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A Study and Analysis of Spectrum Key Functionalities in Cognitive Radio Network

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Abstract: The rapid growth in wireless communications has contributed to a massive demand on the deployment of new wireless services in both the licensed and unlicensed frequency spectrum. To address the poor spectrum utilization problem, cognitive radio has emerged as a promising technology to enable the access of unused frequency bands and thereby increase the spectral efficiency. Hence, one main aspect of cognitive radio network is related to autonomously exploiting locally unused spectrum to provide new paths to spectrum access. This study presents recent developments and open research challenges in spectrum key functionalities in cognitive radio network.

Keywords: Cognitive Radio Networks, Spectrum functionalities, Dynamic spectrum access, Spectrum sensing, Next Generation Network

I. INTRODUCTION

The radio frequency spectrum is a crucial medium bridging transmitters and receivers in wireless communications. The frequency spectrum is regulated and licensed by the government or some other government-aided organizations such as Telecommunication Regulatory Authority of India (TRAI) in India. Under the regulations, frequency bands are statically assigned to different means or purposes for wireless communications in military or civil use. In contrast, a large portion of the assigned spectrum is used sporadically, leading to underutilization of a significant amount of the spectrum [10]. Hence, dynamic spectrum access techniques have been proposed recently to solve this spectrum inefficiency problem.

The radio spectrum frequency allocation in India (NFAP 2002) is illustrated in Figure 1. In the static spectrum allocation, almost no available band left for the future wireless network use. However, the recent studies shows that the fixed spectrum management policy enforced today results in poor spectrum utilization. To address this problem, cognitive radio arises to be a tempting solution to the spectral congestion problem by introducing opportunistic usage of the frequency bands that are not heavily occupied by licenced (Primary) user [1, 11]. Cognitive radio definition adopted by Federal Communication Commission (FCC) is " Cognitive radio: A radio or system that senses its operational electromagnetic environment and can dynamically and autonomously adjust its radio operating parameters to modify system operation, such as maximize throughput, mitigate inference, facilitate interoperability, access secondary markets [2]". Hence, one main aspect of cognitive radio network is related to autonomously exploiting locally unused spectrum to provide new paths to spectrum access [4].

The goal of cognitive radio can be realized only through dynamic and efficient spectrum functionalities. The challenges face by the cognitive radio user in cognitive radio network are Check availability of spectrum hole in statically allocated channel, Choose the best available channel, Coordinate access of the channel with other user and Leave the channel when detect primary user. To address this problem, cognitive radio focusing four key spectrum concepts: spectrum sensing, spectrum management, spectrum sharing, and spectrum mobility are discussed.

II. COGNITIVE RADIO NETWORK ARCHITECTURE

In addition to effectively improve spectrum utilization by spectrum sensing, a Cognitive Radio (CR) in Cognitive Radio Network (CRN) can sense available networks and communication systems around it. A CRN is thus not just like another network to interconnect cognitive radios. The CRNs are composed of various kinds of communication system and networks, and can be viewed as a sort of heterogeneous networks. The heterogeneity exits in wireless access technologies, networks, user terminals, applications and service providers [3]. The design of cognitive radio network architecture is toward the objective of improving the entire network utilization, rather than just link spectral efficiency [10, 13]. As shown in Figure. 2, the Cognitive Radio Users have the opportunity to perform with two different architectures:

A. *CRN with infrastructure:*

In this architecture, all communications of CRN can be achieved through CR base station. CR users can access licensed and unlicensed spectrum bands through CR base station. CR users can also access the primary base station through licensed channels. For access primary base station, CR users need a specific MAC (Medium Access Control) protocol with different access technology.

B. CRN without infrastructure:

CR users communicate with other CR users through an ad hoc (without infrastructure) connection on both licensed and unlicensed spectrum channels [9].

C. Design Challenges:

There are three major challenges to design the cognitive radio network architecture

a. Interference avoidance: CRNs want to use the primary network without any interference. The spectrum sensing is monitor the available spectrum channels, detect the spectrum hole.
b. QoS awareness: Cognitive Radio Networks want to provide QoS communication in allocation of spectrum channels, dynamic spectrum access, and different environments and polices. The key function spectrum decision is introduced to resolve this challenge.
c. Seamless communication: cognitive Radio Network want to provide seamless communication to the CR users when primary network want the specific portion of the spectrum. The key function spectrum mobility and spectrum sharing are introduced to resolve this problem.

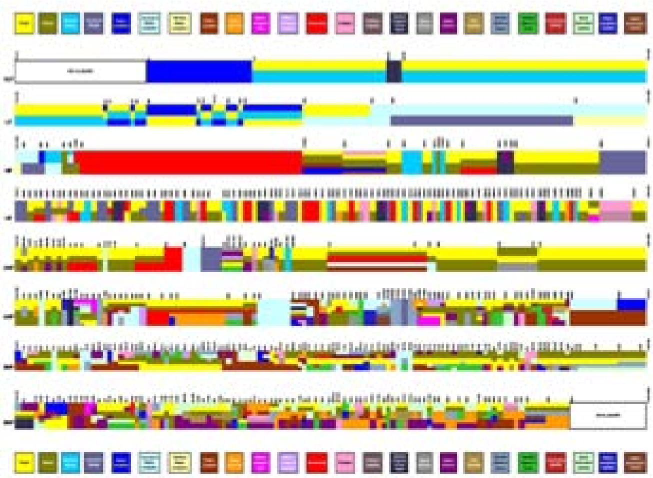

Figure 1. Spectrum Allocation Chart by Govt. of India (As per NFAP 2002)

III. SPECTRUM SENSING

As Cognitive Radio technology is being used to provide a method of using the spectrum more efficiently, spectrum sensing is key to this application [10, 12]. The spectrum sensing is still in its early stages of development. A number of methods are proposed for identifying the presence of signal transmissions. There are a number of ways in which cognitive radios are able to perform spectrum sensing. The ways in which cognitive radio spectrum sensing can be performed falls into one of two categories:

A. Non-Cooperative Spectrum Sensing:

This form of spectrum sensing occurs when a cognitive radio acts on its own. The cognitive radio will configure itself according to the signals it can detect and the information with which it is pre-loaded [4]. Some of the most common techniques in Non-cooperative spectrum sensing techniques are

a. ***Energy Detector Based Sensing:*** The most well-known spectrum sensing technique is the energy detector. It is based on the principle that, at the reception, the energy of the signal to be detected is always higher than the energy of noise. The energy detector is said to be a blind signal detector because it ignores the structure of the signal. It estimates the presence of a signal by comparing the output of the energy detector with threshold which depends on the floor.

b. ***Cyclostionarity-Based Sensing:*** It exploits the periodicity in the received primary signal to identify the presence of primary users. Instead of the power spectral density (PSD), cyclic correlation function is used for detecting signals presents in a given spectrum. Furthermore, Cyclostationarity can be used for distinguishing among different types of transmission and primary users.

c. ***Matched-Filtering:*** It is known as the optimum method for detection of primary users when the transmitted signal is known. The main advantage of matched filtering is the short time to achieve a certain probability of false alarm or probability of misdetection as compared to other two methods. Matched-Filtering requires cognitive radio to demodulate received signals. Hence, it requires perfect knowledge of the primary user signalling features. Matched-Filtering is large power consumption as various receiver algorithms need to be executed for detection.

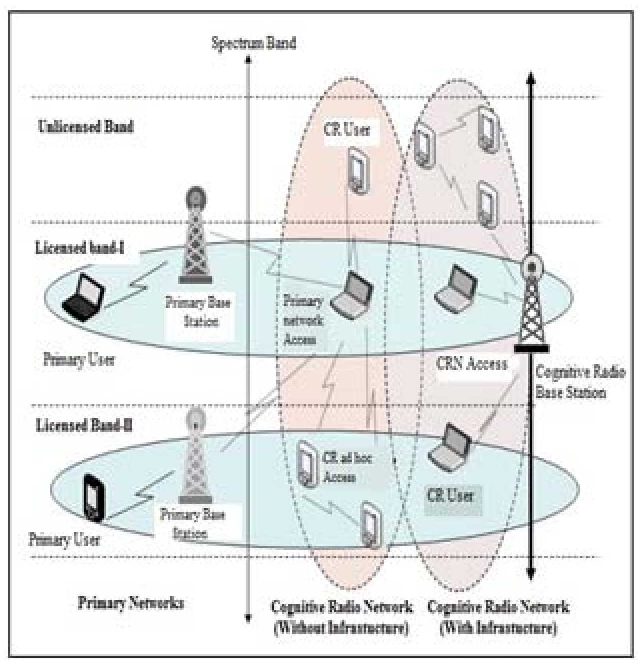

Figure 2. Cognitive Radio Network Architecture

B. Cooperative Spectrum Sensing:

Within a cooperative cognitive radio spectrum sensing system, sensing will be undertaken by a number of different radios within a cognitive radio network [16, 23]. Typically a central station will receive reports of signals from a variety of radios in the network and adjust the overall cognitive radio network to suit. Cognitive radio cooperation reduces problems of interference where a single cognitive radio cannot hear a primary user because of issues such as shading from the primary user, but a second primary user acting as a receiver may be able to hear both the primary user and the signal from the cognitive radio system [5]. The classification of cooperative spectrum sensing is shown in Figure 3.

In centralized cooperative sensing, a fusion center (FC) controls the process of cooperative sensing. This fusion center is central identity of this centralized structure. In distributed cooperative sensing, CR users communicate among themselves sharing results. In Relay-assisted cooperative sensing, some of CR users act as sensing channel and some of CR users act as report channel.

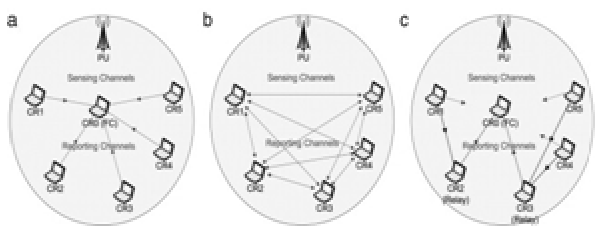

Figure 3. Classification of Cooperative Sensing

(a) Centralized, (b) Distributed, (c) Relay- assisted

IV. SPECTRUM MANAGEMENT

In cognitive radio networks, the unused spectrum bands will be spread over wide range including both licensed and unlicensed bands. These unused spectrum bands detected through spectrum sensing show different characteristics according to not only the time varying radio environment but also the spectrum band information such as the operating frequency and the bandwidth [15].

Since cognitive radio networks should decide on the best spectrum band to meet the QoS requirements over all available spectrum bands, new spectrum management functions are required for cognitive radio networks, considering the dynamic spectrum characteristics [6]. The functions of spectrum management are Spectrum Analysis: In CRNs, the available spectrum holes show different characteristics which vary over time. System analysis is important to understand the characteristics of different spectrum bands. Spectrum analysis enables the characterization of different spectrum bands, which can be exploited to get the spectrum band appropriate to the user requirements.

Spectrum Decision: Once all available spectrum bands are characterized, appropriate operating spectrum band should be selected for the current transmission considering the QoS requirements and spectrum characteristics. Thus, the spectrum management function must be aware of user QoS requirements. Based on the user's requirements, the data rate, acceptable error rate, delay bound, the transmission mode and the bandwidth of the transmission can be determined. Then, according to the decision rule, the set of appropriate spectrum bands can be chosen.

V. SPECTRUM SHARING

The transmission of CR users should be coordinated by spectrum sharing functionality to prevent multiple users colliding in overlapping portions of the spectrum. Spectrum sharing includes channel and power allocation to avoid interference caused to the primary network and a CR medium access control (MAC) protocol along with spectrum sensing. Spectrum sharing can be classified as centralized and distributed; non-cooperative and cooperative; overlay and underlay in terms of different criteria such as architecture, allocation behaviour and access techniques respectively. Spectrum sharing techniques are generally focused on two types: spectrum sharing inside a Cognitive radio network (intranetwork spectrum sharing) and among multiple coexisting networks (internetwork spectrum sharing).

The first classification for spectrum sharing techniques in cognitive radio networks is based on the architecture, which can be described follows

a. ***Centralized Spectrum Sharing:*** In this spectrum sharing, a centralized entity controls the spectrum allocation and access procedures [7]. Moreover, a distributed sensing procedure can be used such that measurements of the spectrum allocation are forwarded to the central entity, and the spectrum allocation map is constructed.

b. ***Distributed Spectrum Sharing:*** In this spectrum sharing is mainly proposed for cases where the construction of an infrastructure not preferable [8]. Accordingly, each node is responsible for the spectrum allocation and access is based on local (or possibly global) policies.

The second classification for spectrum sharing techniques in cognitive radio networks is based on the access behaviour

(a). ***Cooperative spectrum sharing:*** It exploit the interference measurements of each node such that the effect of the communication of one node on other nodes is considered [8]. A common technique used in these schemes is forming clusters to share interference information locally. This localized operation provides an effective balance between a fully centralized and a distributed scheme [20].

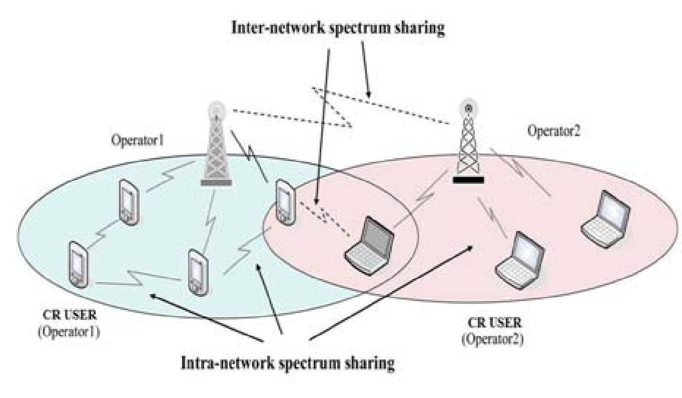

Figure 4. Inter-network and Intra-network Spectrum Sharing in CR Networks

(b). Non-cooperative spectrum sharing: Only a single node is considered in non-cooperative spectrum sharing [22]. Because interference in other CR nodes is not considered, it may result in reduced spectrum utilization. However, these spectrum sharing do not require frequent message exchange between neighbours as in cooperative spectrum sharing.

The third classification for spectrum sharing techniques in cognitive radio networks is based on the access technology [19]:

a) Overlay spectrum sharing: It refers to the spectrum access technique used. More specifically, a node accesses the network using portion of the spectrum that has not been used by licensed users. As a result, interference to the primary system is minimized.

b) Underlay spectrum sharing: The spread spectrum techniques are exploited such that the transmission of a CR node is regarded as noise by licensed users. This technique requires sophisticated spread spectrum technique and can utilize increased bandwidth compared to overlay techniques.

VI. SPECTRUM MOBILITY

If the specific portion of the spectrum in use is required by a PU, the communication must be switched to another vacant portion of the spectrum [6]. This requires spectrum handoff and connection management schemes closely coupled with spectrum sensing. To provide seamless communications, spectrum mobility gives rise to a new type of handoff, in which users transfer their connections to an unused spectrum band is called spectrum handoff [6]. When the link failure eventually occurs caused by the arrival of Primary users, the spectrum handoff stage comes into effect and handover to acceptable unused spectrum band.

The objective of a connection management function is to sustain the QoS of the ongoing transmission or minimize its quality degradation during spectrum switching by interacting with each layering protocol. Once the switching latency information is available, the connection management can be predict the influence of the temporary disconnection on each protocol layer, and accordingly reconfigure each of them in turn.

VII. RESEARCH CHALLENGES

Although cooperative sensing improves detection accuracy, it increases network traffic, resulting in higher latency in collecting information due to channel contention and packet retransmissions. Other then, each cooperating user may have different sensing accuracy due to its location. Thus, cognitive radio networks are required to consider this factor to find an optimal operating point. The multi-user environment, consisting of multiple CR users and primary users, makes it more difficult to sense spectrum holes and estimate interference. Hence, spectrum sensing functions should be developed considering the multi-user environment.

In CRNs, multiple spectrum bands can be used simultaneously used for transmission. Moreover, the cognitive radio networks do not require the selected multiple bands to contiguous. If primary user appears in a particular spectrum band, the CR user has to vacate this band. However, since the rest of spectrum bands will be maintain the communication. Currently, certain spectrum bands are assigned to different purposes, whereas some bands remain unlicensed. Thus, a CR network should support spectrum decision operations on both the licensed and unlicensed bands.

A Common Control Channel (CCC) facilitates many spectrum sharing functionalities. However, because a channel must be vacated when a primary user chooses a channel, implementation of a fixed CCC is infeasible. Moreover, in a cognitive radio networks a channel common to all users is highly dependents on topology and varies over time. Consequently, either CCC mitigation techniques must be exploited for clusters of nodes. The CR ad hoc user determines transmission power in a distributed manner without support of the central entity, which may cause interference due to the limitation of sensing area even if it does not detect any transmission in its observation range. Thus, spectrum sharing necessitates sophisticated power control methods for adapting to time varying radio environment so as to minimize capacity with the protection of the transmission of Primary users.

The next challenge is to design new mobility and connection management approaches to reduce delay and loss during spectrum handoff. The available bands also changes as a user moves from one place to another. Hence, continuous allocation of spectrum is a major challenge in cognitive radio network.

VIII. CONCLUSION

The problem of spectrum scarcity and inefficiency in spectrum usage are addressed by the newly emerging cognitive radio paradigm that allow radios to opportunistically transmit in the vacant portions of the spectrum already assigned to licensed users. The architecture and spectrum key functionalities of cognitive radio networks are described in this research work. Also research challenges in the different spectrum aspects of cognitive radio network are described. However, to ensure efficient spectrum communication, more research is required along lines introduced in this study. This cognitive radio network leaves wide open research to meet these demanding applications.

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