Game Theory and Adaptive Modulation for Cognitive radios

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ABSTRACT

In a multi-user cognitive radio network, there arises a need for coordination among the network users for efficient utilization of the available electromagnetic spectrum. While adaptive modulation alone helps cognitive radios actively determine the channel quality metric for the next transmission, Game theory combined with an adaptive modulation system helps them achieve mutual coordination among channel users and avoids any possible confusion about transmitting/receiving through a channel in the future. This paper highlights how the concepts of game theory and adaptive modulation can be incorporated in a cognitive radio framework to achieve better communication for telemetry applications.

KEYWORDS

Cognitive radio, Game theory, Adaptive modulation, normal form game.

1. INTRODUCTION

The commonly used radio systems are unaware about the electromagnetic environment around them and they operate in a specific band of frequency, given to them by the Federal Communication Commission (FCC). According to measurements done by the FCC, 85% or more of the total allocated spectrum remains unoccupied most of the time [1, 2]. Cognitive radios use these vacant frequency holes to communicate among each other. They sense the immediate Radio Frequency (RF) environment and operate in a band that is available and appropriate, dynamically adjusting its frequencies, modulation, power, coding etc. They are new models of communication system that would be clever enough to work through all kinds of interferences.

In [3], the author talked about how the concepts of adaptive modulation system can be incorporated in cognitive radio systems to best utilize the available channel. The author also discussed basic mathematical models for different fading channels and how an adaptive modulation system adapts to varying channel conditions. With the implementation of an adaptive modulation based cognitive radio systems, the radios can achieve a significant amount of spectral efficiency in a dynamically changing channel, however, they still encounter the problem of a possible conflict in using the channel for transmission and reception in a multi-user environment.

This situation can however be solved by using the concepts of Game Theory proposed in [4]. The authors propose different models of a game and discuss how the interactions of a network of cognitive radios can be mapped into a game.

2. COGNITIVE RADIO AND GAME THEORY

Cognitive radios are adaptive radios that are aware of their environment, capabilities, their intended use, and are able to learn from their experience in new operational scenarios.

Game Theory is a mathematical tool that can be used to model and analyze interactive decision processes. The concept of the game theory lies in the notion of a game. When expressed in normal form, a game $G = \langle N, A, \{u_i\} \rangle$ has the following three primary components [4].

1. A finite set of players (decision makers) typically denoted by $N = \{1, 2, 3, ...\}$.
2. An action space, A, formed by the Cartesian product of each player's action set, $A = A_1 \times A_2 \times A_2$.
3. A set of utility functions, $\{u_i\} = \{u_1, u_2, u_3, ..., u_n\}$, that quantify the players' preferences over the game's possible outcomes. Outcomes are determined by the particular action chosen by player i, a_i , and the particular actions chosen by all of the other players in the game a_{-i} .

In the game, the players are assumed to act in their own self-interest, that is to say, each player chooses its actions in such a way that increases the number returned from its utility function. Typically normal form games are analyzed to identify steady states known as Nash equilibrium. A particular action tuple, a^* in A, is said to be in Nash equilibrium if no player can improve its payoff, $u_i(a^*)$ by unilaterally changing its action [4].

Another typical game model is the repeated game model, in which a sequence of stages where each stage is the same normal form game. A repeated game is fully characterized by a stage game, a player function that defines which players are allowed to adapt play in that stage, and a set of decision rules that describe the rules that each player follows to update its decisions when it is that player's turn to play.

Whenever a cognitive radio system is mapped into a game theoretical model for an adaptive algorithm, there arise five important concerns [4]:

1. If the adaptive algorithms have steady state?
2. What are those steady states?
3. Is/are the steady state(s) desirable?

4. What restrictions need to be placed on the decision update algorithms to ensure convergence?
5. Is/are the steady state(s) stable?

While questions 1 through 3 can be addressed through the traditional game theory techniques, questions 4 and 5 require additional information that can be provided through the introduction of certain game models. In [5], authors argue that determining if a steady state is desirable is best determined by showing the steady state maximizes some global network objective function.

In [3], the author discusses about how the performance of a wireless communication system is affected by multipath fading resulting in rapid fluctuations in radio channels. In such channels adaptive modulation boasts of being a robust and spectrally efficient method of communication. In adaptive modulation, the system alters its transmission parameters like power, data rate, coding and modulation schemes, or any combination of these in accordance with the state of the channel, by taking the advantage of the time-varying nature of wireless channels. However, the problem arises when there are multiple users trying to adapt to the same channel conditions. In such a situation cognitive radios must learn how to co-exist with other radios trying to use the same resource. This mutual harmony among the cognitive radios trying to access the same resource can be best explained by the concepts of Game theory, whose model has been discussed above.

CONCLUSIONS

While a significant amount of work has been done in the development and demonstration of the feasibility of a cognitive radio, the vast majority of the work has focused on demonstrating the gains a single link can achieve when adapting to an interference environment. While results from these works are significant, the underlying assumptions are not realistic because the modeling of the environment and operating conditions fail to consider the existence of multiple cognitive radios, a major source of interference. When a number of cognitive radio are collocated, this interference environment may be constantly changing as the radios adapt to other cognitive radios adaptations, as a result of which serious recursive concerns arise. To address the issues arising due to these situations, game theory incorporated adaptive modulation based cognitive radio systems are well suited. This paper highlighted a few basic ideas about how an adaptive modulation based cognitive radios can benefit from the concepts of the Game Theory.

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