Chapter 4
Self-Organization in IEEE Standard 1900.4-Based Cognitive Radio Networks

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ABSTRACT

Distributing Radio Resource Management (RRM) in heterogeneous wireless networks is an important research and development axis that aims at reducing network complexity, signaling, and processing load in heterogeneous environments. Performing decision-making involves incorporating cognitive capabilities into the mobiles such as sensing the environment and learning capabilities. This falls within the larger framework of cognitive radio (Mitola, 2000) and self-organizing networks (3GPP, 2008). In this context, RRM decision making can be delegated to mobiles by incorporating cognitive capabilities into mobile handsets, resulting in the reduction of signaling and processing burden. This may however result in inefficiencies such as those known as the "Tragedy of commons" (Hardin, 1968) that are inherent to equilibria in non-cooperative games. Due to the concern for efficiency, centralized network architectures and protocols keep being considered and being compared to decentralized ones. From the point of view of the network architecture, this implies the co-existence of network-centric and terminal-centric RRM schemes. Instead of taking part within the debate among the supporters of each solution, the authors propose a hybrid scheme where the wireless users are assisted in their decisions by the network that broadcasts aggregated load information (Elayoubi, 2010). At some system's states, the network manager may impose his decisions on the network users. In other states, the mobiles may take autonomous actions in reaction to information sent by the network. Specifically, the authors derive analytically the utilities related to the Quality of Service (QoS) perceived by mobile users and develop a Bayesian framework to

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obtain the equilibria. They then analyze the performance of the proposed scheme in terms of achievable throughput (for both mobile terminals and the network) and evaluate the price of anarchy which measures how good the system performance is when users play selfishly instead of playing to achieve the social optimum (Johari, 2004). Numerical results illustrate the advantages of using the hybrid game framework in a network composed of HSDPA and 3G LTE system that serve streaming and elastic flows. Finally, this chapter addresses current questions regarding the integration of the proposed hybrid Stackelberg scheme in practical wireless systems, leading to a better understanding of actual cognitive radio gains.

1. INTRODUCTION

In tomorrow's Beyond 3G context, numerous heterogeneous Radio Access Technologies (RAT) will have to coexist including of course the new 3GPP LTE, but also legacy 3GPP technologies (like GSM/GPRS/EDGE and UMTS/HSDPA) and also non-3GPP technologies like WiFi. Since mobile devices are also becoming multi-mode and may hence access several of these technologies, the need for a coordinated resource management encompassing all these technologies arises: an efficient traffic balancing is namely required for an optimal usage of the deployed network equipment and an improved user experience. In the medium term, new Software Defined Radio (SDR) equipment will enable flexible spectrum management like Dynamic Spectrum Assignment (DSA), and dedicated resource management mechanisms will be required (3GPP, 2008). Self-Organizing Network (SON) is currently considered as a key lever to minimize operational costs and optimize delays of deploying and running a network by reducing and eliminating manual configuration and maintenance of network operational parameters at the time of network planning, network deployment, network operations, and network optimization. Different standardization bodies have picked up this topic, and SON functionalities are expected to become widely commercially available with the introduction of 4G networks (3GPP, 2008).

This chapter presents some background on the research leading to the future deployment of the IEEE standard 1900.4. We highlight different classes of techniques and algorithms which attempt to realize the various benefits of introducing game theory as an efficient technique for the analysis of such cognitive radio networks. Based on tools from non-cooperative and Bayesian games, we develop a Bayesian framework to analyze the performance of the proposed IEEE 1900.4 cognitive radio network. In order to improve the performance of the non-cooperative scenario, we investigate the properties of an alternative solution concept named Stackelberg game, in which the network tries to control the users' behavior by broadcasting appropriate information, expected to maximize its utility, while individual users maximize their own utility.

The IEEE Standard 1900.4 offers a solution specifically tailored to answer these needs. It proposes a distributed approach for optimized inter-system resource management: a Terminal Reconfiguration Manager (TRM) entity located in each mobile takes autonomous decisions to access the RAT that will best fit with user-specific expectations (e.g. maximize throughput, or increase battery life, minimize cost, etc.). To guarantee that the global system efficiency will be preserved in spite of individual (and potentially selfish) decisions from the mobiles, a Network Reconfiguration Manager (NRM) entity located in the network gives global recommendations that help the mobiles to take appropriate decisions. These recommendations are conveyed by so-called "policies" broadcast to the mobiles, and constrain the mobiles to take acceptable actions from network point of view. The proposal to introduce a logical