Enhancement of Capacity in a MC-CDMA based Cognitive Radio Network Using Non-Cooperative Game Model

Kalyani J. Kulkarni, Bharat S. Chaudhari

Abstract—This paper addresses the issue of resource allocation in the emerging cognitive technology. Focusing the Quality of Service (QoS) of Primary Users (PU), a novel method is proposed for the resource allocation of Secondary Users (SU). In this paper, we propose the unique Utility Function in the game theoretic model of Cognitive Radio which can be maximized to increase the capacity of the Cognitive Radio Network (CRN) and to minimize the interference scenario. Utility function is formulated to cater the need of PUs by observing Signal to Noise ratio. Existence of Nash Equilibrium for the postulated game is established.

Keywords—Cognitive Networks, Game Theory, Nash Equilibrium, Resource Allocation.

I. INTRODUCTION

COGNITIVE RADIO (CR) is a promising technology which extends the Software-defined Radio concept to improve the spectrum utilization. Secondary User (SU) in a Cognitive Radio Network (CRN) is able to operate in the licensed band by adjusting its transmission parameters. The Cognitive term was introduced in [1] with the new communication system that can observe and learn from the surrounding radio environment as well as can adapt its own transmission parameters by keeping user requirements in view. FCC Spectrum Policy Task Force reported that a large amount of spectrum is under-utilized [2]. In order to improve the utilization of the spectrum, a secondary system must coexist with the primary system (licensed network). This secondary system must bound the interference caused to the primary system. This implies that Resource Allocation (RA) is the key challenge in the successful implementation if Cognitive Radio Technology. The introduction of CR technology poses new Resource Allocation (RA) problems that need to be solved. Compared to conventional wireless communication systems, two new issues arise, namely, the interference power to the PU bands should be kept below a certain threshold and good Quality of Service (QoS) should be provided to CRs in spite of the time-varying nature of the available spectrum. To make unlicensed sharing of the licensed spectrum a reality, PU operation must not be compromised. Thus, CRs should monitor and keep the generated interference to PU bands to an acceptable level. To this end, the FCC Spectrum Policy Task Force [2] has recommended the use of interference temperature for

K. J. Kulkarni and B. S. Chaudhari are with Maharashtra Institute of Technology, Pune, Maharashtra, India (e-mail: kalyanikul@gmail.com).

assessing the level of interference. Specification of an interference temperature limit for a PU corresponds to a maximum allowed level of interference power; CRs can use PU frequency bands as long as the total generated interference power to the PUs is kept below this limit. In a fading environment, a CR signal may undergo deep fading and be received with very little power at the PU receiver. As a result, apart from the spectrum holes, CRs can opportunistically share PU active frequency bands, as long as the total generated interference power at the PU receiver is below the specified interference power threshold. Specifically CRs are required to find the spectrum holes in the spectral band and to decide if the spectrum allocation meets the QoS requirements of different users. Spectral efficiency, channel capacity and outage probability plays an important role in this.

Recent advancements in the technology have led to a persistent need for novel analytical frameworks that can be suited to tackle the variety of technical challenges accompanying the present and next generation wireless challenges. As a result, in the recent years game theory has emerged as a key tool for the design of communication networks. This surge of interest in applying game theoretical tools to communication networks is due to the development of networks where multiple users share a common transmission environment. This enhances the competition for common resources (such as frequency, time, space, power, energy). Future wireless networks needs to incorporate decision-making rules and techniques so as to operate efficiently and meet the user's need in terms of communication services (e. g. ubiquitous internet access, heterogeneous networks, video streaming over mobile networks etc.). A multiuser video transmission system should consider not only the video quality of each individual user but also different perspectives from a network-level point of view. This resource allocation problem can be formulated by using game theoretic platform.

This paper analyzes the QoS problem and finds the solution using the recent analytical techniques. The problem of resource management is addressed by using game theory. The Utility function is formulated so as to maximize the rate of the secondary user while keeping the interference to a primary user is acceptable. Our aim is to realize PU-CR spectrum sharing by optimal allocation of transmit power. It is of importance to determine the number of secondary users which can transmit in the licensed band without affecting the QoS requirements of the primary users. Our main contribution here is to model the CRN using the novel game model and design a

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utility function in order to meet QoS of primary users and secondary users as well. In addition to this, an existence of Nash Equilibrium is established.

The paper is organized as follows. Section II will address the different approaches in resource allocation problem and their comparison with the main focus on centralized and distributed resource allocation. In Section III, we will postulate the game model of the CRN. Section IV will define the algorithms developed for the improvement of capacity and number of cognitive users. Section V will present a game-theoretic algorithm for power allocation along with a discussion of the existence of Nash Equilibrium. In Section VI, we will present the simulation results along with the discussion. The conclusion will be discussed in Section VII.

II. RESOURCE MANAGEMENT IN CRN

With the growing demand for wireless services of higher Quality of Service (QOS) (data rate, latency, coverage, etc), the need for more efficient schemes to provide better utilization of the limited available resources such as spectrum becomes inevitable. The wireless service providers need to support the large number of users with flexibility in their QOS requirements. During the network planning stage, operators decide the number and locations of network devices such as Base Stations and relays to be deployed based on the demand of users', transmission environment and other factors. How to utilize the radio resources in the most effective and efficient way is one of the most important objectives of Radio Resource Management [3]. The effectiveness is to provide the user the satisfactory quality of service and the efficiency to increase the revenue of the network service providers.

In the proposed work, we address the resource management problem in context with CRN. Spectrum allocation can be based on two independent approaches; Centralized and Distributed. In a centralized approach, a central controller is aware of the channel conditions and transmission parameters of SU. In the fast fading environment and specifically in the ad-hoc networks, it is difficult to implement a centralized system. Distributed approach doesn't require knowledge of channel state information of PU.

In [4], a joint power control and admission control was proposed such that the priority of PU should be maintained. Beamforming strategy is used in [5] to solve a problem of resource allocation. A number of distributed resource allocation strategies have been proposed in the literature. In [6], a potential game model of joint channel selection and power allocation is formulated. It is shown that the distributed sequential play converges to a Nash Equilibrium point and quickly satisfies the interference constraint. Game theoretic Max-Logit Learning Approaches are used for Joint base station selection and resource allocation. The exact potential game is proposed to maximize the throughput [7]. The authors in [8] presented an analytical framework in which SU's rate, frequency, and power resource can be optimized under the interference temperature constraints.

III. GAME-THEORETIC MODEL

Game theory is a mathematical tool for analyzing the interaction between two or more decision makers [9]. It has been used in a variety of fields such as economics, political science, and biology. A strategic game consists of mainly three components: a set of players, a strategy set for each player and a utility (payoff) function for each player which measures the degree of "happiness" of the player. Game theory is proved to be very significant in the telecommunications, particularly wireless communication. User's interaction in a wireless network can be modeled as a game in which users' terminals are the players in the game competing for network resources (i.e. bandwidth and energy). Any action taken by a user affects the performance of other users in the network. Resource allocation can be modeled as a game that deals largely with how rational and intelligent individuals interact with each other in an effort to achieve their own goals.

A wireless network can be analyzed with different types of games. This includes cooperative and non-cooperative games.

The non-cooperative game theory focuses on the analysis of competitive decision-making involving several players. The players may have partially or totally conflicting interests over the outcome of the decision process which is affected by their actions. Furthermore, a game can be with complete information or incomplete information. In a game with complete information, each player is aware of the identities of all other players, their strategies, and pay-offs. Incomplete information games can be analyzed using Bayesian theory.

Game for cognitive radio, power control can be formulated as: players are the number of cognitive users (secondary users (SU)) under consideration; action space includes decisions that are defined by strategies of transmission power allocation and utility function and utility function represents the value of the achieved QoS by a player. Game theory analyzes how the decision of one player can affect the performance of other players and how to reach to a Nash Equilibrium (state of equilibrium) that would satisfy most of the players. Game theory is practiced in the field of communication networks to handle the problems in routing, congestion control and power control [10]. Power allocation problem can be analyzed using game theory by considering following scenario:

- Player's pay-off function is a function of his own and other player's transmit power level and signal-interference-noise-ratio.
- The increase in the own power level of player will decrease the power level of other functions.

This can be tackled by introducing the additional cost component to the pay-off function. The Modified pay-off will give fairness to the network.

This paper considers requirements of PUs and SUs. Uplink of a single CRN is considered and primary Base Station (BS) receives its desired signal from the primary transmitter and interference from remaining cognitive users.

We propose a utility function that maximizes the capacity of SUs while protecting PUs to address the problem of resource allocation. In this game problem pay-off function, P, represents SINR constraint and a price function, R represents

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an outage probability function. Thus the utility function, U is defined as:

$$U = P - R \qquad (1)$$

Each secondary user adapts his transmit power to maximize the utility function. Here the power allocation algorithm is developed that will maximize the utility function.

IV. CAPACITY-DRIVEN POWER ALLOCATION

In this section, a mathematical model of the power allocation game is presented. Consider the uplink of a cognitive network consisting a PU, a base station (BS) and N pairs of SUs that are randomly distributed. Secondary user index n lies between 1 to . $g_{l,n}$ is the channel gain from SU l to n. SU transmits with power p_m and maximum power P_{max} . $g_{p,n}$ is the channel gain of primary user p to the SU n. The primary user transmits with power p_p. Protection radius has been defined for the primary user in order to reduce the interference. Thus, it defines the area for cognitive nodes. By considering variance of noise is σ^2, the capacity of the PU is given as:

$$C_p = log_2 \left(1 + \frac{p_p |g_{p,p}|^2}{\sum_{n=1}^{N} p_n |g_{n,p}|^2 + \sigma^2} \right) \qquad (2)$$

It is considered that when the SUs access primary system, n^{th} SU receives interference from the PU and other SUs that transmit on the same band. Capacity of the nth SU is:

$$C_n = log_2(1 + SINR_n) \qquad (3)$$

where

$$SINR_n = \frac{p_n |g_{n,n}|^2}{\sum_{l=1, l \neq n}^{N} p_n |g_{l,n}|^2 + p_p |g_{p,n}|^2 + \sigma^2} \qquad (4)$$

SUs will adapt their transmission parameters in order to maximize the per-user cognitive capacity given by:

$$C_{total} = \sum_{n=1}^{N} C_n \qquad (5)$$

The total sum indicates that there are N SUs are allowed to transmit. It is assumed that SUs are aware of the channel state information (CSI) of their own link but have no information of the channel conditions of other links. Power control aims to preserve the power of SUs and to limit the interference and other impairments such as fading, multipath etc. Interference power is given by:

$$intp = \sum_{l=1, l \neq n}^{N} p_n |g_{l,n}|^2 + p_p |g_{p,n}|^2 + \sigma^2 \qquad (6)$$

SINR can be defined as a function of interference power:

$$SINR_n = \frac{p_n |g_{n,n}|^2}{intp} \qquad (7)$$

and

$$p_n = \frac{SINR_n intp}{|h_{n,n}|^2} \qquad (8)$$

Primary QoS criterion is to protect PU in the network. This criterion is satisfied if the sum of all the secondary users transmitters' power is less than the interference constraint P_{th} . At this time, PU verifies the outage probability constraint. The interference constraint is given by:

$$\sum_{n=1}^{N} p_n |g_{p,n}|^2 \leq P_{th} \qquad (9)$$

Outage probability is the probability that the capacity of the user is below the transmitted code rate. In this work we express outage probability as:

$$P_{out} \equiv Prob\{C_p \leq R_p\} \leq q \qquad (10)$$

where R_p is the data rate of PU and q is the maximum outage probability. Outage failure can be directly fed back from PU to secondary transmitters.

Proposed resource allocation method considers the outage probability as the driving parameter. Specifically, as long as interference from SU is within acceptable range, SU are allowed to transmit along with PU i.e. QoS defined in terms of outage probability should not be affected. By finding out the primary user channel information, we can determine the outage failure. The proposed method also guarantees a certain QoS to SU through outage probability control. Outage probability control has been used in the resource management methods. A centralized control using outage constraint was proposed in [10]. Centralized mode gets this knowledge from the third party controller. To determine outage probability CR system requires knowledge of PU and SU. Authors in [9] propose a centralized user selection strategy combined with an efficient beam-forming technique. Distributed method is discussed in [10] to compute the outage probability without exchange of information between primary and secondary users.

V. GAME-THEORETIC ALGORITHM FOR POWER ALLOCATION

In this section, the utility function is derived for the game-theoretic solution of the power allocation problem. Each SU adjusts its transmitted power in order to maximize it. It composes the pay-off function expressed as the capacity C_n of the SU and a price function composed of the level of interference to the PU and the power consumption. The pay-off function value and price-function value will be adjusted for compromise using the parameter b_n. The utility function is the function of capacity C_n of the SU and a price-function composed of the interference-level to the PU and power consumption. Secondary user capacity can be adjusted by selecting parameter b_n.

Mathematically we can express game as:
Determine

$$p_{n|n=1\ldots\ldots N} = \arg\max_{|p_n|} U_n(p_n, P_{-n}) \qquad (11)$$

with subject to:

$$\sum_{n=1}^{N} p_n |g_{p,n}|^2 \leq P_{th} \& P_{out} \leq q \qquad (12)$$

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p_n denotes the strategy adopted by SU n and P_{-n} denotes the strategy adopted by other SUs. The Utility function is expressed as:

$$U_n = C_n - \left(\frac{p_n |g_{p,n}|^2}{P_{th} - \sum_{l=1, l \neq n}^{N} p_l |g_{l,n}|^2} \right)^{b_n} \qquad (13)$$

Utility function is adopted to maximize the capacity and minimize the interference.

VI. Simulation Analysis

MC-CDMA based cognitive radio network under consideration consists of single primary user and N SUs. A hexagonal cellular system has a primary cell of radius R meters and to protect PU protection area of R_p meters. Channel gains are based on COST-231 model path loss model that includes log-normal shadowing. It is assumed that the radius of the secondary cell is 1000m and radius of the protection area is 400m. Average channel gains can be estimated from the location of users and propagation characteristics. Our main contribution in this work is the development of game model such as to maintain the QoS of the CRN.By using outage probability control; we can guarantee the QoS of PU and to a certain extent QoS of SU also. The vacant spectral band can be identified in order to continue service of the PU. The numbers of active SU links are the function of total number of users and outage probability. Here we get 18 active SUswhich are increased by 10 as compared to the heuristic power allocation scheme. Fig. 1 depicts that increasing the maximum outage probability improves the total number of active secondary users. Fig. 2 indicates capacity of the secondary users wherein the rate stabilizes after reaching specific values of maximum outage probability threshold.

A. Existence of Nash Equilibrium

In a non-cooperative game, it is important to ensure the stability of the system. Nash equilibrium is a state of the non-cooperative game where no player can improve its utility by changing its strategy if the other players maintain their strategies. Definition of a pure strategy $\{p_l{}^*\}_{l \neq n, \, 1 \, \in \, \{1....M\}}$ is a Nash Equilibrium if for every player n:

$$U_n(p*_n, P*_{-n}) \geq U_n(p_n, P*_{-n}), \qquad \forall n \in \{1..N\}$$

i.e. a strategy profile is a pure strategy Nash Equilibrium if no player has an incentive to unilaterally deviate to another strategy, given that the other players' strategies are fixed.

In the proposed scheme, no player i.e. SU has the incentive to deviate from Nash Equilibrium. This will reduce its own utility function. Thus, Nash Equilibrium sets the stability of the game. It can be seen from the figure that a lower limit of QoS can be guaranteed.

VII. Conclusion

Game-theoretic tools can be efficiently used to tackle the problem of resource allocation in cognitive radio. Using the principles of non-cooperative game theory and a defining pricing strategy, we can maximize the capacity of the secondary users while maintaining the QoS of the primary user. The proposed game demonstrates the existence of Nash Equilibrium. Simulation results indicate that a significant number of SU are active while maintaining the QoS of the primary user.
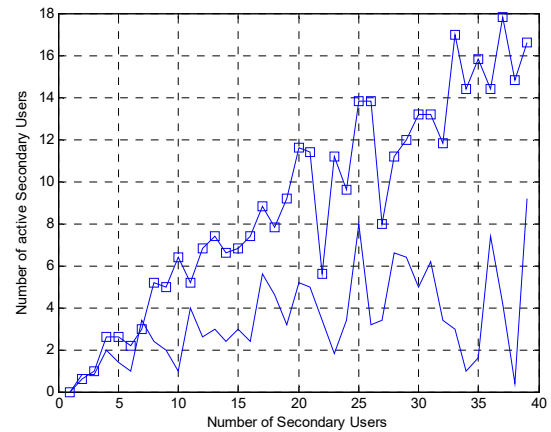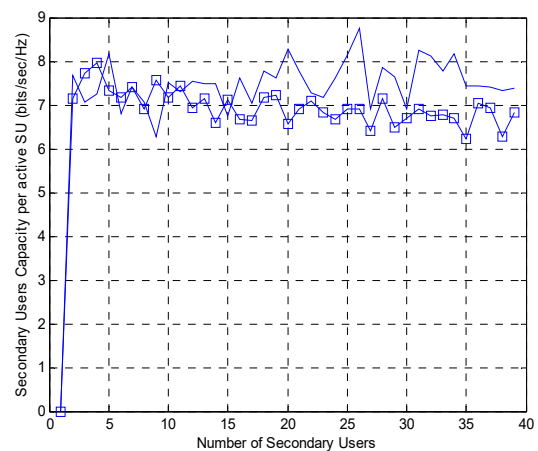

Fig. 1 Number of Active Secondary Users

Fig. 2 Capacity of active secondary users

References

[1] J. Mitola, "*Cognitive radio: an integrated agent architecture for software defined radio,*" PhD Thesis, Royal Institute of Technology, KTH, 2000.

[2] FCC: Cognitive Radio Technologies Proceedings, Web Page: http://www.fcc.gov/oet/cognitiveradio

[3] Baseem Zayen et.al, "Game Theory-based Resource Management Strategy for Cognitive Radio Networks", EURECOM.

[4] Rong Chai et al, "Game Theory-based Joint Pricing and Resource Allocation for Cognitive Radio Networks with Imperfect Channel Information", CHINACOM-2014.

[5] B. Zayen, A. Hayer et al, "Resource Allocation for Cognitive Radio Networks with a Beamforming User Selection Strategy", Asilomar, Nov-1-4, 2009.

[6] Hao He, Jie Chen et al, "Game Theoretic Analysis of Joint Channel Selection and Power Allocation in Cognitive Radio Networks", IEEE xplore-2009.
[7] Haibo Dai, Yongming Huang and Luxi Yang, "Game Theoretic Max-logit Learning Approaches for Joint Base Station Selection and Resource Allocation in Heterogeneous Networks", *IEEE J. in Selected Areas in Commun*, Vol. 33, NO 6, June 2015.
[8] N. Omidvar, B. H. Khalaj, "A Game Theoretic Approach for Power Allocation in the Downlink of Cognitive Radio Networks", CAMAD-2011.
[9] Farhad Meshkati, Vincent Poor and Stuart C. Schwartz, "Enery-Efficient Resource Allocation in Wireless Networks: An overview of Game-Theoretic Approaches" Project under National Science Foundation Grant
[10] M. Haddad, A. Hayer, "Downlink Distributed Binary Allocation for Cognitive Radio Networks", PMRC Cannes, 2008.