International Journal of
Science and Engineering Investigations vol. 4, issue 47, December 2015
ISSN: 2251-8843

# An Overview of Spectrum Management of Cognitive Radio Networks

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***Abstract***- Nowadays, wireless communication has become the most popular communication. As the need of wireless communication applications is increasing, the demand for wireless spectrum is also increasing commensurately. So, the most important challenge is to share the licensed spectrum without interfering with the transmission of other licensed users. In the early days, the spectrum was assigned statically owing to remove the interference problem, and to do so, the fixed spectrum assignment policy was used. Because of the fixed spectrum assignment policy, the spectrum was not efficiently utilized and remained vacant most of the time. This problem can be solved with cognitive radio technology, which can lead to the full utilization of spectrum holes. Cognitive radio technology has the potential of being a disruptive force within spectrum management. It has been a promising technology to increase spectrum utilization through spectrum sharing between licensed users (primary users) and unlicensed users (secondary users). In this paper, we have put emphasis on spectrum management processes, sensing, mobility, Challenges, and sharing, The challenges, issues and techniques that are involved in spectrum management has been discussed in details.

***Keywords***- *Cognitive Radio, Spectrum Management, Wireless Communication, Software Defined Radio*

## I. INTRODUCTION

Radio spectrum is an important resource for wireless communication systems. It has been found that, the allocated spectrum is not utilized properly because of static allocation of spectrum, and in some locations or at some time period of the day, 70 percent of the allocated spectrum may be sitting idle. So, utilizing the limited spectrum in a more efficient way is an important issue. In this situation, “Dynamic Spectrum Management” can improve the utilization of spectrum. Cognitive Radio works on this dynamic Spectrum Management principle which solves the issue of spectrum underutilization in wireless communication in a better way. A cognitive radio is a self-aware communication system that efficiently uses spectrum in an intelligent way [1]. It provides a highly reliable communication. The most significant characteristic of a cognitive radio is the capability to sense surrounding radio environment such as information about transmission frequency, bandwidth, power, modulation, etc. and make a decision to adapt the parameters for maintaining the quality of service [2]. The Cognitive Radio technology gives an efficient design for utilizing the unused available spectrum but it also introduces new challenging problems which are absent in conventional wireless networks. As spectrum sensing is relied on by the secondary users to find the vacant spectrum before their transmissions, so one of the important design problems of the Medium Access Control (MAC) layer of CR is how secondary users should take decisions about which channel they will use and at which time in order to enable secondary user communication while avoiding damage to primary users by analyzing spectrum sensing information provided by the physical layer. Thus, spectrum sensing and spectrum management for cognitive radio networks are the main challenges for this technology. To utilize licensed spectrum effectively, CR user must perform spectrum sensing to extract inactive licensed band [3].

## II. LITERATURE ANALYSIS

Joseph Mitola, the father of cognitive radio, introduced the idea of Software Defined Radios (SDRs) in the early 1990s. The Cognitive radio is a radio that adapts to the conditions of the environment by analyzing, observing and learning [4]. It is basically used for maximum utilization of the radio bandwidth. It can modify its transmission and reception parameters by active monitoring of the radio spectrum, user behavior and other parameters that help to communicate effectively and mitigate the interference between the PUs and the SUs. There are two main types of cognitive radio, full cognitive radio and spectrum-sensing cognitive radio. Full cognitive radio takes into account all parameters that a wireless node or network can be aware of. On the other hand, spectrum sensing cognitive radio is used to detect channels in the radio frequency spectrum. CR aims to improve spectrum utilization in which the primary (licensed) and the secondary (un-licensed) users co-exist simultaneously. The owner of the channel is referred as the Primary User (PU) and all other users are termed as Secondary Users (SUs). SUs are allowed to access the spectrum not used by primary users (PUs). SUs leave the occupied spectrum when PUs requires it. The SUs then get some other vacant spectrum which is not occupied by the PU. Following this procedure, it allows for both PUs and SUs to communicate simultaneously. The cognitive radios need variable parameters for the description of the optimization space. These parameters come from the Software Defined Radio (SDR) [5].

### A. Software Defined Radio (SDR)

Software Defined Radio (SDR) has both the software and hardware in it. It is a radio in which the properties of carrier frequency signal bandwidth, modulation, and network access are defined by software. It is also a fully reconfigurable radio that automatically changes its communication variables depending on the network and user requirements. So, by changing the communication variables adaptively, an SDR can satisfy the required flexibility that a CR needs [6]. Today's modern SDR also implements any necessary cryptography; forward error correction (FEC) coding; and source coding of voice, video, or data in software as well. The basic SDR must include the radio front-end, the modem, the cryptographic security function, and the application function. The RF front-end (RFFE) consists of the following functions to support the receive mode: antenna-matching unit, low-noise amplifier, filters, local oscillators and analog-to-digital (A/D) converters (ADCs) to capture the desired signal and suppress undesired signals to a practical extent. To support the transmit mode, the RFFE will include digital-to-analog (D/A) converters (DACs), local oscillators, filters, power amplifiers, and antenna-matching circuits.

### B. Cognitive Radio Network Architecture

The components of the CR network architecture can be classified in two groups as the primary network and the cognitive radio network.

#### 1) Primary Network

The primary networks have special rights to specific bands. This network includes the primary user and the primary base-station.

*Primary user*: Primary users operate in specific spectrum bands. This operation is entirely controlled by the only primary base-station. These primary users do not require any further enhancements for the coexistence of the primary base-stations and the primary users. Common primary networks include TV broadcasting and cellular companies.

*Primary base-station*: The primary base station is a fixed infrastructure network like the Base Station Transceiver (BTS) in the cellular system. The primary base station is unable to manage the sharing of spectrum between the primary and secondary users but it can modify itself upon request [6].

#### 2) Cognitive Radio Network

The cognitive radio network does not have a license to use the spectrum. Hence, CR networks can be deployed both with infrastructure and without infrastructure (Ad hoc) networks.

The Cognitive Radio User: The cognitive users are the secondary users and do not have the license to use the spectrum and they are using the spectrum opportunistically.

The Cognitive Radio Base-Station: The CR base-station (the unlicensed base station) has a fixed infrastructure component with CR capabilities which helps the unlicensed user access the other networks.

### C. Dynamic Spectrum Access (DSA) in Cognitive Radio Networks

Dynamic spectrum access (DSA) is an important design aspect for the cognitive radio networks. In the early period of wireless communication, the target was to remove interference among users. To avoid interference, "Command and Control" was used to give the license to all the operators. Since the US Radio Act of 1934, the Federal Communications Commission (FCC) has had the regulatory authority to decide which firms should get licenses in order to bring spectrum to its highest and best use. In the early 1980s the number of applications for licenses was growing so large that the command and control system ground to a halt. For this reason, the FCC decided to start awarding licenses by lottery due to enable more capacity for the command and control assignment mechanism. To overcome the inefficiency of spectrum usage, FCC in the US and Office of Communications (OfCom) in the UK are working to improve the spectrum usage. To overcome the inefficiency in spectrum usage, cooperative networks deployed are cognitive networks also known as Dynamic Spectrum Access Networks (DySPANs). Although, a lot of techniques have been proposed to access the spectrum, there are three main distinctions: Exclusive Usage Rights, Spectrum Commons, and Opportunistic Use.

## III. SPECTRUM MANAGEMENT

Cognitive radio has four major functions. They are Spectrum Sensing, Spectrum management, Spectrum Sharing and Spectrum Mobility. Spectrum Sensing is to identify the presence of licensed users and unused frequency bands i.e., white spaces in those licensed bands. Spectrum Management is to identify how long the secondary users can use those white spaces. Spectrum Sharing is to share the white spaces (spectrum hole) fairly among the secondary users. Spectrum Mobility is to maintain unbroken communication during the transition to better spectrum. In terms of occupancy, sub bands of the radio spectrum may be categorized as follows:

White spaces: These are free of RF interferers, except for noise due to natural and/or artificial sources.

Gray spaces: These are partially occupied by interferers as well as noise.

Black spaces: The contents of which are completely full due to the combined presence of communication and (possibly) interfering signals plus noise.

### A. Spectrum Sensing

A CR with spectrum sensing capability and cooperative opportunistic frequency selection is an enabling technology for faster deployment and increased spatial reuse. CRs may sense the local spectrum utilization either through a dedicated sensor or by using a configured SDR receiver channel. The main purpose of spectrum sensing is to provide more spectrum access opportunities to cognitive radio users without interfering with the operations of the licensed network. Moreover, it is also required that the implementation of the spectrum sensing function has a high degree of flexibility, because it should work in various environments with different types of primary network, bandwidth, frequency, propagation property, interferences and other special characteristics. Sensing requirements are based on primary user modulation type, power, frequency and temporal parameters. It is often considered as a detection problem. Many techniques were developed in order to detect the holes in the spectrum band. Focusing on each narrow band, existing spectrum sensing techniques are widely categorized into energy detection [7] and feature detection [8]. The CR network necessitates the following functionalities for spectrum sensing:

*PU Detection*: The CR user observes and analyses its local radio environment.

*Cooperation*: The observed information in each CR user is sent to base-station or exchanged with its neighbours, and spectrum availability is determined accordingly.

*Sensing Control*: The PU detection functionality is controlled and coordinated by a sensing controller, which considers two main issues on i) how quickly a CR user can find the available spectrum band over a wide frequency range for their transmissions, and ii) how long and how frequently a CR user should sense the spectrum to achieve sufficient sensing accuracy during the transmission and detect the presence of transmission in primary networks to avoid interference [9].

*1) Transmitter detection*

In transmitter detection approaches, the detection of primary users is performed based on the received signal at secondary users. The most well-known approaches in this category include Matched Filter (MF) detection, Energy detection, and Cyclostationary-Feature detection.

*Matched Filter (MF) detection:* Matched-filtering is known as the optimum method for detection of primary users when the transmitted signal is known. The main advantage of matched filtering is, it needs less detection time because it requires only O (1/SNR) samples to meet a given probability of detection constraint [10]. However, matched-filtering requires cognitive radio to demodulate received signals. Hence, it requires perfect knowledge of the primary users signaling features such as bandwidth, operating frequency, modulation type and order, pulse shaping, and frame format.

*Energy detection:* It is a non-coherent detection method that detects the primary signal based on the sensed energy. The energy of the received primary signal is measured by squaring and integrating the received signal over the observation interval. To ensure that the PU is present or absent, the output of the integrator is compared with a threshold. The energy detector is very simple and easy in implementation as it only tells about the presence of the signal but cannot distinguish between different signal types. Hence, sometimes the energy detector provides false detection of signals.

*Cyclostationary feature detection:* It exploits the periodicity in the received primary signal to identify the presence of primary users (PU). The periodicity is commonly embedded in sinusoidal carriers, pulse trains, spreading code, hopping sequences or cyclic prefixes of the primary signals [11]. The Cyclostationary-Feature detection has better performance even in low SNR regions, but has higher computational complexity and requires significantly long observation time. The signal of the PU can be detected at very low SNR values if it exhibits strong cyclostationary properties. Although it requires a priori knowledge of the signal characteristics, cyclostationary feature detection is capable of distinguishing the CR transmissions from various types of PU signals.

*2) Cooperative and non-cooperative Detection*

From the viewpoint of detection behavior, spectrum sensing can be divided into non-cooperative and cooperative detection. In the non-cooperative detection, secondary users conduct detection independently by themselves. While in the cooperative detection, secondary users share their detection information to improve the detection performance.

*3) Interference-based Detection*

Interference is typically regulated in a transmitter-centric way, which means Interference can be controlled at the transmitter through the radiated power and the location of every transmitter. The interference temperature management detection manages interference at the receiver according to the interference temperature limit, which is represented by the amount of interference that the receiver could tolerate.

### *B. Cognitive Radio and the Physical layer*

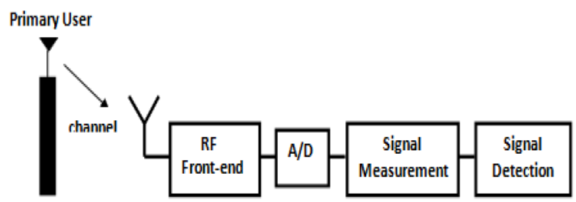


Figure 1. Cognitive Radio Receiver

In the process of sensing the unoccupied spectrum, the signal is detected via the RF-front end, and as the received signal is in analog form, it is converted to the digital form through the Analog to Digital converter (ADC). After the analog to digital conversion, the measurements are made for the detection of the primary user signal. After detecting the unoccupied spectrum, the CR should adapt a feasible modulation technique to utilize the maximum available capacity.

Now coming towards the transmitter side of the CR. The critical issue on the transmitter’s side is the generation of a signal that does not create interference with the primary users.


www.IJSEI.com ISSN: 2251-8843 Paper ID: 44715-02

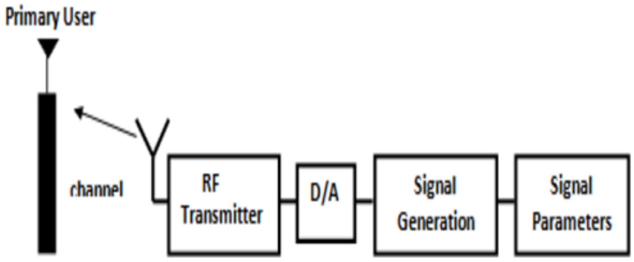


Figure 2. Cognitive Radio Transmitter

### C. Spectrum Analysis

By the opportunistic sensing of the wireless spectrum, white holes are detected. Analysis of these white holes helps to choose the appropriate spectrum from a lot of sensed potion of the spectrum. In spectrum analysis, there are some factors which help to categorize the spectrum holes.

- Interference: Upper bound in interference temperature limit gives us the information about the allowable interference that can exist in the band.
- Path Loss: If operating frequency is increased, the path loss also increases. In order to decrease the path loss at high frequency, the transmission power of cognitive user needs to be kept constant which will reduce the transmission range as well.
- Wireless Link Errors: Error rate of the channel is dependent on the modulation scheme used and on the interference level.
- Link Layer Delay: To tackle the different kind of channel errors, path losses and interference, there is a need of different link protocols at each band.
- Holding Time: Holding time is referred to as the time for which the cognitive user occupies the spectrum without any interruption. It is good to have a large holding time and less handoff.

### D. Spectrum Decision

CR networks require capabilities to decide on the best spectrum band among the available bands according to the QoS requirements of the applications. This notion is called spectrum decision. The following are main functionalities required for spectrum decision:

*Spectrum Characterization*: Based on the observation, the CR users determine not only the characteristics of each available spectrum but also its PU activity model.

*Spectrum Selection*: The CR user finds the best spectrum band to satisfy user QoS requirements.

*Reconfiguration*: The CR users reconfigure communication protocol as well as communication hardware and RF front-end according to the radio environment and user QoS requirements.

- Spectrum Decision Challenges: In the development of the spectrum decision function, several challenges still remain unsolved:

*Decision model*: Spectrum capacity estimation using signal-to-noise ratio (SNR) is not sufficient to characterize the spectrum band in CR networks.

*Cooperation with reconfiguration*: CR techniques enable transmission parameters to be reconfigured for optimal operation in a certain spectrum band. Hence, a cooperative framework with reconfiguration is required in spectrum decision.

### E. Spectrum Sharing

Spectrum sharing is allocation of an unprecedented amount of spectrum that could be used for unlicensed or shared services. Opportunistic communication with interference avoidance faces a multitude of challenges in the detection of sharing in multi-user cognitive radio systems. Spectrum sharing mainly focuses on resource management within the same spectrum with the following functionalities:

*Resource Allocation:* Based on the QoS monitoring results, CR users select the proper channels (channel allocation) and adjust their transmission power (power control) to achieve QoS requirements as well as resource fairness.

*Spectrum Access*: It enables multiple CR users to share spectrum resources by determining who will access the channel or when a user may access the channel.

- Spectrum Sharing Techniques

The sharing of spectrum among cognitive users is divided into three main classes. The first classification is based on the architecture, which can be centralized or distributed:

*Centralized spectrum sharing*: In this technique there exists a central entity that controls the allocation of spectrum and channels.

*Distributed Spectrum Sharing*: Distributed spectrum sharing technique is implemented in the case where there cannot be defined any infrastructure of the network.

The second classification is based on allocation behavior, where spectrum access can be cooperative or non-cooperative.

*Cooperative spectrum sharing:* The measurements of interference made by the individual cognitive users are shared among all users. This information collected from all the users is used for the allocation of the spectrum.

*Non-cooperative Spectrum Sharing:* In non-cooperative spectrum sharing the cognitive users are making decisions based on local observations. They do not cooperate with each other and are making decisions independently from others.

Finally, the third classification for spectrum sharing in CR networks is based on the access technology:

*Overlay spectrum sharing:* In this type of sharing the SUs are accessing the spectrum at the same time the PUs are accessing it, but with as little interference as possible.

*Underlay Spectrum Sharing:* The spectrum is shared in one of the following three ways:

Opportunistic: The spectrum is shared among the SUs whenever the PUs are not using it.

Cooperative: The spectrum is allocated after negotiation with the PUs.

Mixed: The spectrum is accessed in either a cooperative or opportunistic way.

- Spectrum Mobility

The spectrum mobility functions in a cognitive radio network allow an unlicensed user to change its operating spectrum dynamically based on the spectrum conditions .This issue can be addressed in following ways.

*Search for the best frequency band:* A cognitive radio must keep track of available frequency bands so that if necessary, it can switch immediately to other frequency band.

*Protocol stack adaptation:* Since the latency due to spectrum handoff could be high, the modification and adaptation of other components in the protocol stack is required [12].

*Spectrum Mobility Challenges*: The following are the main challenges for efficient spectrum mobility in CR networks:

*Spectrum mobility in the time domain*: CR networks adapt to the wireless spectrum based on the available bands. Because these available channels change over time, enabling QoS in this environment is challenging.

*Spectrum mobility in space:* The available bands also change as a user moves from one place to another. Hence, continuous allocation of spectrum is a major challenge.

## IV. CONCLUSION

Cognitive radio is already being considered as the candidate for the 5th generation of wireless communications. The study of the cognitive radio will be one of the most influential scientific endeavors in the 21st century. It is a promising technology which enables spectrum sensing for opportunistic spectrum usage by providing a means for the use of white spaces. As the usage of frequency spectrum is increasing, it is becoming more valuable. So we need to access the frequency spectrum wisely. For this purpose we are using Cognitive Radio. Spectrum is a very valuable resource in wireless communication systems. CR networks are still in its early stage of development and there are many complex issues which still need to be resolved in future especially regarding common control channel (CCC). In the future, we want to propose efficient channel management scheme from single hop scenario to multi-hop scenarios.

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