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Power trading in cognitive radio networks

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ABSTRACT

Cognitive radio technology has been proposed to improve spectrum utilization by sharing the frequency spectrum bands between licensed and unlicensed users, called primary users (PUs) and secondary users (SUs), respectively. The main objective of the SUs is to achieve their quality of service (QoS) by exploiting the unused parts of the spectrum, while the PUs aim to reap extraordinary profits by leasing their unused portions of the spectrum. Pricing and transmission power are two key issues of interest to both PUs and SUs. Game theory has been considered as a useful tool for discussing the power control issue in wireless networks. In this paper, we consider the issue of power trading and propose two different models. First, a power-pricing model without game theory is developed, wherein the PUs obtain some revenue by renting their unused frequencies to SUs that use suitable power levels to transmit. The suitable power level ensures that the use of the spectrum by SUs does not interfere with other users in the network. Second, a non-cooperative game is applied to the proposed pricing model among the system users (i.e., PUs and SUs), to create balance between them. This balance point is known as the "Nash equilibrium." Performance evaluations of the proposed models are provided, demonstrating their efficiency and how they help in using the frequency spectrum more efficiently. The developed models allow the PUs to increase their gained profit while the SUs can use the spectrum for their data transmissions.

1. Introduction

In modern society, people want to access the Internet from anywhere and at any time. This desire results in the augmentation of spectrum demand. Simultaneously, the number of web-based applications is rapidly increasing; yet spectrum resources remain limited. Therefore, limitations in spectrum resources and high spectrum demand lead to the problem of spectrum scarcity.

In most countries around the world, the spectrum is allocated exclusively to licensed users; however, if the licensed users do not actually use this spectrum, it is still considered used, despite the fact that it is actually unused (wasted). Recent spectrum utilization measurements have shown that the use of the spectrum is concentrated on certain portions of it, while significant amounts are severely under-utilized. The Federal Commission Communication (FCC) chart clearly shows the unused portions of the spectrum, as indicated in Fig. 1 (Mitola, 1999).

In order to increase spectrum utilization in an efficient way, new spectrum-sharing models must be produced. The FCC allows sharing the spectrum among both types of users (i.e., unlicensed users and licensed users), so long as unlicensed users respect licensed users' rights.

Many solutions have been introduced to overcome the spectrum scarcity problem. Dynamic spectrum access (DSA) is one such solution, wherein the spectrum is dynamically utilized. It enables users to adjust communication parameters (such as operating frequency, transmission power, and modulation scheme) in response to changes in the wireless environment (Akkarajitsakul et al., 2011; Mishra et al., 2005; Weiss et al., 2003).

Cognitive radio (CR) has two types of users: the licensed users, which are referred to as primary users (PUs), and the unlicensed users, which are referred to as secondary users (SUs). The PUs get the spectrum bands from their service providers and have the ability to use the bands whenever they want, while the SUs must first detect the absence/presence of PUs in their spectrum bands before using them.

Power is consumed when the spectrum is used by any type of user. This value of power should be in an acceptable range, so that it does not affect the performance of the whole system. The spectrum owners (i.e., PUs) use the full capabilities of their frequency bands, while the SUs can use the partial or full capability of the frequency bands of the PUs. The SUs can use low power levels to transmit over the frequency bands of the PUs; however, if they

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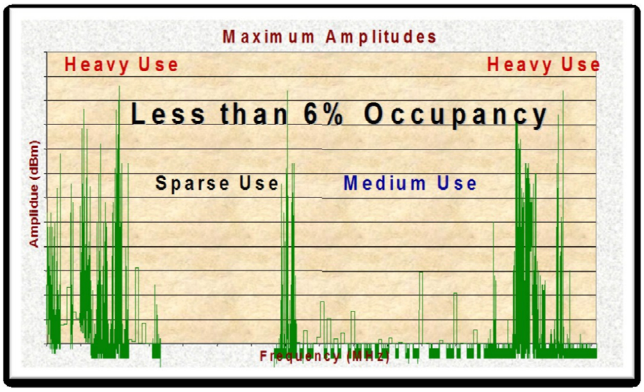

Fig. 1. Spectrum utilization (Mitola, 1999).

want to use the capabilities of the frequency bands, they should pay for it.

Spectrum trading is the process of leasing the frequency bands of PUs to SUs, whereby the SUs pay for the use of the bands. The PUs allow SUs to use proper power levels to achieve the QoS desired by SUs while not harming other users in the network. The PUs reap high revenues from this leasing plan.

The big challenge in CR is determining how to develop a model that represents the spectrum-trading process. Any developed model should take into consideration the different goals of the various types of users and create a balance between these conflicting goals.

Game theory is a tool widely used in both wireless networks and CR networks, and previous studies have shown that more balance is achieved between the different aims of the different users (i.e., PUs and SUs) in the CR network by applying game theory.

We have two main contributions in this paper. First we develop a model for power trading process wherein PUs lease their unused spectrum channels to SUs which are willing to pay the channels rent. Second, we apply the game theory to the power trading model taking in consideration the different users' requirements. The power trading model without game theory aims at increasing the PUs profit by leasing their unused spectrum channels while the power trading model with game theory makes a balance between the conflicting objectives of PUs and SUs by applying the game theory concepts. Both the models have following objectives: to let SUs use proper power levels for their transmissions which should not harm other users in the system, to increase the number of users that utilize the spectrum, to consider the requirements of the SUs in CR networks, to enhance the efficiency of the spectrum utilization, and to consider the conflicting objectives of both types of the users in the CR network.

The rest of this paper is organized as follows: Section 2 shows an overview of cognitive radio network and game theory. Section 3 presents related work. In Section 4 we propose the general view of the system developed. The non-game theoretic approach and its performance evaluation are shown in Section 5. In Section 6 the game theoretic model is shown as well as its performance evaluation. We conclude this paper in Section 7.

2. Background

2.1. An overview of cognitive radio

The principle of cognitive radio (CR) was first mentioned and explained by Mitola (1999). CR is defined as an efficient technology that allows more users to access the available spectrum. It is a radio that can change its transmitter parameters based on interaction with the environment in which it operates. Two characteristics are identified from the previous definition: cognitive capability and re-configurability (Mitola, 1999). Cognitive capability represents the ability of the radio technology to capture or sense the information from its radio environment. Through this capability, the spectrum portions that are unused at specific locations or times can be identified. The characteristic of re-configurability enables the radio to be dynamically programmed in response to the radio environment. As most of the spectrum is assigned to specific users, PUs, the most important challenge is to share the licensed spectrum between licensed users (PUs) and unlicensed users, SUs.

Spectrum management in CR involves SUs sharing the spectrum with the PUs in such a way that the conflicting users' goals may all be attained. Spectrum trading was recently recognized as one of the most important issues of spectrum management in cognitive radio networks (CRNs), wherein the spectrum owners (PUs) try to lease some of their frequency bands to the secondary users (SUs) to use for their data transmission. Each type of user has different objectives within the trading process. The PUs attempt to obtain increasingly greater profits by leasing their channels, while the SUs try to use the spectrum to achieve a higher QoS while simultaneously trying to pay the least amount possible. The QoS goal on the SUs side is to achieve an efficient rate for the transmission of their data while not harming the PUs and other SUs with high interference.

Another issue in spectrum management concerns power control. This refers to the way both users (PUs and SUs) employ proper power levels to transmit over the different spectrum channels. These power levels should be precisely chosen to avoid high levels of interference, which may lead to high noise and lower levels of spectrum utilization. Power trading is considered a new issue to be addressed in CR networks wherein the spectrum management and power control issues are merged together. The main focus of this paper is to develop new approaches that both consider and try to balance the objectives of the different users.

2.2. Game theory

A number of mathematical models and techniques have been developed in economics to analyze interactive decision processes, predict the outcomes of interactions, and identify optimal strategies (Akkarajitsakul et al., 2011). Game theory technique is one such model. Game theory techniques have also been adopted to solve many protocol design issues (e.g., resource allocation, power control, and cooperation enforcement) in wireless networks (Akkarajitsakul et al., 2011). By using game theory, we can find various solutions for many issues appearing in a CRN, such as spectrum sensing, power control, spectrum sharing, and spectrum trading.

One of the most basic yet important elements in game theory is the notion of a game. In each game, there are three components that represent it: the players, their action sets (strategies), and the payoffs.

- Players: A set of rational actors who have their own interests.
- Strategies: A set of actions that have to be applied by the players to achieve their interests.
- Payoff/utility: The outcome from playing the game.

In CRNs, the players are the users, the PUs and SUs. Each type of player (i.e., PU or SU) has his or her own strategy to choose (e.g., the assigned bandwidth, the spectrum price, power level to be used for data transmission, etc.) in order to achieve his payoff, which could be high profit, high efficiency, less delay, low jitter,