Implementing Game Theory in Cognitive Radio Network for Channel Allocation: An Overview

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Abstract

Cognitive radio network has been introduced for better utilization of spectrum in wireless network. With change in environment cognitive radios have to change their operating parameters to achieve certain goals. Traditional approach for resource allocation is not applicable on self organizing networks e.g. Ad-hoc cognitive radio networks (AHCRN). In order to tackle the issues related to spectrum allocation game theory has been used. Game theory analyzes and models the interactions among users and allocates resources to users. In this paper we introduced how game theory has been used to model various interactions among cognitive radios in AHCRN. Game theory can be used at physical layer, data link layer, network layer and at higher layers also.

Keywords: cognitive radio network, game theory, resource allocation

1. Introduction

These days wireless communication is common in the area of communication technology. Wireless spectrum is used by various wireless devices. Some uses licensed band and some used unlicensed band. Unlicensed is used by Bluetooth, 3G, digital cordless phone, wifi, NFS, ZigBee, *etc*. Unlicensed band remains overcrowded and licensed band is not used all the time and remains free for most of the time licensed band. According to a study licensed band is used 15-85% only and hence is underutilized.

The heavy use of unlicensed spectrum caused scarcity of spectrum. To solve this problem cognitive radio network has been introduced [1]. In cognitive radio network licensed users (LU) and unlicensed or CR users coexists. CRN utilizes the spectrum efficiently by allowing unlicensed users to use licensed band when it is not by primary licensed users. LUs are give priority over CRs *i.e.*, LU's transmission should not be interrupted by CRs [2, 3]. All unlicensed users are equipped with cognitive transmitter that senses the holes in spectrum band (white space or spectrum opportunity). Cognitive radios should be aware of dynamic environment and hence changes there parameters accordingly for enhancing network performance. It means CRs must be intelligent about spectrum sensing, have ability to learn observe and must optimize network performance. Traditional spectrum management technique cannot be used in this scenario because it considers static environment and cooperative behavior of users.

Due to co-existence of two types of networks with conflicting goals, users will cooperate only if it is beneficial to them in terms of resources, and hence there is a great challenge while allocating resources to users as they can behave in non cooperative

manner. In order to resolve the challenges in CRN, we need some analyzing tools that can control the CRN and optimize the performance of network. Game theory provides variety of mathematical tool that that can be efficiently used in studying, modeling, and analyzing the cognitive interaction process, and designing efficient, self-enforcing, distributed and scalable spectrum sharing schemes [4].

Game theory is a mathematical tool which is used to study various interactions between rational players. It provides the tools for predicting the result of various interactions between users with conflicting goals. In the recent years game theory has gained popularity in CRN. Game theory plays a significant role for resource management in CRN.

Remaining of the paper is organized as follows. In Section II, resource management problem is shown. In Section III basics of game theory are discussed. How game theory has been applied in CRN for channel allocation is discussed in Section IV. In Section V paper has been concluded.

2. Resource Management in CRN

Objective of spectrum management is to provide good QoS to CR users and minimizing interference to licenses users when resources are allocated to CR users, while keeping two points in consideration [5]: first is channel selection and power control, second is spectrum coordination while sharing spectrum with licensed users. Based on game theory resource allocation technique can be classified as: 1. overlay spectrum sharing 2. Underlay resource sharing.

Table 1. Spectrum Access Technique Description

Spectrum access	Description
Overlay spectrum sharing	LUs allow the CRs to access the spectrum left unoccupied by LUs. Spectrum sensing is required in this scenario to avoid any generated interference to the licensed users. Overlay spectrum put more effort on when and where the CRs may use/leave the available band
Underlay resource sharing	Both LUs and coexist in a network and try to access the same spectrum band. There for the transmission power for CRs should be well-controlled to minimize the interference with LUs within acceptable level. Its primary goal is to provide good QoS for CRs, and to protect LUs from harmful interference.

3. Basics of Game Theory

Game theory is a mathematical tool that analyzes various interactions between rational players [6]. It is a collection of modeling tools that aid in the understanding of interactive decision problems. Game theory was first introduces in 1944 by J. von Neumann and O. Morgenstern. Game theory has been used in various fields from several years and has recently gained attention in the field of CRN.

Broadly game theory is of two types first is cooperative game theory which consider all CR users are cooperative and aims to maximize total network performance by achieving Nash Bargaining state. Individual user shares their vital information like utility with other users in network. Second is non cooperative game theory which considers CR users as rational users and aims to maximize their own utility function *i.e.*, allocating resources. This type of game converges at Nash equilibrium state. Individual users don't have access to the strategies and payoff of other users.As CRN have rational nodes there for non

cooperative game theory has been extensively used to analyze cognitive radio network in game theoretic framework.

Basically game theory has three components 1) set of players: in this context players are nodes of CRN. 2) Set of actions: in this context actions may be available modulation scheme, coding rate, protocol, flow control parameter, transmit power level, or any other factor that is under the control of the node. 3) Utility function: in this context it can be Throughput, delay, SINR, and QoS of CRNs.

Appropriately modeling utility function is one of the most challenging aspects of the application of game theory. Utility Function is a set of objective functions that each player wishes to maximize. Action chosen by a player is denoted by ai and action chosen by other players is denoted by a-i. a lot of utility functions have been considered related to the resource allocation problem in CRNs. Commonly used utility functions is signal-to-interference-plus-noise ratio (SINR)) which has been used to maximize the efficiency of spectrum.

4. Study of CRN in Game Theoretic Framework

Non-cooperative game theory is used to allocate channel to CRs in CRN. Aim of the game theory is to reach at Nash equilibrium state. The utility function of [7] is total throughput of links. For [8] utility function is based on interference to other links and interference from other links. While the utility function considered in [9] is weighted sum of received power, interference to other links and interference from other links. Here links are fixed *i.e.*, network is not mobile. Weights of these terms can be varied according to requirement of network *i.e.*, high overall throughput, low interference or a tradeoff between both. Throughput of CRN should not be increased at the cost of interference. Simulation showed best results when all the terms are weighted 1. Utility function used by system is

$$U_i(s_i, s_{-i}) = +\alpha p_i h_{ii} - \beta \sum_{j=1,j\neq i}^{N} [p_j h_j I(s_i, s_j)] - \gamma \sum_{j=i,j\neq 1}^{N} [p_i h_{ii} I(si, sj)]$$

Where first term denotes the power received at receiver from transmitter on same link, second term denotes the interference from other links and third term, interference to other links. The values of α, β and γ can be varied according to converge the system to a particular point according to the requirements like high throughput, low interference or combination of both.

To measure the performance of network a performance index (PI) for link has been considered based on overall throughput and interference to other users.

$$PI_{ii} = T_{ii} - X(s_{i,\rightarrow,-i})$$

Overall PI is defined as the sum of all N links' Pii.

In this paper [9] both cooperative and non cooperative schemes have been considered. In both cases equilibrium solution (Nash equilibrium) is needed. Here game reaches to multitude of NE.

- Bandwidth allocation based on cooperative game

1. Compare the potential function [8] at (t-1) and (t-2).

$$P(s_i, s_{-i}) = \sum_{i=1}^{N} U(s_i, s_{-i})$$

2. If P (t-1)>P (t-2), increase the value of *width_inc* by certain amount. Where *width_inc* denotes the probability of getting that particular strategy at that time by user *i*.

3. Repeat the above steps for all iteration. The game will converge when all the values of matrix *weight_ch* are 1 or 0. Here 1 represents that channel selected by a user. For remaining channels value corresponding to that user is 0.

- bandwidth allocation using non-cooperative game

1. In non cooperative games as user don't have access to other users' strategy and payoff information therefore instead of potential function, individual utility is considered in above algorithm.

Simulation results showed that cooperative game scheme had better PI as compared to non cooperative scheme for different values of α, β and γ. Highest value of PI is achieved when throughput and interference to and from other links has been considered ([α β γ]=[1 1 1]).

Cooperative game theory considers that nodes share their vital information with other nodes and have all the information before making a decision but players only have partial information in advance for making a decision. This scenario has been considered in [10] and an algorithm has been proposed based on game theory for resource allocation. According to proposed game player are cognitive radio terminals, strategy is to choose best resources differently from the operating environment and the opponent player's choices. A resource allocation matrix Q^π has been used to represent played strategies, which contains the information about the resources allocated to nodes. Some constraints have been applied to matrix. Constraint on maximum number of resources that can be allocated to i[th] user is defined as:

$$\sum_{k=1}^{k} Q_i{}^\pi(k) \le Q^\pi{}_{max}$$

Where $Q_i\Pi$ represents the amount of power the ith user is allocating to kth subcarrier. Minimum amount of resources that should be allocated to k[th] subcarrier for i[th] terminal is given as:

$$Q_\mathrm{i}{}^\pi(\mathrm{k}) \ge \frac{SINR_{min}^\pi (\sum_{j=1,j\neq i}^{p} h_j^\pi(k) p_j^\pi(k) + u^{l\rightarrow\pi}(k)P(k) + N(k))}{h_i^\pi(k)}$$

Eq (1)

In order to protect the primary system maximum amount of resources that can be allocated to k[th] subcarrier for i[th] terminal is given as:

$$Q_\mathrm{i}{}^\pi(\mathrm{k}) \ge \frac{h^l(k)P^l(k)}{SINR_{min}^\pi u^{l\rightarrow\pi}(k)} - \frac{\sum_{j=1,j\neq i}^{P} u^{l\rightarrow\pi} P_j^\pi(k)}{u^{l\rightarrow\pi}(k)} - \frac{N(k)}{u^{l\rightarrow\pi}(k)}$$

Eq (2)

In case above inequalities don't have a common interval of real number resources will not be allocated on that subcarrier. In that case utility function for ith is defined as in eq (3) below

$$u_\mathrm{i}(Q^\pi) = \sum_{j=1}^{K}(Blog_2[1 + SINR_\mathrm{i}(Q^\pi(j)] - \sum_{m=1}^{M} \mu^{\pi\rightarrow l}(j)p_m^\pi(j))$$

From reference [13-15]

$$u_i(Q^\pi) = \max_{p_i p_j} \min_{w_i w_j} [\pi_i(p_i, p_j w_i w_j) + \pi_j(p_i, p_j w_i w_j)]$$

$$= \max_{p_i p_j} \min_{w_i w_j} [p_i(\beta_i - \gamma_i p_i) - w_i(\beta_i - \gamma_i p_i) + p_j(\beta_j - \gamma_j p_j) - w_j(\beta_j - \gamma_j p_j)]$$

Eq (4)

Using equations (1), (2), (3) and (4) a potential function has been derived

$$V(Q_i^\pi) = \max_{p_i, p_j, w_i, w_j} [p_i(\beta_i - \gamma_i p_i) + p_j(\beta_j - \gamma_j p_j) - \lambda c_{si}(\beta_i - \gamma_i p_i) - \lambda c_{sj}(\beta_j - \gamma_j p_j)]$$

$$= \sum_{j=1}^{K} (B log_2[\alpha_i(k) + h_i^\pi(k)p_i^\pi(k)] - \mu_i^{\pi \to I}(j)p^\pi(j) - \beta_i(j) - N(j)$$

The algorithm proposed in [10] achieves higher rates but it cannot be implemented in disturbed way. Its practical use is also not possible as its complexity rises exponentially with raise in number of users. In order to achieve global optimization for distributed channel selection author in [11] proposed a POMDP and a game theoretic framework. This model maximizes the network throughput and minimizes network collision. POMDP is generalization of MDP. This new spectrum sharing model enhances the cooperation between users of network and reduces collision. POMDP determines the access probability of each unlicensed user and reduces the collision with licensed users. Potential game theoretic framework and joint strategy fictitious play determines the access probability of unlicensed user and reduces the collision with other unlicensed users. This enables the cooperation between licensed users and multiple unlicensed users.

A spectrum management model has been proposed by [12] using game theory (SMG) and without game theory considering network performance. SMG has two stages first stage is between licensed users and used Bertrand game concept. Second stage is between licensed users and unlicensed users where stackelberg game concept has been used.

Stackelberg consider licensed users as leader and unlicensed users as follower. Information and strategy sets are defined for both licensed and unlicensed users as QL IL QF IF. Initially Qf=IL. Initial strategy chosen by leader is denoted by qL0 where qL0ϵqL subset of QL Strategy chosen by follower in response to leader is called reaction strategy and is denoted by qF*ϵQF that maximize its payoff UF.

$$q_{F*} = \max U_F(q_F; q_{L0})$$

$$q_{L*} = \max U_L(q_L; q_{F*})$$

After knowing reaction strategy leader chooses a strategy belonging to subset qL of QL that maximize its payoff UL. To optimize utility function of follower (UF) licensed user chooses the price Pbi for spectrum b and unlicensed users selects the best size if spectrum which has higher level of QoS. Based on Bertrand game in this model, the licensed users set different prices that allow unlicensed user to select the lowest price among the offered prices. A price is set by each licensed as given in equation below based on α value. Each LU's objective is to maximize its utility by getting more unlicensed users.

Utility function of unlicensed user consists of five parts:

i.   Satisfaction of its own transmission

ii.   Revenue from selling spectrum to the secondary user

iii.   Profit

iv.   The corresponding payment to the base station

v.   The performance loss due to the shared spectrum with the secondary users.

Its simulation results showed that spectrum management with game theory is better than spectrum management without game theory as it changes the solution dynamically.

5. Conclusion

In this survey we have studied that how game theory has been used in cognitive radio network for channel allocation. Implementing game theory in CRN improves network performance. Future research work is to reduce communication overhead among neighbor nodes. Another direction of research is to work on mobile CRN.

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