International Journal of Enhanced Research in Science, Technology & Engineering
ISSN: 2319-7463, Vol. 5 Issue 6, June-2016

Review Paper on Comparative Study of Non-Cooperative Spectrum Sensing in Cognitive Radio Technology

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ABSTRACT

The technology that enables un-licensed users to dynamically and opportunistically access the licensed spectrum, without affecting the existing users with legacy rights to that spectrum, is the cognitive radio (CR) technology. The key component of CR technology is the ability to sense and ultimately adapt to the continuously changing radio's operating environment. Cognitive radio (CR) has emerged as a promising solution to the current spectral congestion problem by imparting intelligence to the conventional software defined radio that allows spectrum sharing through opportunistic spectrum access. The principal objective of CR is to optimize the use of under-utilized spectrum through robust and efficient spectrum sensing (SS).This paper introduces cognitive functionality and provides an in-depth comparative survey of various spectrum awareness techniques in terms of their sensing accuracy and computational complexities along with their merits and demerits. A classification of SS is presented to address the sensing method selection criterion. Here, both non-cooperative and cooperative sensing schemes are reviewed and open research problems are highlighted to identify future research directions.

KEYWORDS: Spectrum Sensing, Software Defined Radio, Cognitive Radio, Cooperative sensing, Non-Cooperative sensing.

1. INTRODUCTION

In CR terminology, the incumbents of a frequency band are called primary users (PU) while the term secondary users (SU) is reserved for low-priority un-licensed users equipped with a cognitive capability to exploit this spectrum without affecting the operation of PU. Therefore, the most crucial task of SU (also termed as simply CR in literature) is to reliably identify available frequency bands across multiple dimensions like time, space, frequency, angle and code etc., and efficiently exploit them by dynamically updating its transmission parameters under the stringent requirement of avoiding interference to the licensed users of that spectrum. To accomplish this, the secondary users rely on robust and efficient spectrum sensing (SS) to identify vacant frequency bands under uncertain radio frequency (RF) environment and to detect primary users with high probability of detection, as soon as the incumbents become active in the band of interest [1,2].

There are two different types of spectrum sharing scenarios i.e the way in which primary and secondary users share frequency spectrum. They are

- Cooperative scenario
- Non-cooperative scenario

In cooperative scenario, a primary user provides secondary users with all information regarding the occupancy of the spectrum and about the unused spectrum so that the secondary users make use of that unused spectrum and keep away from the occupied spectrum [3,4]. In the non-cooperative scenario [5], a secondary user needs to sense the spectrum for the unused spectrum and use that spectrum band without causing any interference to the primary user [6]. In the cooperative scenario, a malicious user can masquerade as the primary user and provide false information to the secondary user regarding the occupancy of the spectrum, such as the spectrum is unoccupied and the secondary user can use though the primary user occupies the spectrum. With the information provided, the secondary user tries to occupy the spectrum and as a result, interference takes place between the primary user and secondary user. In some cases, the malicious user informs the secondary user as the spectrum is occupied even though the spectrum is free and as a result the spectrum is not utilized either by primary user or by secondary user. Because of these issues, a secondary user must make sure that the information regarding the occupancy of the spectrum is provided by a legitimate primary user. Depending on the available network side information and the regulatory constraints [7] there are three different classes of Cognitive radio paradigms. They are :

1. Underlay
2. Overlay
3. Interweave

The Underlay cognitive radio paradigm is used when the interference between the cognitive users and non-cognitive users is below a certain threshold.

In Overlay cognitive radio paradigm communication is provided by sophisticated signal processing.

The Interweave cognitive radio paradigms opportunistically exploit the white spaces without causing any interference to the other transmissions [7]. Generally, Interweave cognitive radio system is used.

There are four major tasks in a Cognitive radio which it must have to fulfill. They are:

1. Understanding the working environment in which it operates
2. Understanding the user's requirements for a better communication.
3. Understanding all regulatory policies that apply to it.
4. Understanding its own capabilities i.e. spectrum sensing, spectrum management, spectrum mobility and spectrum sharing. [8]

The main purpose of using a cognitive radio over a primitive radio is because of the following advantages:

- Senses the radio frequency environment for the presence of white spaces
- Manages the unused spectrum
- Increases the efficiency of the spectrum utilization significantly
- Improves the spectrum utilization by neglecting the over occupied spectrum channels and filling the unused spectrum channels [9].
- Improves the performance of the overall spectrum by increasing the data rate on good channels and moving away from the bad channels [10].

2. LITERATURE SURVEY

CR has been proposed as a method to more efficiently utilize existing spectrum and intelligently allocate radio resources in future wireless networks [7]. Traditionally, spectrum is allocated to PUs by regulatory bodies through a licensing process. This means that a PU is given exclusive access to the bands of spectrum within which it has been licensed to operate. Artificial spectrum scarcity occurs when the bands licensed to PUs are not fully utilized but at the same time are not available for use by other would-be users. Thus certain currently licensed regions exist, either in time, geographical location or frequency, where spectrum is actually unused or only partially used. Spectrum occupancy measurement studies confirm this [9-11]. These regions may be referred to as 'spectrum holes'. In its broader sense, a CR aims to address the artificial spectrum scarcity problem by exploiting these 'holes' in the spectrum.

Improvements in spectral efficiency may however be achieved by the use of CR and ultra wide band (UWB) technologies. These technologies represent two opposing approaches. A CR follows an overlay approach by exploiting spectrum 'holes' through dynamic spectrum access (DSA). However, in UWB, an underlay approach is followed where, due to bandwidth increases, waveforms may be successfully transmitted at power levels low enough for SUs to coexist with PUs over the entire frequency range [12,13]. The difference between overlay and underlay communication is illustrated in Figure 1.1. In CR the SU (represented by the green block) avoids interference with the PU by operating in a region where no PU (denoted by the maroon triangles) is present. In the UWB case (represented by the orange region) transmission coincides with PUs, causing tolerable levels of interference at power levels that fall below the noise floor [represented by the blue region). Combining the under and overlay approaches to further improve channel capacity has also been proposed [14,15].

International Journal of Enhanced Research in Science, Technology & Engineering
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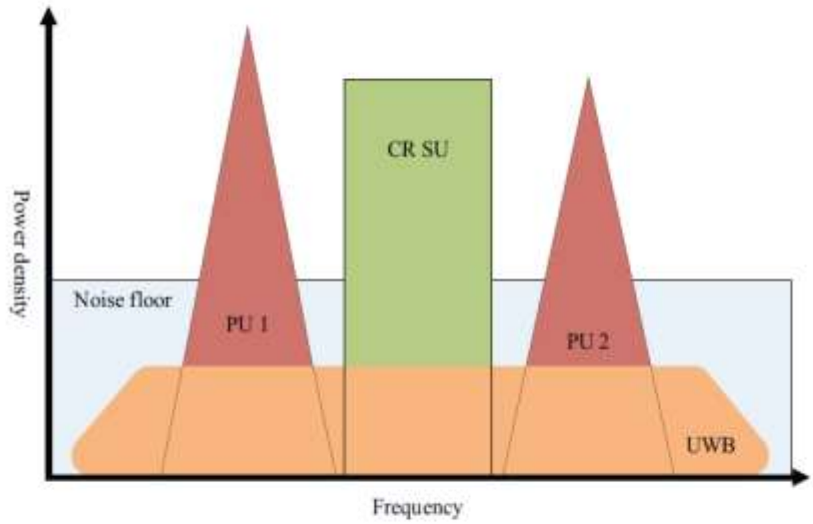


Figure 1.1: The difference between overlay and underlay communication

The IEEE 1900 standard on DSA provides the following definition for CR [16]: “A type of radio in which communication systems are aware of their environment and internal stale and can make decisions about their radio operating behavior based on that information and predefined objectives."

Built on the platform of SDR [17,18], a CR will determine and try to predict when and where spectrum-hole opportunities exist. This spectrum selection and resource allocation is temporary and will thus only be valid for as long as the PU does not need to make use of that portion of the spectrum. Once the PU again requires use of that portion of the spectrum, the SU must immediately vacate the band.

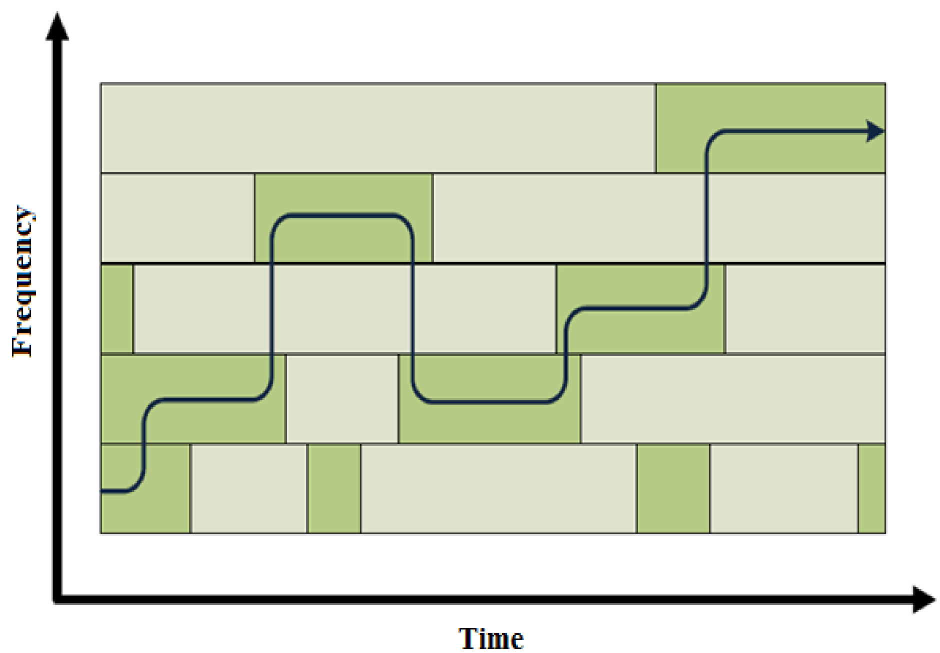


Figure 1.2: PU spectrum occupation over time and frequency

A possible PU occupation pattern encompassing four adjacent frequency channels is illustrated in Figure 1.2. The horizontal blocks represent frequency channels over a period of time, where the green blocks represent unutilized spectrum holes and the grey blocks represent PU activity. When the PU returns to the channel currently occupied by a SU, the SU needs to jump to the next best available channel, as indicated by the arrowed line. To maintain uninterrupted communication, a SU would thus need to continuously operate within the green blocks.

3. COGNITIVE RADIO TECHNOLOGY

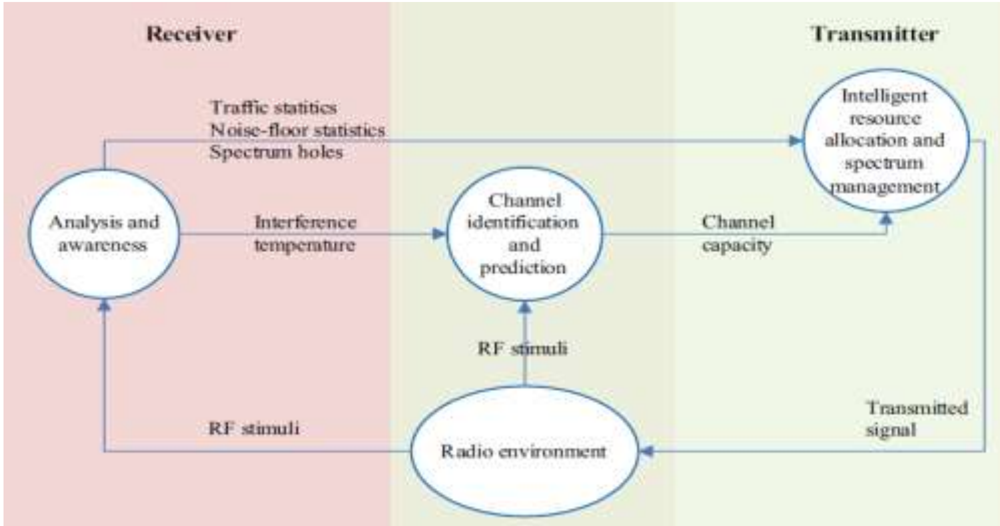


Figure 1.3: Basic description of the CR cycle, adapted from[8]

The primary functionality required of a CR, can be summarized into three broader categories [8].

a. Analysis and awareness of the radio environment,
b. Channel identification and prediction, as well as
c. Intelligent resource allocation and spectrum management.

These three categories of operation form the basis for an intelligent feedback communication system and are repetitively performed within a CR environment. A graphical depiction of his concept is presented in Figure 1.3. The SDR [7] provides the platform upon which this process may be performed.

The practical implementation of the concept of CR relies heavily on technological advances in radio communications hardware. Since a SU in a CR network needs to be able to switch quickly and dynamically between different operating channels, preferably without having to physically change its hardware configuration, the Software Defined Radio (SDR) and the software defined antenna (SDA) are essential enabling technologies for CR communication.

The Software Defined Radio (SDR) is the main enablers of CR. The SDR is a radio communication system that provides for a greater level of communication flexibility than traditionally available. Advances in technology have made it possible for a SDR to access multiple frequency bands at one time. This is made possible by the software implementation of many components previously implemented in hardware. By making use of variable-frequency filters, oscillators and mixers, together with wide-band analogue-to-digital and digital-to-analogue converters (ADCs and DACs), a SDR is able to handle all aspects of the radio

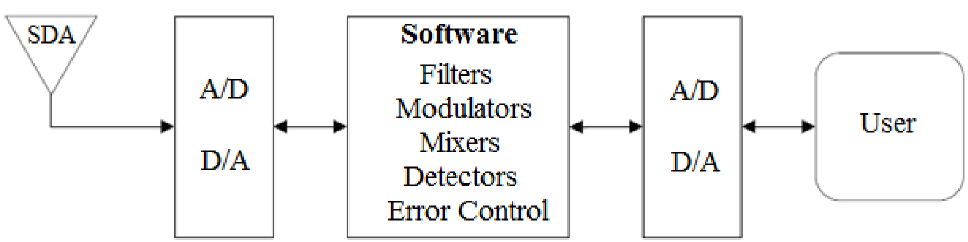


Figure 1.4: SDR using SDA, adapted from [18]

air interface in software [18]. The SDR is thus able to deliver real-time and dynamically programmable communication services through the software implementation of traditional hardware components such as filters, modulators, mixers and detectors. A SDR may be implemented using a personal computer or on embedded platforms such as: digital signal processors (DSP), field-programmable gate arrays (FPGA) or application-specific integrated circuits (ASIC). A basic illustration of a SDR is illustrated in Figure 1.4.

Relationship between Cr and SDR: The adaptability is the main characteristic of CR where the radio parameters (including power, modulation, frequency, and bandwidth) can be changed according to the radio environment and network condition. Software Defined Radio can provide flexible radio functionality by avoiding the use of application specific fixed components and analog circuits. Therefore, CR needs to be designed around SDR. In other words, the core enabling technology for cognitive radio is SDR.

The relation between SDR and CR is described in Figure 1.5. In this simple model, cognitive radio is wrapped around SDR.This model fits well to the definition of CR, where the combination of SDR, cognitive engine and the other supporting functionalities (e.g. sensing) results in CR.

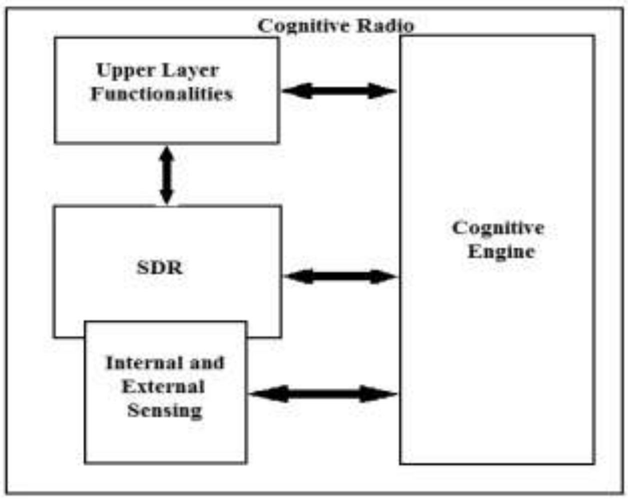
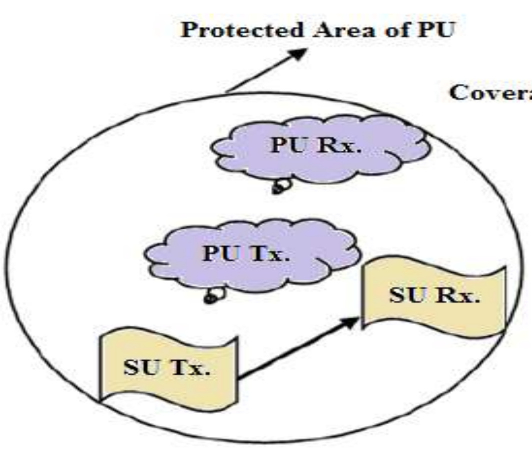


Figure 1.5: Relationship between SDR and CR

Characteristics of Cognitive Radio:

Cognitive functionality described above is achieved by two main characteristics of CR, cognitive capability and re-configurability. Cognitive capability is ability of radio to interact with its real time radio environment to identify un-occupied licensed spectrum bands called spectrum holes [8]. According to observations published by FCC, spectrum holes can be classified into two groups: temporal spectrum holes and spatial spectrum holes. Based upon these two secondary communication schemes [20] ofopportunistic spectrum utilization in time and space domain can be described which are represented in Figure 1.6 and 1.7 respectively.



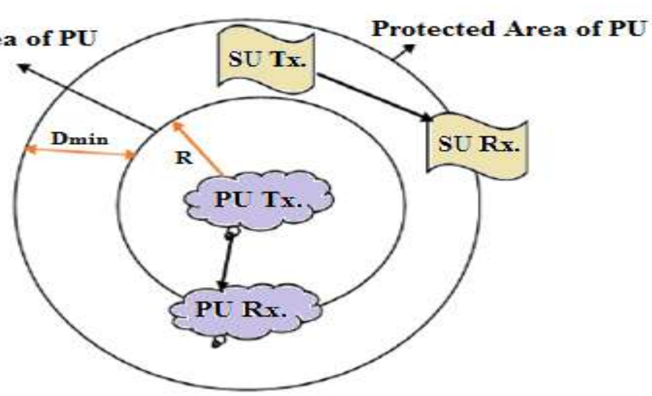


Figure 1.6: Temporal Spectrum Hole **Figure 1.7: Spatial Spectrum Hole**

A temporal spectrum hole i.e. time based occurs when no primary transmission is detected over the interested frequency band for a specific period of time and hence this frequency band is available for SU in that time slot. A spatial spectrum hole i.e. space based is generated when the primary transmissions are confined to a certain area and hence this frequency band is available for SU (it may occur in same time slot as well) well outside the coverage area of PU to avoid any possible interference with PU communication.

The secondary transmission over the spatially available licensed spectrum is allowed if it cause no interference with PU. This puts a strict requirement on SU to be able to effectively detect PU at any place where SU may cause interference to primary transmission. Therefore, a safeguard area of PU is defined wherein SU must be able to detect any PU activity to avoid interference with primary receiver D_{min} apart from SU. The cognitive capability is not only for monitoring power in some frequency band rather it demands great care of other parameters as well i.e. multidimensional spectral awareness. This requires that CR should be able to modify its transmission parameters in order to adapt to its changing radio environment, this characteristic of CR is called re-configurability.

SPECTRUM SENSINGTECHNIQUIES

In order to maintain the primary users' right to interference-free operation, the secondary users need to regularly sense the allocated band and reliably detect the presence of the primary users' signals with little delay. In the IEEE 802.22 standard, for example, the secondary users need to detect the TV and wireless microphone signals and upon their detection, they are required to vacate the channel within two seconds. For TV primary signals, a probability of detection of 90% and a probability of false alarm of 10% should be maintained. Therefore, spectrum sensing plays a crucial role in the cognitive radio technology to prevent damaging interference to the primary users and to reliably and quickly spot the white spaces in the spectrum and utilize the opportunity.

Various spectrum sensing methods are used in literature depending on how much information about the primary signal is available to the secondary users, as discussed in the following.

Matched Filtering Detection:

Matched filtering-based methods are optimal for stationary Gaussian noise scenarios as they maximize the received SNR. For this optimal performance, they require perfect knowledge of the channel responses from the primary user to the secondary user and the structure and waveforms of the primary signal (including modulation type, frame format and pulse shape) as well as accurate synchronization at the secondary user [19].

In cognitive radios, however, such knowledge is not readily available to secondary users and implementation cost and complexity of this detector is high especially as the number of primary bands increases. Therefore, this method is not practical and applicable to cognitive radio technology.

Cyclostationary Feature Detection:

Cyclostationary feature detectors can distinguish between modulated signals and noise. This detector exploits the fact that the primary modulated signals are cyclostationary with spectral correlation due to the built-in redundancy of signal periodicity (e.g., sine wave carriers, pulse trains, and cyclic prefixes), while the noise is a wide-sense stationary signal with no correlation. This task can be performed by analyzing a spectral correlation function. Therefore, cyclostationary feature detectors [20] are robust to the uncertainty in noise power. This is at the price of excessive computational complexity and long observation times. Moreover, it requires the knowledge of the cyclic frequencies of the primary users, which may not be available to the secondary users.

Likelihood Ratio Test (LRT):

Spectrum sensing is a binary hypothesis testing problem, with the null and alternative hypotheses
H0 : Primary user not active
H1 : Primary user active
Based on the Neyman-Pearson (NP) theorem, the test statistic that maximizes the probability of detection for a given probability of false alarm is the likelihood ratio test (LRT) defined as

$$L(X) = p(X|H1)/ p(X|H0)$$

where X denotes the received signal vector and $p(\cdot)$ denotes the probability density function (PDF).

The LRT, which is proven to be NP optimal, requires the exact distributions of primary signal and noise and channel gains which makes it practically intractable [19].

Energy Detection:

For a Gaussian noise model, when the noise power is known to the secondary user energy detection can be applied to detect the existence of the primary signal. This simple scheme accumulates the energy of the received signal during the sensing interval and declares the band to be occupied if the energy surpasses a certain threshold. This threshold is set based on the desired probability of false alarm. Energy detection, unlike the other schemes, does not require any information about the primary signal and channel gains and is robust to unknown fading channel. Compared to other methods it has simpler implementation and hence is less expensive. Therefore, in literature energy detection [20] is mainly adopted for spectrum sensing.

CONCLUSION & FUTURE SCOPE

We studied the concept of CR and its primary functionality. A theoretical platform was laid that covers the key areas of importance to the work described in the review paper that follow. Cognitive Function was discussed as well as Enabling Technology for Cognitive Radio. The SDR and techniques required by SUs in a CR network were also briefly covered and an overview of the most important part of CR operation i.e. SS has been discussed. Future works include increasing the capacity of secondary user and develop an effective method which can obtain better tradeoff between two coexisting systems and obtain overall good capacity performance.

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