a function of use context and to provide radio resources and wireless services most appropriate to those needs*." (Mitola & Maguire, 1999). CR generally refers to a radio device that has the ability to sense its Radio Frequency (RF) environment and modify its spectrum usage based on what it detects (Sherman et. al., 2008).

7.1.1 Game Theory

Game theory is a decision-making mathematical tool that studies and analyzes interactions among decision makers, whether in conflict-of-interests, or in cooperation situations. It is a tool that provides outcome expectations in complex interactive situations. Game theory was first introduced by John Von Neumann and Morgenstern in 1944 upon publishing "*The Theory of Games and Economic*

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