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Fundamentals of Cognitive Radio

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Abstract: ***This document gives an overview of the fundamental concepts related to the working of Cognitive Radio. In today's world, where the demand for wireless applications and services is increasing beyond limits and at the same time, the availability of radio spectrum is diminishing greatly, it is highly required that a technology be developed that could help improve the efficient utilization of the limited spectrum. The concept of Cognitive Radio (CR) was developed with this idea and it has become a great success by allowing more and more users or services to utilize the available spectrum. Cognitive Radio helps is basically rooted on the concept of sensing the radio environment around it and dynamically allotting or sharing the spectrum with additional users at times when the licensed users do not need it, thereby helping in uniformly distributing the usage of the spectrum with minimal or no interference caused to the primary users. The different spectrum sensing techniques and dynamic spectrum access methods employed by the CR are also discussed in this paper.***
Keywords: ***Cognitive Radio, Spectrum Sensing, Dynamic Spectrum Access, Spectrum hole, Spectrum sharing.***

I. INTRODUCTION

Wireless communications has been one of the fastest growing segments of communication field today and as a result, the demand for wireless applications and devices has also been growing rapidly. But the available radio spectrum is limited and hence the utilizable spectrum for each application is becoming very scarce. With the current multiple access methods employed for the allocation of the available radio spectrum to the users for different applications, it can be seen that some of the spectrum bands tend to be unutilized many of the times, while some others tend to be used heavily. This results in an inefficient utilization of the radio spectrum. Different studies and researches are being done in this area to develop a method for better and efficient utilization of the electromagnetic spectrum and one such method is based on the concept of Cognitive Radio (CR).

The conventional methods used for managing the spectrum allocates the spectrum in a static manner because of which, the utilization of the spectrum bands become unevenly distributed. These results in the spectrum allocation being less flexible as far as the users are concerned. This issue can be overcome using two approaches ie. Improved utilization of the spectrum and dynamic spectrum access. Cognitive Radio refers to wireless architectures in which a communication system does not work in a fixed frequency band, but continuously searches and finds an appropriate vacant band in which to operate. The spectrum allocation in CR is performed dynamically and this is achieved using the technique known as Spectrum Sensing. Cognitive radios possess the ability to move in and out of un-used spectrum bands to increase the spectrum utilization efficiency and at the same time, minimize the issue of spectrum overcrowding. Cognitive radio is capable of intelligently detecting which communication channels are in use and can switch to vacant channels while avoiding occupied ones. This helps to optimize the utilization of available RF spectrum simultaneously minimizing interference to other users.

The rest of the paper has been organized as follows. Section II talks about the fundamental principle of CR technology, section III explains the models or methods employed for the dynamic allocation of spectrum in CR. Section IV briefs the different spectrum sensing techniques used in CR and section V concludes the paper.

II. COGNITIVE RADIO

Cognitive Radio is an advanced radio technology which can sense its environment and can change its operating behavior or parameters accordingly [1]. There are basically two types of users in the cognitive radio system namely, the Primary Users (PU) and the Secondary Users (SU). PUs are the licensed users and they have the rights of priority in using certain specific frequency band for communications. SUs are allowed to use the frequency spectrum temporarily only if they do not cause interfere to the PU. So the ability of sensing an idle spectrum and the ability to temporarily utilize a spectrum without interfering with PUs are two essential components required for the efficient working of cognitive radios. The key concepts on which the working of CR is based are sensing, cognition and adaptation [2]. It can serve the needs of both licensed as well as unlicensed applications. CR is a Software Defined Radio (SDR) that additionally performs the tasks of sensing its radio environment, detects the changes and responds depending on its findings [3]. It is an autonomous unit in a communications environment that frequently exchanges information with the networks it is able to access as well as with other CRs. In short, the CR is a radio that can be dynamically configured or

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programmed to use the best wireless channels in its vicinity.

The sub-bands of radio spectrum can be categorized mainly into three types - White space, Gray space and Black space. White space has primary signals with negligible power levels and can be considered to be free of RF interferences except for background noises. Gray space can be considered to be partially occupied by interferers and noise. This includes the spectrum with medium and low power primary signals which are too weak to be decoded by the CR. These signals are considered to be significant sources of interferences to the CR network. Black space refers to the part of the spectra which are almost fully occupied by high power signals that can be decoded by CR receivers.

A. Characteristics of CR

There are two most important properties or characteristics associated with every cognitive radio and they can be described as given below [4]:

1) *Reconfigurability:* Reconfigurability enables the cognitive radio to be programmed dynamically according to the radio environmental factors such as transmission power, frequency, communication protocol, modulation scheme etc.
2) *Cognitive Capability: Cognitive Capability defines the ability to capture or sense the information from its radio environment of the radio technology. This characteristic refers to the ability of the CR to observe the environment continually, take decisions, adapt itself and perform the desired action.*

B. Types of CR

There are two main types or variants of the cognitive radios [4].

1) *Full Cognitive Radio*: Full Cognitive Radio considers the value or state of every possible observable parameter before taking decisions and adapting itself to the environment.
2) *Spectrum Sensing Cognitive Radio*: Here only the channels in the radio frequency spectrum are detected and many different signal detection techniques are used in spectrum sensing.

C. Functions of CR

There are four important functions performed by a CR.

1) *Spectrum Sensing*: This is the most important and sensitive task performed by CR. Cognitive Radio continuously observes the surrounding radio environment and looks for unused spectrum which is also known as the spectrum hole or white space. The first step of spectrum sensing involves determining the presence of primary or licensed user on a band. This step helps in finding out the status of spectrum availability and activity by periodically sensing the target frequency band. A CR transceiver is also capable of determining the method of accessing the spectrum hole without interfering the primary user's transmission. Spectrum sensing can be implemented in two ways - centralized or distributed. The centralized spectrum sensing technique makes use of a common sensing controller to sense the target frequency band and shares the information with other nodes in the system. But in case of distributed sensing, multiple sensors are used for this purpose rather than a centralized or common sensor.

2) *Spectrum Management*: Once the spectrum holes or white spaces are detected, cognitive radio selects the available white space or channel immediately for allocating to secondary users and this function is known as spectrum management. This provides the fair spectrum scheduling method among coexisting users [5]. There are three main steps involved in performing this function. They are spectrum sensing, analysis, and decision making. Once the spectrum sensing is done, spectrum analysis helps in achieving the characterization of different spectrum bands, which is exploited to get the spectrum band appropriate requirements of the user. Spectrum decision includes deciding the transmission mode, bandwidth, data rate etc. Then, the appropriate spectrum band is selected according to the spectrum characteristics and user requirements.

3) *Spectrum Sharing*: Cognitive Radio allocates the unused spectrum to the secondary user as long as primary user does not need it. This property of cognitive radio helps to utilize the spectrum more efficiently and at the same time, reduces the interference to the licensed users.
4) *Spectrum Mobility*: Cognitive Radio vacates the channel when a primary user is detected. This property of CR is called the spectrum mobility or handoff [4]. This step helps the CR to change the frequency of operation. In order to operate in the best

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available frequency band, CR networks typically accesses the spectrum dynamically.

D. Applications of CR

Some of the most vital applications of cognitive radio that have been great successes so far include the following [4].

1) Applications in emergency and public safety services
2) Vehicular Communications
3) Radio networks with opportunistic spectrum access
4) Broadband wireless networking applications which require high data rates
5) Wireless networking services in multimedia
6) Mobile multimedia downloads

III. DYNAMIC SPECTRUM ACCESS

As already mentioned above, the issue of spectrum under-utilization can be solved by performing dynamic allocation. The different dynamic spectrum access can be shown as in Fig. 1 [6].

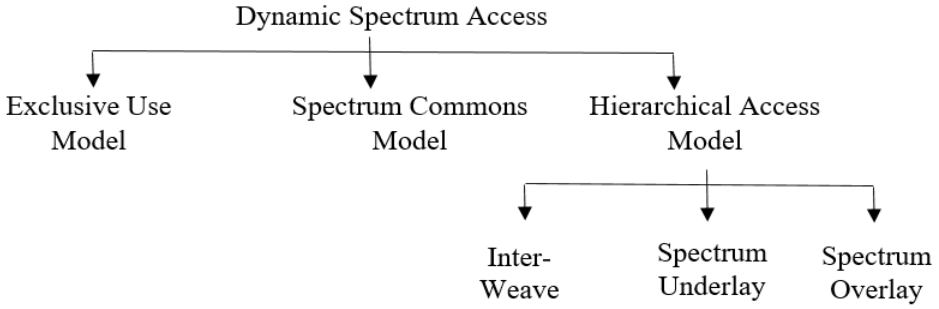


Fig.1 Dynamic spectrum access models

A. Exclusive Use Model

In this method, the spectrum bands are licensed to various services or applications for exclusive use. The main concept used here is to improve the efficiency of spectrum utilization by introducing a factor of flexibility. Temporal and spatial statistics of the traffic of different services are considered and then spectrum assignment is performed dynamically in such a way that sufficient spectrum is made available to services for exclusive use in a given region and at a given time.

B. Spectrum Commons Model

This model is also known as Open Sharing model or the Open Spectrum model. Here, every user in the system has equal rights to use the available spectrum. There are three different types of commons model namely the Uncontrolled-commons (where no particular person or entity has the exclusive authority to use the spectrum band), the Managed-commons (controlled or owned by a group of entities or individuals and characterized by restrictions on how and when to use the resources) and the Private-commons (which allows the usage of advanced technologies so as to allow multiple users to access the spectrum).

C. Hierarchical Access Model

In hierarchical access model, the primary resources are used by the secondary users in such a way that the interference caused to the primary user is limited. There are three main approaches within this model.

1) *Inter-Weave:* The basic concept behind the inter-weave model is to make use of an opportunistic re-use of the spectrum in the spatial domain. So in the geographical areas where primary activity is absent, the primary spectrum is utilized by CRs.
2) *Underlay:* Underlay use of the primary spectrum is unlicensed. In this model, the secondary users operate at very low power levels which are below the noise floor of the PUs. This allows additional users to perform communication without the knowledge of the PUs.
3) *Overlay:* Overlay concept of cognitive radio performs communication at higher powers. This could result in interference to primary users. But this issue is overcome by allowing secondary users to transmit only at times or in areas where the spectrum is unused.

IV. SPECTRUM SENSING TECHNIQUES

Spectrum sensing is the major task of cognitive radio for utilizing spectrum resources efficiently, thereby identifying and making

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use of spectrum holes. Spectrum sensing techniques can be mainly of three major types – the Transmitter (non co-operative) detection, the Co-operative detection and the Interference based detection. The main concepts used in each type of sensing technique can be briefed as given below.

A. Transmitter Detection

This type of sensing is also known as Non-cooperative sensing method. This is further classified into three.

1) Energy detection: Energy Detection is the common way of spectrum sensing for its low computational and implementation complexities. It is a non-coherent detection method which is used to detect the signal from the primary user and is based on the use of FFT (Fast Fourier transform), which transforms a signal from a time domain to a frequency domain representation, determines the power in each frequency of the signal resulting in which is known as the PSD (Power Spectral Density). In this technique, the output of the energy detector compares with a threshold depending on the noise floor and signal is detected [5]. This method does not require the receivers to have any a priori knowledge regarding the signal from the licensed user.

2) Matched filter detection: The matched filter detector is also referred to as coherent detector. This is an optimal detector in Gaussian noise which maximizes the received signal-to-noise ratio (SNR). Matched filter determines the presence of the PU by correlating the signal with time shifted version and comparing between the pre-determined threshold and output of matched filter [5]. Matched filter detection may be preferred in cases where the secondary user has a priori knowledge about the primary user's signal.

3) Cyclostationary feature detection: Cyclostationary feature detection is based on the introduction of periodic redundancy into a signal by sampling and modulation. The Cyclostationary feature detector makes use of the periodicity in the received signal to determine the presence of Primary Users (PU) by means of measuring the property of a signal called as Spectral Correlation Function [5]. This method can help to differentiate the modulated signal from the additive noise and hence can be used for very low signal to noise detection as well, by making use of the information present in the licensed user's signal but not in the noise part.

B. Co-operative Detection

The sensing will be accomplished by a number of different radios within a cognitive radio network in a cooperative cognitive radio spectrum sensing system. Typically reports of signals from different radios in the network are received by a central station which concludes their combined decision by some particular fusion rule.

C. Interference Based Detection

Interference at the transmitter side is controlled by controlling the radiated power which causes the interference. But the same task is accomplished at the receiver side by imposing interference temperature limits, which is the additional amount of interference that can be tolerated by the receiver. But the major drawback associated with this model is that it considers the case with only a single secondary user.

V. CONCLUSIONS

The Cognitive Radio technology has been highly successful in making the utilization of the available radio frequency spectrum much more efficient. With the increase in wireless services and applications, static assignment of spectrum for each service or application results in making the spectrum scarce. The spectrum utilization is overcrowded in some bands and under-utilized in some others. CR has helped in sharing the spectrum of the primary user with additional users with minimal or no interference to the licensed users. The cognitive users continuously monitor the spectrum usage and are allowed to make transmissions as long as it does not cause issues to the primary users and has thus helped in making the utilization of the available spectrum more efficient and distributed.

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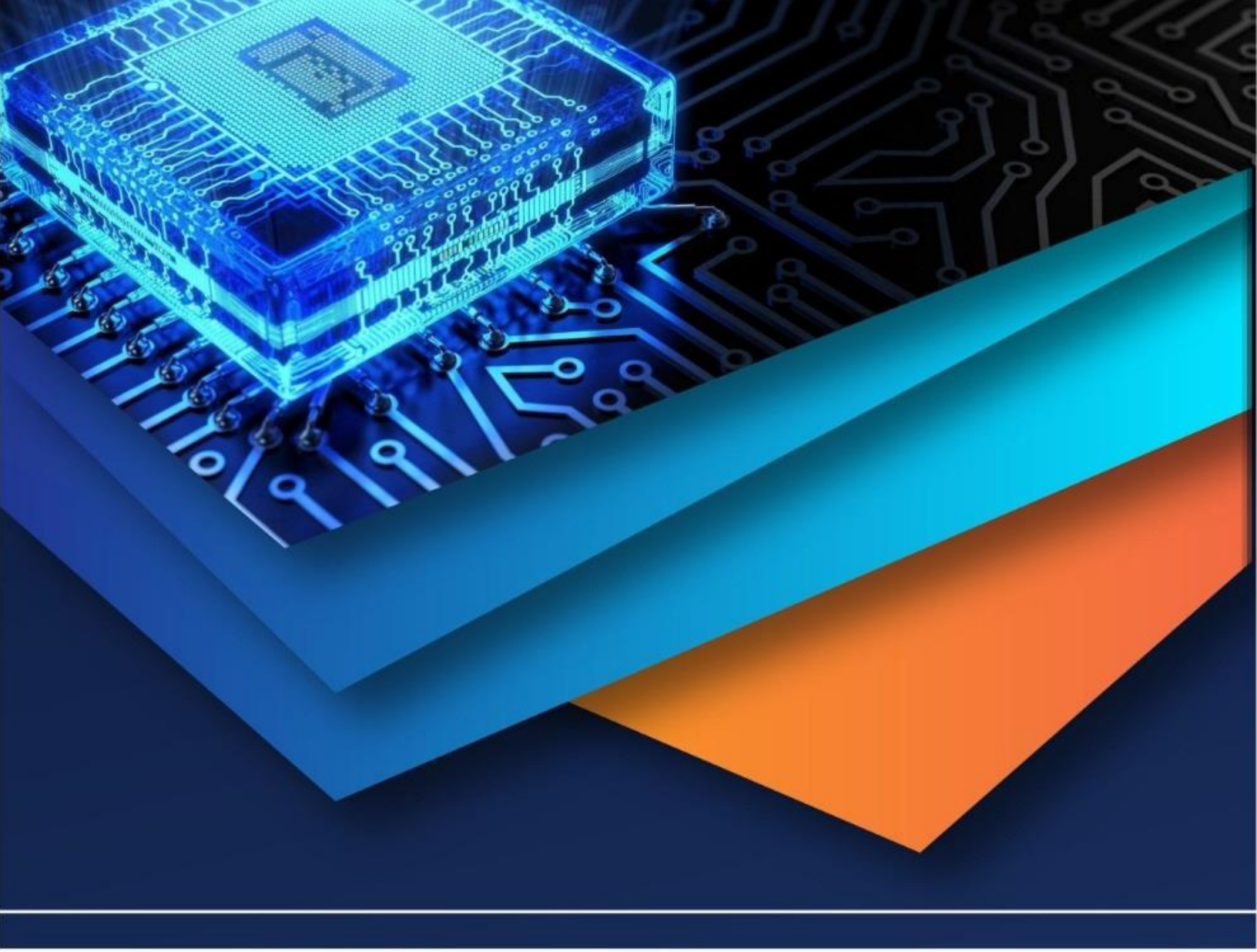
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