Sudan University of Science and Technology

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Evaluation of Interchangeable Spectrum Sensing Scheduling Algorithm

A Research Submitted In Partial Fulfillment for the Requirements of the Degree of B.Sc. (Honors) in Electronic Engineering

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قال تعالى:

Dedication

To our beloved mothers and fathers

Acknowledgement

First and foremost, we are very thankful to Allah for granting us the success and the ability to complete this project and for all the knowledge we acquired during the making of this work.

Apart from the efforts of ourselves, the success of any project depends largely on the encouragement and guidelines of many others. We take this opportunity to express our gratitude to the people who have been instrumental in the successful completion of this project. We would like to show our greatest appreciation to Dr. Sami. We can't thank you enough for his tremendous support and help. We feel motivated and encouraged every time we attend his meeting. Without his encouragement and guidance this project would not have materialized. The guidance and support received from all the members who contributed and who are contributing to this project, was vital for the success of the project. We are grateful for their constant support and help.

Last but not least, we would like to take this opportunity to acknowledge our parents for their support and encouragement during our whole life until we reached this level.

Abstract

Cognitive Radio is a promising technology that is potentially will play an essential role of communications in the future. This technology witnesses a rapid growth in the past few years due to the solutions it provides.

One of the main issues regarding cognitive radio technology is spectrum-sensing methods. Even though many research efforts were dedicated to improve sensing efficiency, it is considered in the early stages.

The novel Interchangeable Spectrum Sensing scheduling algorithm attempted to improve the sensing efficiency through a cooperative sensing scheme. This thesis conduct a throwaway prototype to evaluate this algorithm. Matlab platform was used to simulate the scheduling operation as well as the performance output.

المستخلص

الشبكات الراديوية الذكية هي تقنية واعدة ستلعب دورا أساسيا في مجال الاتصالات في المستقبل. هذه التقنية شهدت نموا متسارعا في السنوات القليلة الماضية نظرا للحلول التي تقدمها.

إحدى القضايا الرئيسة المعتبرة لتقنية الشبكات الراديوية الذكية هي طرق استشعار الطيف. بالرغم من ان الكثير من جهود البحث كُرّست لتحسين كفاءة استشعار الطيف الا ان طرق الاستشعار تعتبر في مراحلها الأولية من حيث الكفاءة.

خوارزمية جدولة استشعار الطيف التبادلية المبتكرة حاولت تحسين كفاءة استشعار الطيف من خلال طرق الاستشعار التعاونية. هذه الاطروحة تجري نموذجا مصغرا لتقييم الخوارزمية أعلاه. استخدم برنامج الماتلاب لمحاكاة عملية الجدولة بالإضافة الى مخرجات الاداء

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List of Abbreviations

CR	Cognitive Radio
CRN	Cognitive Radio Network
ISSS	Interchangeable Spectrum Sensing Scheduling
Pf	Probability of False Alarm
Pd	Probability of Detection
SNR	Signal to Noise Ratio
SDR	Software Define Radio
MF	Matched Filter
UWB	Ultra-Wide Band
PU	Primary Users
LO	Local Oscillator
SU	Secondary Users
WRAN	Wireless Regional Area Network
ISP	Internet Server Provider
GPS	Global Positioning System
BS	Base Station
MPME	Multiband Primary Network Environment
CR-CPE	Cognitive Radio Customer Premises Equipment
IBSHO	Inter-Band Soft Handover

QOS	Quality Of Service
GSM	Global System Mobile
CPE	Customer Premises Equipment
Ps	Probability of successful Transmission
PC	Probability of collision

List of symbols

$y(n)$	received signal
$s(n)$	detected signal
$w(n)$	additive white Gaussian noise
H	channel response
V_{T}, λ_{E}	energy detection Threshold
σ_N	noise power

Chapter One

Introduction

1. Chapter One

Introduction

1.1 Preface

Cognitive radio seen as one of the most important approaches to utilize the radio frequency spectrum efficiently. Traditionally, regulation authorities allocate fixed frequency band to each licensed user, thus ensure minimum amount of interference. However, as the demand for more frequencies increases, the available wireless bands are almost occupied, as an example in United States National Telecommunication and Information Administration reported that the frequency bands are entirely occupied [1]. Furthermore, Federal Communication Commission reported that, 15% to 85% of the licensed spectrum is idle in various time and geographic locations depend on the customer distribution and their individual usage (FCC 2002) [2].

As a result, concept of secondary user has emerged in order to exploit the unused frequency band in efficient manner where or when the band is not occupied.

Now, it is convenient to define the primary and secondary users "primary users can be defined as the users who have higher priority or legacy rights on the usage of a specific part of the spectrum. On the other hand, secondary users, which have lower priority, exploit this spectrum in such a way that they do not cause interference to primary users. Therefore, secondary users need to have cognitive radio capabilities, such as sensing the spectrum reliably to check whether a primary user is using it and to change the radio parameters to exploit the unused part of the spectrum" (Yucek and Arslan 2009) [3].

1.2 Problem Statement

Spectrum sensing in cognitive radio networks (CRN) depends on two metrics, probability of detection (P_d) and probability of false alarm (P_f). Some techniques are proposed in order to improve the sensing performance metrics, such as the interchangeable spectrum-sensing algorithm (ISSS). The algorithm improved the probability of detection, albeit the false alarm probability increased, which lead to degradation of the cognitive system performance. The simulation seeks optimum sensing performance.

1.3 Proposed solutions

A test-bed is to be implemented to simulate a multi-band environment system using ISSS which improves the utilization of the radio spectrum. Some scenarios should be developed to calculate the system performance metrics under different circumstances (different SNR and band occupancy). Before deploying a new system the performance must be calculate depending on bands condition, then a Comparison between the different bands system's performance must be done to get the optimum number of band that must be used at the system.

1.4 Methodology

A Matlab code is used to simulate the channels status depending on the activity of the primary user then deploys a systems that use different number of bands and calculate their contribution at increasing the detection probability over the single band system. After that, the system is used at noisy environment with specific SNR to calculate the noise influence on the false alarm probability of each system.

1.5 Research outlines

The rest of this thesis is organized as follow:

Chapter Two: presents a literature review of general cognitive radio history beside a spectrum sensing overview, **Chapter Three**: presents the methodology of implementing the Interchangeable Spectrum Sensing algorithm and all parameters that used in the performance evaluation, **Chapter Four**: presents the simulation and discuss the results, **Chapter Five**: concludes the thesis and presents recommendations of the future work.

Chapter Two

Background

2. Chapter Two

Background

2.1 Introduction

The wireless communications plays an important role in the world today. The exponentially increasing numbers of spectrum usage in both civil and governmental applications led to spectrum scarcity over time (Haykin 2005) [4].

Cognitive Radio is an option to utilize non-used parts of the spectrum that actually are assigned to what is known as “primary user”. In other words, cognitive radio is proposed to solve the unbalance between spectrum scarcity and underutilization of the spectrum.

2.2 Basic Concepts

Cognitive radio networks consist of three elements (Xiao and Hu 2008) [5]:

- The cognitive radio (CR) user, the CR user do not have a licenses band, this user use the band of the primary user opportunistically when the band is free. Sensing task is applied internally on the CR user. However they do not make a decision on the spectrum band availability, they only report the sensing results to a base station.

-The CR base station, the CR base station is a fixed infrastructure in a CR network that manages and controls the spectrum. CR users report their sensing result to the CR base station in order to make a decision on the spectrum availability. Furthermore CR base station provides synchronization in the sensing operations among the CR users.

-Spectrum broker, Spectrum broker is a centralized entity that allows CR networks to share the available spectrum resources. It is not directly responsible for the sensing operation, it only manage the available spectrum resources according to the sensing information collected by each network.

2.2.1 Software Defined Radio (SDR)

Software-define radio (SDR) is a radio in which the RF operating parameters including, but not limited to, frequency range, modulation type, or output power can be set or altered by exchanging the hardware devices(e.g. mixers, filters, modulators /demodulators, detectors , etc.) are instead implemented by means of software on a personal computer or embedded systems (Burns 2002)[6].

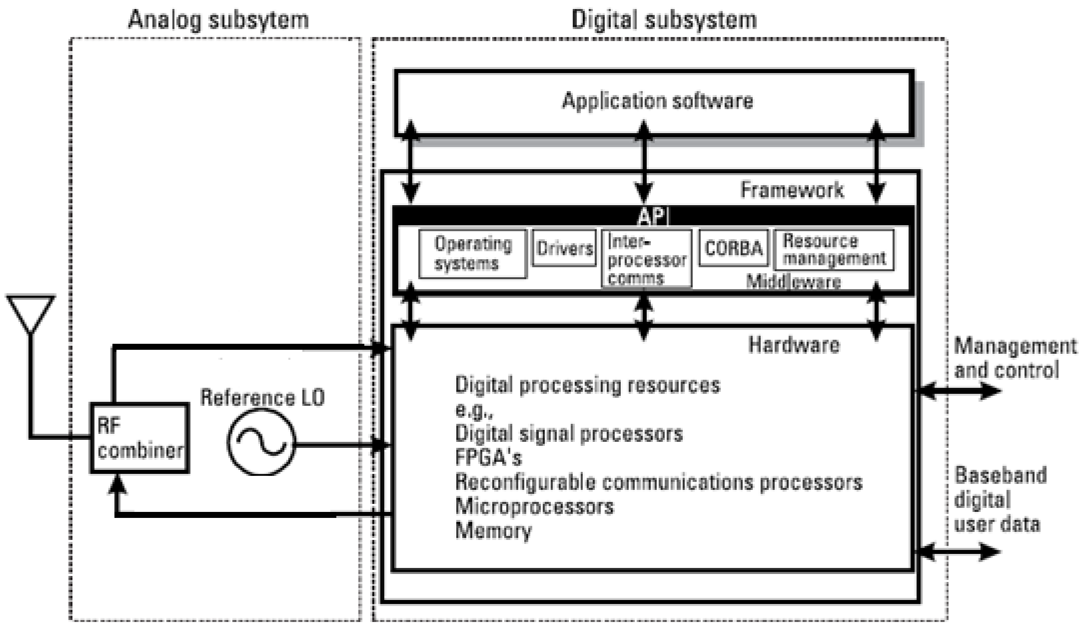

Figure 2.1 Ideal software defined radio [6]

Figure 2.1 shows the ideal structure of SDR. The only hardware devices are the antenna, combiner and oscillator. all other funtions are deployed at digital processing device (e.g. FPGA, DSP, etc.) .

2.2.2 Spectrum sensing overview

According to (Yücek and others 2009) [7] Spectrum sensing is the task of gaining awareness about the spectrum usage and existence of primary users in a geographical area. This awareness can be obtained by using geolocation and database. Although spectrum sensing is traditionally understood as measuring the spectral content, or measuring the radio frequency energy over the spectrum, when cognitive radio is considered, it is a more general term that involves obtaining the spectrum usage characteristics across multiple dimensions such as time, space, frequency, and code. It also involves determining what types of signals are occupying the spectrum including the modulation, waveform, bandwidth, carrier frequency, etc. However, this requires more powerful signal analysis techniques with additional computational complexity.

One way of classification depends on the need of spectrum sensing as stated below (Subhedar and others 2011) [8].

2.2.2.1 Spectrum Sensing for Spectrum Opportunities

a. *Primary transmitter detection*:

In this case, the detection of primary users is performed based on the received signal at CR users. This approach includes matched filter (MF) based detection, energy based detection, covariance based detection, waveform based detection, cyclostationary based detection, radio identification based detection and random Hough Transform based detection.

b. *Cooperative and collaborative detection:*

In this approach, the primary signals for spectrum opportunities are detected reliably by interacting or cooperating with other users, and the method can be implemented as either centralized access to spectrum coordinated by a spectrum server or distributed approach implied by the spectrum load smoothing algorithm or external detection.

2.2.2.2 Spectrum Sensing for Interference Detection

a. Interference temperature detection:

In this approach, CR system works as in the ultra-wide band (UWB) technology where the secondary users coexist with primary users and are allowed to transmit with low power and are restricted by the interference temperature level so as not to cause harmful interference to primary users.

b. Primary receiver detection:

In this method, the interference and/or spectrum opportunities are detected based on primary receiver's local oscillator leakage power.

Table 2.1: comparison between primary transmission detection schemes [9]

Type	Test statistics	Advantages	Disadvantages
Energy detector	Energy of the received signal samples	• Easy to implement • Not require prior knowledge about primary signals	• High false alarm due to noise uncertainty • Very unreliable in low SNR regimes • Cannot differentiate a primary user from other signal sources
Feature detector	Cyclic spectrum density function of the received signal, or by matching general features of the received signal to the already known primary signal characteristics	• More robust against noise uncertainty and better detection in low SNR regimes than energy detection • Can distinguish among different types of transmissions and primary systems	• Specific features, e.g., cyclostationary features, must be associated with primary signals • Particular features may need to be introduced, e.g., to OFDM-based communications
Matched filtering and coherent detection	Projected received signal in the direction of the already known primary signal or a certain waveform pattern	• More robust to noise uncertainty and better detection in low SNR regimes than feature detector • Require less signal samples to achieve good detection	• Require precise prior information about certain waveform patterns of primary signals • High complexity

2.2.3 Primary Transmitter Detection

2.2.3.1 Energy Detection

Energy detector based approach is the most common way of spectrum sensing because of its low computational and implementation complexities, since it uses a squaring device followed by an Integrator (Abdulsattar 2012) [10].

In addition, it is more generic as receivers do not need any knowledge on the primary users' signal. The signal is detected by comparing the output of the energy detector with a threshold, which depends on the noise floor.

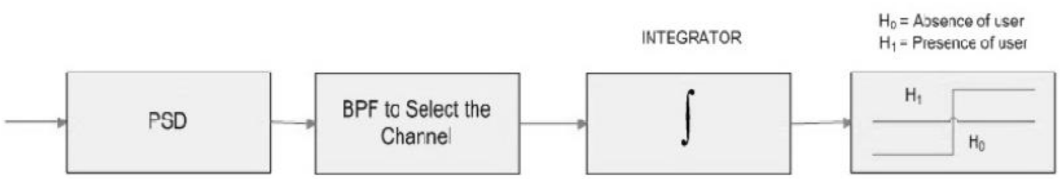

Figure 2.2 Energy Detection block diagram

The block diagram for the energy detection technique is shown in the Figure 2.2. In this method, signal is passed through band pass filter of the bandwidth W and is integrated over time interval. The output from the integrator block is then compared to a predefined threshold. This comparison is used to discover the existence of absence of the primary user. The threshold value can set to be fixed or variable based on the channel conditions.

Let us assume that the received signal has the following simple form

$$y(n)=s(n)+w(n) \tag{2.1}$$

Where s(n) is the signal to be detected, w(n) is the additive white Gaussian noise (AWGN) sample, and n is the sample index. Note that s(n) = 0 when there is no transmission by primary user. The decision metric for the energy detector can be written as

$$M = \sum_{n=0}^{N} |y(n)|^{n} \tag{2.2}$$

Where N is the size of the observation vector. The decision on the occupancy of a band can be obtained by comparing the decision metric M against a fixed threshold λ_E. This is equivalent to distinguishing between the following two hypotheses:

$$y(n) = w(n) \ldots\ldots\ldots\ldots\ldots\ldots\ldots H0 \tag{2.3}$$

$$y(n) = h*s(n) + w(n) \ldots\ldots\ldots\ldots\ldots H1 \tag{2.4}$$

Energy detection is considered the simplest sensing technique because it doesn't need any information about the signal but it also has several drawbacks [8]:

i) Sensing time taken to achieve a given probability of detection may be high.

ii) Detection performance is subjected to the uncertainty of noise power.

iii) Energy detection cannot be used to distinguish primary signals from the CR user signals.

2.2.3.2 Matched Filter

Matched filter (MF) is a linear filter designed to maximize the output signal to noise ratio for a given input signal. When secondary user has a priori knowledge of primary user signal, matched filter detection is applied. Matched filter operation is equivalent to correlation in which the unknown signal is convolved with the filter whose impulse response is the mirror and time shifted version of a reference signal. The operation of matched filter detection is expressed as:

$$Y[n] = \sum_{k=-\infty}^{\infty} h[n-k].x[k] \tag{2.5}$$

Where 'x' is the unknown signal (vector) and is convolved with the 'h', the impulse response of matched filter that is matched to the reference signal for maximizing the SNR. Detection by using matched filter is useful only in cases where the information from the primary users is known to the cognitive users.

When the cognitive radio user knows the information of the primary user signal, matched filter detection is optimal detection in stationary Gaussian noise but if the information is not accurate, MF performs poorly. On top of that, the most significant disadvantage of MF is that a CR would need a dedicated receiver for every type of primary user (Akyildiz 2011) [11].

2.2.3.3 Cyclostationary Feature Detection

It exploits the periodicity in the received primary signal to identify the presence of primary users (PU). The periodicity is commonly embedded in sinusoidal carriers, pulse trains, spreading code, hopping sequences or cyclic prefixes of the primary signals. Due to the periodicity, these cyclostationary signals exhibit the features of periodic statistics and spectral correlation, which is not found in stationary noise and interference (Tkachenko 2007) [12]. Thus, cyclostationary feature detection is robust to noise uncertainties and performs better than energy detection in low SNR regions. Although it requires a priori knowledge of the signal characteristics, cyclostationary feature detection is capable of distinguishing the CR transmissions from various types of PU signals. This eliminates the synchronization requirement of energy detection in cooperative sensing. Moreover, CR users may not be required to keep silent during cooperative sensing and thus improving the overall CR throughput (Tandra 2008) [13].

This method has its own shortcomings owing to its high computational complexity and long sensing time. Due to these issues, this detection method is less common than energy detection in cooperative sensing.

2.2.4 Interference Based Detection

2.2.4.1 Primary Receiver Detection

In general, primary receiver emits the local oscillator (LO) leakage power from its RF front end while receiving the data from primary transmitter. It has been suggested as a method to detect primary user by mounting a low cost sensor node close to a primary user's receiver in order to detect the LO leakage power emitted by the RF front end of the primary user's receiver which are within the communication range of CR system users. The local sensor then reports the sensed information to the CR users so that they can identify the spectrum occupancy status. We note that this method can also be used to identify the spectrum opportunities to operate CR users in spectrum overlay [8].

2.2.4.2 Interference Temperature Management

The basic idea behind the interference temperature management is to determine an upper interference limit for given frequency band in specific geographic location so the CR users are not allowed to cause harmful interference while using the specific band in specific area.CR user transmitters control their interference by limiting their transmission power based on their locations with respect to primary receivers. This method basically concentrates on measuring interference at the receiver (Thanayankizil 2008) [14].

2.2.5 Cooperative spectrum sensing

In the CR networks there is a lack of interaction between PU and SU. Transmitter detection based sensing merely detect weak transmitter signals .hence, the primary transmitter detection techniques cannot avoid interference with the primary signal because the lack of information , also the hidden node and shadowing problems can result in inaccurate sensing information causing interference as shown in figure 2.3. Therefor sensing information from other CR users is needed to obtain better sensing accuracy. This is referred to as cooperative sensing.

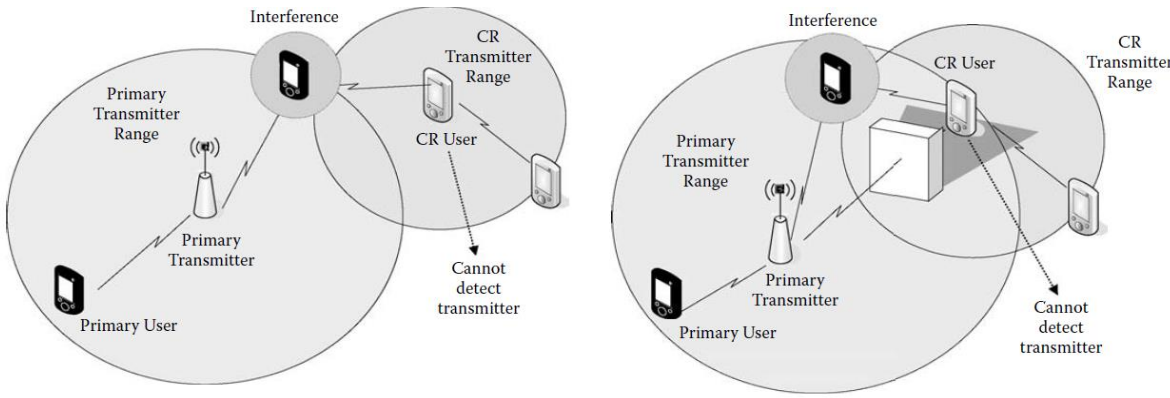

Figure 2.3 Hidden node and shadowing problems [5]

The cooperative spectrum sensing can be classified into three categories based on how they share sensing information between them: centralized, distributed and relay-assisted. These three types are illustrated in figure 2.4.

In centralized spectrum sensing technique, a central identity called base station transceiver control the three steps process of sensing:

1- The base transceiver chooses the frequency bands and instructs all the CR users to perform sensing.
2- The CR users report the sensing results to the base transceiver.
3- The base transceiver compares the results to determine the presence of PU and send the decision to all cooperating CR users.

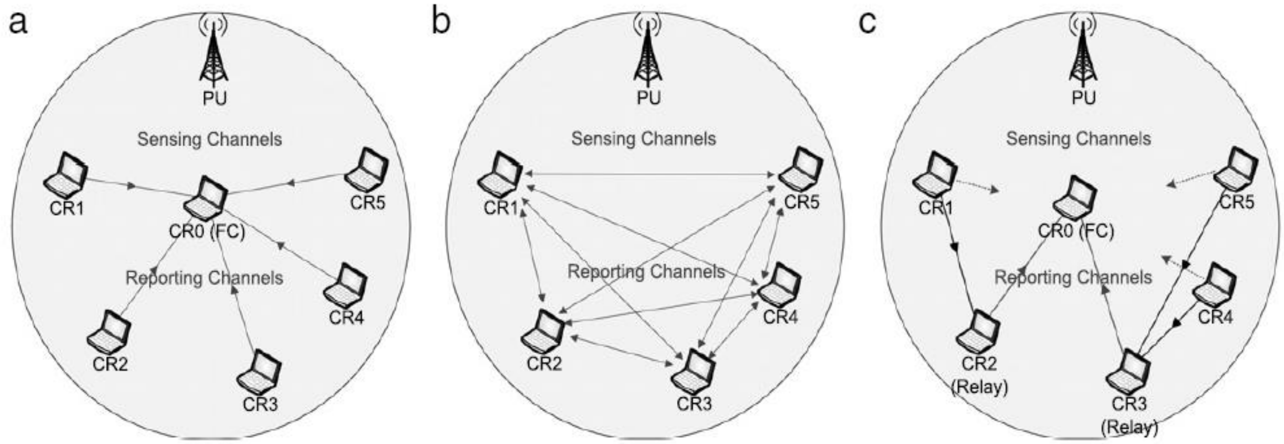

Figure 2.4. Cooperative sensing techniques: a) centralized b) distributed

c) relay-assisted [11]

Centralized schemes can be further classified according to their level of cooperation as: Partially cooperative where network nodes cooperate only in sensing the channel. CR users independently detect the channel and inform the base transceiver which then notifies all the CR users; and totally cooperative Schemes where nodes cooperate in relaying each other's information in addition to cooperatively sensing the channel [8].

For reporting sensing data, two major control channel requirements must be satisfied in cooperative sensing: bandwidth, reliability [11].

Bandwidth requirement:

The bandwidth of the control channels as one of the factors of determining the level of cooperation. This is because the amount of local sensing data that can be transmitted to the base station transceiver or shared with the neighbors is limited by the control channel bandwidth.

***Reliability requirement**:*

In addition to the bandwidth requirement, the reliability of the control channel has the great impact on cooperative sensing performance. Like data channels, the control channel is susceptible to multipath fading and shadowing. Hence, the channel impairments must be considered in the reliability issue of the control channel.

While cognitive radio cooperative spectrum sensing is obviously more complicated than a single non-cooperative system, it has many advantages that outweigh the added complexity. Naturally cooperative spectrum sensing is not applicable in all applications, but where it is applicable, considerable improvements in system performance can be gained [7].

Hidden node problem is significantly reduced*:* One of the chief problems with non-cooperative spectrum sensing is that even though the cognitive radio may not be able to detect a primary user transmitter, it may still interfere with receivers who may be able to detect both the primary user and also the cognitive radio system transmissions. By using a cooperative sensing system, it is possible to reduce the possibility of this happening because a greater number of receivers will be able to build up a might more accurate picture of the transmissions in the area.

Increase in agility*:* An increase in the number of spectrum sensing nodes by cooperation enables the sensing to be more accurate and better options for channel moves to be processed, thereby providing an increase in agility.

Reduced false alarms*:* By having multiple nodes performing the spectrum sensing, channel signal detection is more accurate and this reduces the number of false alarms.

More accurate signal detection*:* Cooperative spectrum sensing provides for more accurate signal detection and a greater reliability of the overall system.

There are many advantages to incorporating a cooperative spectrum sensing system within a cognitive radio network wherever possible.

2.2.6 Sensing performance

The performance of the detection algorithm can be summarized with two probabilities: probability of detection P_d and probability of false alarm P_f [7]. P_d is the probability of detecting a signal on the considered frequency when it truly is present. Thus, a large detection probability is desired. It can be formulated as

$$Pd = \Pr(M > \lambda e \quad H1) \tag{2.6}$$

P_f is the probability that the test incorrectly decides that the considered frequency is occupied when it actually is not, and it can be written as

$$Pf = \Pr(M > \lambda e \quad H0) \tag{2.7}$$

P_f should be kept as small as possible in order to prevent underutilization of transmission opportunities. The decision threshold λ_E can be selected for finding an optimum balance between P_d and P_f. However, this requires knowledge of noise and detected signal powers. The noise power can be estimated, but the signal power is difficult to estimate as it changes depending on ongoing transmission characteristics and the distance between the cognitive radio and primary user. In practice, the threshold is chosen to obtain a certain false alarm rate. Hence, knowledge of noise variance is sufficient for selection of a threshold.

As demonstrated in (Salih and others 2013) [15], cooperative detection is more accurate in terms of detecting the primary transmitter activities; this scheme is obviously increase the detection probability obtained by

$$Pd^c = 1 - (1 - Pd)^N \quad (2.8)$$

Where N is the number of cooperative CR-CPEs. On the other hand, this scheme also increases the false alarm probability as follows;

$$Pf^c = 1 - (1 - Pf)^N \quad (2.9)$$

2.2.7 IEEE 802.22

The worldwide first application of cognitive radio (CR) networks in unlicensed television broadcast bands is IEEE 802.22 wireless regional area network (Subramanium and others 2014) [16].

IEEE 802.22 standard is known as cognitive radio standard because of the cognitive features it contains. The standard is still in the development stage. One of the most distinctive features of the IEEE 802.22 standard is its spectrum sensing requirement.

Larger amounts of unoccupied TV White Space spectrum are available in low population density or rural areas that tend to be underserved with other broadband options such as Digital Subscriber Line or cable. This makes this spectrum of particular interest for Wireless ISP operations in rural areas where the population is normally unserved or underserved with broadband access. Each available Television channel provides 6 MHz of spectrum capacity that can be used for broadband connectivity.

IEEE 802.22 based wireless regional area network (WRAN) devices sense TV channels and identifies transmission opportunities. The functional requirements of the standard require at least 90% probability of detection and at most 10% probability of false alarm for TV signals with -16 dBm power level or above.

The sensing is envisioned to be based on two stages: fast and fine sensing.

In the fast sensing stage, a coarse sensing algorithm is employed, e.g. energy detector. The fine sensing stage is initiated based on the fast sensing results. Fine sensing involves a more detailed sensing where more powerful methods are used. Several techniques that have been proposed and included in the draft standard include energy detection, waveform-based sensing (PN511 or PN63 sequence detection and/or segment sync detection), cyclostationary feature detection, and matched filtering. A base station (BS) can distribute the sensing load among subscriber stations (SSs). The results are returned to the BS which uses these results for managing the transmissions. Hence, it is a practical example of centralized collaborative sensing.

Another approach for managing the spectrum in IEEE 802.22 devices is based on a centralized method for available spectrum discovery. The BSs would be equipped with a global positioning system (GPS) receiver which would allow its position to be reported. The location information would then be used to obtain the information about available TV channels through a central server [15].

Chapter Three

Interchangeable Spectrum Scheduling

3. Chapter Three

Interchangeable Spectrum Scheduling

3.1 Introduction

In the previous chapters, a brief overview of the cognitive radio literature is presented. On the other hand, in this chapter, the inter-changeable spectrum sensing algorithm (ISSS) is explained and the evaluation parameters are demonstrated.

In practical implementations of opportunistic spectrum access, the user needs to exploit multiple spectrum bands to mitigate the fluctuations in a single band operation. The environment in which the CR network is mounted assumed to be a Multiband Primary Network Environment (MPNE) which have a multiple primary network, each one of these networks have an exclusive right to access its band. In contrast CR network is only serves its customers opportunistically without interference with the licensed operations.

3.2 ISSS Operation

ISSS uses a centralized cooperative sensing technique which has a central base transceiver cover the area of interest and multiple cognitive radio customer premises equipment (CR-CPE) distributed at the system area called cognitive radio network (CRN) clients. Each CRN client has two transceivers, one to communicate data and the other to exchange control signal with the base transceiver. At last, the control channel should be error free to protect control signal and avoid causing interference to the primary users. Therefore, the control channel state is one of the important factors that determines the performance of cognitive radio system.

The transmission time is the key parameter to achieve the maximum benefit from the cognitive radio, however increasing the transmission time will cause inaccuracy at the sensing results because the sensing time will reduce. ISSS could achieve a high transmission rate without affecting the accuracy of sensing by distributing sensing task between the CR-CPE clients then pass sensing information to the central base transceiver, then it will provide to each CR-CPE client the information it needs using the error free control channel.

The main concept of ISSS is to make each CR-CPE sense its own spectrum also provide sensing information for the other users bands. Figure 3.1 describe the operation of the algorithm in a system has n CR-CPE ,each CPE has a sensing time in which it sense all system bands then start transmission and the next CPE take responsibility of sensing and so on.

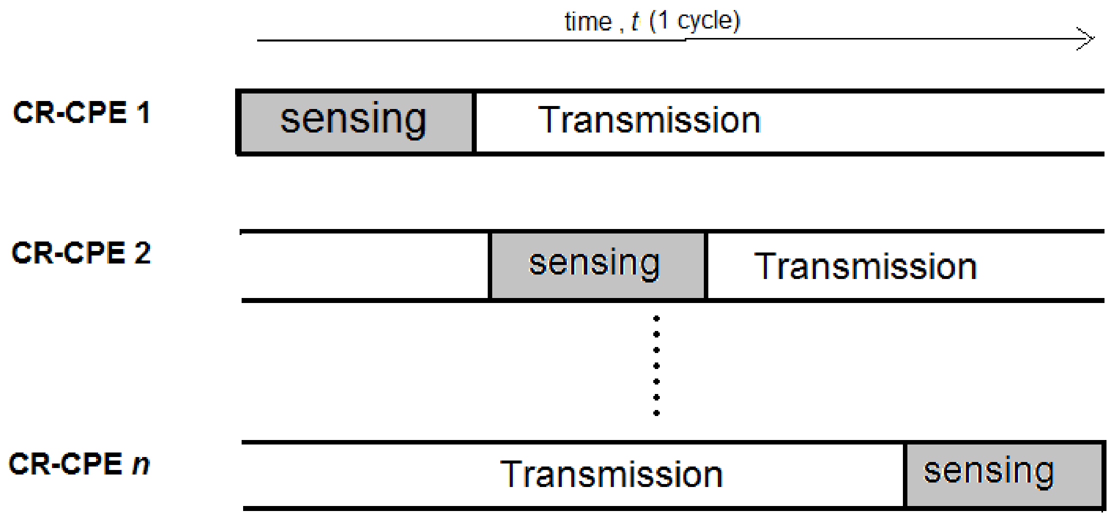

Figure 3.1 ISSS operation

The number of cooperating CPEs is one of the most important factors that determine the performance of the system, the more users cooperate together the more sensing information will be provided and the cycle period will increase thus the transmission time to each user will increase without affecting the performance of the system.

3.3 Inter-Band Soft Handover

Like in ordinary mobile system, hand over process takes place in ISSS to grantee that no interference occurs to the primary user. The central base transceiver takes the responsibility of performing the handover according to the sensing information. When the primary user appear at the band, the central base transceiver immediately search for a new empty band to assign it to the CR-CPE instead of the busy one using the ***inter-band soft handover(IBSHO)***. The handover process should be performed very fast so the secondary user doesn't affect the QOS that primary user needs for its communication [15].

3.4 Performance parameters

The performance of cognitive radio system is determined by many factors including the probability of detection and the probability of false alarm, to get an optimum performance the sensing technique must find a good trade-off between false alarm and miss detection probabilities.

Another way to address the performance of the system from the MAC-layer view point by the throughput of the secondary user and the interference (collision) with the primary users. If the interference with the primary user exceed the noise floor, it considered as a collision.

To calculate the collision and successful transmission probabilities simple relationship between (P_d, P_f) and (Ps,Pc) is used as follow (Wyglnski 2009) [17].

$$Ps = (1 - \mathrm{Pf})\,\mathrm{Pr}[H0]\,, \qquad Pc = (1 - Pd) \tag{3.5}$$

where:

Ps=probability of successful data transmission

P_f =probability of false alarm

Pr [H0] = probability of idle channel

Pc=probability of collision

Pad=probability of detection

The successful transmission can be defined by two logical conditions: the reception at the secondary receiver being successful and the transmission from the secondary transmitter being harmless (doesn't interfere with primary transmitter). However, it is worth mentioning that in some scenarios the probability of collision is not equal to the probability of miss detection. Furthermore, correctly detected opportunities may lead to failed data transmission, and miss detection may lead to successful data transmission as illustrated in figure 3.2

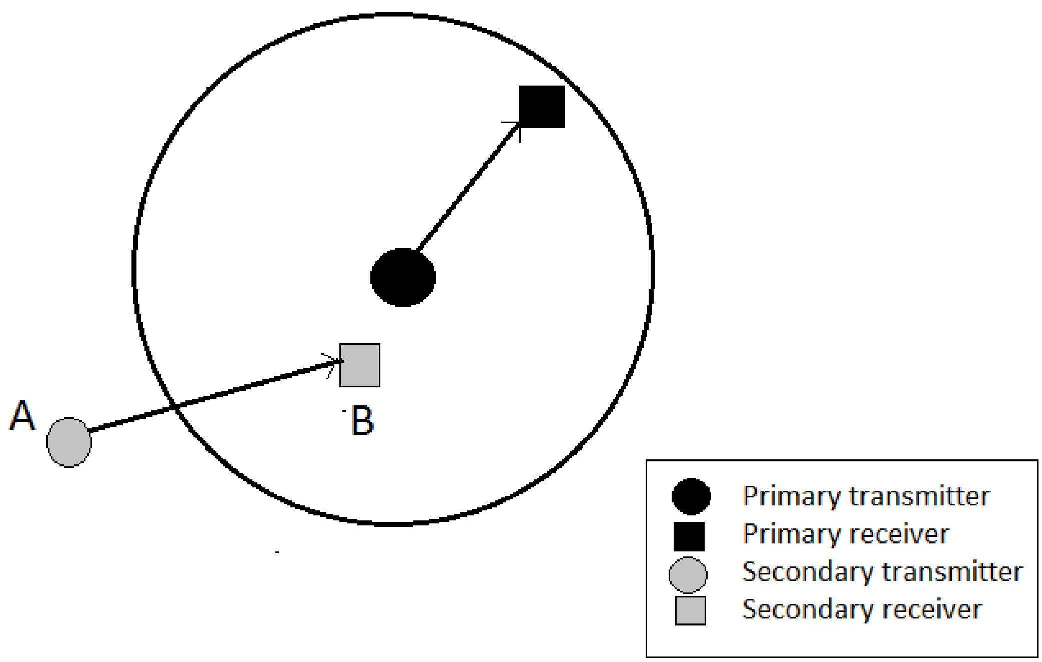

Figure 3.2 Useful miss-detection scenario

Consider a pair of secondary users A and B seeking to communicate using opportunistic communication with the presence of primary users as shown in figure 3.2. If the receiver B was responsible of sensing process and miss detected the primary user activity the secondary transmitter A will start to transmit to B while the primary users are communicating. However, the secondary transmission will be done successfully without interfering the primary user. So although miss detection occurs no collision happened so the probability of collision can be defined as

$$Pc \leq (1 - Pd) \tag{3.6}$$

That mean in some scenarios the miss detection of primary user can be useful by creating a new opportunities. On other hand the false alarm also may be useful by protecting the system from colliding with the primary user as demonstrated in figure 3.3

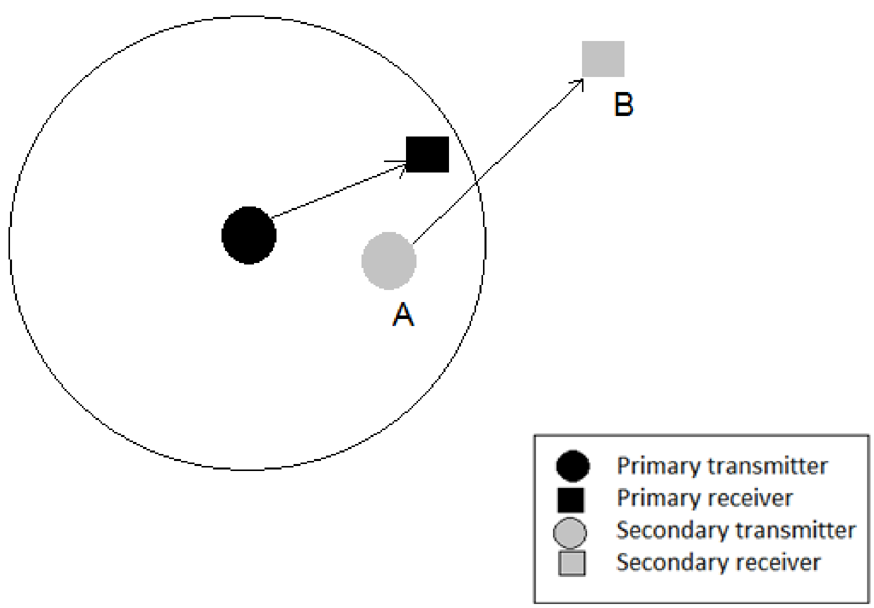

Figure 3.3 Useful false alarm scenario

If B is responsible from sensing process it can't see the primary transmitter because it is outside of the primary transmitter coverage area so if it decided that the channel is free A will start sending causing a collision at the primary receiver. However if a false alarm occurred at B this will protect the primary users communication from the interference.

3.5 Energy threshold for sensing

As mentioned previously, energy detection sensing is considered simple, since it does not require knowledge about the primary user signal structure. The main issue explained here, is the selection of the threshold in order to distinguish the spectrum holes in the noisy wireless channel.

The selection of a reasonable threshold is based on the radar detection theory [8]

$$V_T = \sqrt{2\sigma_N^2 \log \frac{1}{Pf}} \tag{3.7}$$

Where V_T is the voltage threshold, and σ_N^2 is the noise power Pf is the probability of false alarm

Chapter Four

Implementation and Results

4. Chapter Four

Implementation and Results

4.1 Introduction

In real world, a number of bands in cognitive radio network are exploited simultaneously in order to mitigate the fluctuating nature of the opportunistic spectrum access. However, high number of bands may lead to degradation of overall performance due to the overutilization of the spectrum.

In this chapter, the simulation implementation and the results are discussed. Matlab tools are used to simulate the practical cognitive radio environment of ISS cooperative sensing as well as evaluation method by calculating the performance parameters of the system.

4.1 Assumptions

- The system is operating in a geographical location that is already covered by multiple licensed networks such as GSM, WiMAX and TV which referred to as Multiband Primary Network Environment (MPNE).

- The cooperation topology assumed to be centralized architecture with a base station for processing, synchronization and signaling

- An error free signaling channel providing signaling information with guaranteed availability.

4.2 Sensing in ISSS algorithm

Decision fusion in cognitive radio networks aimed to increase the detection probability while keeping the false alarm probability at an acceptable level. Primary network activity has a major effect in the probability of detection as well as the probability of false alarm. The ISSS algorithm suggested that the probability of detection increases with the primary user activity that is because the primary user operation would meet the sensing time slot at a higher percentage, the reason behind that is discussed later in this chapter. The following Pseudo code simulate sensing task.

Sensing Pseudo Code

```
% perform sense task for each band
    for x=1:n
        for y=1:t/n^2                              % sensors time slots
            for j=0:n-1
                if  NChStatus(x,n^2*y-n^2+x+j*n) > 0
                    if diff(x,n^2*y-n^2+x+j*n)==1

                        FA(x)=FA(x)+1;              % False alarm occurs

                        continue;
                    end
                    sensematrix(x,(y-1)*n^2+1:y*n^2)=j+1;      % Detection occurs
                     break
                else
```

```
                    sensematrix(x,(y-1)*n^2+1:y*n^2)=0;           %No detection nor false alarm
end
```

As demonstrated in the sensing simulation code the channel time is splited to frames with length *n^2* (where n is the number of bands at the cooperative system). Then sensing process is done by all contributing CPEs to each band at different time slot at the frame. Figure 4.1 show an example of sensing process for a system uses 4 bands (4 CPEs).

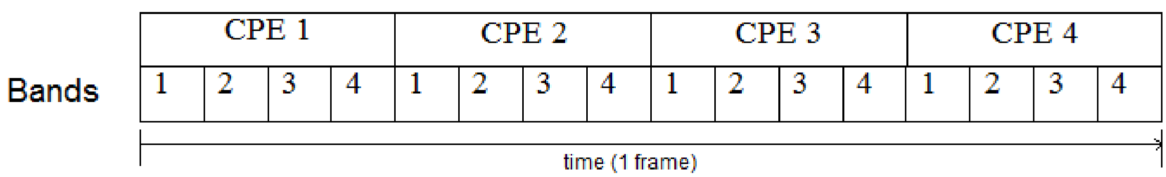

Figure 4.1. Sensing task at 4-bands system

As shown in the figure the sensing is done to each band 4 different time slots at the frame by the 4 CPEs, if the primary signal is detected by any CPE the rest of the frame is considered to be busy and sense matrix will save that the primary signal is detected and determine the CPE that detected it.

4.3 Probability of detection

Figure 4.1 shows the contribution of the ISSS algorithm in reducing interference with the primary user. The contribution is calculated according to the equation (4.1).

$$ISSS\_contribution = I_{ISSS} - I_{Single} \tag{4.8}$$

Where I_{Single} is the interference detection probability before applying ISSS algorithm, and I_{ISSS} is the interference detection probability after applying the algorithm.

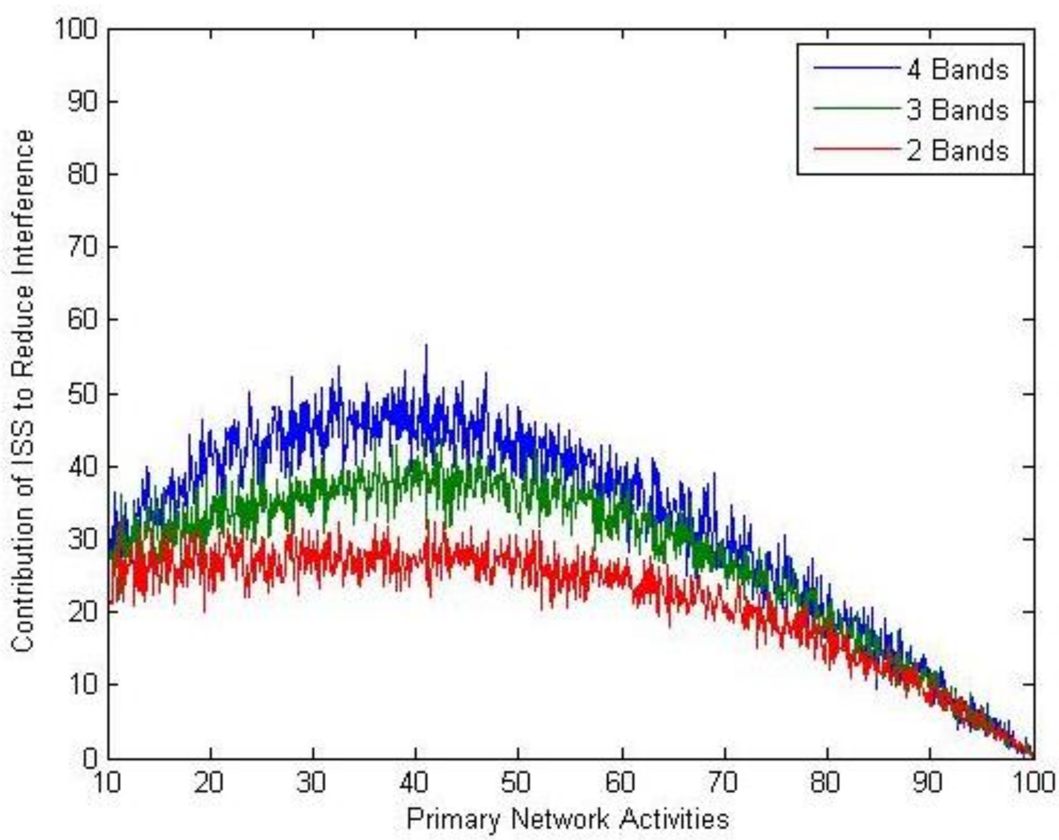

Figure 4.2. ISSS contribution to reduce interference

Vs. primary network activity

As illustrated at the figure, the different number of bands start almost with the same contribution at the very low primary user activity, but after increasing the activity, the probability of detection increases differently. So the system with highest number of band achieve a greater contribution faster than a few bands system, then the contribution decrease because the cooperative system already reached about 100% detection probability but the single band is still increasing. When the primary user activity reaches 100% there is no deference between the ordinary sensing method and the ISSS method that is because the sensing in going to be scheduled at the exact same time as the primary user signal appears, regardless of the sensing schedule.

4.4 Probability of false alarm

Figure 4.3 shows the relation between false alarm probability and primary user activity.

The figure illustrate that increasing the number of bands will increase the false alarm probability, also at low primary user activity the probability of false alarm take the highest value and start decreasing with activity increasing until it reach 0% at the 100% activity because the band is already occupied and there is no opportunity to be missed.

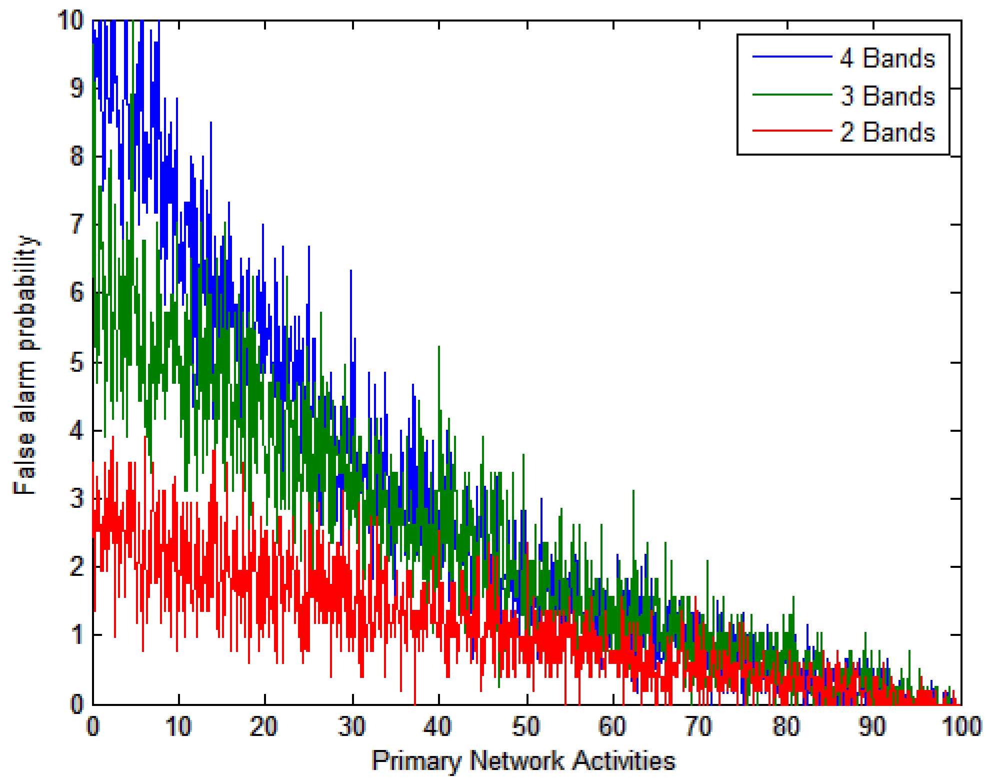

Figure 4.3. False alarm probability

4.5 Results

Below tables show the performance metrics according to different number of bands at 5dB SNR channels with a various primary user activities 20%, 40%, 60% and 80%

.

Table 4.1: performance metrics with 5dB SNR

No. of Bands	20%		40%		60%		80%	
	Pd %	Pf %	Pd %	Pf %	Pd %	Pf %	Pd %	Pf %
2	59.75	3.12	74.64	2.78	86.27	1.31	96.37	0.53
3	57.24	4.08	77.95	2.97	93.46	1.57	99.27	0.62
4	61.24	5.07	86.91	3.12	98.14	1.95	99.7	0.68
5	66.38	5.95	92.17	3.56	99.74	2.17	100	1.0
6	72.36	6.73	95.21	3.66	97.87	2.19	99.43	1.1
7	78.32	7.35	97.53	4.98	99.32	2.23	99.93	1.28
8	81.83	8.39	98.24	4.49	100	2.22	100	1.38

By deploying different SNR value, the performance metrics (P_d , P_f) values varies too, when SNR increases the probability of detection increases and the false alarm probability decreases and vice versa. Considering that the variations are applied to noise only, then by increasing the SNR to 10dB, the performance of the system will change as follow

Table 4.2: performance metrics with 10 dB SNR

No. of Bands	**20%**		**40%**		**60%**		**80%**	
	Pd %	**Pf %**	**Pd %**	**Pf %**	**Pd %**	**Pf %**	**Pd %**	**Pf %**
2	61.84	1.84	72.56	1.28	86.20	0.42	96.08	0.15
3	60.12	1.75	75.23	1.15	92.10	0.44	99.24	0.24
4	63.65	3.05	86.87	1.95	97.42	1.01	100	0.23
5	70.48	3.25	86.92	1.98	99.07	1.20	100	0.46
6	73.34	3.86	95.03	2.10	98.20	1.17	99.43	0.58
7	80.15	4.24	93.1	2.37	98.43	1.23	100	0.603
8	84.21	4.68	98.59	2.35	100	1.25	100	0.625

Chapter Five

Conclusion and Recommendations

5. Chapter Five

Conclusion

5.1 Conclusion

Spectrum is a precious and scarce resource in wireless communication systems, and it has been a focal point of research and development over the past few decades. Cognitive Radio gained a lot of attention recently since it holds the promising solution for today's wireless communication problems. Cognitive Radio enables the utilization of the available spectrum more efficiently through the opportunistic spectrum usage.

Spectrum sensing is a crucial element in cognitive radio networks since it detect the opportunities in the spectrum. The Interchangeable Spectrum Sensing Scheduling algorithm (ISSS) is an attempt to improve the spectrum-sensing task through the multiband cooperative sensing.

In this thesis, (ISSS) algorithm was simulated and evaluated in terms of the contribution to reduce the interference with the primary user as well as the opportunity losses, and it is worth mentioning that the simulation results have gotten in the worst case of the PU activity. In reality the PU activity are less random.

So far, this algorithm assume that there is no means of interaction between the primary user and the secondary users, thus all the scheduling and resource sharing is a secondary network task. Consequently, more computational processing resources needed and the primary user regards the secondary user as a source of noise or intrusion.

5.2 Recommendations

This thesis built a test-bed to evaluate the ISSS algorithm based on inductive reasoning approach, however, the following is recommended for future work:

- For the evaluation of false alarm AWGN noise is considered, however, it is recommended to include other types of noise and to measure the detection probability based on that.
- ISSS scheduling algorithm uses energy detection, it is recommended to incorporate other sensing methods such as interference temperature to mitigate the waste of opportunities.

References

[1] Ntia.doc.gov, 'Home Page | NTIA'. N.p., 2011. Web. 17 Sept. 2015.

[2] Commission, F. C. (2002). Spectrum Policy Task Force. Rep. ET Docket no. 02-135, Nov.

[3] Yücek, T. and H. Arslan (2009). "A survey of spectrum sensing algorithms for cognitive radio applications." Communications Surveys & Tutorials, IEEE 11(1): 116-130.

[4] Haykin, S. (2005). "Cognitive radio: brain-empowered wireless communications." Selected Areas in Communications, IEEE Journal on 23(2): 201-220.

[5] Xiao, Y. and F. Hu (2008). Cognitive radio networks, CRC press.

[6] Burns, P. (2002). Software defined radio for 3G, Artech house.

[7] Yücek, T. and H. Arslan (2009). "A survey of spectrum sensing algorithms for cognitive radio applications." Communications Surveys & Tutorials, IEEE 11(1): 116-130.

[8] Subhedar, M. and G. Birajdar (2011). "Spectrum sensing techniques in cognitive radio networks: A survey." International Journal of Next-Generation Networks 3(2): 37-51.

[9] Wang, B. and K. Liu (2011). "Advances in cognitive radio networks: A survey." Selected Topics in Signal Processing, IEEE Journal of 5(1): 5-23.

[10] Abdulsattar, M. A. and Z. A. Hussein (2012). "Energy detection technique for spectrum sensing in cognitive radio: a survey." International Journal of Computer Networks & Communications 4(5): 223-242.

[11] Akyildiz, I. F., B. F. Lo, et al. (2011). "Cooperative spectrum sensing in cognitive radio networks: A survey." Physical Communication 4(1): 40-62.

[12] Tkachenko, A., D. Cabric, et al. (2007). Cyclostationary feature detector experiments using reconfigurable BEE2. New Frontiers in Dynamic Spectrum Access Networks, 2007. DySPAN 2007. 2nd IEEE International Symposium on, IEEE.

[13] Tandra, R. and A. Sahai (2008). "SNR walls for signal detection." Selected Topics in Signal Processing, IEEE Journal of 2(1): 4-17.

[14] Thanayankizil, L. and A. Kailas (2008). "Spectrum sensing techniques (II): receiver detection and interference management." Report, Available at: http://aravind. kailas. googlepages. com/ece_8863_report. pdf.

[15] Salih, S. H., M. Suliman, et al. (2013). A novel spectrum sensing scheduler algorithm for Cognitive Radio Networks. Computing, Electrical and Electronics Engineering (ICCEEE), 2013 International Conference on, IEEE.

[16] Subramanium, P. and R. D. Raut (2014). "Improvement of BER on different fading channel using IEEE 802.22 standard." Science 1(1): 1-5.

[17] Wyglinski, A. M., M. Nekovee, et al. (2009). Cognitive radio communications and networks: principles and practice, Academic Press.

[18] Rao, A. M., B. Karthikeyan, et al. (2010). "Energy detection technique for spectrum sensing in cognitive radio." SAS_TECH journals2010volume 9.

Appendix

```
function  Yout=ISSm(t,n,m,a)
% t = simulation time
% n = Number of available bands
% m = channel or State number, allways = 2, then m=1;
% a = Primary network activity
clc,close all
SNR=input('Enter the SNR : ');
% Initiation
i=0;        %  initial value, start @ level i
time(1)=0;  %  start at time 0
ChStatus(1)=i;  %  @ time 0 : level i

for x=1:n
   for y=1:t
      signal(y)=sin(y);
   end
   noise(x,:)=abs(awgn(signal,SNR)-signal(y));      %generate noise
   th(x)=sqrt(2*(sum(noise(x,:))/t)^2*log(1/0.06));    %calculate energy detection threshold
end
for band =1:n
   for k=2:t
      if rand <= a;
         if i < m
            i=i+1;    % Birth Occure
         end
      elseif i > 0
         i=i-1;    % Death Occure
      end
% Primary NW Activities
      ChStatus(band,k)=i;
      time(k)=k;
   end
```

```
    %plot the process
    if n >1
        h=ceil(sqrt(n));
        g=round(sqrt(n));
        subplot(h,g,band)
        stairs(time, ChStatus(band,:));
        axis([0 t 0 2])
        xlabel('Time')
       ylabel('Channels')
    end
end
for x=1:n
    for y=1:t
        if noise(x,y)>th(x)
            NChStatus(x,y)=1;
            if ChStatus(x,y)== 0
                diff(x,y)=1;
            else
                diff(x,y)=0;
            end
        else
        NChStatus(x,y) = ChStatus(x,y);
        diff(x,y)=0;
    end
    FA(x)=0;
end
figure(2)
subplot(h,g,x)
stairs(time, NChStatus(x,:));
axis([0 t 0 2])
xlabel('Time')
ylabel('Channels')
```

```
% ISS behaviour, n = number of sensor i.e. CR-CPEs

for x=1:n
   for y=1:t/n^2 % sensors time slots
      q=0;
      for j=0:n-1
         if NChStatus(x,n^2*y-n^2+x+j*n) > 0
            if diff(x,n^2*y-n^2+x+j*n)==1
               if q==0
                  FA(x)=FA(x)+1;
               end
               q=1;
               continue;
            end
            sensematrix(x,(y-1)*n^2+1:y*n^2)=j+1;
            if j+1==x
               sensesingle(x,(y-1)*n^2+1:y*n^2)=j+1;
            else
               if NChStatus(x,n^2*y-n^2+x+(x-1)*n) > 0
                  if diff(x,n^2*y-n^2+x+(x-1)*n)~=1
                     sensesingle(x,(y-1)*n^2+1:y*n^2)=x;
                  end
               end
            end
            break
         else
            sensematrix(x,(y-1)*n^2+1:y*n^2)=0;
            sensesingle(x,(y-1)*n^2+1:y*n^2)=0;
         end
      end
      IdleCH(band,l)= m-i;
```

```
        opportuity = opportuity + length(sensematrix(x ==0,:))
    end

    for z=1:t
        time(z)=z;
    end

    figure(3)
    subplot(h,g,x)
    stairs(time, sensematrix(x,:))
    axis([0 t 0 n+1])
end

% ISS performance

for x=1:n
    N_Idle(x) = 0;
    % Percentage of the Busy & Idle states
    for y=1:t/(n^2)
        if ChStatus(x ,(y-1)*n^2+1:y*n^2) == 0
            N_Idle(x)=N_Idle(x)+1;
        end
    end
    N_Busy = (t/n^2) -  N_Idle;

    % percentage of detection by single goup
    N_Single(x) = sum(sensesingle(x,:)==x);

    %   percentage of detection by ISS
    N_ISS(x) = sum(sensematrix(x,:)~=0);
```

```
end
% % percentage of detection by single goup

P_Single = 100*N_Single/(n^2*N_Busy);
P_ISS    =  100*N_ISS /(n^2*N_Busy);

FixPercentage = P_Single / P_ISS ;% 1/ N. of Bands % here is 25%

Interfernce_Single =  100*(N_Busy - N_Single/n^2)./N_Busy;
Interfernce_ISS    =  100*(N_Busy - N_ISS/n^2)./N_Busy;

ISS_contribution = Interfernce_Single - Interfernce_ISS;
ISS_contribution_dB = 20 * log10 ( ISS_contribution);
ChStatus = ChStatus;
sensematrix = sensematrix ;

avg_fa=0;
for x=1:n
   FA(x)=FA(x)/( t/n^2)*100;
   avg_fa=avg_fa+FA(x);
end

avg_fa=avg_fa/n
Yout=[P_Single,P_ISS,avg_fa];
```

```
function  Yout=ISS
for i=1:1000
   Result_ISS4 = ISSa(1024,4,1,i/1000);
   Result_ISS3 = ISSa(1152,3,1,i/1000);
   Result_ISS2 = ISSa(1024,2,1,i/1000);
   t(i)=i/10;
   Diff_4(i) = Result_ISS4(2)-Result_ISS4(1);
   Diff_3(i) = Result_ISS3(2)-Result_ISS3(1);
   Diff_2(i) = Result_ISS2(2)-Result_ISS2(1);
   FA_4(i) = Result_ISS4(3)
   FA_3(i) = Result_ISS3(3)
   FA_2(i) = Result_ISS2(3)
 end

%'Contribution of ISS to Decrease the Interference'
figure('Contribution of ISS to Decrease the Interference')
plot(t,Diff_4,t,Diff_3,t,Diff_2)
axis([1 100 0 100])
xlabel('Primary Network Activities')
ylabel('Contribution of ISS to Reduce Interference')
legend('4 Bands','3 Bands','2 Bands');

%False alarm probability
figure('False alarm probability')
plot(t,FA_4,t,FA_3,t,FA_2)
axis([0 100 0 100])
xlabel('Primary Network Activities')
ylabel('False alarm probability')
legend('4 Bands','3 Bands','2 Bands');
```