Spectrum Sensing for Cognitive Radio

A Comparitive Study of Interweave and Underlay Approaches

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Chapter 1

Cognitive Radio: A Brief Overview

1.1 Introduction

Technology is advancing rapidly, especially in the filed of wireless communications. New communication devices and signal architectures are invented every day, and therfore there is a dire need for higher data rates. However, the radio frequency (RF) spectrum is limited, and not all the devices can be allocated spectrum with the present allocation schemes. A dynamic spectrum allocation has to be introduced to accomodate new technologies, and use the spectrum efficiently. This report discusses a possible solution to the problem of spectrum sharing - Cognitive Radio. Chapter 1 discusses the basics of Cognitive Radio, its requirements and the challenges. A deeper insight into methods of Spectrum Sharing (Interweave and Underlay) is given in Chapters 2 and 3.

1.2 Radio Spectrum

The radio spectrum is a limited natural resource [1]. This spectrum is divided into frequency bands, each for a particular service, and certain technologies. Frequency allocation is decided by the International Telecommunication Union (ITU), an agency of the United Nations, at the international level, and national regulatory authorities at the national levels [2]. Frequency assignment is done at the national level, wherein subdivisions of the spectrum are assigned to specific parties licensed to use them. This static allocation of the spectrum leads to inefficiency in the spectrum usage. Interference Protection and Dynamic Spectrum Access are very important for efficient spectrum usage.

1.2.1 Interference Protection

[3] states that interference protection is central to effective spectrum management. RF devices are designed and operated based on interference regulations and protocols. If the standards for interference protection are not met, it can lead to ineffective communication. Interference protection agreements are negotiated and formulated based on the allowed in-band power and admissible out-of-band emissions. The problem with these regulations is that they have to be updated regularly to meet the requirements of new technologies, methods of transmissions and also environmental changes. The first major concern is the sudden increase in RF devices sharing the spectrum, and their demand. Mobile phones, TV remotes, electronic doors, automatic lights, WiFi, Bluetooth, smart vehicles, radios are only few of the many RF devices that have to share the spectrum on a daily basis, and a static interference protection paradigm cannot set the standards of communication. Another major problem is the variety of signal architectures and modulation types utilized today, compared to a few years back. Even a single device uses multiple architectures to communicate. This further supports the fact that a static protection paradigm is not sufficient.

1.2.2 Dynamic Spectrum Access

The static allocation of radio spectrum results in its underutilization. The frequency bands vary in usage - some are heavily used, while some are partially occupied, and the rest are mostly unoccupied for large periods of time [1]. This results in spectrum holes. [4] defines a spectrum hole as a *"band of frequencies assigned to a licensed user, but, at a particular time and specific geographic location, the band is not being utilized by that user."* This can be depicted from figure 1.1. Spectrum Sensing provides a way to

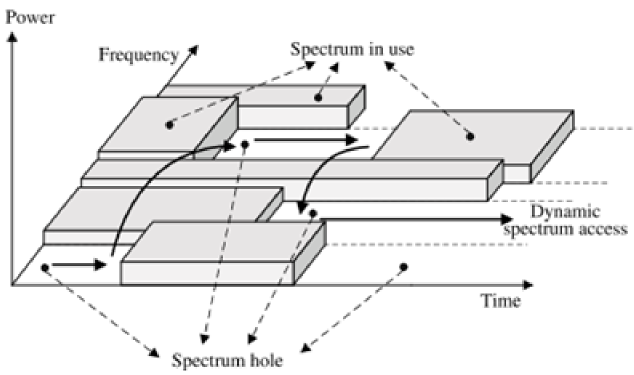


Figure 1.1: Spectral Holes [5]

sense these spectral holes, and utilize them, thereby increasing efficiency of spectrum usage. This, however requires a Dynamic Spectrum Access scheme, in which the non-licensed users utilize the spectrum, when they sense it is not being utilized by the licensed users.

1.3 Cognitive Radio

The term "Cognitive Radio" was first coined by Mitola and Maguire, in 1999, in an article they wrote together [6]. The Cognitive Radio (CR) is described as an intelligent radio, which understands its surroundings and can adapt its communication accordingly. The Federal Communications Commission (FCC) defines a CR as *"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 interference, facilitate interoperability and access secondary markets."* [7] In simpler words, it is a smart radio, that can sense and understand the channel characteristics, the transmission properties, the interference policies and regulations and other operating restrictions, and then adapt to the best communication strategy based on its own capabilities.

1.3.1 The Cognitive Cycle

The three main operations of a cognitive radio are *"observe, decide and act"* [6] as shown in figure 1.2.

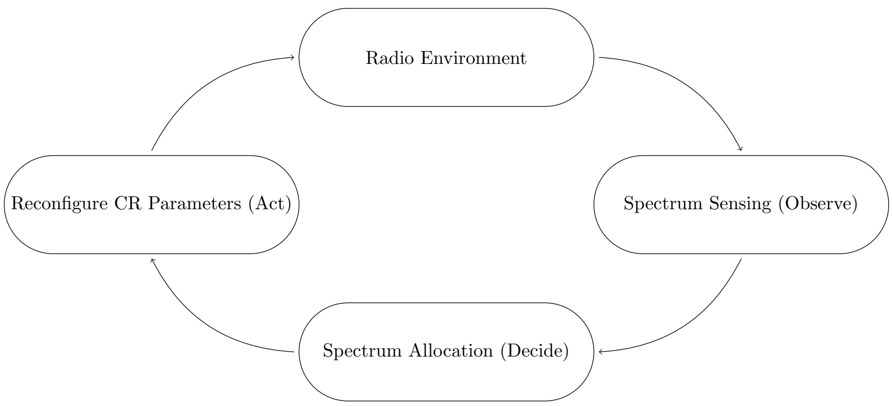


Figure 1.2: The Cognitive Cycle

The *observe* step refers to the cognitive radio sensing the channel parameters, and the presence of a licensed user, and the licensed user's transmission characteristics. Based on these observations, the cognitive radio has to *decide* whether or not to allow the non-licensed user to communicate. It has to calculate the allowed interference levels, power levels, and duration of transmission for the non-licensed user in the given time frame. These decisions are passed on to the *act* phase, where the radio reconfigures itself, to satisfy its decisions. This is a continuous cyclic process, wherein the radio has to reconfigure itself dynamically, for any change in operating or transmitting characteristics. This dynamic reconfigurability of the CR helps increase the spectrum utility.

1.3.2 Spectrum Sensing

There are two types of users, namely primary and secondary users. Primary users, or licensed users, pay for a particular band of frequencies, and utilize it for their services. Secondary users, or non-licensed users, tend to use the licensed spectrum whenever the primary user is not transmitting, or without interference to the primary user. To maintain Quality of Service at the primary user side, i.e no loss of data, and permissible interference, the CR should be able to sense when a primary user is communicating, and the transmission parameters being utilized. This process, called Spectrum Sensing, is the core of Cognitive Radio. [2] states that sensing in CR systems can be classified into two ways - non-cooperative sensing and cooperative sensing.

Non-Cooperative Sensing

In a system employing non-cooperative sensing, each radio acts individually, sensing its environment for primary transmissions and relaying that information to the secondary users in its range. The main problem which arises in this method is the hidden node problem, i.e a transmitter can be near the CR but not be detected, due to fading in the sensing signal. This leads to the decision that the spectrum is unoccupied, when it is actually occupied. Another problem is the time taken to sense is very high in this case, as each node acts for itself. So, cooperative sensing is suggested as a means to overcome these problems.

Cooperative Sensing

Cooperative sensing employs a network of nodes sensing the spectrum together, and relaying information among one another. The *Centralized* approach consists of a central node, and a network of nodes around it. This network senses the spectrum, and relays its decisions back to the central node, which processes the information and makes a decision as to whether the spectrum is occupied or not. This information is then passed back to the nodes. Another approach is the *Distributed* approach, where there is no central node, but the network of nodes share information amongst one another and make decisions based on their requirements. The cooperative sensing approach overcomes the hidden node problem, as though the transmitter may not be sensed by one node, it would be sensed by another node in the network. The time required for detection of primary user considerably reduces, due to collaboration of all the nodes.

1.3.3 Spectrum Sharing Approaches

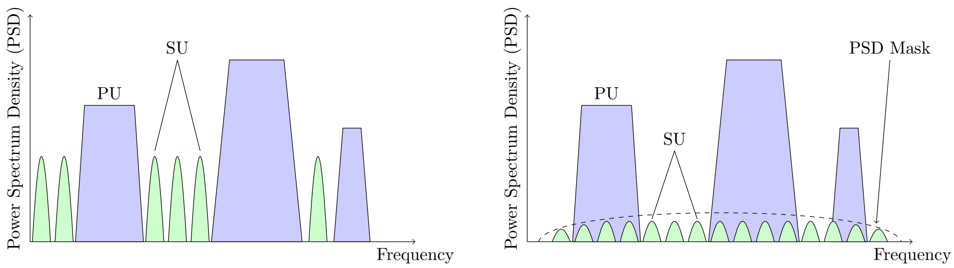
Once the CR has sensed the spectrum, it has to decide on an approach to share the spectrum between the primary and secondary user, keeping in mind all the operating restrictions, regulations and policies. The spectrum sharing approaches are of three types - Interweave, Underlay, Overlay.

Interweave Approach

The Interweave approach exploits the occurrence of spectral holes. The cognitive radio has to periodically monitor the spectrum, and allow for transmission of secondary users only when the primary user is not transmitting, i.e. at the occurrence of a spectral hole, as shown in figure 1.3a. This ensures minimal interference at the primary side. The main disadvantage in this approach is that there are delays in sensing that a spectrum is free, and also when the primary user starts to transmit again. The different sensing mechanisms utilized for this approach are discussed in Chapter 2.

Underlay Approach

The Underlay approach allows for simultaneous transmission of the primary and secondary user information. However, the secondary user is restricted to transmit at a low power, which does not exceed the allowed interference at the primary side, as shown in figure 1.3b. Due to the restriction on power at the secondary side, this approach is not suitable for long-range communication. The various system enabling techniques used in the underlay approach are discussed in Chapter 3.



(a) Interweave Approach (b) Underlay Approach

Figure 1.3: Spectrum Sharing Approaches

Overlay Approach

The Overlay approach also allows for simultaneous transmission of primary and secondary user information. In this case, the secondary user uses part of its power for secondary transmission, and the remaining power to assist the primary user transmission. This is more of a cooperative approach, and is not discussed further in this report.

1.4 Conclusion

The RF spectrum is limited, but in great demand, due to increase in technology, and devices utilizing the RF spectrum. Cognitive Radio is a possible solution to the problems arising in sharing the spectrum - interference protection and spectrum sensing. CR observes the surroundings, the transmission characteristics, regulations and policies and its own operating characteristics, and based on thes parameters takes a decision. This is a dynamic spectrum access method, whereing the interference protection protocols are updated dynamically, and the spectrum is utilized more efficiently. A deeper understanding on the sensing and sharing approaches is discussed in the subsequent chapters.

Chapter 2

The Interweave Approach to Spectrum Sharing

2.1 Introduction

2.2 Problems

2.3 Possible Methods

2.3.1 Hypothesis Testing

2.3.2 Energy Detection

2.3.3 Matched Filters

2.3.4 Feature Detection

2.3.5 Cyclo-Stationary Detection

2.4 Advantages and Disadvantages

2.5 Conclusion

Chapter 3

The Underlay Approach to Spectrum Sharing

3.1 Introduction

3.2 Problems

3.3 Possible Methods

3.3.1 Power Control

3.3.2 Interference Mitigation

3.3.3 Beamforming

3.3.4 Ultra Wide Band

3.3.5 SpreadSpectrum Sensing

3.3.6 Null Space MIMO

3.4 Advantages and Disadvantages

3.5 Conclusion

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