Chapter 2
Cognitive Radio Networks

2.1 Introduction

As more and more wireless devices and services become available, there is a greater need for radio spectrum. Radio waves are a scarce resource for wireless communication technologies, in contrast to the vast bandwidth of optical fiber networks. Each user in today's cellular wireless networks has licensed access to a certain frequency band and must stay inside that band when using the network. Unfortunately, spectrum allotment leaves very little bands of frequency for new wireless networks to operate. Because of the need for high-speed data services, the RF spectrum is becoming increasingly congested. Growing demand for wireless devices combined with the current system of assigned frequencies could soon lead to a shortage of usable radio frequencies (RF). Get an access of licensed spectrum; the spectrum policy task group proposed a secondary spectrum access solution to this problem in the year of 2002 [1]. According to studies and real-world testing, the frequency allocated to traditional wireless systems is underutilized. There is a growing need for more radio spectrum, which is a finite resource, due to the proliferation of wireless technologies and their attendant uses. In addition to the high cost, bandwidth is scarce since the best frequencies are already in use by other companies.

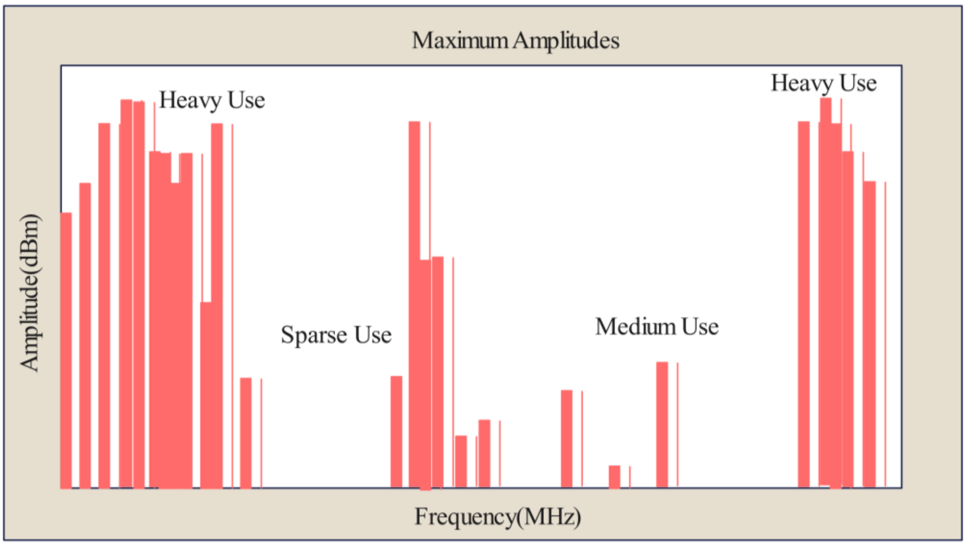

Figure 2.1: Utilization of Frequency Spectrum band [2]

This technique is susceptible to spectrum scarcity in some bands of the electromagnetic spectrum as a result of the fixed frequency spectrum assignment [2]. There are also a sizeable number of frequency bands in the spectrum that are not being used or are not being occupied for the majority of the time, while some other frequency bands are being filled in an incomplete manner and certain frequency bands are being used extensively. This results in a considerable portion of the spectrum being underutilized, as can be seen in the above figure 2.1. This implies there are numerous potential windows of opportunity to use spectrum availability to allow cognitive radios. Joseph Mitola is credited as being the first to use the term "Cognitive radio [3] - A radio that is self-aware that may modify its operating parameters in response to changes in the surrounding environment." The goal is to create a cheap and highly adaptable wireless device that allows unlicensed users to exploit spectrum voids without significantly impacting licensed users.

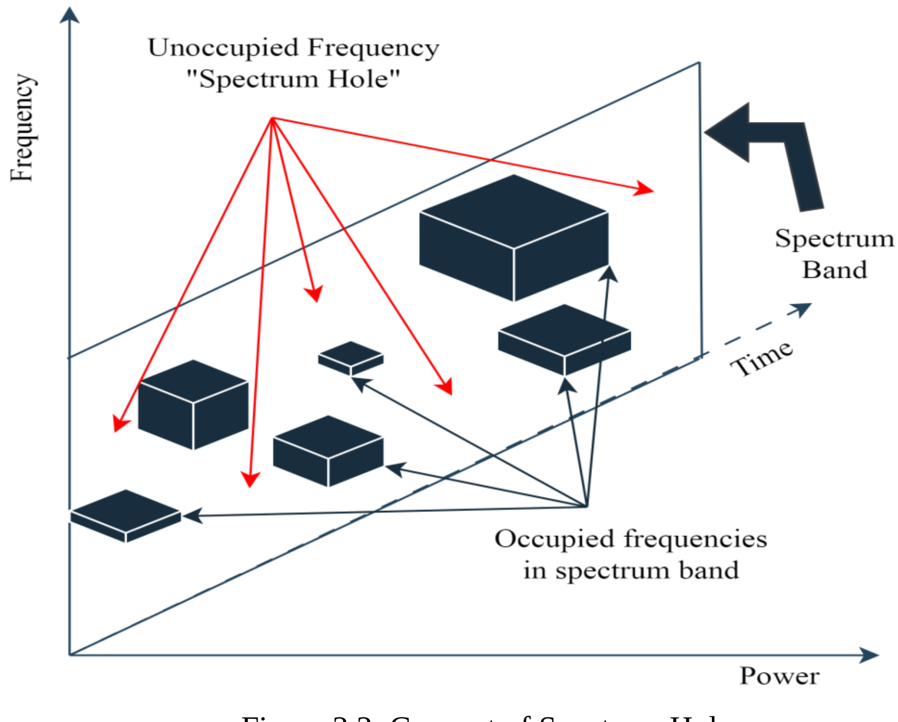

Figure 2.2: Concept of Spectrum Hole

As shown in figure 2.2, a spectrum hole occurs when a portion of the radio spectrum that was allocated to a licensed user goes unutilized at a given time and location. Because of its ability to provide cognitive wireless terminals with on-demand access to idle spectrum (Spectrum holes). Sub bands of the radio spectrum can be broken down further according to their occupancy, as seen in the figure 2.2. Black space, grey space, and white space are three basic categories that may be applied to frequency ranges [5]. White spaces are regions of the electromagnetic spectrum that are free from RF interferences, with the possible exception of noise introduced by natural and/or manmade sources. A grey area occurs when both interferers and noise occupy just a portion of the available spectrum. Black spaces are ones whose contents are completely in use owing to user communication, interference from other signals, and background noise. CR has emerged as one of the technologies capable of keeping up with the expansion of wireless communication services.

2.2 Approaches for Secondary spectrum access

There are three approaches that can be utilized by SUs in order to gain effective access to the spectrum [6], [23].

- Underlay approach
- Overlay approach
- Interweave approach

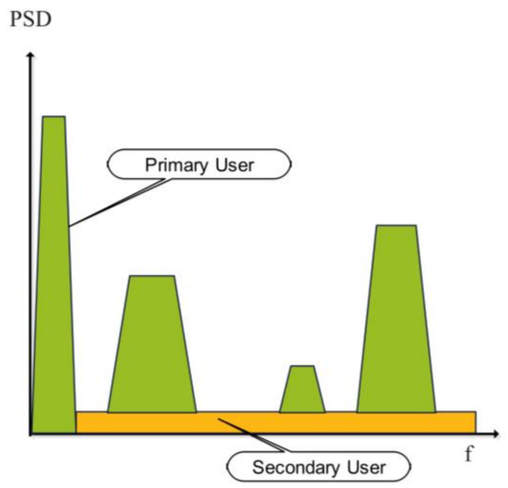

Figure 2.3(a): Underlay Approach

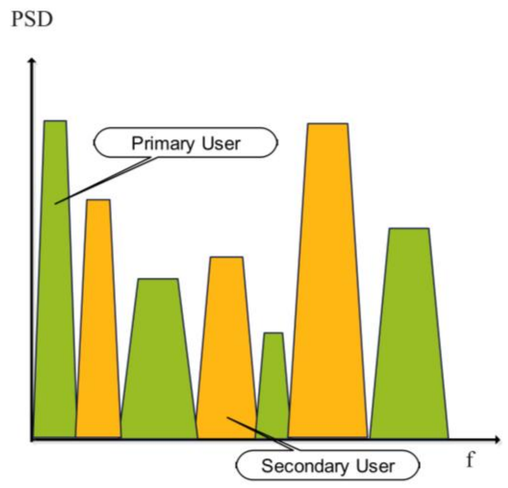

Figure 2.3(b): Overlay Approach

The underlay approaches allows for simultaneous primary and secondary broadcasts in ultra wideband (UWB) systems. In order to keep their interference with primary users below the allowable noise level, underlay systems block secondary signals. If the secondary signal can be spread and dispread over a large bandwidth, the signal-to-noise ratio of the secondary connection can be greatly improved (SNR). Power constraints imposed by interference from the underlay system confine conversations to close proximity.

The overlay approaches, primary and secondary transmissions might happen at the same time. Secondary users can relay primary signals and utilize some of the primary signal's energy for secondary communication, making overlay systems possible. A primary user's SNR can improve from secondary relaying and suffer from secondary communication interference, respectively, depending on how the power is divided.

2.3 Fundamental Terminologies Linked to Cognitive Radio

To find a vacant frequency without interfering with a licensed user's signal, a cognitive radio can adapt its operating circumstances based on its physical location. This improves the efficiency with which unused spectrum is utilized, hence making it easier for unlicensed users to gain access. Within the domain of cognitive radio, there are a few fundamental terminologies that may be summarized as follows:

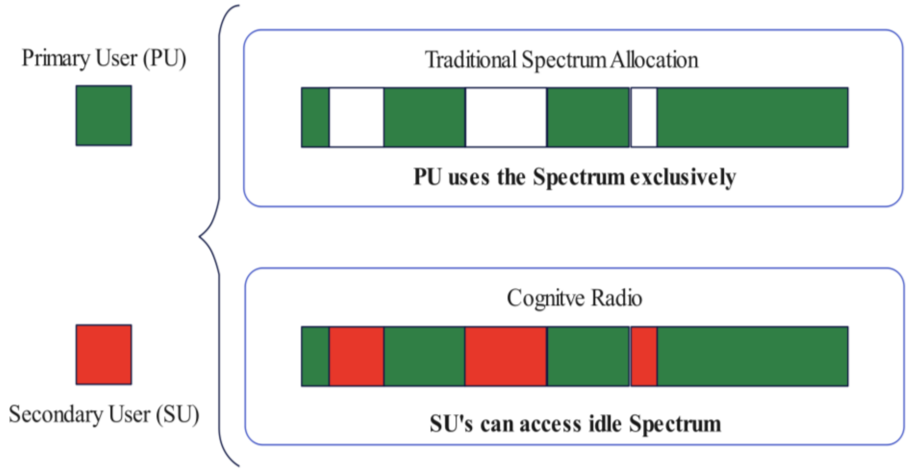

Figure 2.4: Fundamental Terminologies Linked to Cognitive Radio

Spectrum Hole: The term "Spectrum Hole" refers to a frequency that is portion of a radio spectrum that is either geographically or temporally underused and is under consideration to be employed by cognitive radio [7-8].

Primary User: A primary user is one form of licensed user. It is possible to describe it as a user who makes use of the frequency from the licensed frequency band and who has first priority when it comes to making use of that spectrum [4], [6], and [7].

Secondary User: An unlicensed user is known as the Secondary-user. It is possible to describe it as a user who makes use of the empty frequency inside the licensed frequency band that is not being utilized by primary users so that they manner in which they not create any interference for primary users [4], [5], [6], and [7].

2.4 Cyclic approach for Cognitive Radio

Cognitive capabilities and the ability to be configured are two of the most important aspects of a cognitive radio. Cognitive capability is the ability to recognize and record underutilized elements of one's immediate radio environment. It will allocate spectrum bands to secondary users with optimal operational settings, thus maximizing the effective exploitation of the spectrum band [8], [9].

Re-Configurability refers to the radio's ability to undergo a dynamic configuration without requiring any changes to its hardware components. The cognitive radio can be set up to act as either a transmitter or a receiver, even at widely varying frequencies. Cognitive radios can adapt their transmission power and modulation methods to the characteristics of the underlying communication channel [8], [9].

These are the most important requirements that must be met to become a CR in the network. Spectrum sensing, decision making, spectrum sharing, and spectrum mobility are the several duties that a CR is responsible for performing in order to provide real-time interaction with the surrounding environment [3], [7], [8], [9], [10],[24]. The cognitive cycle is depicted in figure 2.5 [8], [9].

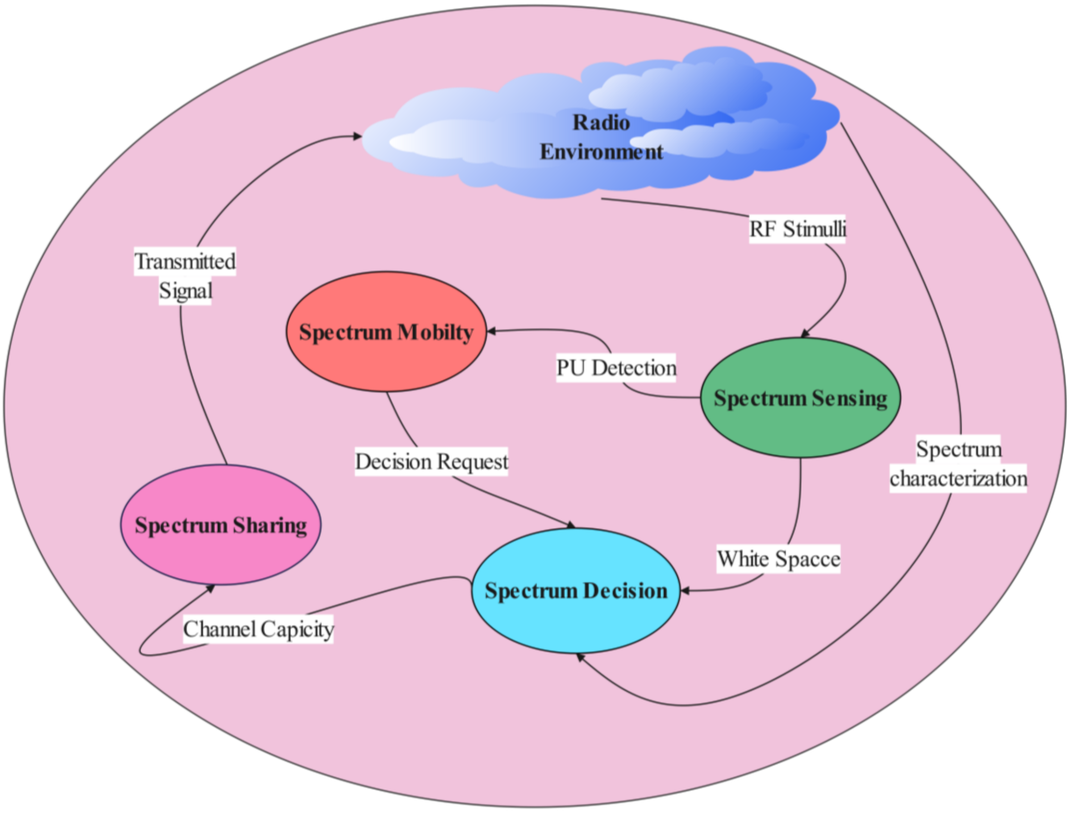

Figure 2.5: Cyclic approach for Cognitive Radio

2.4.1 Spectrum Sensing

Cognitive radio must also keep an eye on all the different frequency ranges and step back from the empty spots when primary users need to reclaim their frequencies. Spectrum sensing is the ability to measure, sense, and be knowledgeable of the factors relating to the radio channel attributes, accessibility of spectrum and transmit power, radio's functioning environment, interference and noise, user requirements and applications, accessible networks (infrastructures), and nodes, local policies, and other in-service limitations [7]. By sensing the spectrum, the primary purpose of a CR is to identify the presence or absence of PU activity or to determine whether or not PU is present. CRs are actively searching the spectrum for areas where there are gaps. The usage of the spectrum by the PU will not be disrupted in any way by the CRs, since they will instead go on to use other frequencies. It is possible that there will be a break in the spectrum that the CRs will utilize for communication if the PU is not present. The most important performance indicators are the detection probability (P_d), the false alarm probability (P_{fa}), and the missed-detection probability (P_{md}). ROC curves, also known as receiver operating characteristic curves, are a useful tool for making this assessment [11]. Increasing the P_d , while simultaneously reducing the P_{fa} and P_{md} leads to an improvement in sensing performance.

2.4.2 Spectrum Decision Making

Cognitive users are capable of picking up on more than one frequency emanating from the radio environment around them. This provides them with a wider number of possibilities from which to choose a particular frequency until sending out any broadcasts [3], [7].

2.4.3 Spectrum Sharing

Cognitive radio will continue to grant access to underutilized portions of the spectrum to secondary users so long as the primary users continue to have a requirement for it. Additionally, unlicensed users are a contributor to the licensed users of the spectrum. This characteristic of cognitive radio is frequently referred to as "spectrum sharing"[7], [8], [9].

2.4.4 Spectrum Mobility

A secondary user is expected to quickly exit the radio spectrum when cognitive radio identifies a licensed user using the same frequency range at the same time. Spectrum mobility is the term used to describe this quality in the context of cognitive radio [7], [9]. In the absence of other users, CRs are free to make use of the licensed frequencies at will. Once the primary user returns to the band, the CRs must immediately quit the spectrum and transfer to a different, vacant sector to prevent interference.

2.5 Basic Proposition about Spectrum Sensing

Many challenging research issues for CR are implied by the cognitive cycle introduced in 2.4. Therefore, the focus of this study will be on just one phase of the cognitive process - the "Spectrum Sensing" phase.

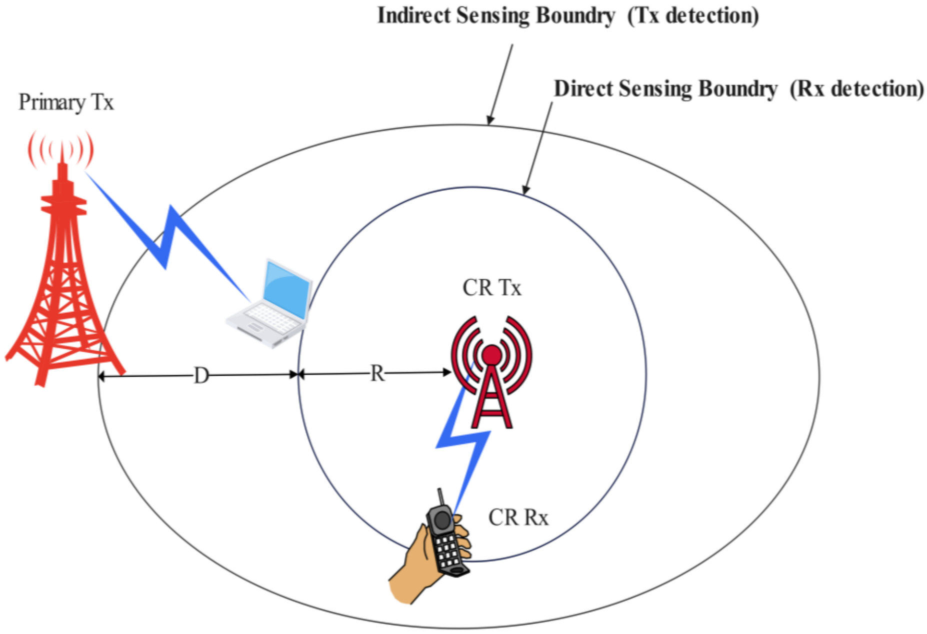

Figure 2.6: Basic Proposition about Spectrum Sensing

Every CR user's primary responsibility, as described in the Spectrum Sensing phase of the cognitive cycle, is to ascertain whether or not the PU's are present. To do this, CRs may detect and exploit spectrum holes while the PU's are not actively using their resources, known as "spectrum holes," without negatively impacting the performance of the PUs. Another option is for the CR to use the available spectrum at the same time as the PUs, so long as the CR keeps the hindrance to the PUs below some threshold. As a result, the efficiency of spectrum sensing detection is crucial to the operation including both PU and CR networks. The detection performance may be measured in two ways: the false alarm probability (the percentage of times a CR user reports a PU is there when none is present) and the detection probability (the percentage of times a CR user reports a PU is present whenever the spectrum is really occupied by the PU). When considering the detection capability they provide, Spectrum Sensing can be further broken down into two unique implementation methodologies, both of which are depicted in below figure 2.6 [7], [9], [21], [22]. Figure 2.6 shows the basic proposition Sensing procedure. In this picture, the PU transmitter (Tx) sends data to the PU receiver (Rx) while staying inside the legal frequency range for that connection. By sensing the nearby PU receiver (Rx), also known as direct Spectrum Sensing, it is able to quickly detect the spectrum hole. Similar, albeit more indirect methods exist for detecting spectral gaps in the PU-Tx environment. Indirect spectrum sensing describes this kind of detection.

2.6 Causes and consequences of Cognitive Radio

Successful implementation of cognitive radios in wireless applications appears promising. Extensive research is being done to make this concept more practical and usable in the actual world. However, the CR technology, like any other technology, faces challenges [12], [13], [14], [15].

The efficiency of the network has a direct bearing on the accuracy of the sensing data. Interference management requires high-performance spectrum sensing. Obtaining low PF and PMD values while keeping a high PD value is challenging. Interference can be caused by a variety of different phenomena, such as multipath fading and shadowing, which ultimately leads to a decline in the performance of the network. Implementing CRs in a real time context is both extremely challenging and prohibitively expensive. The complexity of certain algorithms that are utilized for carrying out cognitive activities contributes to an increase in the amount of computation that is required. Cognitive radio networks (CRNs) are vulnerable to threats and attacks despite their reliability, flexibility, and adaptability. In order to keep their secondary user status in the CRN, secondary users must adhere to specific requirements [16], [17], [18], [19] [20].