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Spectrum Management Techniques in Cognitive Radio

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Abstract—*Cognitive radio is an intelligent wireless communication system that is aware of its surrounding environment and adapt its internal states to variations in the incoming radio frequency (RF) stimuli by making corresponding changes in certain operating parameters (e. g. , transmit power, carrier frequency, and modulation strategy) in real time. Cognitive Radio makes efficient utilization of the available radio spectrum by identifying the white spaces in spectrum and making them available for secondary users(unlicensed). The secondary users use the spectrum in such a way that they cause no interfernce to the primary user(licensed) and the primary users are always given a priority. The spectrum management in Cognitive Radio is done in four steps namely Spectrum sensing, Spectrum Decision, Spectrum Sharing and Spectrum mobility. Sensing is done to detect spectrum holes by three methods namely Transmitter detection, receiver detection and interference temperature management. Spectrum decision, involves choosing a band from the available ones, keeping in mind the QOS requirements. Spectrum is shared based on architecture, spectrum allocation behavior and spectrum access technique. Spectrum mobility at last refers to the handing of the frequency the secondary user is working on, if it is required by the primary user. These spectrum management techniques thus prove to be a good solution to the problem of spectrum scarcity.*

1. INTRODUCTION

Today the access to radio resources usually is regulated by government agencies that execute a nation's rights in spectrum usage. Spectrum is assigned to network operators or other organizations on a long-term basis and usually for large geographic regions. As recent measurements indicate, this procedure can lead to spectrum scarcity. To overcome this scarcity, the most liberal vision for future spectrum usage is that the resources should be allocated only where and as long as they are needed[2]. Cognitive Radio is a wireless technology that uses the spectrum effieciently and adapts according to the environment. A cognitive radio is a self reconfiguring radio. A cognitive radio is a radio that can change its transmitter parameters based on interaction with the environment in which it operates. The architecture of CR is very similar to that of an SDR(Software Defined Radio) , the difference being the control bus[3]. Each component can be reconfigured via a control bus to adapt to the time-varying RF environment fig1. The characteristic of cognitive radio transceiver is a wideband sensing capability of the RF front-end. This function is mainly related to RF hardware technologies such as wideband antenna, power amplifier, and adaptive filter. RF hardware for the cognitive radio should be capable of tuning to any part of a large range of frequency spectrum.

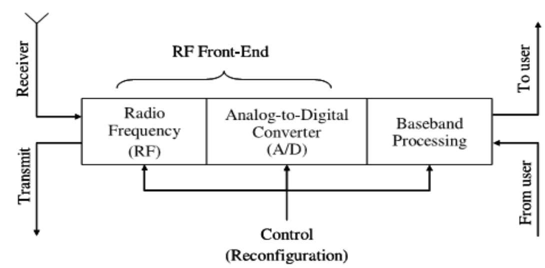


Fig. 1

A CR(Cognitve Radio) should be flexible so as to change the operational parameters while working according to the real time situation and considering the environment. It should have sensing ability to observe the environment and look out for spectral holes or white space. White space is that part of spectrum that is not being used or is free. CR with the help of its real time sensing can detect the spectrum holes and use it for communication, but care has to be taken so that no inference takes place and that the primary user is given preference. Through real-time interaction with the radio environment, the portions of the spectrum that are unused at a specific time or location can be identified. This enables the usage of temporally unused spectrum[6].

So in a cognitive radio environment two types of users may be identified primary(licensed) and Secondary (unlicensed). Whenever a CR needs a channel and its own spectrum is all in use or busy it searches for white spaces in other CR's spectrum to which it becomes a secondary user.

Interoperability is an another important feature of cognitive radio. Different systems today are working on different wireless standards which may sometimes cause problem in communication in case of emergencies, CR may help remove this problem as it is reconfigurable. A CR must know its location. This knowledge may help in assessing the environment as far as radio transmission conditions are concerned. The electromagnetic environment differs in rural areas from urban areas. Location determination must be performed periodically. When setting up a connection with another CR, both partners must know about their particular location, because this may help to make optimal use of the channel. This underlines the remark of Haykin that CR requires a feedback channel. The location of a CR is determined by employing localization systems like GPS.

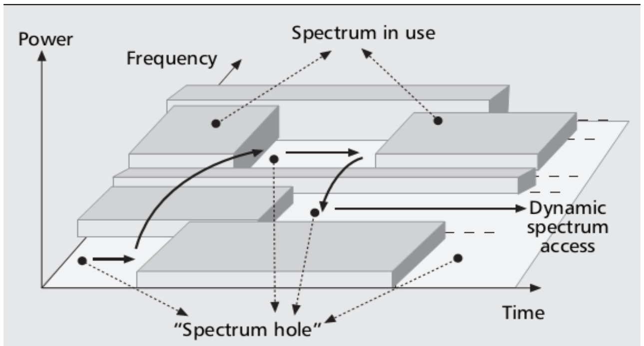


Fig. 2

2. SPECTRUM MANAGEMENT

Spectrum management means managing the available white space without causing any interference to licensed user. It consists of four major steps;Spectrum sensing, Spectrum decision, Spectrum sharing, Spectrum mobility.

1 Spectrum Sensing- Spectrum sensing means a CR user should monitor the available spectrum bands, capture their information, and then detect spectrum holes. Spectrum sensing enables CR users to adapt to the environment by detecting spectrum holes without causing interference to the primary network. Generally, spectrum sensing techniques can be classified into three groups: primary transmitter detection, primary receiver detection, and interference temperature management. Transmitter detection is based on the detection of a weak signal from a primary transmitter through the local observations of CR users. But there are certain problems in this method as depicted in the figure below with the transmitter detection, the CR user cannot avoid the interference due to the lack of the primary receiver's information[8]. Moreover, the transmitter detection model cannot prevent the hidden terminal problem**.**

An xG transmitter can have a good line-of-sight to a receiver, but may not be able to detect the transmitter due to the shadowing. Consequently, the sensing information from other users is required for more accurate detection. Sensing information from other users required for more accurate primary transmitter detection — referred to as **cooperative detection**[6].

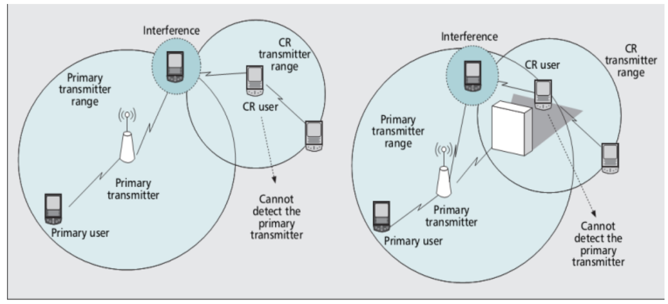


Fig. 3

Cooperative detection is theoretically more accurate because the uncertainty in a single user's detection can be minimized through collaboration. Moreover, multipath fading and shadowing effects can be mitigated so that the detection probability is improved in a shadowed environment.

Although cooperative detection reduces the probability of interference, the most efficient way to detect spectrum holes is to detect the primary users that are receiving data within the communication range of a CR user. This is called as **Primary Reciever Detection**. The local oscillator (LO) leakage power emitted by the RF front-end of the primary receiver is measured. However, because the LO leakage signal is typically weak, implementation of a reliable detector is not trivial. This method is only suitable in the detection of TV receivers. [6]

Interference Temperature Management

Traditionally, interference can be controlled at the transmitter through the radiated power and location of individual transmitters. However, interference actually takes place at the receivers. Therefore, a model for measuring interference, referred to as interference temperature, has been introduced by the Federal Communications Commission (FCC). This model limits the interference at the receiver through an interference temperature limit, which is the amount of new interference the receiver could tolerate. As long as CR users do not exceed this limit, they can use the spectrum band. Although this model is the best fit for the objective of spectrum sensing, the difficulty of this model lies in accurately determining the interference temperature limit.

2. 2 Spectrum Decision

CR networks require the capability to decide which is the best spectrum band among the available bands according to the QoS requirements of the applications. This is called spectrum decision. After the available spectrum bands are characterized, the most appropriate spectrum band should be selected, considering the QoS requirements and spectrum characteristics. To describe the dynamic nature of CR networks, a metric primary user activity is proposed , which is defined as the probability of a primary user appearance during CR user transmission[8]. Because there is no guarantee that a spectrum band will be available during the entire communication of a CR user, it is important to consider how often the primary user appears on the spectrum band. However, because of the operation of primary networks, CR users cannot obtain a reliable communication channel for a long time period. Moreover, CR users may not detect any single spectrum band to meet the user's requirements. Therefore, multiple noncontiguous spectrum bands can be simultaneously used for transmission in CR networks, as shown in Fig4.

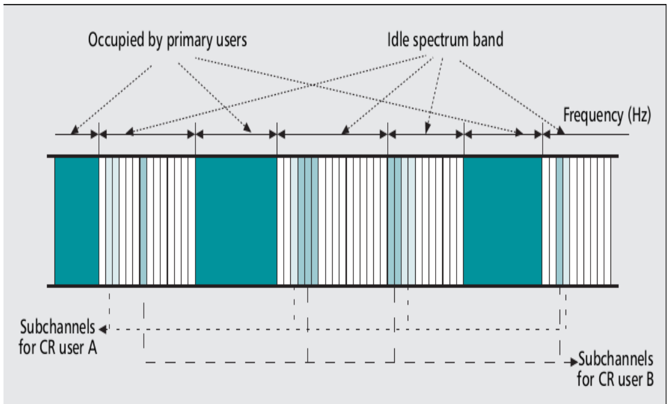
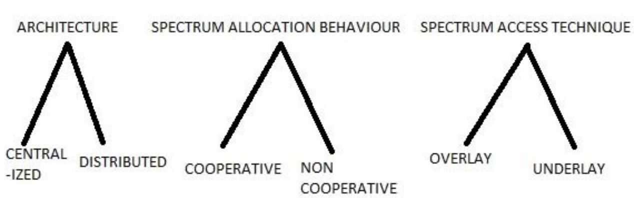


Fig. 4

This method can create a signal that is capable of high data throughput, and is also immune to interference and primary user activity. Even if spectrum handoff occurs in one of the current spectrum bands, the rest of the spectrum bands will maintain current transmissions.

2. 3 Spectrum Sharing

The shared nature of the wireless channel requires the coordination of transmission attempts between CR users. This is called spectrum sharing. It can be classified in following ways:



2.3.1 Centralized spectrum sharing: In this the spectrum allocation and access procedures are controlled by a central entity. A distributed sensing procedure is used such that measurements of the spectrum allocation are forwarded to the central entity, and a spectrum allocation map is constructed. Furthermore, the central entity can lease spectrum to users in a limited geographical region for a specific amount of time. Incase of competition for the spectrum, competition for users can also be considered through a central spectrum policy server.

2.3. 2Distributed spectrum sharing: Spectrum allocation and access are based on local (or possibly global) policies that are performed by each node distributively. Distributed solutions also are used between different networks such that a base station (BS) competes with its interferer BSs according to the QoS requirements of its users to allocate a portion of the spectrum. The recent work on comparison of centralized and distributed solutions reveals that distributed solutions generally closely follow the centralized solutions, but at the cost of message exchanges between nodes.

2.3.3Cooperative spectrum sharing: Cooperative solutions exploit the interference measurements of each node such that the effect of the communication of one node on other nodes is considered. 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.

2.3.4 Non-cooperative spectrum sharing: Only a single node is considered in non-cooperative solutions. Because interference in other CR nodes is not considered, non-cooperative solutions may result in reduced spectrum utilization. However, these solutions do not require frequent message exchanges between neighbors as in cooperative solutions.

2.3.5 Overlay spectrum sharing: Nodes access the network using a portion of the spectrum that has not been used by licensed users. This minimizes interference to the primary network.

2.3.6 Underlay spectrum sharing: The spread spectrum techniques are exploited such that the transmission of a CR node is regarded as noise by licensed users.

2.4 Spectrum Mobility

The fourth step of spectrum management, as explained earlier, is spectrum mobility management. After a CR captures the best available spectrum, primary user activity on the selected spectrum may need that the user change its operating spectrum band(s), which is referred to as spectrum mobility. Spectrum mobility gives rise to a new type of handoff in CR networks, spectrum handoff. Each time a CR user changes its frequency of operation, the network protocols may require modifications to the operation parameters. The purpose of the spectrum mobility management in CR networks is to ensure smooth and fast transition leading to minimum performance degradation during a spectrum handoff. An important requirement of mobility management protocols is information about the duration of a spectrum handoff[8]. This information can be provided by the sensing algorithm. After the latency information is available, the ongoing communications can be preserved with only minimum performance degradation.

3. CONCLUSION

In the present scenario where the need of communication is increasing at an exponential rate, the frequency spectrum needs to be utilized very efficienty to meehe demands of all users. Cognitive Radio is an excellent way out to tackle the spectrum scarcity being faced with the various spectrum management techniques, where the white spaces are utilized by the secondary users. Not only is the spectrum utilized efficiently but the property of Cognitive Radio to adapt according to the environment results into a very good quality of service.

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