Cognitive Radio Spectrum Sensing and Radio Resource Management using A Game Theory approach

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***Abstract*— Cognitive Radio is a radio network which has a capability to obtain knowledge of its environment, autonomously and dynamically adjust to the operational parameters, establishing policies and learning from the results obtained. Radio spectrum is a scarce resource in wireless network so efficient utilization it is becomes an important issue.**

Resource provisioning is one of the most challenging and important aspect of communication networks. The communication sector is undergoing through significant changes in terms of services and number of platforms available. It also plays a significant role in emergencies. Public switched telecommunication network (PSTN) provides universal access which also means, the network has been designated as the one for universal service. Broadband subscribers are growing tremendously and the new value added services & applications are provided to broadband users on IP platform. Migration towards Next Generation Networks (NGN) changes the network topology, which involves several structural changes such as changes in network hierarchy levels, reorganization of network nodes etc. To sustain in the competitive world the market players/service providers have to make their systems more effective, flexible, and scalable to efficiently manage an increasingly complex product portfolio. This multidimensional problem requires optimized processes, accurate operational data and integrated solutions.

***Index Terms*— Cognitive Radio, Spectrum Sensing, Resource Management, Spectrum pooling, Game Theory**

I. INTRODUCTION

Traditionally, the ‘‘best-effort’’ model has characterized service provisioning over Internet Protocol (IP) networks. This approach has proved to be best for Internet traffic, but is insufficient when trying to provide carrier grade services with real-time characteristics such as Voice over IP (VoIP) or IP television (IPTV). Furthermore, the delivery of future and converged services to an increasing number of heterogeneous user terminals and with the constraints of multiple business models requires an evolution of network architectures [1].

Next Generation Networks (NGN) are packet-based networks that can support all types of services, including basic voice telephony services, data, video, multimedia, advanced broadband and management applications[2]. The sudden rise of Internet companies and their related melt down have brought renewed attention to the concept of network pricing. Telecommunications networks are moving towards full convergence of voice and data services as well as seamless access via mobile and fixed networks. This implies a transformation of the underlying transport network technology (moving towards IP) as well as the way that transport resources can be shared across multiple applications and controlled from the intelligence domain.

With the increase in global roaming, mobility management is a key issue for the networks. Terminal mobility can be divided into two categories: (a) radio mobility (b) network-layer mobility. Moreover, mobility management schemes for voice and data traffic, though quite similar, have some differences. Hence, we shall examine the two separately, pointing out the similarities and differences where necessary.

In the Mobile-IP protocol, the mobile host always retains its home address. The Home Agent (HA) is a database (similar to the HLR for voice services) that stores all information about a particular mobile terminal registered, while the Foreign Agent (FA), similar to the VLR, keeps track of all mobiles currently visiting the network. When a mobile host moves to a foreign network, it is assigned a temporary IP address (foreign address).

Various game models are proposed for pricing based resource provisioning in communication networks. Most of the game models use Nash equilibrium game for solving problem of resource provisioning in communication services. Fixed frequency assignment of the spectrum leads to inefficient utilization of it. The concept of cognitive radio, basically an intelligent radio, can be used to find solution to this problem. There are various models available to evaluate spectrum sharing/allocation technique. The situation in which unlicensed users compete for the unlicensed spectrum is also called open spectrum sharing problem. The strategic decision making of selecting unused spectrum (white spaces) at particular time slot can be modeled by using game theory.

II. COGNITIVE RADIO

A cognitive radio is a transceiver which automatically detects available channels in wireless spectrum and accordingly changes its transmission or reception parameters so more wireless communications may run concurrently in a given spectrum band at a place. This process is also known as dynamic spectrum management. In response to the operator's commands, the cognitive engine is capable of configuring radio-system parameters. These parameters include "waveform, protocol, operating frequency, and networking"[3].

Depending on transmission and reception parameters, there are two main types of cognitive radio:

Full Cognitive Radio (Mitola radio), in which every possible parameter observable by a wireless node (or network) is considered [4].

Spectrum-Sensing Cognitive Radio, in which only the radio-frequency spectrum is considered [5].

Spectrum pooling is a spectrum management strategy. In this multiple users coexists within a single allocation of radio spectrum space.

The term cognitive radio is derived from "cognition". According to Wikipedia cognition is referred to as

- Mental processes of an individual, with particular relation
- Mental states such as beliefs, desires and intentions
- Information processing involving learning and knowledge
- Description of the emergent development of knowledge and concepts within a group

Resulting from this definition, the cognitive radio is a self-aware communication system that efficiently uses spectrum in an intelligent way. It autonomously coordinates the usage of spectrum in identifying unused radio spectrum on the basis of observing spectrum usage. The classification of spectrum as being unused and the way it is used involves regulation, as this spectrum might be originally assigned to a licensed communication system. This secondary usage of spectrum is referred to as vertical spectrum sharing.

The mental processes of a cognitive radio based on the cognition circle from [6] are depicted in Figure 1

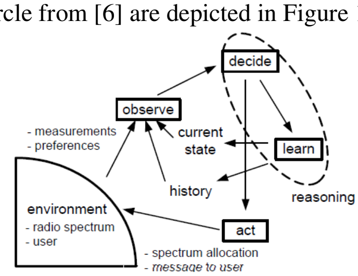

Figure 1: Mental process of a cognitive radio based on the cognition cycle[8]

Primary and Secondary radio systems are the terms used for licensed and unlicensed radio system in spectrum sharing.

Cognitive Radios will have to share spectrum (i) either with unlicensed radio systems with limited coexistence capabilities enabling them to operate in spite of some interference from dissimilar radio systems or (ii) with licensed radio systems designed for exclusively using spectrum. The sharing of licensed spectrum with primary radio systems is referred to as vertical sharing, as indicated in Figure 2, and the sharing between equals as for instance in unlicensed bands is referred to as horizontal sharing. These terms of horizontal and vertical spectrum sharing are first mentioned in [7].

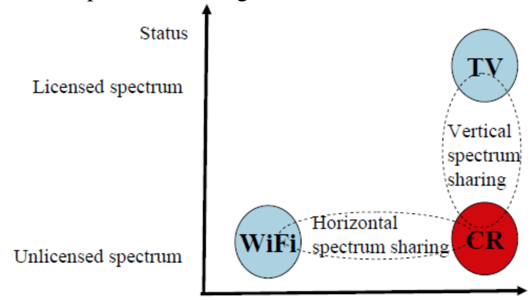

Figure 2: cognitive radio share spectrum with different radio systems. Depending on regulatory status, vertical or horizontal spectrum sharing is done [8].

Another example for horizontal spectrum sharing is the usage of the same spectrum by dissimilar cognitive radios that are not designed to communicate with each other directly. These dissimilar cognitive radio systems have the same regulatory status, i.e., similar rights to access the spectrum, comparable to the coexistence of devices operating in unlicensed spectrum. Vertical spectrum sharing promises to have the advantage that neither a lengthy and expensive licensing process nor a re-allocation of spectrum is required [8].

III. GAME THEORY

A set of mathematical tools used to analyze interactive decision makers is called Game theory. The fundamental component of game theory is the notion of a game, expressed in normal form:

$G = \langle N, A, \{u_i\} \rangle$ where G is a particular game, $N = \{1,2,\ldots,n\}$ is a finite set of players (decision makers), Ai is the set of actions available to player i, $A = A_1 \times A_2 \times A_3 \times \ldots \times A_n$ is the action space, and $\{u_i\} = \{u_1, u_2, u_3, \ldots, u_n\}$ is the set of utility(objective) functions that the players wish to maximize. Each player's objective function, u_i, is a function of the particular action chosen by player *i*, *ai*, and the particular actions chosen by all of the other players in the game, *a-i* and yields a real number. Other games may include additional components, such as the information available to each player and communication mechanisms. In a repeated game, players are allowed to observe the actions of the other players, remember past actions, and attempt to predict future actions of players" [9].

Nash equilibrium is a solution concept of a game involving two or more players, in which each player is assumed to know the equilibrium strategies of the other players, and no player has anything to gain by changing only his own strategy unilaterally. If each player has chosen a strategy and no player can benefit by changing his or her strategy, while the other players keep their unchanged, then the current set of strategy choices and the corresponding payoffs constitute Nash equilibrium [10].

Fundamental terms used in Game theory are as follows [9]:

- *Players*
  Players are the decision making entities in the modeled system.
- *Actions*
  An action set represents the choices available to a player. Note that these choices may be quite complex and, for instance, may represent a sequence of real world actions. Each player in the game has its own action set and makes its decision by choosing an action from its action set. A choice of actions by all players in the game produces an *action vector* or *action tuple*. All possible action vectors in the game are contained within the game's *action space*. The action space is formed the Cartesian product of every player's action set.
- *Outcomes*
  Each action vector produces a well defined and expected *outcome*. Note as an outcome is jointly defined by every player's action choice, there is an interactive relationship. Thus in every game there exists a mapping from the action space to some outcome space. As this mapping is presumed subjective, most game analyses ignore outcomes and focus solely on the actions that produce the outcomes.
- *Utility Functions*
  While games can be analyzed based on the ordinal relations implied by preference relations, cardinal relations have a richer tool set and are generally preferred for analysis. Utility functions (objective functions) transform the ordinal relationships of players' preference relationships to cardinal relationships. Generally a utility function is constructed over the action (outcome) space so that if one *a* is preferable to *b*, then the cardinal value assigned to *a* will be greater than the cardinal value assigned to *b*. Thus in light of utility functions, it may be fair to treat the reference operator, $\succsim$, as the greater than or equal to operator, ≥.

IV. GAME THEORY FOR RADIO RESOURCE MANAGEMENT

Distributed adaptive behavior in a wireless network will generally lead to recursive behavior wherein the decision of one radio will subsequently influences the decision of other radio in the network. In order to successfully deploy these networks, it will be necessary to determine if the network will eventually reach a steady state. If the adaptive behavior does not reach a network steady state, resources can be appropriately allocated and performance anticipated; otherwise these tasks are virtually impossible [9].

We will provide the problem reformulation and will introduce the game model by defining the utility function to compute the transmitted power of each SU. Game theory was at first a mathematical tool used for economics, political and business studies. It helps understand situations in which decision-makers interact in a complex environment according to a set of rule [11]. Many different types of game exists which are used to reflect to analyzed situation for example potential games, repeated game, cooperative or non-cooperative games. In the cognitive radio network (CRN), the formal game model for the power control can be defined as follows:

Players: are the cognitive users (secondary users (SUs)).

Actions: called also as the decisions, and are defined by the transmission power allocation strategy.

Utility function: represents the value of the observed quality of-service (QoS) for a player, and is defined later in this section.

The central idea in game theory is how the decision from one player will affects the decision-making process from all other players and how to reach a state of equilibrium that would satisfy most of the players [12].

We formulate the problem of resource allocation in the context of a Cognitive Radio Networks (CRN) to reflect the needs of Primary Users (PUs) and Secondary Users (SUs). We consider the primary uplink of a single CRN, where cognitive transmitters transmit signals to a number of SUs, while the primary Base Station (BS) receives its desired signal from a primary transmitter and interference from all the cognitive transmitters.

To resolve the problem of resource allocation, we propose a utility function that meets the objective to maximize the SUs capacity, and the protection for PUs. Specifically, we define a payoff function that represents the Signal to noise and interference ratio (SNIR) constraint, and a price function specifies the outage probability constraint. The utility function is defined as:

Utility function = payoff function - price function (1)

We introduce a payoff to express the capacity need of SU m, and a price function to represent the protection for PUs by means of the outage probability. And each SU adjusts its transmitted power to maximize its utility function. This defines a power allocation algorithm that maximizes the defined utility function to compute the transmitted power of each SU [13].

V. CONCLUSION AND FUTURE WORK

The problem of spectrum pricing in a cognitive radio network where multiple primary service providers compete with each other to offer spectrum access opportunities to the secondary users can be optimized. Using an equilibrium pricing scheme, each of the primary service providers aims to maximize its profit under quality of service (QoS) constraint for primary users. The QoS degradation of the primary services is considered as the cost in offering spectrum access to the secondary users[14].

We can implement open spectrum game model as a one shot game and can study of behavior of throughput function and parameter dependency [Bit Error Rate (BER)]. One shot game can be played multiple times to enforce cooperation and comparing the results may give most effective scheme for maximizing throughput. The open spectrum repeated games can be evaluated for different punishment strategies like 'tit for tat' and fictitious play to discourage the player deviation.

Dynamic spectrum access is an essential approach for increasing efficiency in spectrum use. It is used to counteract the observed spectrum scarcity. One concept to utilize occurring spectrum holes in the time/frequency plane are overlay systems that are deployed in the same frequency band as a licensed system. To avoid collisions as well as mutual interference, the overlay system has to periodically perform measurements to detect the allocation of the licensed system and dynamically adapt its system parameters [15].

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