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Enhancement the Detection Performance for the Primary User Traffic in Cognitive Radio Networks

A THESIS
SUBMITTED TO THE COMMUNICATION TECHNIQUES ENGINEERING DEPARTMENT
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE TECHNICAL MASTER DEGREE
IN COMMUNICATION TECHNICAL ENGINEERING

By

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بسم الله الرحمن الرحيم

فَبَدَأَ بِأَوْعِيَتِهِمْ قَبْلَ وِعَاءِ أَخِيهِ ثُمَّ اسْتَخْرَجَهَا مِنْ
وِعَاءِ أَخِيهِ كَذَٰلِكَ كِدْنَا لِيُوسُفَ مَا كَانَ لِيَأْخُذَ أَخَاهُ فِي
دِينِ الْمَلِكِ إِلَّا أَنْ يَشَاءَ اللَّهُ نَرْفَعُ دَرَجَاتٍ مَنْ نَشَاءُ وَفَوْقَ
كُلِّ ذِي عِلْمٍ عَلِيمٌ

صدق الله العظيم

[سورة يوسف:٧٦]

Dedication

To my mother

who taught me the value of studying and persevering and gave me continuous support.

To my brothers, my wife and my friends.

To the soul of my father and martyr brother.

To all who supported me and encouraged me to achieve my success

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AKIL HASSAN HAMIED

Supervisor Certification

We certify that this thesis titled **" Enhancement the Detection Performance for the PU Traffic in Cognitive Radio Networks"**

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Abstract

Cognitive Radio(CR) is considered the most effective wireless system to solve the problem of scarcity of spectrum by finding the best technologies and methods in order to accommodate the largest number of secondary users in sharing the radio spectrum. The system was launched for the purpose of restoring the balance in the use of the spectrum in a better and optimal manner. The CR system enables unauthorized users to use the bandwidth for some time, when the license owner begins to use his bandwidth, the unauthorized user immediately leaves the band and cannot restore an until the initial user terminates their connection. Conventional detection methods have proven ineffective in sensing the frequency spectrum from dynamic primary user (PU) detection, as they assume that the PU is either absent or completely present during the Duty or Activity period. An algorithm has been proposed that aims improve sensing by using the dynamic threshold formula instead of a static threshold. The dynamic of the PU named the Activity period (A), also increases the detection ratio. This algorithm is designed based on the dynamic threshold diagram and the dynamic movement of the PU together. This is to enhance PU detection in CR networks. The derivations and mathematical analyzes related to the sending and receiving parameters were performed to find the detection equation. Therefore, the algorithm test was performed over the AWGN channel under two different conditions, firstly, the Formula of the detection without noise uncertainty factor and finding the detection ratio, and secondly, formula of the detection with influence noise uncertainty factor on results of detection. In both cases, the algorithms provided results within the acceptable detection criteria by running a number of tests through the Matlab simulation program on a number of samples as well as using the signal-to-noise ratio relatively low. The energy detection new formula by using a dynamic threshold was implemented and also a dynamic PU (DED-DT) as well as the use of the

Constant False Alarm Rate (CFAR) technology. The reliable detection of performance to the low signal sensing was investigated. The proposed algorithms gave relatively improved results compared to traditional detection methods.

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List of Abbreviations

A	Activity Period
AWGN	Additive White Gaussian Noise
ADC	Analog-To- Digital Converter
BPF	Band Pass Filter
CR	Cognitive Radio
CRN	Cognitive Radio Network
Q	Complementary Accumulated Function
CFAR	Constant False Alarm Rate
CSS	Cooperative Spectrum Sensing
CF	Cyclo-Stationary Feature
d	Dynamic Factor
DED	Dynamic Energy Detection
DSA	Dynamic Spectrum Access
DTD	Dynamic Threshold Detection
DT	Dynamic-Threshold
*E*D	Energy Detection
5G	Fifth Generation
Hz	Hertz
IEEE	Institute of Electrical and Electronics Engineers
MF	Matched Filter
NU	Noise Uncertainty
PU	Primary User
PU-A	Primary User With Activity period
PDF	Probability Density Function
PM	Probability of Miss-Detection
PD	Probability of Detection

PF	Probability of False Alarm
QoS	Quality of Service
RF	Radio Frequency
Pr	Received Power
ROC	Receiver Operation Characteristics
SU	Secondary User
SDR	Soft-Defined Radio
SS	Spectrum Sensing
TRAI	Telecom Regulation Authority Of India
Ofcom	The Office of Communication
UHF	Ultra High Frequency
VHF	Very High Frequency
WLAN	Wireless Local Area Network

List of Symbols

λ_d	Dynamic-Threshold
σ_S^2	The Signal Variance
σ_n^2	The Noise Variance
5G	Fifth Generation
d	Dynamic Coefficient
D(X)	Test Statistic
H0	Null Hypothesis
H1	Busy Channel
L	Number of Samples
N	Normal Distribution
P	Noise Uncertainty Factor
Q	Error Function
R(x)	Received Noisy Signal
S(x)	Received Signal
SNR(γ)	Signal to Noise Ratio
W	Noise Signal
X(n)	Received Signal
λ	Threshold

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Spectrum Sensing Detection for Non-Stationary Primary User Signals Over Dynamic Threshold Energy Detection in Cognitive Radio System

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Abstract— **Nowadays, global evolution and technological revolution of wireless communication development, without observing the current radio spectrum assignment policy, cause the spectrum to be more depleted. Cognitive Radio (CR) is the most effective technique for solving the problem of spectrum scarcity, particularly in light of the desire to transmit data very quickly, as unauthorized users are able to use a spectral bandwidth. Whenever the owner of the license begins to use the domain, the connection of the unauthorized user will be cut until the authorized user ends his connection. Conventional methods have proven to be ineffective in detecting the frequency spectrum in comparison to dynamic Primary User (PU) methods, where the PU is either completely present or completely absent. In this paper, an algorithm is suggested which aims to improve energy sensing and increases the efficiency of detection through sensing and noticing the random dynamic move of the PU. This algorithm has been designed based on these rapid changes of the PU, and is called the Activity period (*A*). In addition to activities of the PU during the sensing period, it also focuses on the dynamic threshold factor through which the detection is enhanced. The new formula is applied through the Dynamic Energy Detection-Dynamic Threshold (*DED-DT*) method with a constant false alarm rate analysed mathematically, realizing a reliable performance with a low signal-to-noise ratio (-12 dB) achieved through simulation. Therefore, the proposed algorithm showed relatively improved results when compared to those of traditional detection methods.**

CHAPTER ONE

INTRODUCTION

1.1 Background

Among the main causes of spectrum congestion is the rapid growth in wireless communication, in addition to the large numbers of users. Yet, the spectrum lack is mostly a result of the ineffective static spectrum allocations [1]. The traditional fixed distribution policy that defines the spectrum for authorized users has contributed to the scarcity of the spectrum, as shown in the Federal Communications Commission (FCC) report [2]. Based on the survey of FCC's Spectrum Policy task force in 2002, it has been explained that there is an unbalanced utilization (from 15% to 85%) of the frequency spectrum in a geographical region, time, and space. On the other hand, Cisco has contributes to a study on Global Mobile Data Traffic and showed that there will be a seven-fold growth in mobile data traffic between 2016-2021 [3].

Some researchers have shown that the spectrum is unlimited, but the problem occupies in the poor management of this spectrum because the licensed spectrum is not wholly utilized; only few parts are used, thereby leading to the insufficient use of the spectrum [4]. To overcome all these problems, a smart wireless network called CR has emerged. Consequently, the primary importance of CR rests in the inefficient spectrum utilization [4], as it can serve its users through filling in the spectrum holes without the cause of harmful interference to the PU. This is realized by means of continuous Spectrum Sensing(SS) for detecting the PU. As soon as the licensed user is discovered, the CR is supposed to withdraw from the spectrum immediately to reduce any form of interference [5].

CR performs a range of different functions, among which the four main ones are the sensing, management, sharing, and mobility of the spectrum [6]. Spectrum sensing is one of the essential functions of CR which should be done first in advance so as to allow a secondary user to reach a vacant licensed channel. In other words, it is at the core of CR and includes the determination of the unused spectrum holes. Several dimensions are involved in determining and collecting the spectrum usage properties, including time, frequency, space, and code, and identifying what type of signals are filling the spectrum [6] [7].

1.2 Problem Statement

Despite the promising expectations and possibilities related to the CR system, many challenges still remain, such as the way of defining the independent transmission process of CR on the primary user's network without causing any harmful interference to its network.

In general, the fixed PU can become dynamic during the sensing cycle (in other words, the sensing and transmitting periods of the secondary user), and this indicates the actual behaviour of the PU signal..

The PU with Activity period (PU-A) was initially developed as a method or approach to analyze spectrum sensing efficiency through the use of ED energy detection schemes. The proposed model aims to improve detector efficiency as well as detection accuracy.

The derivation of closed mathematical expressions is carried out, and the Probability of Detection(PD) is calculated whenever the PU is partially present during the sensing period via the channel of Additive White Gaussian Noise (AWGN). Thus, the proposed model represents the energy detector for evaluating the detecting efficiency of PU-A.

This thesis aims to suggest and find some solutions for the above-mentioned problems, such as decreasing the effect of noise uncertainty, and improving the detecting efficiency of the fixed and dynamic PU signal.

1.3 Motivations

Wireless communication systems during the past two decades have been growing rapidly. The distribution of radio spectrum is based on the fixed allocation policy without taking into consideration that the current spectrum is fixed source and limited, and thus this thesis focus on a study of increase the efficiency of using the spectrum, in order to exploit the passive band of the spectrum.

Since its priorities to the use of the spectrum by CR are low, any form of interfering with the PU needs to be avoided. Meanwhile, the energy detection low computational cost, ease of implementation, also without Need, any prior Information about PU, as well as the CR network does not require any changes to the infrastructure of the PU's network for sharing the CR, whereby the latter can discover the PU's signal during its operation independently. A significant function of the cognitive user is its detection capability.

Current research work concentrates on the function of spectrum sensing in the CR network. the dynamic sensing algorithms have been introduced and suggested. The main focus in research is on the energy algorithm being the simplest sensing method, as it is relatively less complicated. Other major motivations for this work include that it is based on and deals with energy only, regardless of the type of inclusion, frequency, or other factors, and can accommodate as many signals as possible.

1.4 Research Scope

The scope is limited to some considerations, focusing on non-cooperative methods where some possibilities and assumptions were used to detect the spectrum for a single secondary user, so as to ensure the integrity of the sensor algorithm. These assumptions could be described as follows: firstly, explaining the fundamental principles of CR work, secondly, learning the principle of detecting and false alarm probabilities, thirdly, knowing the principle of the dynamics of the initial signal and its impact on the spectrum sensing efficiency (and thus its impact on the final detection results), and finally the activities of the PU were studied during the sensing cycle so as to reflect the real results of the utilized spectrum by means of simulations software.

1.5 Research Objectives

The main concern and important thing of this work is the quality of sensing, which is the core and essential function of the CR system. Consisting of two components, the PD and the Probability of False alarm (PF), sensing is the most important and primary goal of this system. Detection is improved through developing spectrum sensing algorithms so as to be employed in detecting the dynamic PU signal and for ensuring the sensing safety and detection efficiency in the cognitive network.

For achieving the major aim, multiple sub-objectives need to be achieved:

1. Proposing an efficient Spectrum Sensing (SS) detection model for static and dynamic PU signals over the AWGN channel.
2. Deriving the closed-form expression of average detecting probability for the proposed model.

1.6 Research Contribution

The contributions of this thesis could be summed up by the following:

1. Derived the average probability of detection for detecting the dynamic PU using the dynamic threshold is enhanced its performance in two instances:
   a. Without the presence of a Noise Uncertainty factor
   b. With the presence of a Noise Uncertainty factor.
2. CR detection scheme is proposed in this thesis based on the Dynamic-threshold scheme for the detection of the dynamic PU in the CR network..

1.7 Thesis Outline

This thesis is organized as follows:

Chapter Two: This chapter introduces the structure, some applications, and potential functions of CR devices, as well as an overview of research and important topics such as the basics and types of CR, and it pros and cons. Finally, the focus of the chapter shifts to the sensing function with the use of energy detection techniques, and introduces detection algorithms for the dynamic PU in the respective radio spectrum.

Chapter Three: This chapter presents some derivations and analyses which rely on the technique of fixed false alarm rate, and the proposed algorithms are presented for sensing and detection in the CR system using energy detection according to the simulation of the AWGN channel. planners are presented through the analysis of the detection performance, where two cases are considered: the lack of a noise uncertainty coefficient, and the state of the noise uncertainty coefficient. This chapter provides an analysis of the proposed detection using a constant and dynamic threshold.

Chapter Four: The results presented in this chapter mainly rely on the vision and standards of the IEEE802 international organization, which assumed that the system performance would be acceptable if the false alarm rate was no more than 10% and achieved a detection rate of not less than 90%. Moreover, the simulation results are provided in both the present and absent state of the noise uncertainty factor.

Chapter Five: The major ideas of the thesis and conclusions are summed up, several ideas for further work and research are offered.

CHAPTER TWO

LITERATURE REVIEW AND PRINCIPLE

2.1 Introduction

With the rapid growth of wireless communications, the radio spectrum becomes more and more scarce as a natural and limited resource [8]. The fastest-growing system in the scope of communications engineering is the wireless communication system, where these system provide and support the exchange of information and data between people and devices within the limits of communications. This vision allows people anywhere in the world to operate a virtual office through devices with intelligent phone and computer and modem connections[3].

Many fields and companies rely in their work on the use of the radio spectrum, such as mobile broadband and narrowband communications, scientific research, marine communications, as well as emergency services. Therefore, wireless communications and services are significant for the development of plenty of matters in the future [1].

According to a Cisco survey of mobile phone traffic globally, it was indicated that data traffic will grow up to 7 times between 2016 and 2021[7]. Another 2002 FCC survey in the USA on spectrum use policy states that radio spectrum use is minimal, ranging between 15% to 85% of the radio spectrum [7]. Most wireless networks feature fixed radio spectrum distribution technology, but due to the increasing demand for spectrum usage by users, this policy suffers from spectrum scarcity in some bands [9].

In other words, the radio spectrum is used, for example, as a physical layer for the transmission of information and data. Meanwhile was done and focused mainly on increasing the speed of this data instead of using the spectrum efficiently, this actually caused the overuse of the spectrum, which has recently become a scarcity of this fixed resource. The new wireless technique that should be addressed now is a better access and more effective utility of the radio spectrum bands[3].

Figure (2.1) illustrates the spectrum allocation in the United States, where governmental and non-governmental agencies allocate the spectrum so that interference can be managed and prevented from benefiting by increasing the number of users. International organizations and agreements allocate this spectrum[1].

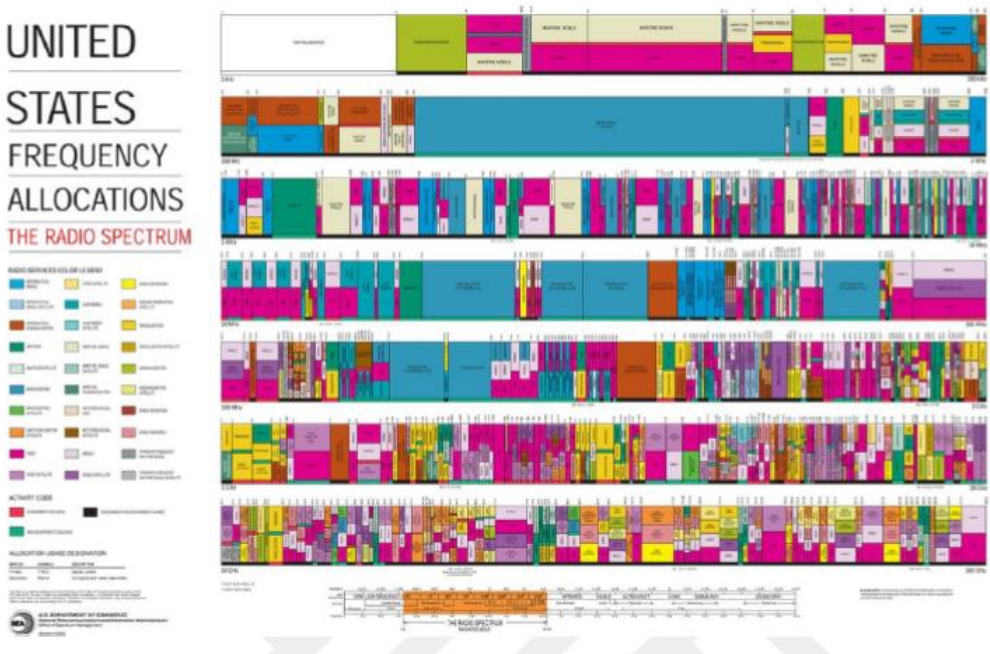

Fig. 2.1: The United States of America Frequency Allocation[1].

the distribution above illustrates of radio spectrum in the USA for the frequency bands of the entire country. Each color represents a particular service within an area[1].

Figure (2.2) presents the distribution of the private radio spectrum in New Zealand. The spectrum distribution varies from region to region and from country to country, as it was noted in the previous forms that the intensity of spectrum use in the United States is higher due to the massive allocation of service frequencies, commercial organizations, defense, and air traffic technologies, etc. In Fig. (2.2), it is observed that there is a difference in intensity for some of the areas through used the radio spectrum [1].

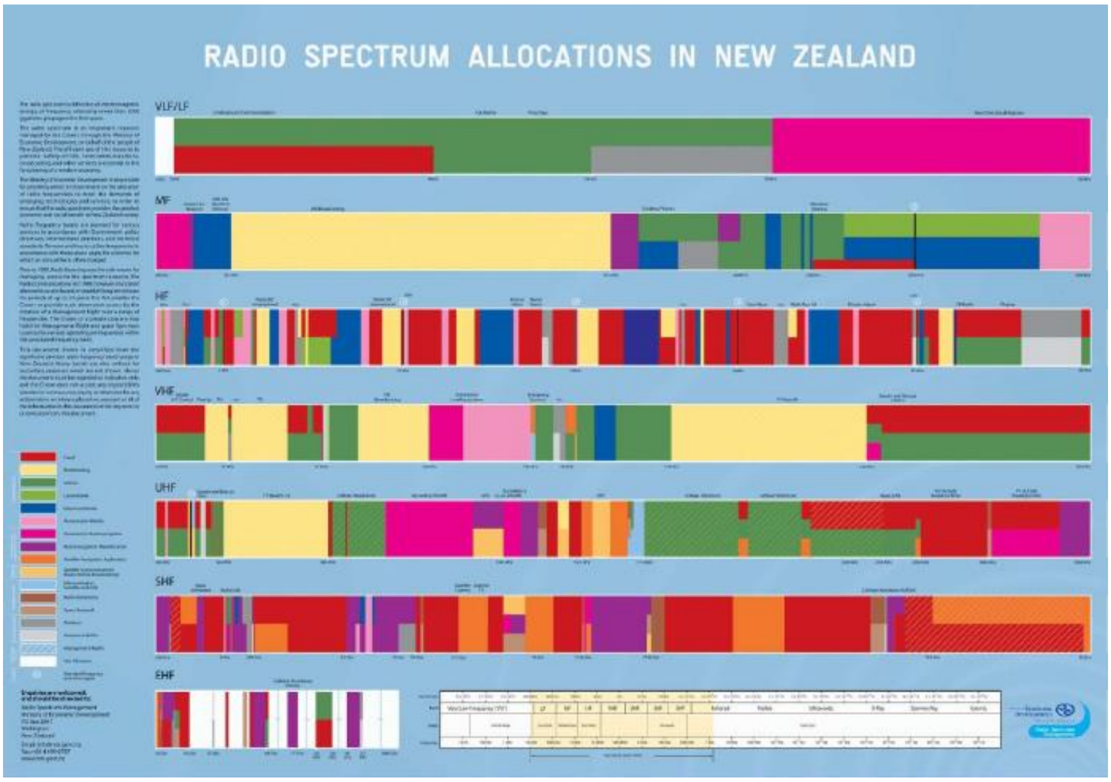

Fig. 2.2: The Spectrum allocation of New Zealand[1].

Since there is a discrepancy in the use of spectrum, the current optimal solution is a CR technology, as it was introduced for reducing the spectrum scarcity and the use of unused spectrum holes so as to seize opportunities anywhere and anytime [3].

CR technique is one of the main modern technologies emerging for the dynamic accessing approach, which allows the sharing of cognitive wireless channels with authorized users opportunistically [9]. CR is a system or radio that can sense the electromagnetic environment and automatically adjusts radios operating parameters dynamically for modifying the operation of the system, such as facilitating and understanding the task of being able to interpret, reduce interference, and increase productivity [7].

CR networks must present high bandwidth for users with dynamic spectrum accessing technology. However, CR networks face some challenges due to fluctuations in spectrum provision. To overcome some problems and challenges, the perceptual radio user must be able to identify some environmental parts, for example, to identify the activities of the licensed users and determine the best available channels, as well as maintain continuous coordination with other CR users to access the channel and evacuate the channel user upon arrival. Authorized user [9].

CR should continue to detect the spectrum. Common basic techniques in spectrum sensing including, energy detection technology, circular feature detection, and Match filter technique, are generally used. The energy detecting technique is utilized its lower complexity, which has been dependent on the dynamic threshold technology as well as introducing the noise factor techniques based on the technique of fixed noise level (p=1) and the non-fixed noise power technique (p>1). In these techniques, it is not possible to repair the noise variance of the signal under the practical scenario, which leads to a noise uncertainty. The latter issue can be improved through the use of the suggested dynamic threshold, which resists the noise contrast and rises the likelihood of detecting while maintaining and fixing the PD value, simulating them to observe the impact of these factors and parameters on the detection results [10].

2.2 Principle of Cognitive Radio

CR was first introduced in August 1999 by Mitola and Maguire. The idea is to change the band occupancy pattern in a more efficient way. The main feature of the CR system is the spectrum sensing function in terms of whether or not it occupies a certain band [3][11].

Mitola discussed the likelihood of enhancing the flexibility of wireless communication through CR technology. CR is described as a smart wireless device with the potential to completely reconfigure its environment (as for transmitting power, transmission frequency and modification strategies) so that it responds to environmental changes [12].

CR systems can be defined as "the new approach to improving the use of valuable natural resources: the electromagnetic radio spectrum”. For the purpose of providing wider bandwidth and improving spectrum efficiency for mobile phone users, work has been developed on the generation (XG) network communication program [2]. Also, Fig. (2.3) illustrates dynamic access technologies. The working group IEEE called the wireless regional area network (WRAN, IEEE802.22) to enable CR technologies of sharing unused geographical spectrum TV with no interference [2].

The IEEE802.22 system is the first interface for CR networks, mainly according to the principle of opportunistic use in the television broadcasting spectrum. The major aim of such a standard is providing reliable and widespread communication in rural or remote areas. The Federal Communications Commission (FCC) has identified and selected waves operating within the range of VHF and UHF in the radio spectrum[3].

Figure (2.3) below illustrates the spectrum holes as well as the notion of Dynamic Spectrum Access.

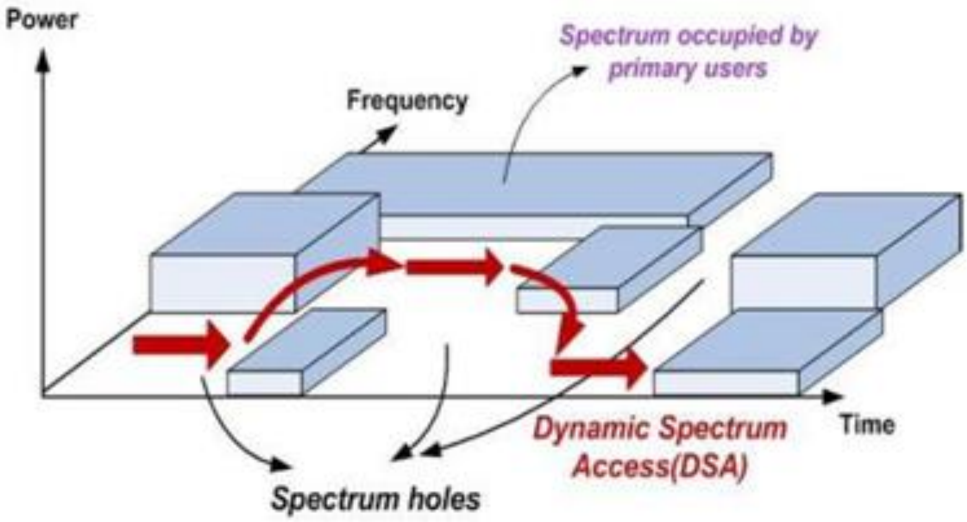

Fig. 2.3: Dynamic Spectrum Access [13].

The definition of spectrum holes could be sketched as a band of frequencies that are currently vacant for the use of the PU within a particular time and geographic area [2]. It represents the possible chances of unsafe use of spectrum and could be taken into consideration in light of multidimensional regions within frequency, time, and space [13].

CR is intelligent in such a way that it raises awareness of its surrounding environment in the communication process by making operational decisions and behavior that will coexist with those goals and pre-determined information. Another type of radio is programmatically defined radio, and it also uses adaptive radio and other technologies for the purpose of checking desired targets [14].

At the present time, models of CR work are generally classified into two categories:

1. Opportunistic spectral access
2. Spectrum sharing.

In the spectral opportunistic accessing model, secondary users must first sense the surrounding radio environment and then send in unused or vacant from the spectrum without affecting or interfering with the PU.

Meanwhile for the spectrum sharing model, the secondary user transmission is synchronized with the PU and the same range is used, implying that the degradation of the PU achievement is acceptable and results from the secondary user transmission, and controlled by imposing some restrictions on the secondary user transmission [12].

Figure (2.4) represents the traffic on public roads and auto traffic priorities as something similar and somewhat close to describing radio spectrum use, traffic priorities and the use between PUs and CR users.

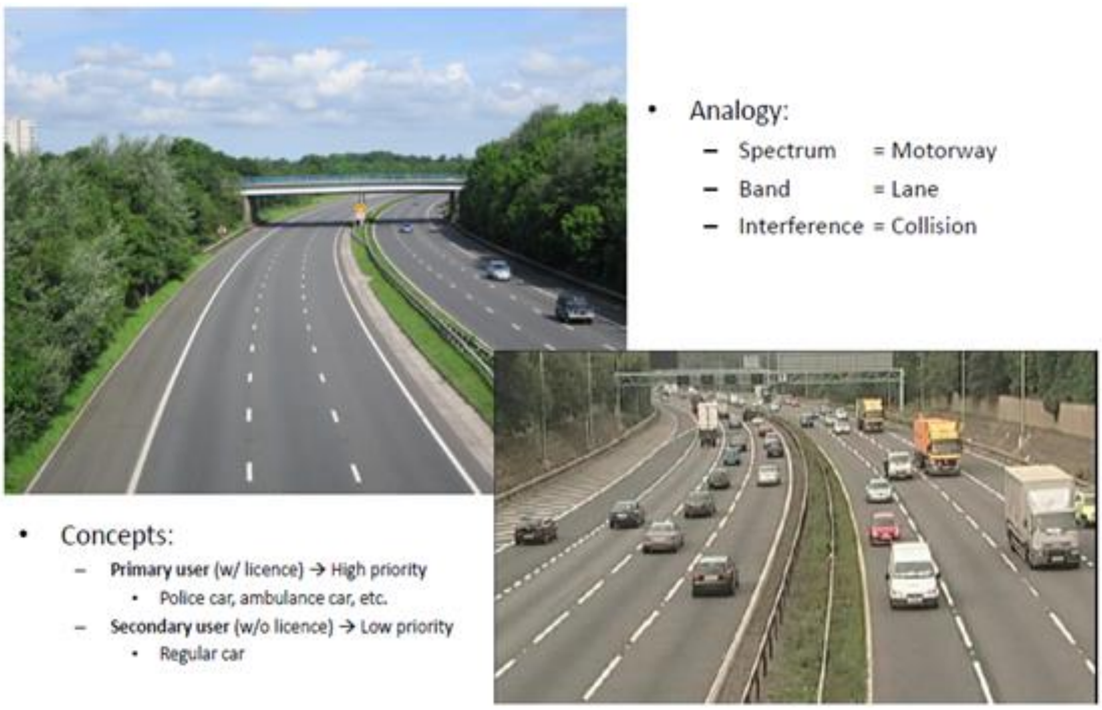

Fig. 2.4 Exemplification of opportunistic spectrum access [15].

Mitola described the innovative new approach to wireless communication systems as "identifying the point where wireless PDAs and smart-related networks are sufficient and smart, from an arithmetic point of view on wireless resources and related computer-to-computer communication, so as to discover user communication which requires a context functional use, and for providing wireless resources and wireless services most suited to the aforementioned requirements. ” Since then, regulatory administrations have come from different countries, such as (FCC in the USA, Ofcom in the UK and PTS in Sweden), to the conclusion that the radio spectrum was not used Efficiently[3].

In 2003, the FCC proposed a regulation through which customary radio for the opportunistic spectrum sharing can be considered [14]. Another distinction is made between types of CR regarding the use and availability of spectrum[13].

2.3 Preliminaries of Cognitive Radio Networks

The majority of the present radio systems designed to operate in predefined bands are not sufficiently aware of their radio system environment, as they use a particular access system. The general spectrum could be clarified through enabling secondary users of having dynamic access to the spectrum holes not occupied by the authorized users at the current time in the respective geographical area and as Figure (2.3). The following some characteristics linked to the access the PU are[13]

2.3.1 Spectrum Holes

The definition of spectrum holes could be presented as a range of frequencies currently vacant for the PU in a specified geographical area and time [16]. These gaps form possible chances for unsafe spectrum use, and are multi-dimensional regions within time, frequency, and space, where these spectral holes can be identified with time and frequency[13].

1. Spectrum Hole in Frequency Domain:

In this field or the frequency range, the activities of the secondary user won’t result in some form of harmful interference with the PU units. The secondary user can make use of the opportunity to reach the holes through modern techniques of spectrum sensing and their use without damaging the PUs available in part of the frequency spectrum[13].

2. Spectrum Hole in Time Domain:

The spectral hole in this field can be defined as the range that is vacant at the current time for PUs and for a particular time span, where a portion of the spectrum may be available at some time. To state it differently, bandwidth is not always employed continuously. Sometimes the spectrum is available for opportunistic use[13].

3. Spectrum Hole in Spatial Domain:

Spectrum holes in this field can be available in specific geographical areas, while being occupied in others at a certain time. This is considered within the loss the spread of space spread. This could be understood through considering the levels of interference: no interference means that there is no current use of the PUs in the local area[13].

2.3.2 Radio Spaces

Radio space could be describes as an area occupied by radio signals, where these areas have the dimensions of the site, frequency, angle, access, etc. There are a number of important radio spaces, namely:

1. ***White Spaces*: **There are no licensing ranges here at times which are not currently occupied only natural noise, like broadband heat and pulsed noise exist.
2. ***Gray Spaces*: **These can be defined as partially filled spaces in which the energy interference is low.
3. ***Black spaces*: **They can be defined as the areas that are filled with high-priority licensed users and they are called PUs.

According to space classifications, there is no cognitive wireless work in black space once the PU nodes are activated, but transmission can take place across the white space as well as the gray spectrum[17].

2.4 Types of Cognitive Radio

CR is generally of two types, the first type is called (Mitola radio), where all radio networks are considered, whereas the second type is (WRAN), where only the radio-frequency spectrum is considered here[18].

2.4.1 Licensed Band of CR

This kind targets specific bands where the secondary user can sell and use them under licenses. The IEEE802.22 standard specifies regional area network (WRAN) bands that allow the use of television bands within the range of 54 to 862 MHz, in order to achieve technical targets. For CR, this band is used within the IEEE802.22 standard to prevent any interference with TV Bands [17][19].

2.4.2 Unlicensed Band of CR

CR could only use the unlicensed radio frequency spectrum. These bands utilize only unlicensed sections of the radio frequency, so there is only one system within the coexistence group IEEE802.15 (TG2) which is considered and focuses on the coexistence process between noise and WLAN [18].

2.5 Characteristics of Cognitive Radio

Literally, it means perception and recognition of the process either through perception, intuition, pronunciation, or knowledge, in other words, learning through understanding. This approach, along with CR, have two significant major features that are worth mentioning [20]. They have the ability and portability to restart and can be described as follows:

2.5.1 Cognitive Capability

Cognitive capability is the ability and portability to obtain environmental information about the spectrum that us not used within the radio environment for providing the users with operating parameters in order to utilize the spectrum in the best way, without interference with the PUs. It involves the ability to make interactions with the radio spectrum effectively through environmental detection of the necessary communication parameters, which are appropriate for secondary users to be used. Thus, CR performs the main tasks in a currency called the cognitive cycle. This is

thesis specifically focuses on one of the main cognitive tasks which are most important, namely radio spectrum sensing. Cognitive ability means the awareness and calculation of the radio-frequency environment and its identification according to [14]:

1. The activity of the first users (licensers activity).
2. The temporal and spatial environment changes.
3. Determining the parts of the unused spectrum.
4. Selecting the best transmission and spectrum parameters.

2.5.2 Re-configurability

Dynamic radio programming means the reconfiguration of a programmatic radio without any modification to the devices or components hardware. CR can be used as a transmitting and receiving device during its reprogramming, and can also operate at different frequencies in connection with communication as the use of variable transmitting power and different technologies. This possibility can be achieved through developing software Defined radio (SDR), a smart wireless device with the ability to modify communication parameters to the network or user requirements by complete reconfiguration. SDR is a software-defined wireless communication system tunable to a particular frequency or band and receive any modifications. Re-configuration is the capability of adapting operating parameters to the environment that surrounds it, according to [14]:

1. Transmission power.
2. Frequency of operation.
3. Modulation.
4. Communication protocol.

Through a frequency spectrum and software control, CR can coexist within the spectrum. In other words, software radio can switch between different wireless protocols and multiple applications but has users must request it. It is noted from what has been previously mentioned that the reconfiguration ability is in the sense of reconfiguring any transmitting parameters throughout the process. This process implies that CR has the ability to configure receiver and transmitter parameters for switching to different bands so as to complete the communication process [21].

2.6 Architecture of Cognitive Radio

Figure (2.5a) illustrates the general structure of the transmitter/receiver of CR device and its main components, consisting of an RF front end and the basic baseband processing unit that performs several functions like modulation/demodulation, and coding/decoding. The control vector function is responsible for controlling all components, so that the radio is adapted to the wireless environment. The front RF interface enables the amplification of the received signal first, then combines this signal to a lower band, after which the conversion of analog signals into digital signals takes place. The baseband unit encodes the signal, after which it is modified or decoded, based on the transmission or reception of the signal.

The baseband signal processing unit is like the rest of the common devices for transmission and reception, but the RF front-end direction of radio frequencies is specially designed in order to suit the need for CR in order to sense the spectrum and fit in real-time. A real and important demand for RF devices is being able to synthesize the sections that remain of the radio spectrum. The principal parts of RF front-end of the CR system are shown in Fig. (2.5b) [3] [22]:

1. **RF filter:** The radiofrequency band pass filter selects the suitable and appropriate wave in operation by filtering the received wave from the radio frequency signal.

2. **Low noise amplifier (LNA):** it is Amplifies the signal required as well as reduces the amount of noise at the same time.
3. **Mixer:** The resulting RF is mixed locally with the received signal , after which its conversion into the intermediate frequency (IF) or the so-called baseband frequency takes place to facilitate further processing.
4. **Voltage Controlled Oscillator (VCO):**It is responsible for generating signals at particular frequencies that are required to mix with the incoming signals, as such a process includes the conversion of the generated signals into the IF.
5. **Phase locked loop (PLL):** It implies that the frequency is constant and undergo not change over time.
6. **Channel Selection Filter:** The channel filter chooses the needed bands or frequencies and declines the adjacent ones.
7. **Automatic Gain Control (AGC):** It is utilized maintain the gain or output power level of a fixed across a wide range of input signal levels.
8. **A/D converter:** It is responsible for converting analog signals into digital information so as to process it easily during the base processing [3][22][23].

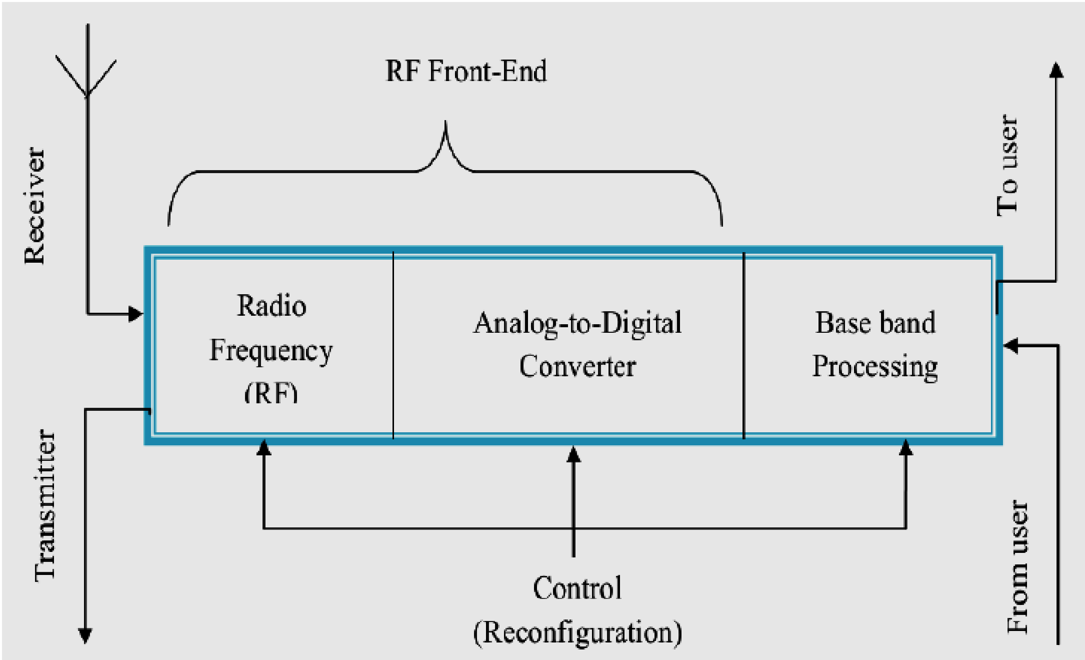

Fig. 2.5a: Cognitive Radio Transceiver[22].

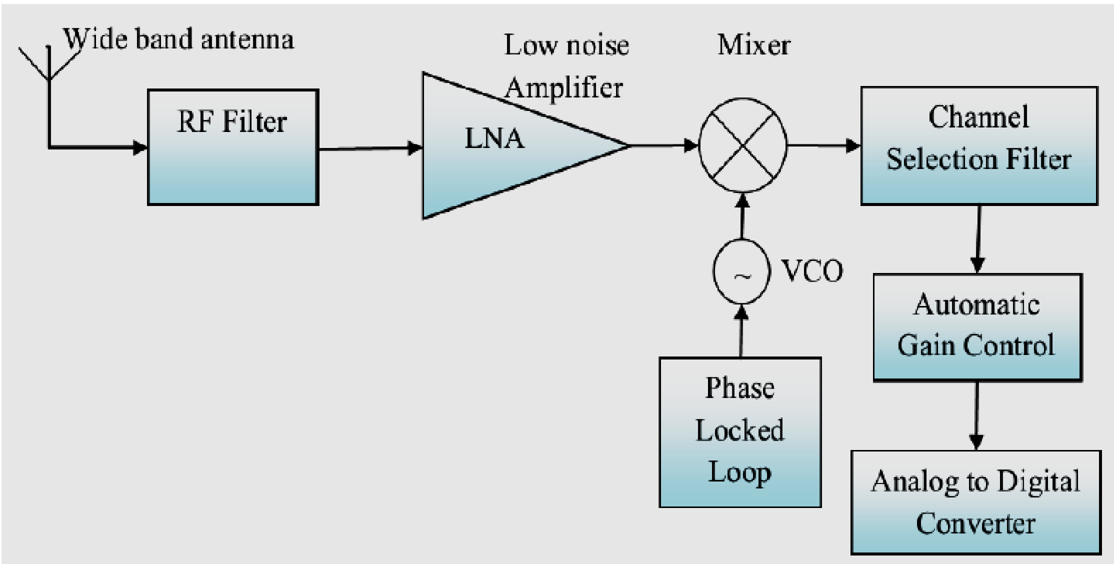

Fig.2.5b: Radio front-end [22]

2.7 Application of Cognitive Radio

Developing methods of spectrum sensing and accessing techniques facilitated the applications of the secondary user in several fields. It started with smart and medical networks, emergency services, public safety, and military uses, with the prospect that they will play a wide-ranging role in wireless communication networks in the future. Some application of the secondary user that one can benefit from include:

1. TV White Space:

The United Kingdom issued a year the Office of Communication(*Ofcom*) agency in 2013, with regards to white spaces and their uses [24]. Cognitive hardware networks known as White Space Devices (WSD) are enabled so as to discover spectrum holes within the TV bands using geolocation data. Various applications such as the rural domain and Wi-Fi, and M2M applications can be acquired[25].

2. Smart Grid:

This is used in smart grid technologies, such as office and home networks. The use of femtocells techniques, increased deployment femtocells, and their signals can lead to problems and interference in the use of the spectrum. These interventions can be reduced by specific methods [26] [27].

3. Emergency Networks:

The communications of the emergency as states, like a terrorist attack or natural calamity, the importance of wireless communication systems becomes apparent. Even though special emergency Bands exist allocated, However, these services are sometimes prevented from the public network, due to the range is limited . Cognitive devices can respond to emergency situations, so the importance of cognitive radio comes in, as this network can be built without an infrastructure [25].

2.8 Advantages and Drawbacks of Cognitive Radio

CR is more useful than traditional radio. A number of benefits and drawback of CR can be stated as follows:

1. Advantages of CR

- It improves the utility of the existing spectrum (moving away from the idea of full-spectrum and vacant spectrum), resolves constraints and eases disabilities to reach the spectrum;
- It improves the efficiency of the wireless network through spectrum utilization and increasing user productivity, which increases system reliability;
- The scarcity of the radio spectrum through the sensing spectrum can be overcome by using CR devices as these broadcast on an unused spectrum whenever no interference exists with the PU signal.
- It improves satellite communication by using noise prediction devices such as rainy weather, such knowledge devices function in improving the quality of communicating service wherever and whenever the information is needed[3].

2. Drawbacks of CR

There are a number of technical problems and difficulties that must be solved within real-world scenarios in order for the secondary user to become a system ready for operation. Among the most prominent of these challenges and difficulties are the primary hidden users, which lead to interference with the secondary user's devices. Figure (2.6) illustrates the so-called hidden problem architecture for the PU[3].

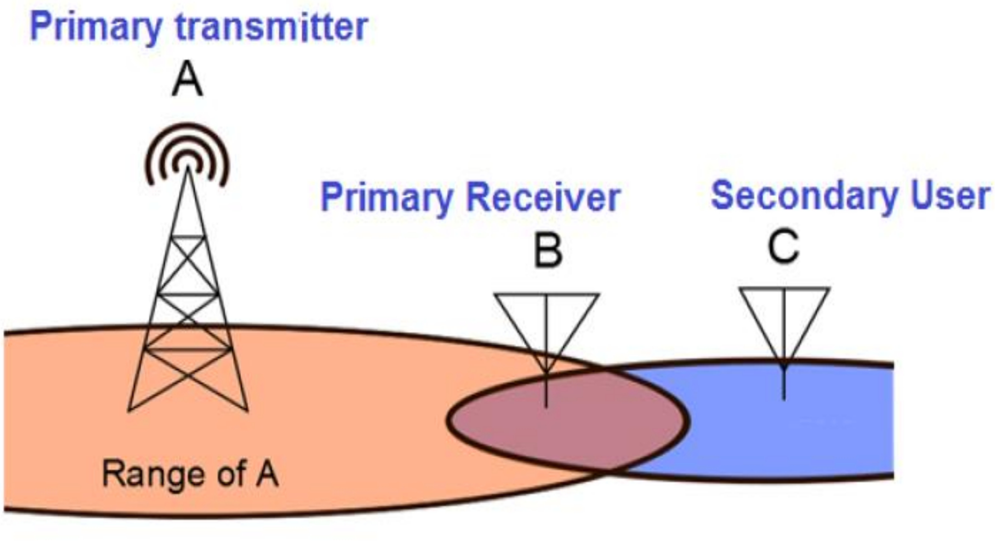

Fig. 2.6: Hidden terminal problem [3].

If the primary transmitter is A, and the receiver is B, then C is a secondary user that intends to broadcast on the licensed spectrum for users A and B. Before operating, C begins with the measurement of the energy within the band and is compared with a predetermined threshold for determining the state of the band (whether it runs),as to solve the issue of the secondary user outside the transmitting range between the A and B, C has concluded that the spectrum is vacant and there is no authorized user currently in the vicinity. So, he starts using the spectrum directly, facing the problem when the secondary user starts transmitting. Even though C is further away from A, it may be basic that user B is closer to A to receive his signal, so interference may hinder or prevent transmissions to use the currently licensed spectrum between A and B, which represents the worst case [3][31].

2.9 Functions of Cognitive Radio

Mitola coined for the first time a term called CR in [2]. the official definition CR is a smart wireless communication systems characterized by that it realizes what is surrounding it within the environment (the outside world) and uses the method of building for learning through understanding the environment and adapting its cases to statistical changes the interior has alarms (RF) and is performed through applying some changes corresponding to the operating parameters (for example, wave frequency, transmission power, and a portion of the modification strategies) and is performed in actual time with two main objectives [2][29]:

1. Communications of high reliability where and when required.
2. Good and sufficient use of the radio spectrum.

These two basic features of the CR could be summarized by the ability to reconfigure through the cognitive ability and intelligently specifying the communication factors according to the service criteria and their Quality of Service (QoS). This could be applied through a basic cycle diagram as shown in Figure (2.8)[30].

2.9.1 Spectrum Sensing

The spectrum sensing function is one of the most significant functions of CR. This function represents the continuous sensing of the spectrum range allocated to some secondary users and it is important to know all the parameters of the PUs and that even whenever they want to contact the spectrum again the secondary users should evacuate the range immediately [7].

2.9.2 Spectrum management

This utility management is compulsory for cognitive radio for meeting the requirements of users through using the best spectrum bands for ensuring better Quality of Service (QoS), so that the secondary user must adopt the best bands and channels in the radio spectrum [7]. Therefore, the essential objective of spectrum management is developing as well as implementing policies and procedures for allocating and providing frequencies within the radio spectrum for specific users [8].

2.9.3 Spectrum mobility

When cognitive callers using the current spectrum move from one cell to another or change their positions over time, the need arises for this functional method as the CR system must transform into new bands that enable it to continue its communication in a smooth manner [7].

2.9.4 Spectrum Sharing

The important difficulty in spectrum usage is to provide intelligent and balanced dynamic spectrum allocation to allow the vacant spectrum to PUs [7][31]. The fig.(2.7) below shows the simplest diagram of CR functions[7].

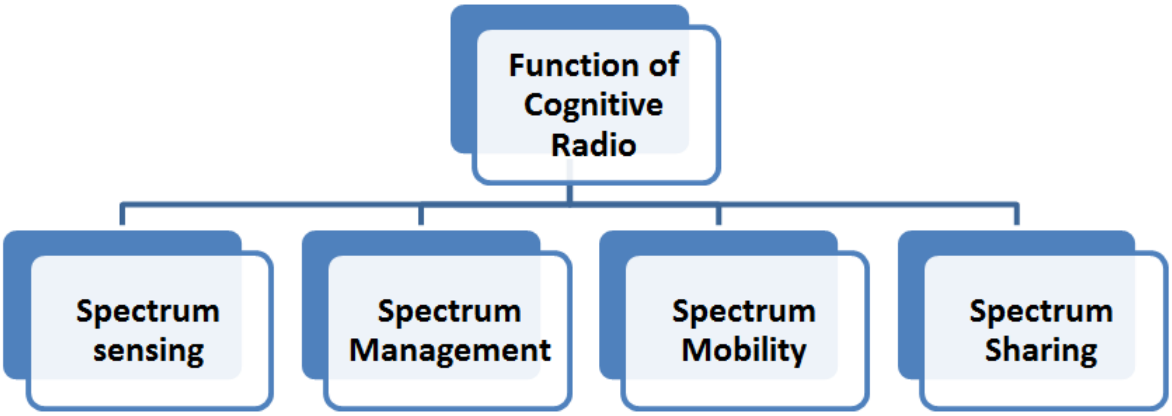

Fig 2.7: Simple scheme for the functions of CR [7].

2.10 Spectrum Sensing Function

In the current literature, radio spectrum sensing by cognitive devices and detection techniques is still limited and under continuous development, as cognitive networks, or what is known as a secondary user, need to coexist with the PUs that have the authority to utilize the radio spectrum. Therefore, they must have a guarantee and protection without interference with secondary users [21].

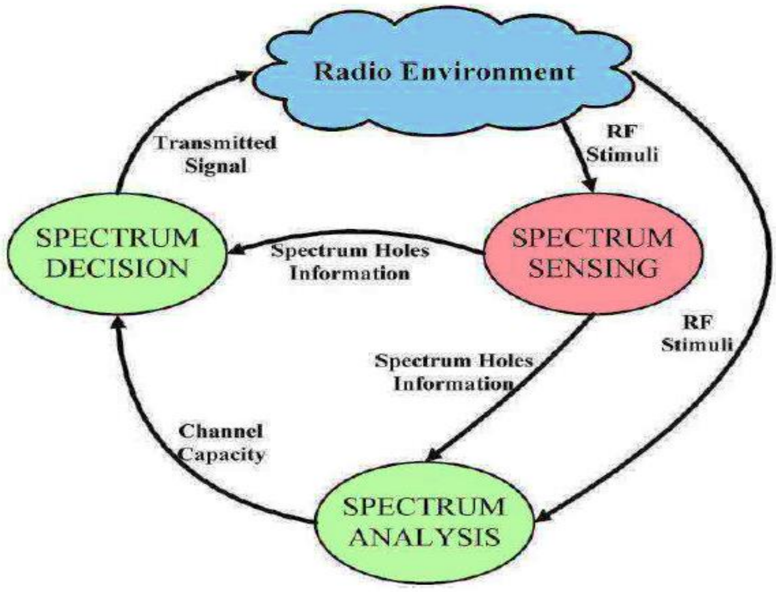

Fig. 2.8: Cognitive Radio Cycle[35].

Obviously, the PU has the right to be able to communicate freely without any form of interfering. Therefore, a secondary user needs to check the spectrum reliably on a regular basis for detecting whether the PU is making use of their band. According to the IEEE 802.22 standards, for example, secondary users have to sense the spectrum for detecting wireless microphone signal and TV signal. Whenever the busy status is detected by the secondary user, it has to leave the channel within just two seconds. Here, the probability of detecting is indicated as being 90%, whereas the rate for false alarm is just 10%. In CR systems, sensing is considered to be among the more significant functions of CR systems. This parameter works to prevent collisions between secondary and PUs [1].

Spectrum sensing as in Fig. (2.9) is the method of checking the spectrum or what is called a specific range sensing within the spectrum, and making sure if it is vacant. In this process, the secondary users should check all parameters associated with the range in order to ensure efficient and suitable communication among users [7].

The spatial spectrum is the spectrum unoccupied from the PU of some spatial areas, so that the secondary user can benefit from it. For the classification in terms of the power of the incoming radiofrequency energy, as the black spaces, overlap heavily and their high or local capacity cannot be utilized, and grey spaces can interfere partially and their energy is low or is partially usable. This depends on the accuracy and efficiency of the algorithm. Moreover, the white spaces are areas without interference (except for Gaussian white noise) and have no energy. Secondary users can make use of it as long as they are white [17].

Since the priority of use for PU systems is higher than for secondary users, CR equipment should avoid interference to PU systems. The interference level should be kept below the threshold level for exploiting spectrum holes, CR should discover spectrum opportunities. The majority of roles are mainly dependent on the spectrum sensing function[15].

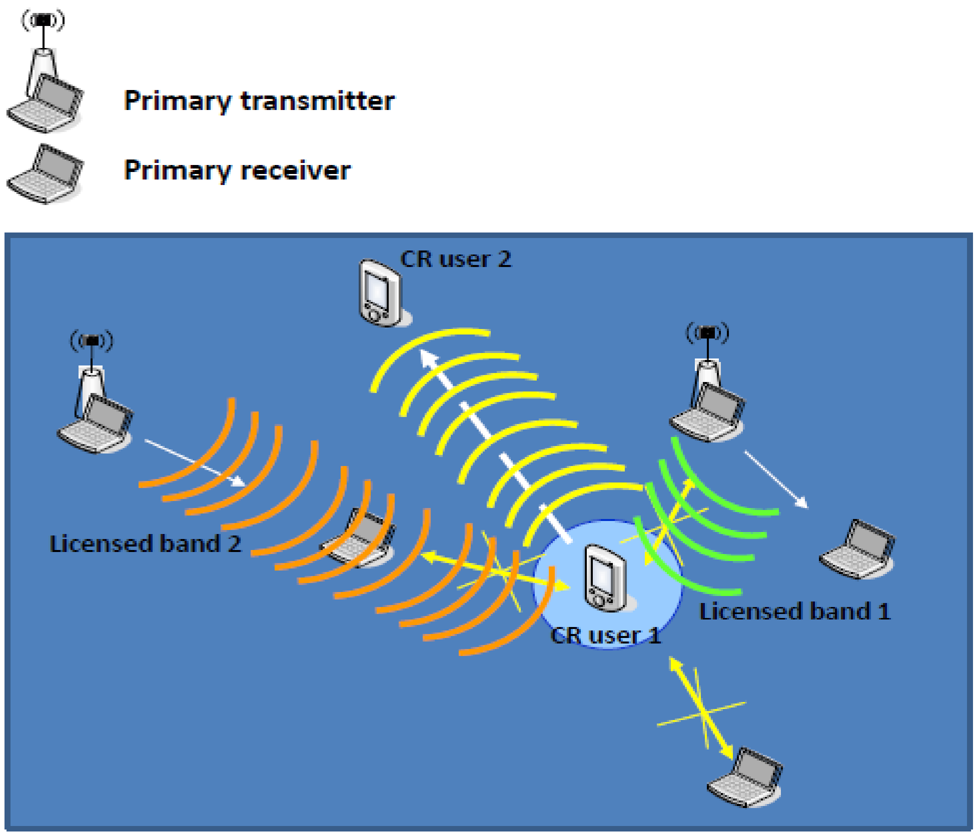

Fig.2.9: Spectrum awareness (spectrum sensing)[15].

The figure shown above represents a group of PUs and users of CR, as no interaction exists among the primary transmitting/receiving station and CR users. For inferring the PU activity, secondary users (CR users) must rely on calculated signals. The cognitive user exploits (meaning domains 1 and 2) are now avoided during the communication between perceptive users' devices[15].

Spectrum sensing is a method for checking or sensing a specific range in terms of whether it is busy or not. It has two sub-divisions::

Cooperative and Non-Cooperative Sensing. A general scheme for the formation of major and minor categories and of radio spectrum sensing classifications is shown the fig(2.10)below [2]:

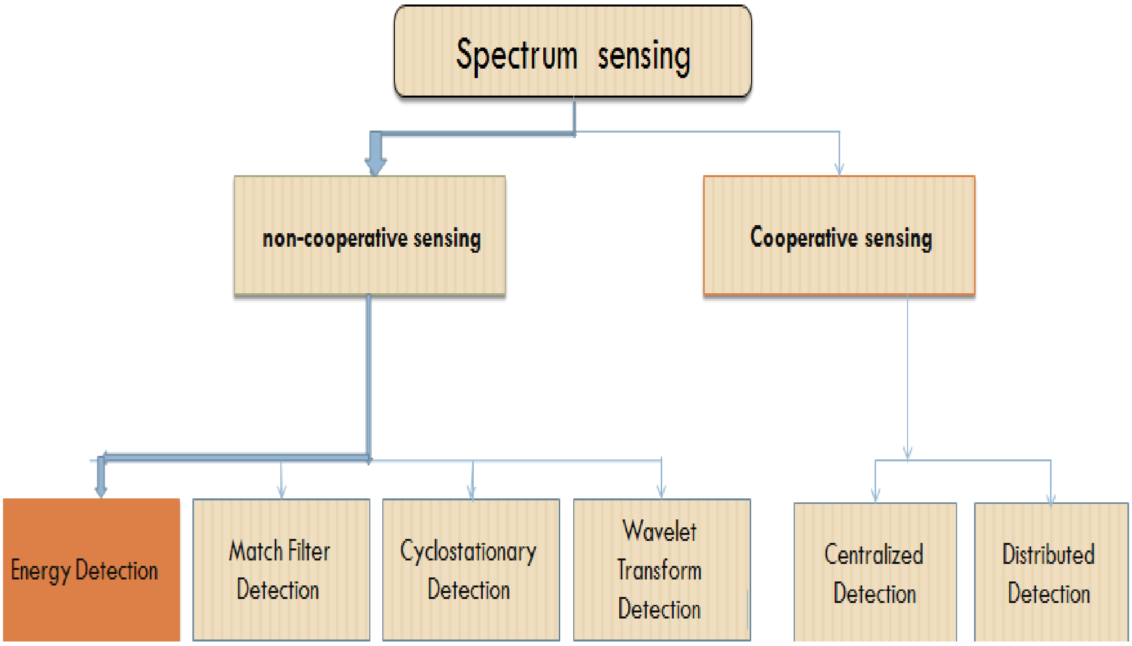

Fig. 2.10: Classifications of spectrum sensing [7].

2.10.1 Non-cooperative Sensing

It means that each device operates and gives a decision independently of whether or not the PU exists within a particular band, so the devices of the secondary users must be very smart when having the intention of sharing the spectrum with the rest of the licensed devices. It is also called non-cooperative spectrum sensing by detecting the sender. A brief overview is presented in Fig. (2.11).

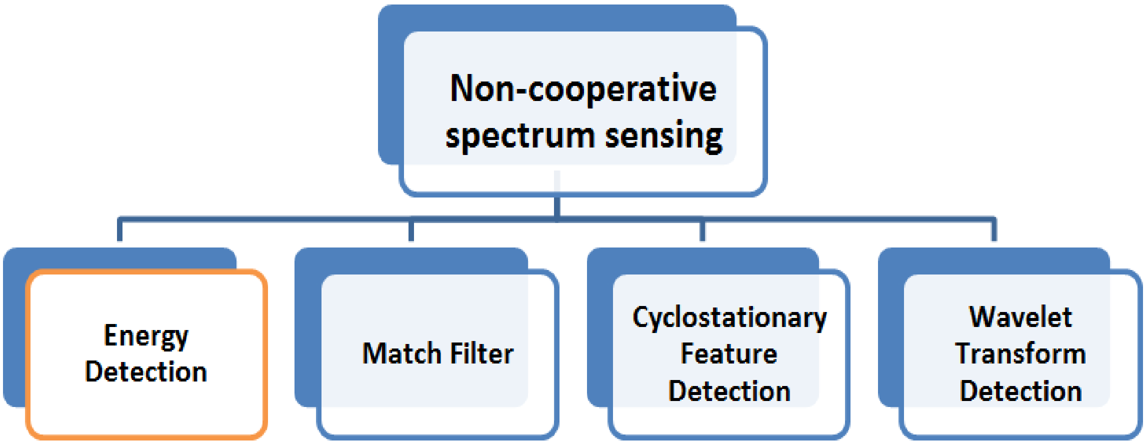

Fig. 2.11: Classification of non-cooperative spectrum sensing[7].

2.10.1.1 Energy Detection

It is a general approach for sensing the frequency spectrum, and the detection of signal energy is dependent on the collection of samples of received signals, through accumulating the primary signal and taking the average value of it. It is put into comparison to a predetermined threshold, to detect on the levels of energy received at the secondary user. However, there does not seem to be a particular way for distinguishing between various signals from differing systems, and interference is not distinguished on the PU signals, as well as the noise is not distinguished; it only tells if the signal energy exceeds the noise energy level. Yet, such energy detectors are most appropriate when estimations are made about the use of channels other aspects of other functioning [3][4].

The method of the energy detector was mainly adopted through some of the previous literature, mainly for its easy implementation and the fact that no information about the PU signals is needed in advance, such as data rate, type of adjustment and frequency [3][4].

The output of the energy detector being a test statistic and its calculation as the total (average power) of the permissible signal, could be carried out either in the frequency field or the implementation of the time field in programs and devices, as well as the implementation of the energy detector (PD and PF). The signal strength, noise strength, and detection time are all affected, whereas high signal strength, and longer detecting time result better in terms of small noise strength [6].

Next, a decision is made on whether or not the spectrum is occupied by comparing the predetermined threshold energy with the average received energy. If $X(D) \geq \lambda$, then the detector gives a resolution and the spectrum is considered idle, otherwise the spectrum range is occupied by the PU [5]

Energy detection is usually used in wireless cognitive networks for radio spectrum sensing for its lower complexity and does not require prior information about the PU signal [2]. In this method, the channel's radiofrequency energy (RF) is around the acceptable signal strength indication for determining if the channel is occupied. The power detector diagram is presented in Fig.(2.12) [6].

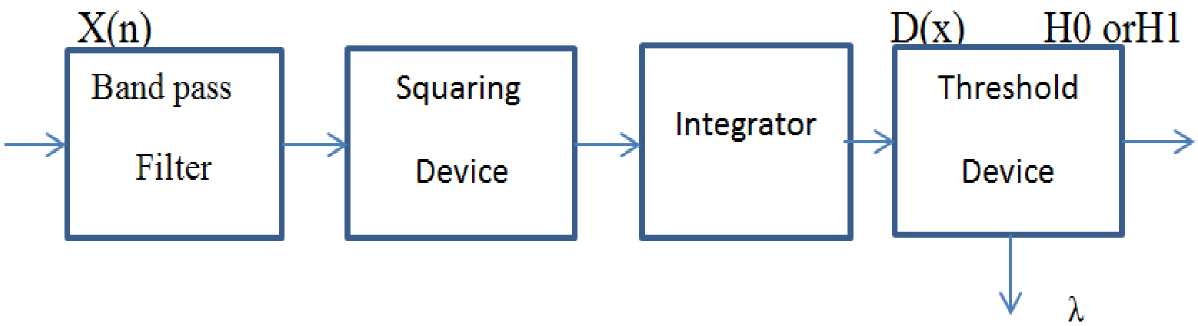

Fig. 2.12: Simple block diagram for Energy Detection method[2].

Various signals are inserted into the power detector, initially classified through the band-pass filter to choose the bandwidth, the outputs are then squared and combined throughout the observed T period. Finally, the output of the Integrator stage is put into comparison to a predetermined threshold and this can be done randomly without information on the basic user signals [3].

However, the energy detector still suffers from some negativity. The main problem is the poor performance whenever the signal-to-noise ratio decreases, which leads to noise uncertainty. The probability of miss detection and false alarm rate are shown in the chart (2.13)[7].

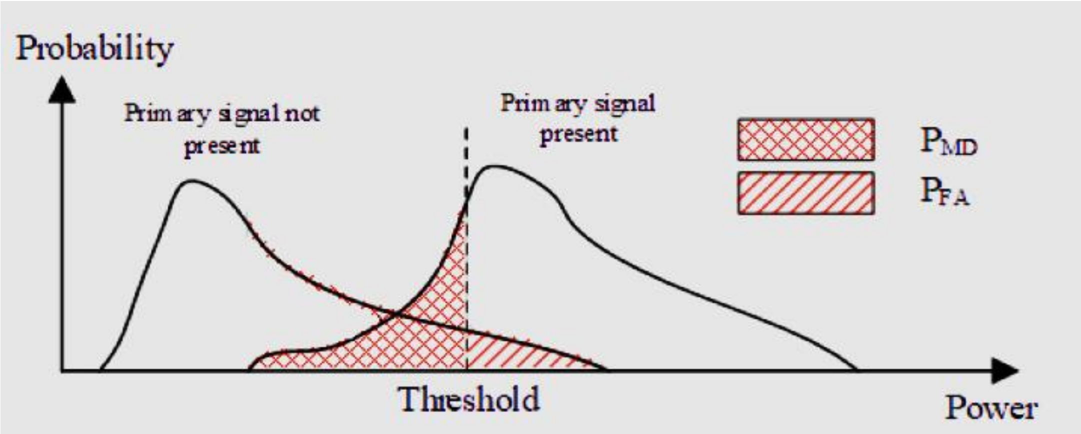

Fig. 2.13: Threshold setting in Energy Detection[7].

In case the predefined threshold value is very low, the PD increases, but the PF increases as well. On the other hand, if the threshold remains unnecessarily high, then the probability of error detecting increases, which results in an overlap with an active user [6].

To target a specific unused spectrum, the PF remains constant at the smallest value as possible (for example 5%). The PD increases to the maximum extent possible, and the probability of detecting errors is set to the lowest value (for example 95%) i.e. in recent times the false alarm probability has fluctuated [7].

A - Conventional Energy Detection and Hypothesis Concept

Traditional studies consider that the PU is static throughout the sensing period and remains in the same state without changing the length of the transmitting period. To exemplify, if the PU is busy throughout the transmission period and remains until the next sensing period, such as television broadcasting, the duration between states of change ranges in hours and verse versa. Yet, several practical scenarios exist such as the wireless systems with frequent changes. The application process in these wireless systems do not take more than a few seconds.

In order to detect and sense the radio spectrum whether the channel is occupied or not, it is important to think about other different schemes for developing methods of modeling signals. Generally, noise and signal are modeled as follows[32][33].

$$X(n) = w(n) \qquad H_0(\text{Idle Channel}) \qquad (2.1)$$

$$X(n) = w(n) + s(n) \qquad H_1(\text{Busy Channel}) \qquad (2.2)$$

Where :

$X(n)$: Signal received at CR (secondary receiver).

$w(n)$: it is Random Gaussian noise with zero mean and power spectrum density.

S(n) : A primary signal transmitted over a wireless channel.

Binary Hypotheses:

H_0 : Signal Absent

H_1 : Signal Present

Figure(2.14) is a simple flow chart of the energy detection method. It is commonly used in radio spectrum sensing for its simplicity as well as low implementation complications. First, the loud signal received in the energy detector, is passed through the ideal band filter, then the result is squared along the observed time period, after which the mean of the samples is obtained for the statistical test D(X). The results of the test statistics are compared to the decision threshold for determining if it was busy. The energy detector is calculated as[4]:

$$E = \sum_{n=0}^{L-1} |X(n)|^2 \qquad (2.3)$$

Where *E* represent the energy value, *L* is the number of sample, and *X(n)* is the received signals at CR nodes.

There are some challenges for the energy detector, such as the selection as well as determining detecting thresholds for PUs. The power detection deteriorates somewhat whenever the signal-to-noise ratio decreases. Another challenge for the power detector is indistinguishable between PU signals and noise signals. The test statistics for the energy detection method could be obtained through the following formula[10]:

$$D(X) = \frac{1}{L}\sum_{n=0}^{L-1} |X(n)|^2 \qquad (2.4)$$

Where, *L* represents how many samples were taken dur observation period and *D(X)* is the test statistics. To obtain one threshold value **λ**, the presence or absence of a license station could be stated as[10]:

$$D(X) \geq \lambda: \text{ Licence terminal is present}$$
$$D(X) < \lambda: \text{ Licence terminal is absent}$$

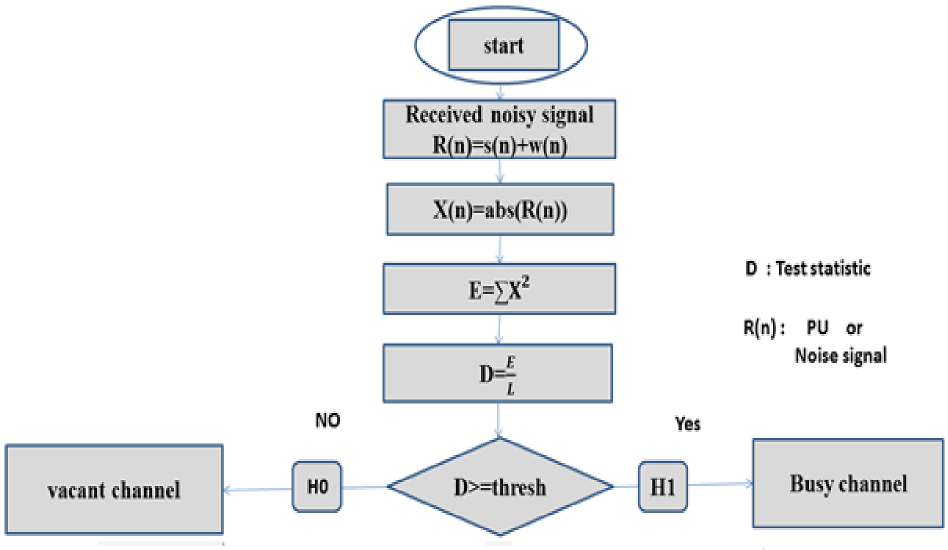

Fig.2.14: Simple Flow chart of the Energy Detection[3].

In CR networks, the efficiency of spectrum sensing can be calculated by using the PF and PD, where the latter means the actual detection of a primary signal, whereas the former means that the detector makes the decision that the PU is present but does in fact not exist. Both probabilities can be expressed mathematically in the following equations[28]:

$$P_F = \mathrm{pro}(D(X) \geq \lambda / H_0) = Q\left(\frac{\lambda - \sigma_n^2}{\sqrt{\frac{2}{L}}\sigma_n^2}\right) \qquad (2.5)$$

$$P_D = \mathrm{pro}(D(X) \geq \lambda / H_1) = Q\left(\frac{\lambda - (\sigma_{n+}^2 \sigma_S^2)}{\sqrt{\frac{2}{L}}(\sigma_n^2 + \sigma_S^2)}\right) \qquad (2.6)$$

Where,

L : The number of samples for the received signal

σ_n^2 : Noise variance

σ_S^2 : primary signal variance

λ : Threshold of decision

Q : Complementary Accumulated Function

The threshold selection factor is important for the detection process in the receiver, as it is chosen for achieving the lowest PF percentage, in order to reduce the missing detection. According to the relationship between the threshold and the PF, the threshold could be calculated accordingly to Equation(3.5):

$$\lambda = \left(Q^{-1}(P_F)\sqrt{\frac{2}{L}} + 1\right)\sigma_n^2 \qquad (2.7)$$

Where,

L :The number of signal samples received .

σ_n^2 : the Noise Variance.

PF : PD.

B - Noise Uncertainty Factor and Dynamic Threshold

The noise uncertainty factor is considered as one of the important parameters within the detection and sensing performance parameters, as it has a clear impact on this test performance. Practically, the noise factor might be not present at all times, so this factor is sometimes neglected, (i.e. P=1). Therefore, no effect has been reflected upon the sensing process in this case[33].

For the purpose of conducting the sensing task in an effective and reliable way, especially with a certain number or a few samples, this factor is slightly greater than one (i.e. P>1). It can be the distributional representation of the noise factor ($\sigma^2\epsilon[\sigma_n^2 p\ ,\frac{\sigma_n^2}{p}]$), where there is an negative correlation between detection probability and noise uncertainty coefficient. The PD may decrease significantly with a gradual increase in the value of the noise uncertainty factor [34][35].

In general, two kinds of unstable noise exist: uncertainty about environmental noise, and uncertainty about receiver device noise. Therefore, it is difficult to accurately determine the noise strength. Finally, the spectrum sensing time should be low. Whenever the secondary user is in one of the spectrum slots, the radio channel should be vacated in the shortest time possible for avoiding any form of interference with the PU [14].

The efficiency of the sensing method is clearly improving after that the notion of the dynamic threshold is introduced, as this technique has been exhibited and used to address and combat severe deterioration due to increased noise uncertainty factor. The noise factor caused a marked decrease in the performance of CR, which made there a serious overlap between cognitive users and licensed users.

To reduce the effect and avoid the noise factor problem, a dynamic threshold coefficient scheme is applied. The dynamic threshold factor d or d>1 is assumed to be closer to one. The dynamic threshold limits can be defined as ($\lambda' \epsilon [\lambda d\ , \lambda/d$)[36].

It is seen through the use of this factor that an increase exists in the Pd at a low-value SNR. Moreover, the desired detection ratio can be achieved with a slight and trivial increase with the dynamic threshold parameter, as better performance could be realized with a small number of samples[32].

2.10.1.2 Match Filter

The filter method is the ideal method for sensing the spectrum, especially for different noise scenarios compared to the rest of the spectrum detection methods, as this method increases the signal-to-noise rate if additional noise is found, and the required observation time is less and thus leads to better gains. The major drawback related to this technique is the way it is not available the CR equipment where implementation is not easy, expensive, very complicated and also because it requires pre-radiation around the PU signal. These, and other reasons, will result in a decreased use with secondary networks. The graph shows in the fig(2.15) corresponding filter time [2][3][7].

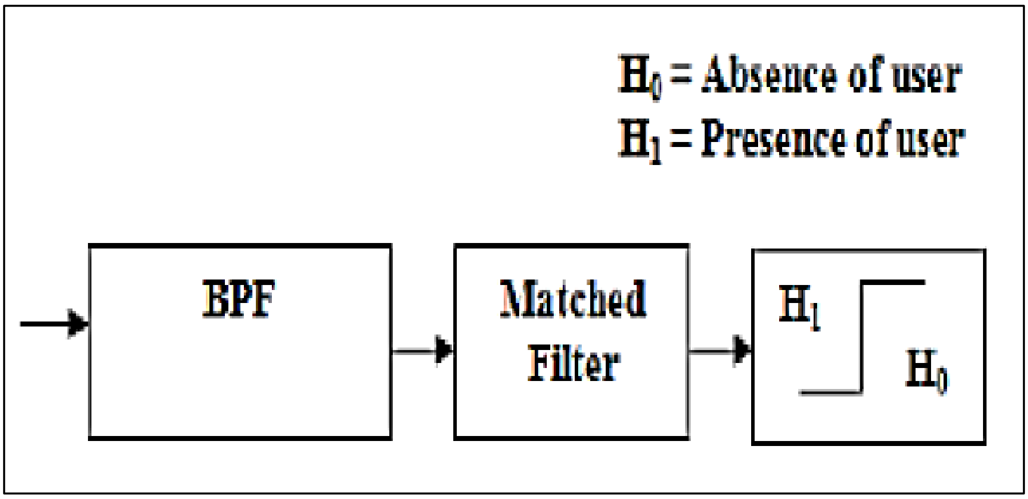

Fig.2.15: Matched filter Block diagram [9].

2.10.1.3 Cyclostationary Feature Detecting

A remarkable distinction of cyclostationary is its ability to distinguish between the noise signal and the signals formed by the PU, which are usually rotational due to periodic repetitions of the signal, while the noise is wide-sense stationary (WSS) constant and with no correlations [8].

The feature detectors depend on the circular features and can distinguish between noise and distorted signals, where the cyclostationary signal is related to the spectrum based on the periodic signal repetition, while the noise is a random signal that has no correlation or regularity. This identifies the noise signal, as these devices work well and are therefore more attractive, whereas rotational detection techniques try to take advantage of the general nature that most of the signals are associated with. These are formed by sinusoidal carriers, which indicates that there is a periodicity connected to the received signals that distinguishes the PU signal from noise. The main drawback of the accuracy of this method is the need to monitor longer time and it is more complex to see periodic signals or PU indicated and a simplified detector rotation feature [1][3].

2.10.1.4 Wavelet based Sensing

This method is based on the received waves and is sometimes called edge detection fig.(2.16). It allows to find and analyze the signal parameters, and conduct the decomposition time to what corresponds to the frequency, where the continuous waves of the signal are converted for performing power density so that the highest power spectral density is in correspondence with the edge. Thereby a comparison is drawn with the threshold for deciding whether or not to operate the spectrum. It provides the flexibility to adapt to a wide dynamic spectrum [2][37].

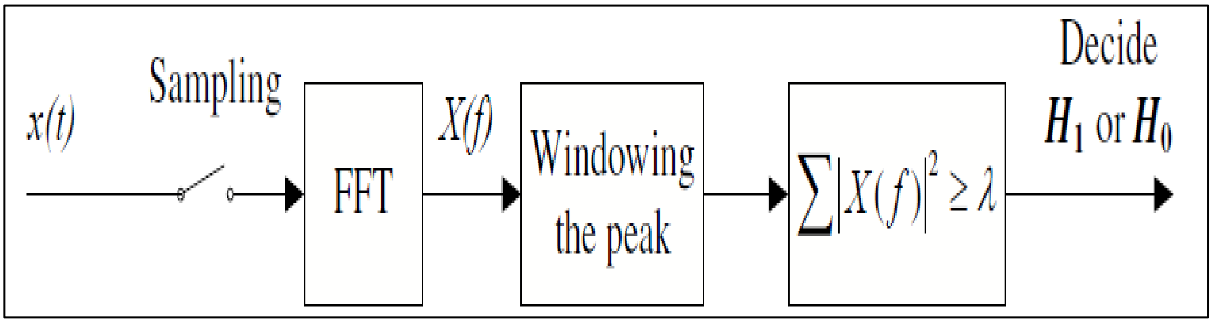

Fig. 2.16: Wavelet based Sensing Block diagram.

Table 2.1: Advantages and Disadvantages of Spectrum sensing Techniques

Spectrum Sensing Techniques	Advantages	Disadvantages
Energy Detecting	1. Low computation cost 2. No need for any prior information	1. Unable to work in low SNR 2. Unable to distinguish Users 3. Shares the same channel.
Match Filter	1. Optimal detecting efficiency 2. Lower computing costs	1. Demands knowledge about PU in advance
Cyclostationary Detecting	1. Robust in low SNR. 2. Robust interference.	1. Demands partial information of PU 2. Higher computational costs.
Wavelet Detecting	1. Sufficient with wide-band signals	1. Higher computational costs. 2. Unable to work for spread spectrum signals.

2.10.2 Cooperative Spectrum Sensing(CSS)

For improving the efficiency of spectrum sensing, cooperative sensing (CS) is introduced, knowing that there is a possibility to direct spectrum sensing by one knowledge network. Yet, there are many inherent problems that arise with this method, and therefore cooperative sensing has been introduced, which works by receiving different signals from different knowledge radio devices, and thus prevents a possible treatment. Various problems are addressed, the most important of which is the problem of questioning the fading noise of multiple paths, as shown in Fig. (2.17). The problems can be briefly summarized as follows:

- Shadowing and uncertainty problem
- Cooperative PUs faded by composite fading.
- Sensing time.

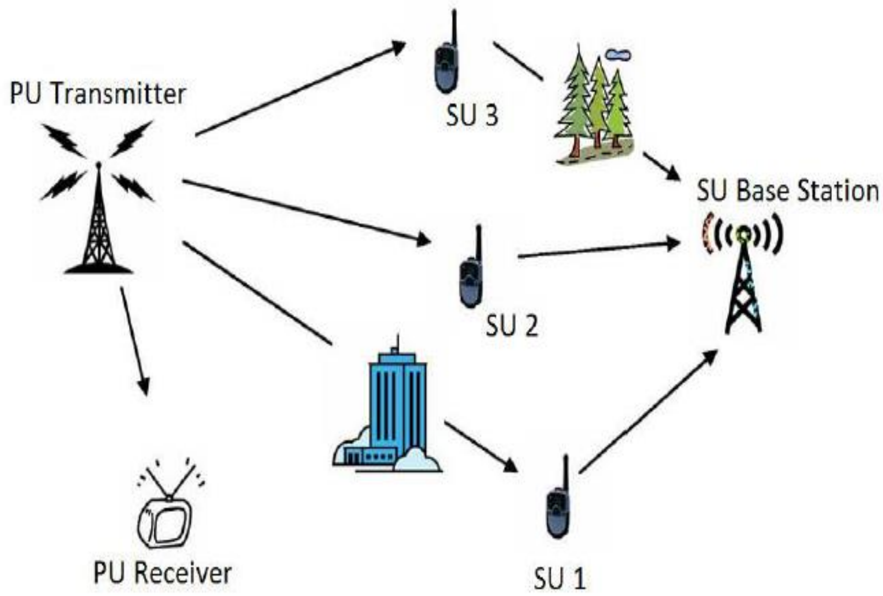

Fig.2.17: Centralized cooperative sensing[4].

In general, cooperative sensing is classified into centralized or distributed sensing [38].

2.10.2.1 Centralized Sensing

In this category, a fusion center collects the sensor data from knowledge devices, which determines the available spectrum based on the information these devices receive and then centrally transmits the result to all local CRs or exchanges information directly between them. Centralized sensing is also divided into two categories:

a) Partially Cooperative Networks: The radio spectrum is detected by CR users independently, later each secondary user sensing in particular and directly transmits information to the fusion center as shown in fig.(2.18).

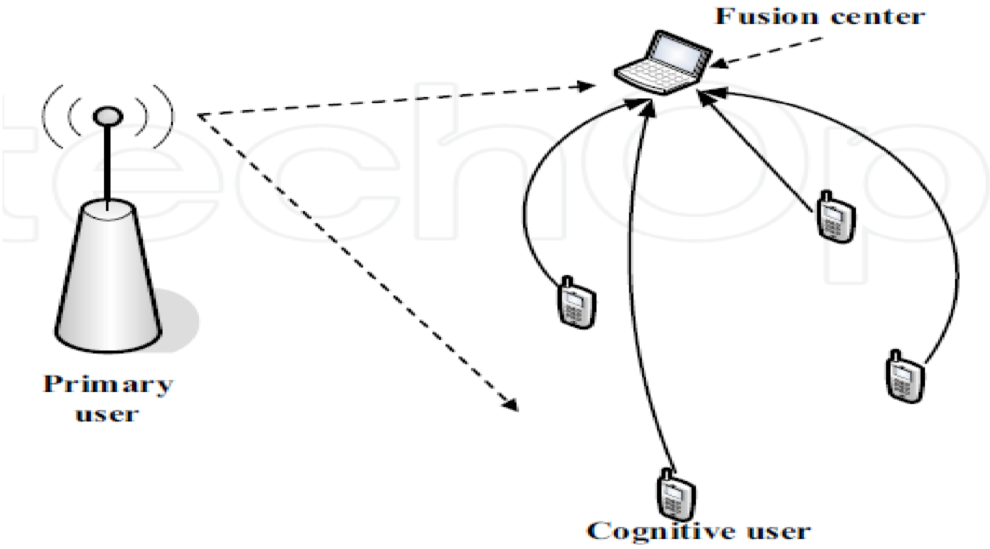

Fig.2.18: Scheme of partially cooperative network[11].

b) Totally Cooperative Network: The radio spectrum is sensed cooperatively, the secondary users share a collaboration, and then transmit the sensed information or local decision to the fusion center as shown the fig.(2.19)**.**

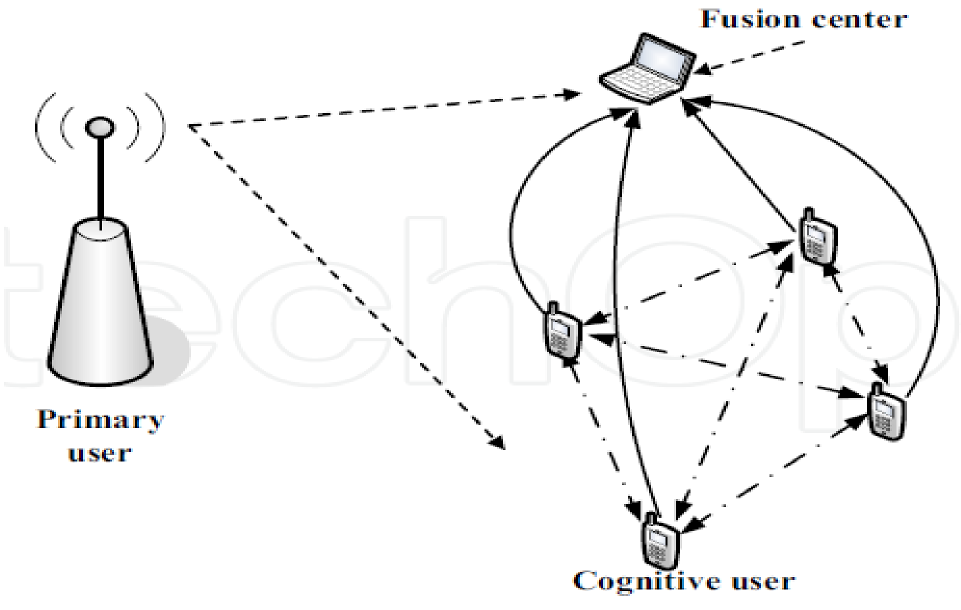

Figure 2.19: Scheme of totally cooperative network[11].

2.10.2.2 Distributed sensing

In this way, information is shared among the cognitive users' devices, who make the decision, and there is no need for infrastructure as in the central case.

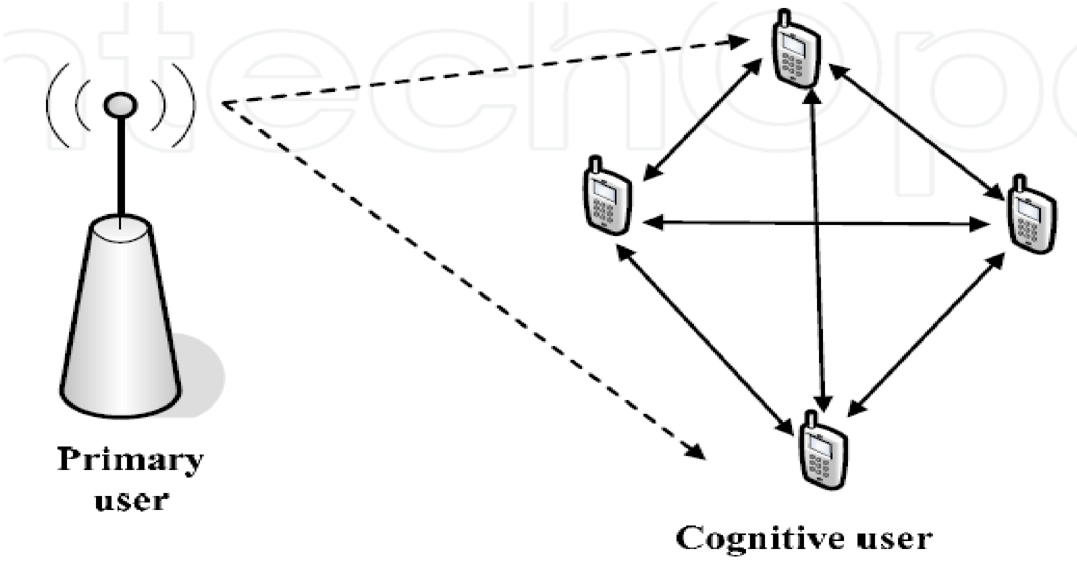

Figure 2.20: Scheme of distributed sensing[11].

In general, both types of sensing (cooperative and non-cooperative), there are some advantages and disadvantages. Table 2.2 briefly presents some of these pros and cons about the types of sensing.

Table (2.2) Non-cooperative V.S Cooperative detection

Sensing Technique	Advantages	Disadvantages
Non-cooperative Detecting	1. Simple implementation	1. Hidden nodes problem
Cooperative Detecting	1. Highly accurate 2. Lower sensing time 3. No issues regarding hiding and shadowing.	1. Very complex system collaborating sensors 2. Over-head trafficking

2.10.3 Spectrum Sensing Challenges:

1. Hidden Node Problem*:* In wireless systems, secondary users of low power can sometimes be hidden, caused to detection problems called hidden wireless nodes as fig.(2.21)[39], which indicate the hidden PU. Here, the spectrum sensing is dimmed by the transmitted nodes while the receiving node channel is good. The transmission or sensing node then senses a free and the begins to trade-on, which harmfully interferes with the primary transmission. Consequently, fading is presented here to solve the problem of estimating the wrong sensing. Therefore, the type of cooperative sensing has been suggested.

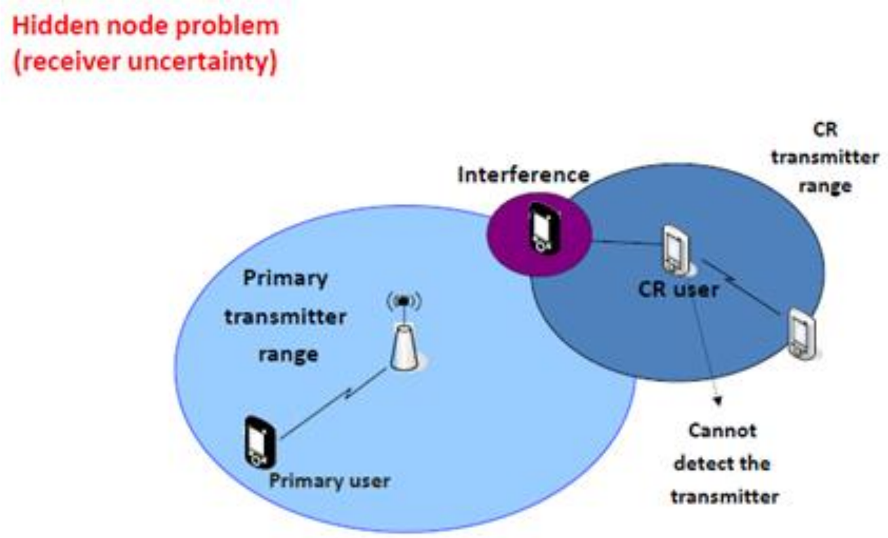

Fig. 2.21: Hidden node problem[15]**.**

2. Limited Sensing Ability**:** In [40] it is emphasized that CR only has a "sense of hearing", which is the main feature in detecting the holes in the radio spectrum, therefore its ability is limited. This indicates and denotes that CR discovers a multi-dimensional environment with only one sense. For example, as a blind person who attempts to pass through a crowded place of movement, he uses the sense of hearing just like the CR. To overcome this problem, there are several advanced techniques for a reliable and fast spectrum band detection.

3. Wideband Sensing: Among the most important vacancies in sensing the spectrum is the task of defining the boundaries of the spectrum and sensing it. Instead of sensing the wide range, one can work in limited areas using the current technology. Moreover, the sensitive difficulties in the broadband could be limited to an acceptable rate [21]. An expensive analog front end can be avoided for a range of spectrum. For general considerations, agencies must regulate spectrum bands for differing kinds of radio devices in light of the ranges in which they operate [40].

4. Spectrum Sensing in Multi-Dimensional Environment: In general, radio systems consist of a number of unauthorized secondary users with authorized PUs [40]. Having many secondary users poses some challenges, such as overlapping with other secondary users in the same environment, which leads to a lack of sensing for the PU. To overcome such an issue, aspects of cooperative sensing need to be considered necessarily, such as transmitted power, cooperation with other unauthorized users, and the need for PUs to collaborate [21].

5. Sensing Time: PUs could use their own frequency bands at any time. Cognitive devices must detect the spectrum as fast as possible for accommodating secondary users. In [4], the spectrum must also be sensed within a limited period of time and must also take into account the number of sensing times that the cognitive secondary user performs. Spectrum sensing needs to take place constantly in order to not miss opportunities. There are some other challenges when designing radio-sensing algorithms, for example, broadband sensing, implementation complexity, tonnage, power consumption, and interference [14].

2.10.4 Pros and Cons of Radio Spectrum Sensing Function

1. The use of the sensing function is not primarily dependent on another (external) system [15].
2. When using this function, no changes occur to the (legacy) platform.
3. It is suitable for dynamic spectrum ranges.
4. Despite the positives, the sensing information is inaccurate and sometimes referred to as spectrum sensing errors.

2.11 Non-Stationary Primary User and CFAR Concept

The notion of CR mainly relies on dynamically accessing the spectrum because it allows unauthorized users to use the spectrum owned by licensed PUs as long as it interferes at the minimum with the PU. The sensors in cognitive radio-enabled networks are required to perform dynamic access to the spectrum, and the licensed channel repeatedly senses to find idle channels. [41][42].

A more unstable PU model is spectrum sensing researches, as authors have acknowledged this to be more general and realistic to be applied practically. When applying the latter with CR, it would be more desirable to have a sensing period that matches a shorter period than the transmitting one in a sensing cycle, for allowing more time for secondary user data transmission [4]. Configuring the sensing cycle has two parts: sensing interval and the transmission interval. The shorter the sensing period, the more user productivity and transmission time [43].

Through the use of the wireless radio spectrum and setting priorities, the PU and the SU can coexist through a specific policy. One common way to help discover the spectrum is the random movement of basic user activity. This movement means changing the PU status from inactive to busy or vice versa during sensor activity. Since the transmitting period is longer than the sensing one in this activity time span, this study has focused on patterns of random change for the PU during the transmission period. This is acceptable for slow PU movement in a televised broadcast, but in fast cellular data traffic such as the WLAN and WiMAX it cannot be ignored [44][45]. This means that the possibilities of PU change throughout the sensing period cannot be ignored, indicating that the traditional fixed sensing model is no longer valid in this case.

It is not guaranteed to make an accurate decision regarding the randomness of the PU traffic, so it must take into account the dynamic PU's sensing and the status changes in each of the transmitting and sensing periods [46].

At the present time, there is no common consensus regarding sensing, sensor standards, or constraints and objectives to be considered in the spectrum sensing process, which makes it difficult to draw a comparison between improvement and development performance across studies where systems models and standards apply different approaches. Some sensor parameters include channel sensor time [44] [47][48] and transmission time [43] [49], but the most common objective is the efficiency of the sensor to describe the throughput of the secondary user to compare the transmitting period with the sensor period. Yet, authors in [46] have different definitions for sensor efficiency and built different models and parameters.

Constant False Alarm Rate (CFAR) technology is a method for reducing the impact of noise in energy detections, where the maximum values of the test statistics and different sequences are determined and the best threshold is selected to result in good detecting and a lower PF, which is in turn significant for the Spectrum sensing results [50].

In general, two main obstacles need to be implemented despite the methods or techniques used to improve the sensing schemes. First, interference with the PU is needed, because its protection is very important, and therefore the interference restrictions between the PU and the secondary user ought not to be violated. Second, the loss of opportunities for the secondary user should reduce the missed opportunities to the minimum, and therefore a balance should exist between the missed opportunity restrictions and the restrictions of interference, subjected to separation and met at the same time to ensure the safety and efficiency of the secondary user networks [5] [19].

2.12 Literature Survey

Several detection systems and schemes and some scenarios used to detect loud signals received that have been mentioned in some literature over the years have been presented with the proposed model.

Ambrish Pandey and Brijendra Mishra (2015)[34]Dynamic detection was used as a way of spectrum sensing through the use of matching filtering technology and energy detection technology, and the PU was considered to remain constant. The dynamic threshold seems to be more favorable than using the fixed threshold because the latter is very sensitive to noise uncertainty. Also, detection in these algorithms could be enhanced through the increase in SNR or number of samples.

Ibrahim Atef, le .al (2015)[51]Mathematical derivations and analyzes were performed while assuming the random arrival and departure for the PU during the transmission or sensing periods of the secondary user. An analysis of the mean detection and false alarm using energy technology based on Bayes theory was obtained. Some gains were obtained without using the ideal threshold. Funky for the purpose of improving detection further by reducing errors

Fikreselam Gared Mengistu and Mohammed Abd-Tuko (2016)[52]The authors proposed an improved technology for spectrum sensing and energy detection, simulation results showed a development in the efficiency of the energy detector through the use of mutual correlation by monitoring the change in the signal during time. Thus, this algorithm reduced misuse and improved the likelihood of detection.

Hadi T. Ziboon and Ahmed A. Thabit (2016)[8]The authors proposed an approach to spectrum sensing using a fixed threshold and a constant false alarm rate for energy-sensing where various signals were created to evaluate detection performance using a double stage. The results of detection and sensing showed great reliability.

Garima Mahendru and Anil K Shukla (2017)[35]The authors presented a spectrum sensing method by means of the energy detection technique, for improving the detection probability and sensing duration in an environment with a lower signal-to-noise rate and an uncertain noise factor. The proposed approach is to link the dynamic threshold with the sensing duration.

Xiao-Li Hu, le .al(2018)[53]The authors presented a new blueprint for spectrum sensing through energy detection and sensing, as the scheme includes adapting between two basic principles: the principle of Constant False Alarm Rate (CFAR) and the principle of Continuous Detection Rate(CDR).this results in setting a practical policy for the rate and size of samples to be monitored and determining the time required for detection to achieve to less interference and better efficiency.

Xiao-Li Hu , le .al(2019)[54]The authors analyzed the statistical features of PF through the use of noise variation by analyzing the noise variation. By analyzing the upper limits of the variance, this results in obtaining a more accurate and more appropriate false alarm rate to give a false alarm probability close to the predetermined prediction as much It is possible for the detection system to be more efficient and more reliable.

Yin Mi, el.al (2019)[55]The authors analyzed a commercial scheme similar to the trade-off between the cost of the range and the performance of the sensing, where the spectral sensing strategy was built on the basis of three units: first, starting with the local detection unit to detect energy. secondly, The fusion center for the data received from the local detection decision .Third, a global decision unit. Thus, the greater the number of cognitive users, the better the detection.

Youness Arjoune and Naima Kaabouchthis(2019)[56] study aim to conduct a survey of developments research in spectrum sensing, as well as the work and efficiency of each of the sensing techniques for both narrowband and broadband, were discussed, and the process of integrating the cognitive network and how it has been implemented with other future networks

Within the framework and concept of this work, an algorithm Dynamic Energy Detection was proposed for detecting the dynamic PU signals in the CR systems. The detection was improved through the use of the dynamic threshold rather than the use of static thresholds through the AWGN Channel, the results were better when as compared with conventional detection.

CHAPTER THREE
IMPLEMENTATION AND ANALYSIS OF PROPOSED METHODOLOGY

3.1 Introduction

According to the information mentioned in the second chapter of this thesis, this chapter analyzes the radio spectrum sensing process using energy detector technology, which is commonly used in CR systems, as its implementation complexity is low and no advance information is required about the PU signal whether this user is stationary or non-stationary. CR devices are needed to create a dynamic balance between the PF versus the PD. Therefore, uncomplicated and very useful methods are referred to because CR computational resources are restricted. The primary objective of this thesis is to further explore the basic dynamic user interface.

3.2 Research Methodology

This study begins by reviewing the significant literatures of theory for identifying particular research problems linked to spectrum sensing schemes. This task is carried out with the development of the other stages throughout the research period, where continuous reporting of other activities is performed. The Required PD is determined by the dynamic detection rate, where detection must be achieved regardless of the sign SNR, which means that the ratio of signal to noise must be known to the secondary user and at all times.

In this research, the active period will be combined and included in the detection equation. It is the actual PU activity period that is part of the sensing sequence, since the activity period is equal to the cumulative period of actual user presence cases divided by the total time period. Formulation of the decision threshold is mainly according to the false alarm ratio and the number of signal samples received, in addition to the slight changes to the dynamic PU signal, which are all involved in determining the detection decision threshold of whether any transmission exists.

Since the false alarm rate approach will be used, dynamic detection rate and dynamic decision threshold are provided in light of PU presence probability during the sensing cycle. Moreover, the work is divided into several stages using the new detection model of the Energy Detector (ED) via the AWGN channel. This proposed model can certainly reveal the dynamic initial user signal, which changes randomly and repeatedly during a limited period, to reflect a more practical and realistic model.

3.3 Influence of PU Traffic On Spectrum Sensing Performance and PU Activity Period

Traditional spectrum sensing in CR networks considers the PU to remain fixed and always in the active state constant with the Activity cycle. This study concentrates on the non-stationary spectrum sensing which assumes that the PU signal is not fixed and may change from one state to another during the sensing cycle. As the PU activities increase in the radio spectrum, the Pd may, for example, increase through improved detector performance and spectrum management. Therefore, most unconventional devices are formulated and implemented in spectrum sensing on this basis, as they differ from conventional devices which assume that the PU signal is completely present or absent throughout the spectrum sense cycle. In this chapter, traditional devices are examined in terms of how they are affected when they involve random changes in PU movement and an unknown activity period during sensing[4].

The traditional detector compares the statistic test resulting from the PU signal (assumed to stay fixed during the sensing period) with the previously defined static threshold. Although there are statistical tests under the null hypothesis and the alternative hypothesis for achieving probability and a fixed threshold, yet the PU signal is not fixed and its status differs during the sensing period, the latter exhibiting a working cycle. Therefore, new test statistics that differ from the traditional ones are created. The fixed threshold is no longer flexible and consequently generates a new detection performance test statistics wherever the dynamic decision threshold is used. However, the detection performance calculated on the assumption of the PU is static, and the fixed threshold does not reflect the practical reality and actual detection efficiency of the non-stationary PU[4].

$P_{DD/A}$ represents the efficiency of the new detector, with the PD when the PU displays Activity period (**A**). $P_{DD/A}$ can be used to analyze detection when A = 1 under H_1, whenever the PU is partially absent under (A <1) within the sensing period, then $P_{DD/A}$ equals the PD value. Similarly, H_0 traditionally indicates that A=0 and computes PF under H_0 (A>0), if the PU not completely absent during the sensing period, then the $P_{DD/A}$ equals the PF value of the detector when PU displays the Activity period. There are special cases when A = 1, as $P_{DD/A}$ equals PD (PU signal totally present), and A = 0, where $P_{DD/A}$ is equivalent to PF (PU signal absent).

The following section studies the detecting efficiency of the common spectrum sensing detector whenever the detector is used in detecting a PU signal exhibited within an activity period that is not known by the detector. The sense detector is an energy detector. When the PU SNR is considered identified, the dynamic detecting threshold is applied to present the lowest limit of decision failure under each of the two hypotheses as it ensures that PF=1- $P_{DD/A}$. The more disagreeable efficiency of the lowest decision wrong detector is ($P_{DD/A}$ =

PF = 0.5), which implies that the detector might no longer be operational beyond $P_{DD/A}$ = 0.5[4].

A description of the analyzing process can be presented as follows: first, the detection threshold λ is calculated by introducing the conventional detection model as well as the fixed X(n) test, which results from the observed signal the traditional detection provided, assuming that the non-stationary PU with PF and PD, represent the $H_0$and H_1 hypotheses respectively. Next, the new test $P_{DD/A}$ is generated with the non-stationary PU effect of the Activity period(A). Finally, $P_{DD/A}$ is compared to the threshold λ, providing the new detection performance $P_{DD/A}$ where the non-stationary PU is detected by including the Activity period A into the detector work. That marks the beginning of the analysis with the conventional detector, which is formulated with the fixed base detection PU so that[34]:

$$\text{If } X(n) < \lambda \qquad \text{Declare } H_0$$
$$\text{If } X(n) \geq \lambda \qquad \text{Declare } H_1$$

The traditional signal model considers a static PU signal, thus the signal observed under H_1 includes S (n) which can be is detected low due to noise, while the signal observed under H_0 includes only noise W(n). Neglecting the influence of fading, a description of the signal model of y could be presented as follows[34]:

$$X(n) = \{\ W(n) \qquad n = 0 \ldots .L \qquad H_0\ (vacant\ Band) \qquad 3.1$$
$$X(n) = \{\ w(n) + s(n) \quad n = 0 \ldots .L \quad H_1(occupied\ Band) \qquad 3.2$$

On the other hand, regardless of the hypotheses previously mentioned, nonstationary PU signal could occupy part of the observed signal. Thus, their pattern depends on the duration and location of the PU signal. To exemplify, if we assume that the PU is present only at the beginning of the observed signals, the structure of the received signals will be as follows:

$$X_{AED} = \{ w(n) + s(n) \qquad for\ n = 0 \ldots\ldots\ldots LA - 1$$
$$X_{AED} = \{ w(n) \qquad for\ n = LA \ldots\ldots\ldots L - 1$$

The signal structure applies to both the $H_1$and the H_0 due to the presence of a signal and noise under both hypotheses.

3.4 Derivation and Analysis of Energy Detection for CR Systems without Noise Uncertainty Impact

The Energy Detector (ED) works as a test statistic for the energy calculation of the observed signal $X(n)$, where the result of the detector output is put into comparison with a predefined mathematical value called the fixed threshold λ, which is in turn dependent on the noise level.

3.4.1 Stationary PU Based on Fixed-threshold Scheme and CFAR Technique

The traditional detector gives the decision whether or not to use the spectrum by means of a fixed threshold and the test statistics $D(X)$, which represent the PU signal that remains fixed during the sensing cycle. The energy detector compares the outputs with the predetermined threshold value, if the value $D(X)$ larger than or equals the threshold then the user is totally present, (i.e. the ON state and the received signal is the PU signal), otherwise, the PU is not present in the radio spectrum (i.e. the OFF state and the received signal is noise only). In this case, the spectrum could be exploited by CR. The energy of detector is calculated as[4]:

$$\mathrm{E} = \sum_{\mathrm{n}=0}^{\mathrm{L}-1} |\mathrm{X}(\mathrm{n})|^2 \qquad (3.3)$$

Where E represent the energy value, L is the number of sample, and *X(n)* is the received signals at CR nodes. For simplicity, the general and common approach to conventional PU signal modelling is followed, assuming the noise to be zero mean and the AWGN is a variation of σ_n^2 so that $w(n) \sim N\ (0, \sigma_n^2)$.

Moreover, the PU signal was also designed as a zero mean, a Gaussian random variable with variance $\sigma_s^2 = \gamma\sigma_n^2$, so that $\sigma_s^2 \sim N\ (0, \sigma_n^2)$ where γ represents the primary signal to noise rate. The signal received at the secondary user is[31]:

$$X(n) = \sum_{n=0}^{L-1} |w(n)|^2 \qquad H_0$$

$$X(n) = \sum_{n=0}^{L-1} |s(n) + w(n)|^2 \qquad H_1$$

Where $w(n)$ and $s(n)$ are the noise signal and the PU signal respectively. The Spectrum sensing rule is a Binary Hypothesis for the test of problems. The composition of the received signals at the secondary user for the binary hypothesis could be defined for nth sample, $1 \leq n \leq L$ [9]. In the ED technique, SU detects whether or not the PU exists by estimating a narrow band signal identified as a received signal $X(n)$. The $X(n)$ may consist of either both signal and noise or noise only.

Moreover, in the detection of the signal, it is either present or absent, and it is characterized by the two hypothesis, first one being an alternate hypothesis H_1, whereas the second one a null hypothesis H_0. The test statistics for the energy detection method may be obtained through the following equation[10]:

$$D(X) = \frac{1}{L}\sum_{n=0}^{L-1} |X(n)|^2 \qquad (3.4)$$

Where, L is the number of samples taken in the observed period, and *D(X)* is the Test Statistics. To obtain one threshold value **λ**, the presence or absence of a licensed station could be stated as[35]:

$$D(X) \geq \lambda : \ \text{PU is present}$$

$$D(X) < \lambda : \ \text{PU is absent}$$

Thus, the binary hypotheses for the traditional energy detector to the test statistics as the following:

$$D(X)\sim\{Norm(\sigma_n^2, \frac{2}{L}\ \sigma_n^4) \qquad H_0(\text{Idle Channel})$$

$$D(X)\sim\{Norm\left((\sigma_n^2+\sigma_s^2), \frac{2}{L}\ (\sigma_n^2+\sigma_s^2)^2\right) \qquad H_1(\text{Busy Channle})$$

The PD and PF values are found through obtaining the comprehensive distributing function of $X(n)$[37]:

$$PF = prob(D(X) \geq \lambda/H_0) = Q(\frac{\lambda-\sigma_n^2}{\sqrt{\frac{2}{L}}\sigma_n^2}) \tag{3.5}$$

$$PM = prob(D(X) \geq \lambda/H_1) = 1 - PD$$

$$= 1 - Q\left(\frac{\lambda-(\sigma_n^2+\sigma_s^2)}{\sqrt{\frac{2}{L}}(\sigma_n^2+\sigma_s^2)}\right) \tag{3.6}$$

$$PD = prob(D(X) \geq \lambda/H_1) = Q\left(\frac{\lambda-(\sigma_n^2+\sigma_s^2)}{\sqrt{\frac{2}{L}}(\sigma_n^2+\sigma_s^2)}\right) \tag{3.7}$$

As Q(·) indicates the standard Complementary Distribution Function (CDF), and λ represents the threshold value. PD, PM, and PF are the detecting, missing, and false alarm probability rates, respectively.

From Equation (3.5), and through the mathematical relationship between false detection alarms and thresholds λ, the fixed-threshold detection can be found as follows:

$$\lambda = Q^{-1}(PF) \times \sqrt{\frac{2}{L}}\ \sigma_n^2 + \sigma_n^2 \tag{3.8}$$

Where λ represents fixed-threshold.

This system is based on equation (3.5) and (3.7) in this chapter by determine the number of samples (L) at the specified PF to obtain PD. As for the detection equation PD, it mainly depends on the threshold (λ) value to obtain the

PD by applying (3.8) into (3.7). Thus, the general formula for the traditional detection of the PU signal by means of the fixed threshold is presented in Equation (3.9):

$$\mathrm{PD} = Q^{-1}\left(\frac{Q^{-1}(PF) \times \sqrt{\frac{2}{L}}\ \sigma_n^2 + \sigma_n^2 - (\sigma_n^2 + \sigma_s^2)}{\sqrt{\frac{2}{L}}(\sigma_n^2 + \sigma_s^2)}\right) \tag{3.9}$$

By deriving the detection Equation In(3.9), the number of sample L could be obtained through the following:

$$\mathrm{Q}^{-1}(\mathrm{PD}) \times \sqrt{\frac{2}{\mathrm{L}}}(\sigma_\mathrm{n}^2 + \sigma_\mathrm{s}^2) = \mathrm{Q}^{-1}(\mathrm{PF}) \times \sqrt{\frac{2}{\mathrm{L}}}\ \sigma_\mathrm{n}^2 + \sigma_\mathrm{n}^2 - (\sigma_\mathrm{n}^2 + \sigma_\mathrm{s}^2)$$

$$\mathrm{Q}^{-1}(\mathrm{PD}) \times \sqrt{\frac{2}{\mathrm{L}}}(\sigma_\mathrm{n}^2 + \sigma_\mathrm{s}^2) = \mathrm{Q}^{-1}(\mathrm{PF}) \times \sqrt{\frac{2}{\mathrm{L}}}\ \sigma_\mathrm{n}^2 - \sigma_\mathrm{s}^2$$

$$\sigma_\mathrm{s}^2 = \mathrm{Q}^{-1}(\mathrm{PF}) \times \sqrt{\frac{2}{\mathrm{L}}}\ \sigma_\mathrm{n}^2 - \mathrm{Q}^{-1}(\mathrm{PD}) \times \sqrt{\frac{2}{\mathrm{L}}}(\sigma_\mathrm{n}^2 + \sigma_\mathrm{s}^2)$$

$$\mathrm{SNR} = \mathrm{Q}^{-1}(\mathrm{PF}) \times \sqrt{\frac{2}{\mathrm{L}}} - \mathrm{Q}^{-1}(\mathrm{PD}) \times \sqrt{\frac{2}{\mathrm{L}}}(1 + \mathrm{SNR})$$

$$\gamma = \frac{\sigma_s^2}{\sigma_n^2} = \mathrm{SNR}$$

Where γ is the signal to noise ratio.

$$\mathrm{SNR}^2 = \frac{2}{\mathrm{L}}[\mathrm{Q}^{-1}(\mathrm{PF}) - \mathrm{Q}^{-1}(\mathrm{pd}) \times (1 + \mathrm{SNR})]^2$$

$$\mathrm{L} = \frac{2[Q^{-1}(PF) - Q^{-1}(pd) \times (1 + SNR)]^2}{SNR^2} \tag{3.10}$$

Where L is the number of samples.

In (3.10), the L is associated by the desired PD at SNR value for a particularized PF system based on the constant false alarm rate principle CFAR (i.e. the PF can be set to a determined value to select a threshold (λ) value and obtain the desired PD).

Equation (3.10) combines the L with the desired PD at SNR value for a specified PF scheme based on the CFAR policy, i.e. the PD can be set to a determined value to choose the threshold value and capture the desired detection probability. This requires the system to obtain the desired detection probability at a specific value of SNR. The achievement of the system is based on the Receiver Operating Of Characteristics (ROC). This explains the connection between the PF and PD: as the number of samples rises, the PD increases, but the sensor time takes a longer time as well.

Figure (3.1) represents a simplified flowchart of the Energy Detector method.

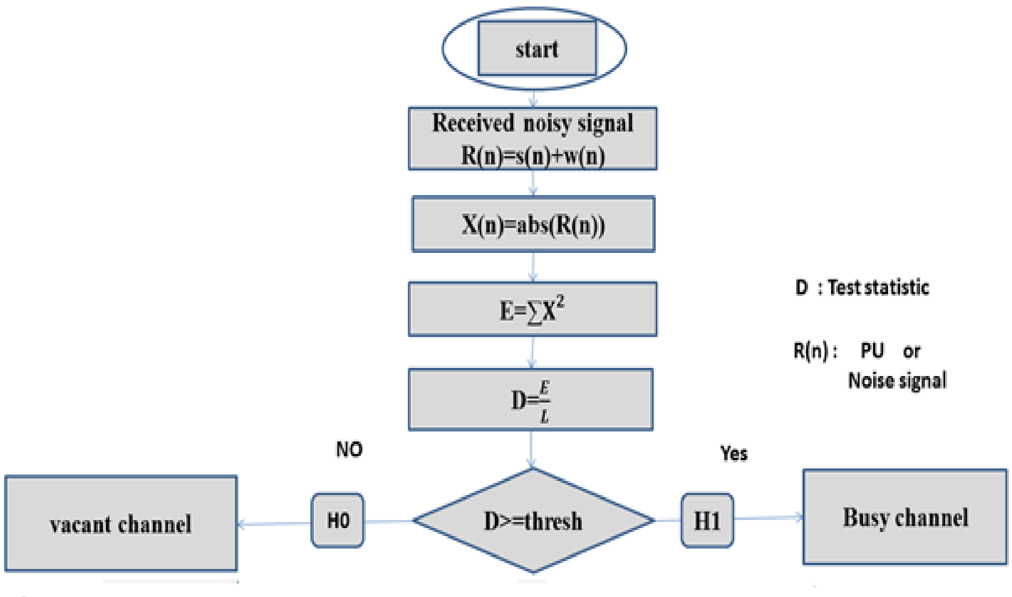

Fig. 3.1: Simple Flowchart of Energy Detection.

Firstly, the signal received is either the PU signal in addition to noise or noise only. It is absolute, and the result is squared so that the signal energy is obtained. Then, the average is calculated. Next, the final results are put into a comparison with the threshold for determining whether it is only noise or signal plus noise.

3.4.2 Non-stationary PU Based on Dynamic-Threshold Scheme and CFAR Technique

In this model, the assumption is made that a knowledge station exists. This station requires the detection of primary station signals by means of energy detector technology. This technique does not comprehend whether the signal's power is transmitted to the basic system. The energy is first detected and compared to a specific threshold for determining whether or not the radio spectrum range is available. In case the received and detected signal energies are larger than the detection threshold value, then the power detector will indicate the presence of the PU, represented by an existing hypothesis H1, otherwise the PU does not exist, which is represented by null hypothesis H0.

The performance of radio sensing has been measured by two parameters: false alarm probability, This hypothesis indicates that the PU is present in the spectrum while in reality, it is not as stated. Second, the PD hypothesis indicates that the PU is already in the spectrum. This parameter must be rather large to protect PUs from interfering with secondary users. Therefore, a mathematical analysis needs to be performed and the detection parameters have to be defined.

The energy detector decision is to choose the hypothesis as follows[33]:

$$\mathrm{X(n)} = \{\ \mathrm{w(n)} \qquad\qquad \mathrm{H_0}\ \ (\text{Signal Absent})$$

$$\mathrm{X(n)} = \{\ \mathrm{w(n)} + \mathrm{s(n)} \qquad\qquad \mathrm{H_1}\ \ (\text{Signal Present})$$

Where, n = 0,1,2,3 ... N indicates the number of samples (detection period), $X(n)$ is the signal received by the secondary user, $w(n)$ indicates that it is a noise signal considered to be a random, independent, and uniformly distributed process for zero meaning white Gaussian noise added with variance σ_n^2 , and $s(n)$ is the PU signal.

If there are no known characteristics about the deterministic knowledge signal (x), defined as the average signal strength only, then the energy detector seems to be the optimal radiometer, and the testing statistics are obtained through[37]:

$$D(X) = \frac{1}{L}\sum_{n=0}^{L-1} x(n) \quad \begin{cases} \geq \lambda & H_1 \\ < \lambda & H_0 \end{cases}$$

Where, $D(x)$ and λ represent the decision variable and threshold, respectively, and L is the number of samples. When the noise variance is identified and without noise uncertainty factor, according to the Central Limit Theorem assumption (CLT), become to:

$$D(x/\,H_0) \sim N\,(\sigma_n^2\,, 2\sigma_n^4/L) \qquad H_0(Idle\ Channel)$$
$$D(x/\,H_1) \sim N\,(\sigma_n^2 + \sigma_s^2)\,, 2/L(\sigma_n^2 + \sigma_s^2)^2 \qquad H_1(\text{Busy Channle})$$

where σ_s^2 is the average of the primary signal power, and σ_n^2 represents the noise variance. Then, the PF and PD could be achieved respectively:

$$PF = prob(D(X) \geq \lambda|H_0) = Q\left(\frac{\lambda - \sigma_n^2}{\sqrt{2/L}\,\sigma_n^2}\right) \qquad (3.11)$$

For increasing and improving the reliability of detection, dynamic threshold schemes are used, as the dynamic threshold factor d approaches closer to 1 and the single dynamic threshold, Which can be represented by the mathematical relationship $\lambda' \epsilon\ [{}^{\lambda}/_{d}]$, The PD value can be determined as:

$$PD = prob(D(X) \geq \lambda \backslash H_1) = Q\left(\frac{\lambda' - (\sigma_n^2 + \sigma_S^2)}{\sqrt{2/L}\,(\sigma_n^2 + \sigma_S^2)}\right) \qquad (3.12)$$

Where PF and PD are the probability rates of false alarm and detection, respectively.

When the relationship between the SNR and PD and PF is known, it could be employed in the calculation of the resolution fixed-threshold value from Equation (3.11):

$$PF = Q(\frac{\lambda - \sigma_n^2}{\sqrt{2/L}\,\sigma_n^2})$$

$$Q^{-1}(PF) = \frac{\lambda - \sigma_n^2}{\sqrt{2/L}\,\sigma_n^2}$$

$$Q^{-1}(PF)\left(\sqrt{2/L}\right)\sigma_n^2 = \lambda - \sigma_n^2$$

$$\lambda = Q^{-1}(PF)\left(\sqrt{2/L}\right)\sigma_n^2 + \sigma_n^2 \qquad (3.13)$$

where λ represents the *fixed- threshold.*

$$PD = Q\left(\frac{\lambda' - (\sigma_n^2 + \sigma_S^2)}{\sqrt{2/L}\,(\sigma_n^2 + \sigma_S^2)}\right)$$

$$PD = Q\left(\frac{\lambda\,/\,d - (\sigma_n^2 + \sigma_S^2)}{\sqrt{2/L}\,(\sigma_n^2 + \sigma_S^2)}\right) \qquad (3.14)$$

Now putting the value of λ from Equation (3.13) into Equation (3.14) to get:

$$PD = Q\left(\frac{Q^{-1}(PF)\left(\sqrt{2/L}\right)\sigma_n^2 + \sigma_n^2 - d(\sigma_n^2 + \sigma_S^2)}{\sqrt{2/L}\,d(\sigma_n^2 + \sigma_S^2)}\right) \qquad (3.15)$$

When the PU Activity period is within the detection equation (or so-called unstable PU) and the single dynamic threshold is used, the detection approach becomes in the following formula:

$$PD/A = Q\left(\frac{Q^{-1}(PF)\left(\sqrt{2/L}\right)\sigma_n^2 + \sigma_n^2 - (1 + SNR \times A)\sigma_n^2 \times d}{\sqrt{2/L}\,(1 + SNR \times A)\sigma_n^2 \times d}\right)$$

$$PD/A = Q\left(\frac{Q^{-1}(PF)\left(\sqrt{2/L}\right) + 1 - (1 + SNR \times A) \times d}{\sqrt{2/L}\,(1 + SNR \times A)d}\right)$$

$$PD/A = Q\left(\frac{Q^{-1}(PF)\left(\sqrt{2/L}\right) - (1 + A \times SNR)d + 1}{\sqrt{2/L}\,(1 + SNRA \times A)d}\right) \qquad (3.16)$$

The sensing performance is greatly improved with the dynamic factor included in the PD/A detection equation. This improvement is evident especially at a low-noise signal level less than (-10 dB). A gradual growth in the dynamic factor enables the desired detection to be achieved. Under this factor, detecting the PU signals may be improved with a small number of samples. Moreover, the effect of the dynamic threshold factor on sensing performance without noise uncertainty factor was studied. The dynamic factor interacts to detect the PU signal regardless of this is the signal whether it is static or dynamic. Thus, the detection has been improved also even when the signal-to-noise ratio decreases.

3.4.3 Non-stationary PU Based on Double Dynamic-Threshold Scheme and CFAR Technique

The new work in this thesis is used for the detector to indicate $P_{DD/A}$ where the PU is the non-static used with the dynamic threshold instead of the fixed threshold and without noise uncertainty impact. The new statistical test X_{AED} is compared with the dynamic threshold λ_d and thus an evolution in the performance of the detector is established, which in turn increases the PD dynamic PU signals.

Ordinary spectrum sensing for CR presumes that the PU is fixed (i.e. PU-static within the sensing period) and remains inactive or in a fixed status, whereas in fact the primary signals might be unstable or nonstationary and change their states during a sensing period. Several researches have accepted and approved this notion, and utilized the activity modality of the PU to enhance the above-mentioned method in terms of performance, such as spectrum management and spectrum sensing whenever the PU is nonstationary and present throughout the spectrum period with Activity period *A*. This thesis takes into account the scenario of random activities of the basic user movement throughout the sensing period called the Activity period (*A*), where $0 < A < 1$. In this case, the traditional methods cannot be applied because of the Dynamic PU randomly during the observed period.

The performance detection of $P_{DD/A}$ represents the activity period (*A*) for energy detection .when no activity is observed ,which mean *A*=0 regardless of the SNR values, it indicates that the user is absent and that the received signal is noise. On the other hand, *A*=1 indicates that the user is completely present in this case, and increases the discovery rate significantly. It is therefore noted that the $\mathrm{P}_{\mathrm{DD/A}}$ performance is primarily associated with dynamic factor acquisition and activity of the PU from both operators for improved detection.

Through of the remaining sensing results, the observed signal which consists of two parts including PU signals seems to have a form of corruption through noise with a total power of length LA, including PU signals corrupted by noise with total power σ_n^2 of length LA, and another part including only noise with power σ_n^2 of length L (1-A), whereas the normal distribution with zero mean and variance is $\sigma_n^2(\gamma.A+1)$. The static $X(n)$ test is used for the result of the sum of the energy of approximately two different parts. Whenever it is related to a Gaussian distribution, the Energy detection calculates the Energy of the observed signals, thus the PU signal location will affect the test output according to the following distribution:

$$X_{AED} \sim N\left((\gamma A+1)\sigma_n^2, \frac{2}{L}(\gamma A+1)^2\sigma_n^4\right) \qquad (3.17)$$

Where N is Normal distribution, γ is the SNR for the secondary user, σ_n^2 is Noise variance, L is number of samples, and A is the Activity period. According to the effect of the PU signal activity period $D_A(X)$, statistics can be performed by calculating the cumulative distribution function through the AWGN channel in Equation(3.4)[4].

$$X(n)_{AED} = \sum_{n=0}^{LA-1} |s(n)+w(n)|^2 + \sum_{n=LA}^{L-1} |w(n)|^2 \qquad (3.18)$$

Where w (n), s (n) and $X(n)_{AED}$ denote AWGN with zero mean and variance σ^2, the transmitted signals from PU, and the received signal at CR (i.e. secondary user) with Activity period respectively. To calculate the statistical test $D_A(X)$, L samples are used for the observed signal, and the PU signal location has no effect on the statistical distribution of testing.

In the conventional energy detection algorithm, the performance is lower with uncertainty about noise being a fixed threshold, which implies the choice of stationary threshold is not adequate anymore, especially when being uncertain about noise, so a flexible dynamic threshold is actually needed instead of to be used when necessary [6]. The typical method used in formulating the PU-A decision threshold in this thesis is a signal-based CFAR approach. In the CFAR scheme, a principle is adopted in the sense that the PF is fixed on a small value so that the PD is getting to the maximum.

The calculation of dynamic threshold occurs as a variable function, and the threshold is affected according to fluctuations and conditions that occur during the signal path, with the assumption that the false alarm probability and the variable and affected detection principle are established according to the same fluctuations and conditions that of the threshold.

System performance decreases significantly when noise uncertainty increases, especially with the use of the Energy detector method, as interference results appear at the licensed PU terminal. For improving and increasing the reliability of the PU signal detection, a dynamic decision threshold scheme and policy is used. It is implemented by using the dynamic threshold parameter which is closer to 1, (i.e. $d \geq 1$). The limits of the dynamic parameter can be expressed mathematically through this relationship $\lambda'' \in [\lambda/_{d} \quad , \lambda\, d]$, as it represents that there is a dynamic change in the signal level .

In light of the determined relationship between the SNR and the PD and PF, the resolution dynamic threshold can be calculated as:

$$\text{PF} = \text{Q}\left(\frac{\lambda' - \sigma_n^2}{\sqrt{2/L}\,\sigma_n^2}\right) \tag{3.19}$$

$$\text{Q}^{-1}(\text{PF}) = \frac{\lambda\,\text{d} - \sigma_\text{n}^2}{\sqrt{2/\text{L}}\,\sigma_\text{n}^2}$$

$$\text{Q}^{-1}(\text{PF})\left(\sqrt{2/\text{L}}\,\sigma_\text{n}^2\right) = \lambda\,\text{d} - \sigma_\text{n}^2$$

$$\lambda_\text{d} = \frac{1}{\text{d}}[\text{Q}^{-1}(\text{PF})\left(\sqrt{2/\text{L}}\,\sigma_\text{n}^2\right) + \sigma_\text{n}^2\,] \tag{3.20}$$

$$\text{PDD} = Q\left(\frac{\lambda'' - (\sigma_n^2 + \sigma_S^2)}{\sqrt{2/L} \times d(\sigma_n^2 + \sigma_S^2)}\right)$$

$$\text{PDD} = Q\left(\frac{\lambda_d\,/\,d - (\sigma_n^2 + \sigma_S^2)}{\sqrt{2/L} \times (\sigma_n^2 + \sigma_S^2)}\right)$$

$$\text{PDD} = Q\left(\frac{\lambda_d - d(\sigma_n^2 + \sigma_S^2)}{\sqrt{2/L} \times d(\sigma_n^2 + \sigma_S^2)}\right)$$

$$\text{PDD} = Q\left(\frac{\lambda_d - d(1 + SNR)\sigma_n^2}{\sqrt{2/L} \times d(1 + SNR)\sigma_n^2}\right) \qquad (3.21)$$

Where λ_d represents dynamic threshold.

Now, putting the value of λ_d from Equation (3.20) into Equation (3.21) to obtain the detection formula using dynamic-threshold and static-PU results in:

$$\text{PDD} = Q\left(\frac{\frac{1}{d}[Q^{-1}(PF)\left(\sqrt{2/L}\,\sigma_n^2\right) + \sigma_n^2] - (1 + SNR)\sigma_n^2 \times d}{\sqrt{2/L}\,(1 + SNR)\sigma_n^2 \times d}\right) \qquad (3.22)$$

Whenever PU signals with an Activity period (A) are detected, the A is add for distributing the hypotheses H_1 only for the Dynamic Energy Detection (DED). Consequently, the PD efficiency can be determined by the proposed updated formulas, given the effect of the random movement of the PU-A, which is referred to as A. The activity period is in a closed-form, compared to the test of the cumulative distribution function which was formulated for the fixed PU who does not realize the random movement A that may occur during the sensing period.

The deterministic effects of fading in the AWGN channel are not taken into consideration as in this Hypothesis, and therefore a Dynamic Energy Detection chart is presented to demonstrate the decision regarding the presence of the signal S(n). This section presents a form of the dynamic spectrum sensing formula with the dynamic threshold DED-DTD under CFAR and is compared to the models conventional over the AWGN channel, presenting an ideal example of comparing the different methods of sensing the spectrum in CR networks. The DED-DTD method assumes fluctuations in signal level variation to be due to the change in the noise level, reducing the sensitivity of the sensing and eventually decreasing how accurate the detecting takes place in CR networks. This results in harmful interference with the PU, as the traditional energy detection algorithm depends on a stationary threshold which is rather sensitive to noise fluctuations. Given that the stationary threshold is of no validity at the stability of the noise level, it is therefore significant to suggest a dynamic threshold DT scenario and an efficient method for addressing noise fluctuations, as well for enhancing the detecting sensitivity.

Therefore, the new DED-DT proposal based on the dynamic threshold scenario and also Dynamic PU will take into consideration as the random return of the PU during the sensing process PDD/A, which could be measured in a closed model on the Additional White Gaussian Noise channel by the cumulative distributive function of statistics according to Equation(3.18).

The test in Equation(3.4) is applied with the compatibility threshold calculated in (3.19). Accordingly, the detection performance is evaluated when the primary signal that shows the Activity period (A) is detected by applying λ_D into X_{AED} , so as to obtain the detection formula using dynamic-threshold and dynamic-PU and neglect the noise uncertainty coefficient, as follows:

$$P_{DD/A} = \left(\frac{\frac{1}{d}\left[Q^{-1}(PF)\left(\sqrt{2/L}\,\sigma_n^2\right) + \sigma_n^2 \right] - d(SNR \times A + 1)\sigma_n^2}{\sqrt{\frac{2}{L}}\; d(SNR \times A + 1)\sigma_n^2} \right)$$

The above detection algorithm in this model becomes as follows when tested through the AWGN channel. The assumption has been made that the PU is non-stationary and is represented by an activity period:

$$P_{DD/_A} = Q\left(\frac{\frac{1}{d}\left[Q^{-1}(PF)\left(\sqrt{2/L}\,\sigma_n^2\right) + \sigma_n^2\right] - d(SNR \times A + 1)}{\sqrt{\frac{2}{L}}\ d(SNR \times A + 1)}\right) \quad (3.23)$$

Where $P_{DD/_A}$ is the approximate equation for the probability of performing a closed-form detection of a DED scheme according the Dynamic-Threshold, which has been tested over the AWGN channel when viewing the PU and A represents the activity period. $P_{DD/_A}$ can be used to analyze both false alarm and detection probabilities under H_0 and H_1 respectively, assuming the dynamic threshold coefficient d ≥1 and specifying a range of $[\lambda/_d\ , \lambda\, d]$ values. As for the special case when d=1 , $P_{DD/A}$ is the conventional detection probability (PU signal existent) and equals the traditional PF rate (PU signal not existent). As well, the SNR can be obtained as follows:

$$SNR = \frac{Q^{-1}(PF) - Q^{-1}(PD)}{Q^{-1}(PD) - \sqrt{\frac{2}{L}}} \qquad (3.24)$$

The equation represents the SNR with the change in *PD* ratio and the number of samples observed, with the assumption that the false alarm rate is constant. The improvement of the detection, as explained above, is achieved by applying Equation (3.23) which represent the main model of this work.

It is worth noting that traditional detection uses the fixed threshold (λ) (Equation 3.8) with the PD equation (Equation 3.9), while the dynamic detection used the dynamic-threshold coefficient. The dynamic threshold has been mentioned in this thesis due to the effect of (d) on the PF (Equation 3.19) at threshold (Equation 3.20) . This work takes into consideration the effect of (d) on the PF (Equation 3.5) as well as on the PF (Equation 3.7), resulting in that as shown in Equation (3.23) without the noise factor, Equation (3.31)) With a noise factor, a double dynamic threshold is required to accommodate the PU's movement.

3.5 Detection For Non-stationary PU Based on Double Dynamic-Threshold with Noise Uncertainty Factor

The noise uncertainty factor is an important parameter, usually indicated as p. In fact, perhaps the noise factor may not always be present at all times, but to ensure an effective and reliable sensing method with fewer samples or a faster response in the noise model we assume that there is a Variable noise, in other words, the noise coefficient is greater than one. For practical requirements, the input factor p can be represented as the uncertainty factor for variable noise, Whereas the fluctuation of the uncertainty factor can be represented as[36]:

$$\sigma^2 \epsilon [p\sigma_n^2 , \sigma_n^2/p]$$

When the noise uncertainty factor becomes greater than one (i.e. p> 1) and is included in the detection equation as follow:

$$\mathrm{D(X)} = \sim\{Norm\left(\sigma_n^2 , \frac{2}{L}\sigma_S^4\right) \tag{3.25}$$

$$\mathrm{D(X)} = \sim\{Norm(\sigma_n^2/p + \sigma_s^2), \frac{2}{L}\left(\frac{\sigma_n^2}{p} + \sigma_s^2\right)^2 \tag{3.26}$$

$$\mathrm{PD} = \mathrm{pro}\left(\mathrm{D(X)} \geq {}^{\lambda}/_{\mathrm{H_1}}\right) = \mathrm{Q}\left(\frac{\lambda'' - \left(\frac{\sigma_n^2}{p} + \sigma_s^2\right)}{\sqrt{\frac{2}{L}}\ \left(\frac{\sigma_n^2}{p} + \sigma_s^2\right)}\right) \tag{3.27}$$

When λ'' indicating for a dynamic-threshold which is also indicated λ_d

$$\mathrm{PM} = 1 - \mathrm{p_d} = 1 - \mathrm{Q}\left(\frac{\lambda'' - \left(\frac{\sigma_n^2}{p} + \sigma_s^2\right)}{\sqrt{\frac{2}{L}}\left(\frac{\sigma_n^2}{p} + \sigma_s^2\right)}\right) \qquad (3.28)$$

===

$$\mathrm{PF} = \mathrm{pro}\left(\mathrm{D(X)} \geq {}^{\lambda}/_{\mathrm{H_0}}\right) = \mathrm{Q}\left(\frac{\lambda_d - \sigma_n^2}{\sqrt{\frac{2}{L}}\ \sigma_n^2}\right) \qquad (3.29)$$

$$Q^{-1}(p_F) \times \sqrt{\frac{2}{L}}\ \sigma_n^2 = \lambda_d - \sigma_n^2$$

$$\lambda_d = \frac{1}{d}[Q^{-1}(p_F) \times \sqrt{\frac{2}{L}}\ \sigma_n^2 + \sigma_n^2] \qquad (3.30)$$

$$\mathrm{PDD} = \mathrm{Q}\left(\frac{\frac{1}{d}[Q^{-1}(p_F) \times \sqrt{\frac{2}{L}}\ \sigma_n^2 + \sigma_n^2] - d\left(\frac{\sigma_n^2}{p} + \sigma_s^2\right)}{\sqrt{\frac{2}{L}} \times d\ \left(\frac{\sigma_n^2}{p} + \sigma_s^2\right)}\right)$$

$$\mathrm{PDD} = \mathrm{Q}\left(\frac{\frac{1}{d}[Q^{-1}(p_F) \times \sqrt{\frac{2}{L}} + 1]\sigma_n^2 - d\left(\frac{1}{p} + \mathrm{SNR}\right)\sigma_n^2}{\sqrt{\frac{2}{L}} \times d\ \left(\frac{1}{p} + \mathrm{SNR}\right)\ \sigma_n^2}\right)$$

The general formula in this work $P_{DD/_{Ap}}$ for the detection equation is the combination of the effect of the noise factor, the dynamic parameter, and the PU Activity period (*A*) over AWGN channel as follows:

$$P_{DD/_{Ap}} = \mathrm{Q}\left(\frac{\frac{1}{d}[Q^{-1}(p_F) \times \sqrt{\frac{2}{L}} + 1] - d(\mathrm{SNR} \times A + {}^{1}/_{p})}{\sqrt{\frac{2}{L}}\ d(\mathrm{SNR} \times A + {}^{1}/_{p})}\right) \qquad (3.31)$$

In this case, the noise uncertainty is considered to be the noise strength which either increases or decreases according to the surrounding conditions. The focus of this study revolves around the assumption that the noise strength is in its worse condition and the performance of the energy detector has been analyzed and evaluated using the dynamic threshold and dynamic PU signal

CHAPTER FOUR

CR SYSTEM MODIFICATIONS PROPOSED

4.1 Introduction

In this chapter, the performance is evaluated to detect the signal energy through the use of expressions and mathematical analyses. As shown in Chapter Three the Matlab program is used to test the performance and results of the detection of the proposed CR system. The test is performed for many of the detection algorithms. Simulation of radio spectrum sensing was performed using the dynamic PU signal energy detection technique, where it is assumed that there is no noise uncertainty factor or P=1 for the conceptual performance of the detection and the different paths. As for the other part, the simulation was performed for the sensing also, but with the use of the noise factor model P>1, so as to ensure the accuracy of performance and reliability of the disclosure of the proposed detectors. Different values have been used for SNR. These simulations focus on the value SNR = -12dB, which is a low value and the number of samples L=1000 samples to prove the results and perform the test. The parameters of the Monte Carlo simulation are taken.

4.2 Performance Evaluation For the CR Based on Mathematical Analysis

The performance of the proposed detection methods energy detection in the CR system is evaluated based on some analyses and using analytical expressions resulted in the general new detection formulas as in Equations (3.23) and(3.31). The Matlab simulation is supported by a number of samples with a size (L). The white noise w(n) can be modeled as a zero-mean Gaussian random variable with variance σ_n^2 .while PU modeled as s(n) with variance σ_s^2 . The model for s(n) is more complicated as noise uncertainty should also be considered.

The PU signal and the noise signal are collected by the test statistic according to Equation(3.4). The detection threshold λ is calculated in Equation (3.8). If X(n) is greater than the threshold , then the presence of the PU signal is declared and the average performance is detected and versa is an absence PU.

4.2.1 Simulation Performance of CR at Activity Period

Simulations are done using the Matlab program through the Additive Gaussian Noise channel (AWGN). A different number of samples was taken at the signal-to-noise ratio (-12dB) which is considered a low percentage to some extent. In the following detection schemes, the common pattern was that the false alarm probability ratio (PF=0.1). The ratio has been acceptable and common by which the PD is measured, as will be illustrated in several figures later on.

Figure 4.1 explains the performance of the detection algorithm for energy detection in the CR system. The detection performance was evaluated by simulating Matlab for this system. $P_{D/A}$ presented the detection performance introduced the activity period of A for energy discovery, where the detector is created to perform $\mathrm{PF} = 1 - \mathrm{PD}$ as any PU SNR. Regardless of the value, SNR is chosen, whereby $P_{D/A}$ deviates at A=1 and at A=0 (i.e. it is assumed that there is no activity period). As mentioned earlier, the analysis designed in CR depends on the threshold decision. These parameters are given in Table (4.1), and are chosen according to the requirements of analysis and design.

Table 4.1: parameters of Detector at NO. of samples.

Parameters	Values
Number of samples	1000, 2000
SNR ranges	0dB, -2dB, -4dB, -6dB, -8dB
PF	0.1
Number of iterations	100, 1000

The following Fig. 4.1 shows the relationship between the Activity period A and the probability of detecting PD, where a Matlab simulation of the CR system showed that the more the activity of PU, the PD increased when the number of samples is1000 where each sample is drawn and repeated 100 times using CFAR at PF = 0.1.

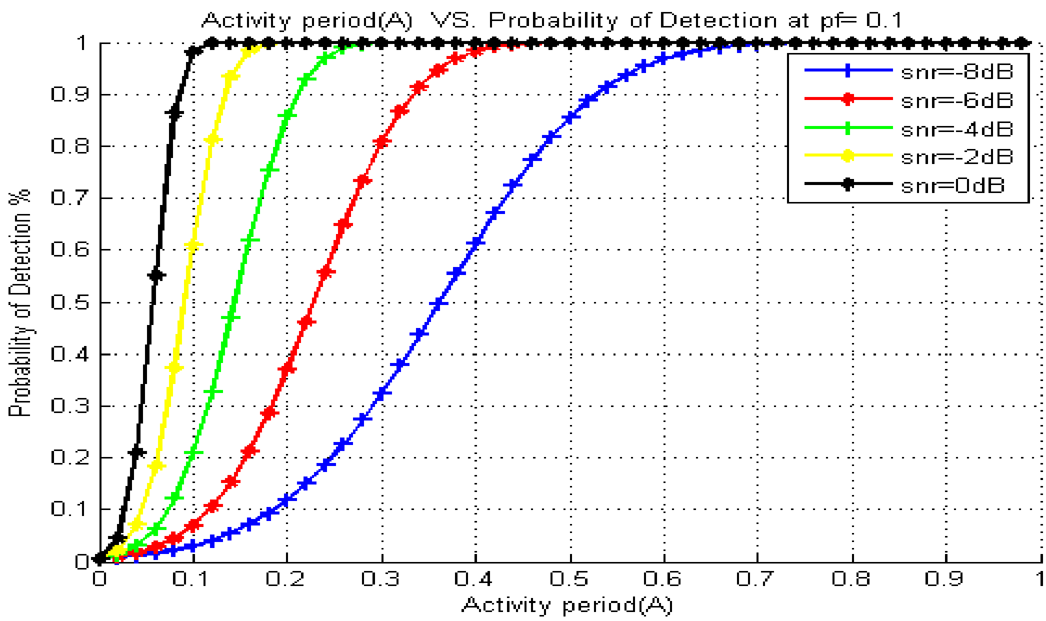

Fig. 4.1: Probability of Detection by varying (A) at different values of SNR PF= 0.1, L= 1000.

In Figure (4.1) the detection performance observed for the energy detector deviates from the default value of PD and PF for the stationary when the PU is actually non-stationary and exhibits an activity period.

It is noted that PD=100% when SNR= 0dB and PD==70% when SNR=-2dB for an activity period A=0.1, while P_{DA} is less than 25% when SNR is less than -5 and for the same activity period. For that case, the P_D increases as the signal-to-noise ratio increases, and vice versa. Likewise, the greater the activity period ratio is, the higher PD becomes, which indicates that the signal-to-noise ratio is related to the PU movement represented by an activity period A. Both factors may improve the PU signal detection process faster.

In Figure 4.2, it is found that the ratio of the PD increases with an increasing number of samples from L=1000 to L=2000 with repetition equal to 1000 to these samples at Activity period A=0.1. It has been observed that the PD has an increase proportion with the increase in number of samples or the length of the message. When SNR=-2, the detection increased and became PD=90% instead of 70% at the number of samples 1000, as in the earlier figure.

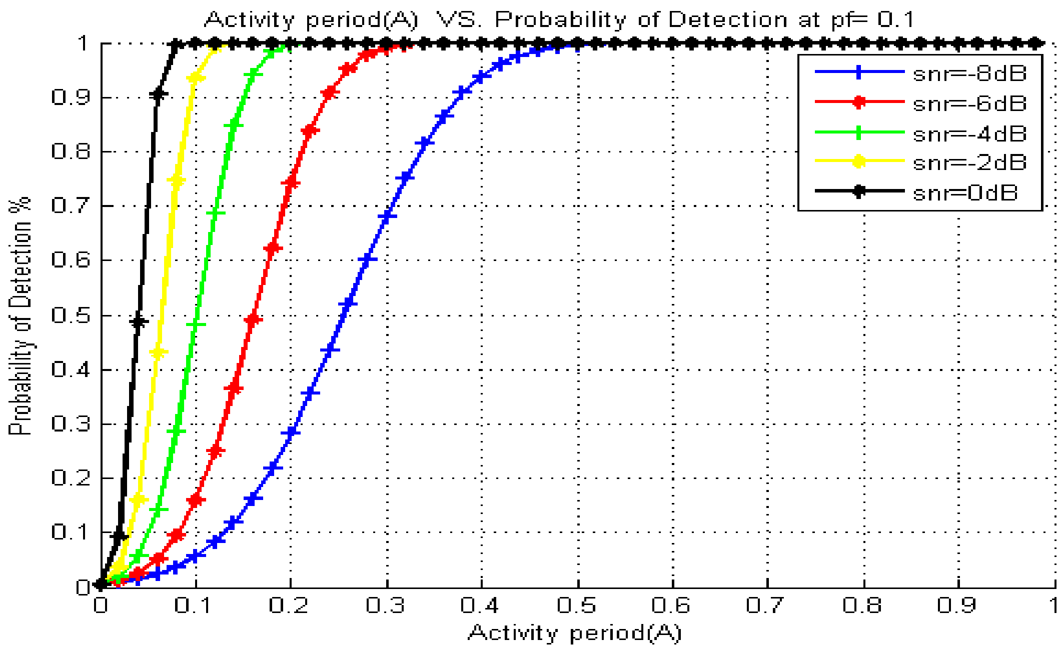

Fig. 4.2: Probability of Detection by varying (A) at different values of SNR PF = 0.1, L= 2000.

4.2.2 Simulation Performance of CR at Dynamic Factor

Figure (4.3) shows the PD against the dynamical threshold, when the value of constant false alarm rate PF=0.1, while the number of samples, in this case, is different. We may notice that the detection increases as the dynamic factor increase. The proposed method realized a good achievement in light of the reduced number of assumed samples with a low signal-to-noise ratio.

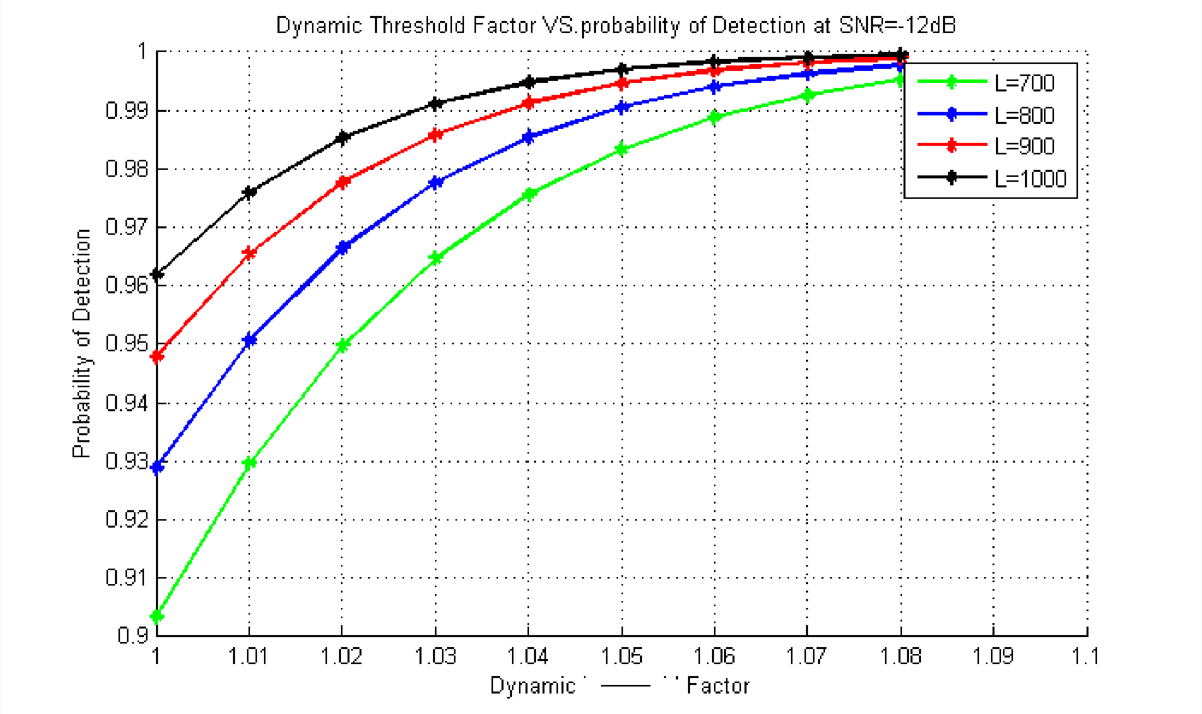

Fig. 4.3: Effect of Dynamic Factor on the PD with varying number of samples.

4.3 Evaluation of Detection Performance of the PU in CR System without Noise Uncertainty Factor

In this scheme, the detection system for CR is simulated on the basis of the received detecting signal energy at SU without the noise uncertainty factor, as the results were examined and confirmed by many different paths.

4.3.1 Simulation Performance of Activity period at dynamic threshold

Figure(4.4) shows the results of the performance of the detector through the relationship between the PD and the Activity period A, but here the dynamic threshold coefficient is used instead, which has been shown a significant improvement in the detection process. Table (4.2) shows the parameters and their designed values.

Table 4.2 the parameters for Detection at the Dynamic factor.

Parameters	**Values**
Number of samples	1000
SNR	-0dB, -2dB, -4dB, -6dB, -8dB
PF	0.1
Number of iterations	1000
Dynamic coefficient	1.02

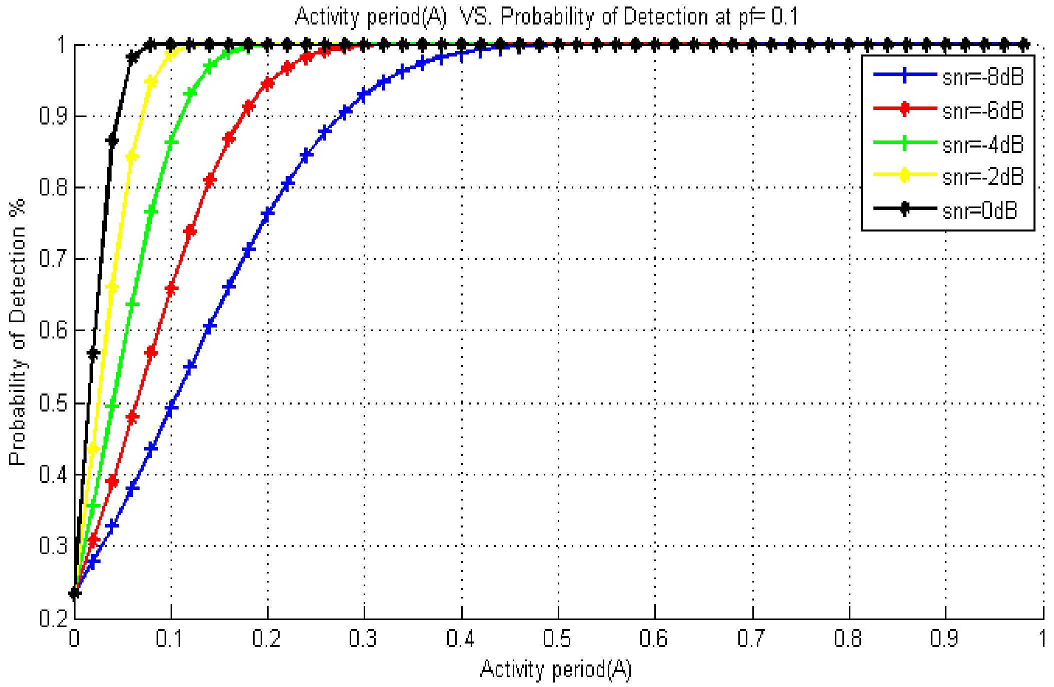

Fig. 4.4: Effect of Dynamic Threshold coefficient (d) on the Probability of Detection with varying SNR values (L=1000).

It is noted that PD = 99% approximately at SNR=-2dB, and the period of activity is A=0.1 with the number of samples L=1000. Through the dynamic coefficient d the detection has improved by 29%. The results showed that the dynamic threshold factor is responsible for the improvement in the detection process.

4.3.2 Simulation Performance of ED at Dynamic Threshold

The detection scheme evaluates a specific range of values of the PF by drawing the system Receiver Operation Characteristics (ROC). Figure (4.5) shows the curve for (1000) of repetitions, in light of the relationship between the PD and the PD. Table (4.3) presents the direct parameters designed.

Table 4.3: parameters of Detector for increase Dynamic threshold factor.

Parameters	**Values**
Number of Samples	1000
SNR	-12
Number of iterations	1000
Dynamic coefficient	1.01,1.03
PF	0.1

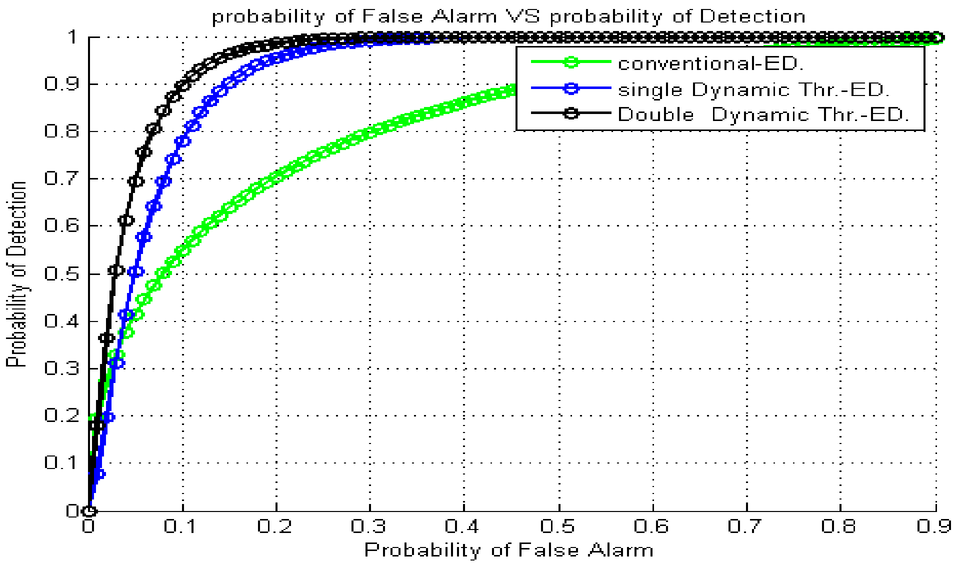

Fig. 4.5: ROC of fixed and dynamic threshold CR detection for d=1.01 and L= 1000.

It has been noticed that the detection probability level PD=55% at PF=0.1 when SNR=-12dB in the conventional fixed detection approach. The detection probability increased for PD=80% for the single dynamic detection approach at PF=0.1 with the same value to SNR, while the detection probability level reached PD=90% for the non-stationary detection system approach by double dynamic threshold at the same the values of the PF, as well as the value of SNR mentioned.

4.3.3 Simulation Performance of ED at Dynamic-Threshold with Activity period and Discussion

Figure (4.6) shows that the detection probability PD=55%, PD=95%, and PD=100% for stationary conventional detection, single dynamic threshold detection, and double dynamic threshold detection, respectively. The traditional detection remained the same while dynamic detection improved by 15% with a single dynamic threshold, and 20% with a double dynamic threshold once the dynamic coefficient increased by a rate of 0.02%.

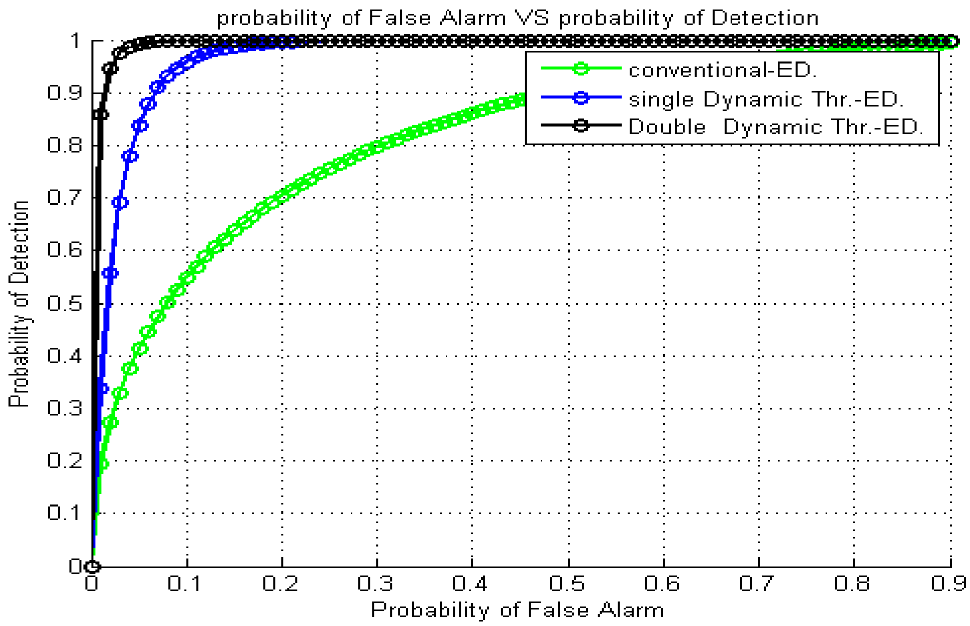

Fig. 4.6: ROC of fixed and dynamic threshold CR detection for d = 1.03 and L= 1000.

4.3.4 Simulation Performance of ED at Static and Dynamic Threshold Scheme with Static and Dynamic PU and Discussion

Figure 4.7 shows the relationship between the probability of detecting PD for a non-stationary PU signal at a specific percentage from the total observed period, represented by the values of the Activity period A and the false alarm probability PF. This is done so as to measure the benefit and effect of using the dynamic threshold on the detection probability as using the dynamic threshold increased the PD by 40% compared to the fixed threshold. Table (4.4) shows the special values for the operating parameters of the simulation process.

Table 4.4: parameters of Detector for Activity period with Dynamic threshold.

Parameters	Values
Number of samples	1000
SNR	-12
Dynamic coefficient	1.00 , 1.02
Activity period	0.5 , 0.6 , 0.7
PF	0.1
Number of iterations	1000

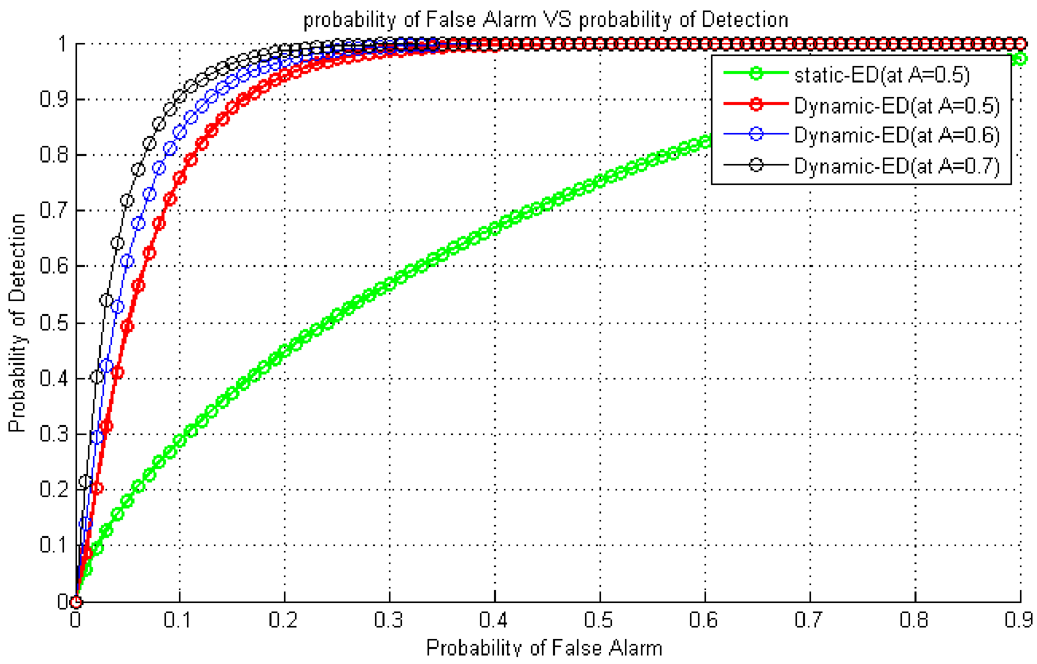

Fig. 4.7: Effect of dynamic threshold coefficient (d) and varying (*A*) values on ROC detection at L=1000 for CR systems.

The Receiver Operating Characteristics (ROC) is drawn to evaluate the performance of the non-stationary signal detection systems PD for 1000 repetitions. It supposes that the number of samples used L=1000 when SNR=-12dB. The results for the non-stationary PU signal and the static threshold (i.e. d=1.0), the PD is PD=30%, while PD=75% for the non-stationary PU and the dynamic threshold detection *d*=1.01, and the same goes for the other parameters.

On the other hand, it is observed that the PD increases with the increase in the Activity period(*A*) (that is, the value of *A* increases), which means that the probability of the PU being present in the radio spectrum increases during the total period of the observed signal. The simulation results show that PD=30% at *A*=0.6 while PD=75% at *A*=0.7. This indicates that the PU Activity period(*A*)in the radio spectrum has an effect on the signal detection process and has given a marked improvement to this task at the same value of the dynamic parameter d.

4.3.5 Simulation Performance of ED with a Different States for PU

The proposed detection equation (3.23) is used for the CR system to detect the signal energy within the parameters required. These parameters are presented in Table (4.5), chosen and tested according to the requirements of analysis. figure(4.8) is relationship between the PD and SNR.

Table 4.5: parameters of Detector with and without Activity period.

Parameters	Values
Number of sample	1000
PF	0.1
Dynamic Coefficient	1.01
Activity period	0.0, 0.1
Number of iteration	1000

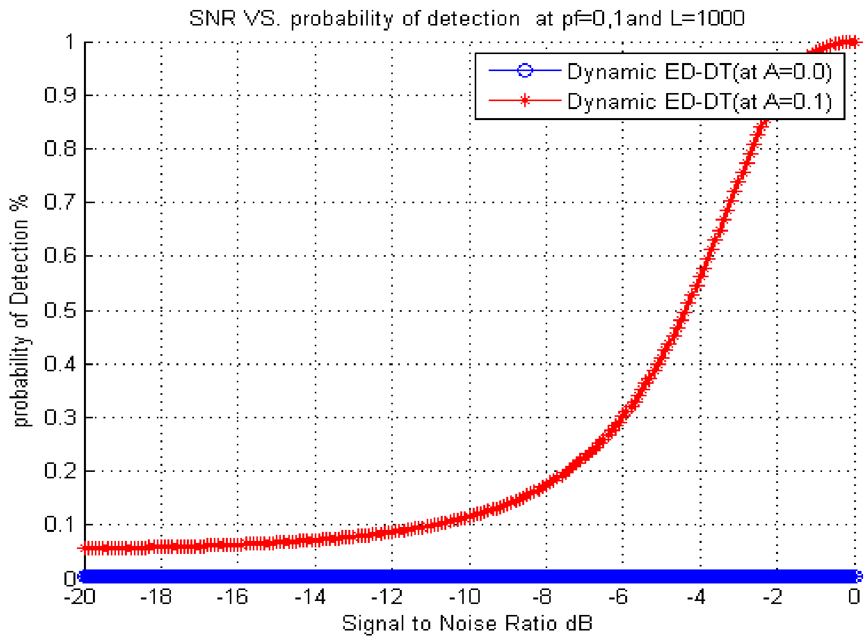

Fig. 4.8: The relationship between the PD and SNR =-12dB (L=1000, N=1000).

It is observed that whenever the Activity period is zero, the PU is not present in the radio spectrum and the detected signal is the noise signal only. Otherwise, whenever an Activity period exists for the PU (as A=0.1), this implies that the PU exists partially within the spectrum during the observed period (as appeared in the spectrum later on).

4.3.6 Simulation Performance of ED at Static and Dynamic Threshold Scheme for Non-stationary PU and Discussion

Figure (4.9) shows the relationship between SNR and the PD, where detection algorithms are simulated such as the traditional detection algorithm and dynamic detection algorithms. It is noted that the simulation results are shown so that the more dynamic the signal is the better the detection.

Table 4.6: parameters of Detector for the different Activities period.

Parameters	Values
Number of sample	1000
Activity period	0.5 , 0.6 , 0.7
PF	0.1
Number of iteration	1000
Dynamic Coefficient	1.01

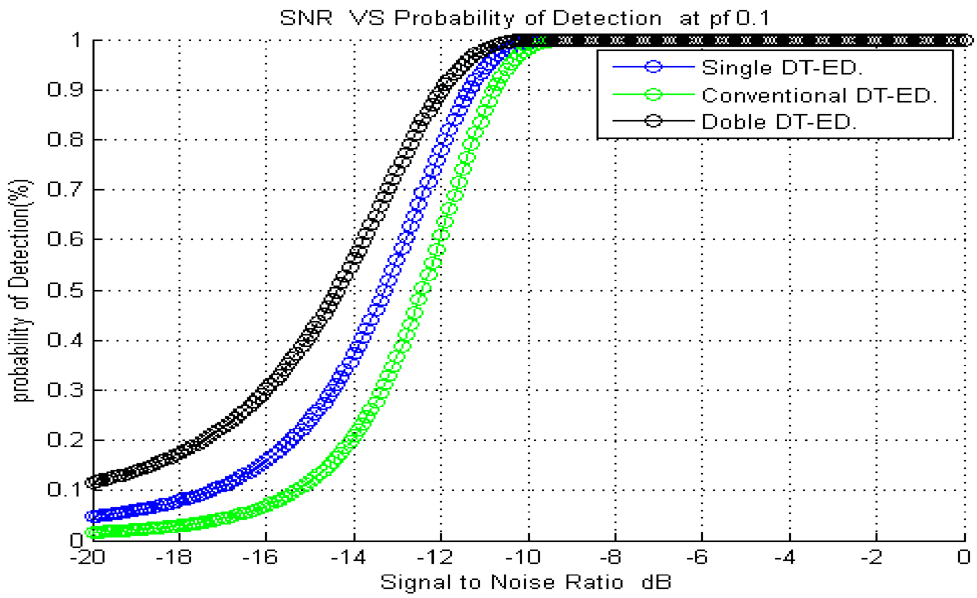

Fig. 4.9: Relation between SNR and PD (L=1000 at PF =0.1

In the conventional detection algorithm, the detection ratio PD=90% is at SNR=-11dB when is PF=0.1, and the detection algorithm with a single dynamic threshold was PD=90% at SNR=-11.7dB, while this detection PD=90% at SNR=-12dB has been achieved in the detection algorithm with the double dynamic threshold. It has been observed that this ratio (i.e. PD=90%) was achieved with a lower signal-to-noise ratio, thereby showing that the dynamic algorithm is better than the traditional algorithm for energy detection.

At the same length of the message (i.e. L=1000) the detector is tested to reveal the dynamic primary user signal (as shown in Fig. 4.10) where various periods of Activity are dealt with but the dynamic coefficient remains at the same value (i.e. d=1.01). The results indicate that the dynamic detection test is better than the results of the fixed detection test of the non-stationary user, where it has been noted that the PD=90% at SNR>-8dB when PF=0.1 is with the use of the fixed threshold, while this ratio (i.e. PD=90%) at SNR=-8.5dB is achieved with the use of the dynamic threshold when the PU is partially present in the radio spectrum. As A=0.5 is true for both of them, it is also noted that

PD=90% was achieved at SNR=-9dB when A=0.6 and PD=90% at SNR=-11dB when A=0.7, and so on.

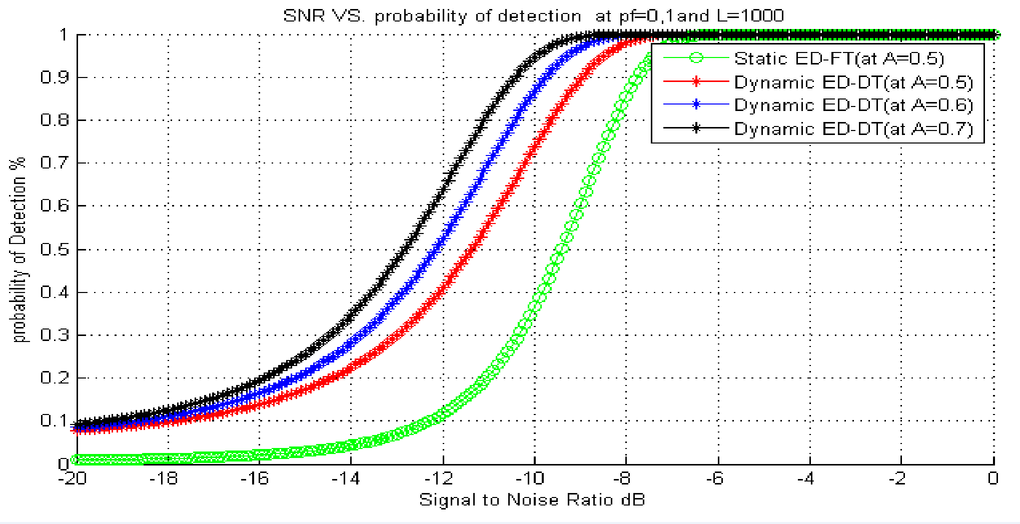

Fig. 4.10 Relation between SNR and probability of detection with different *A* L=1000 and PF =0.1

The results of using the detection algorithms of dynamic threshold are relatively better than those of using detection algorithms of a fixed threshold and non-stationary user.

4.4 Noise Uncertainty Factor and Evaluation of Detection Performance of the PU in CR System

In previous analysis and simulations, it is assumed that there was no noise uncertainty coefficient. The fact that this factor is not always present in practice, as there cannot always be noise, so it is sometimes assumed that p = 1. However, in this current part, the effect of the uncertainty factor is assumed to be present P>1, as it is taken into account that it is an important parameter. The radio spectrum sensor becomes more effective and reliable in the PU signal detection scheme, and is also more probable.

4.4.1 Simulation Performance of CR at Noise Uncertainty Factor

Figure (4.11) shows the PU against the Noise Uncertainty coefficient, when the value of constant false alarm rate PF=0.1, Due to the difference in the number of samples in the case, it can be seen that the detection decreases with an increase in the noise uncertainty coefficient and also changes with the length of the received message. The method accomplished well despite the presumed number of samples reduced, in addition to the low signal-to-noise and the dynamic coefficient value. Through the values of the parameters presented in Table (4.7), the simulations were performed.

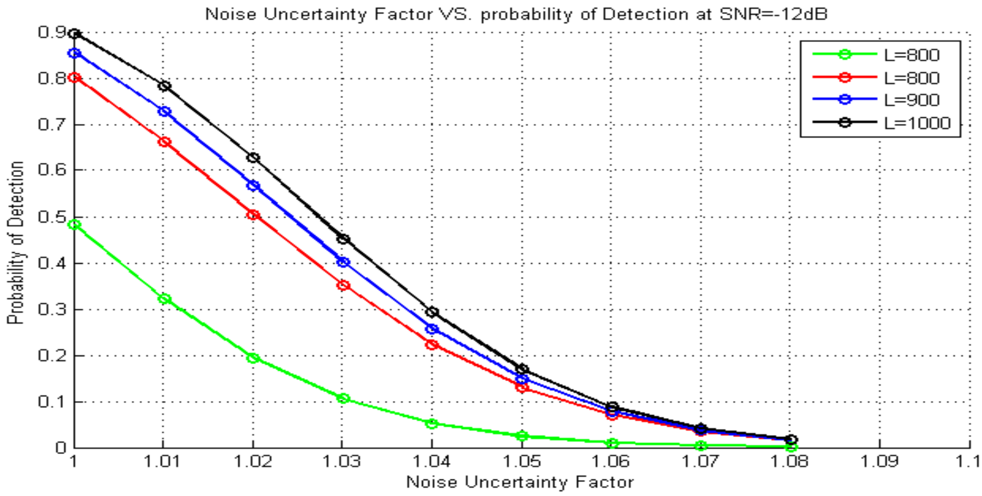

Fig. 4.11: Effect of Noise Uncertainty Factor on the Probability of Detection with varying Number of Samples.

It is noted that the results of the detection PD=32% at P=1.01 and the dynamic Factor d=1, but when the dynamic coefficient is greater than one d=1.01 it seems that the detection increased by 35% to become 67% at p=1.01. The detection also increases with the increase in the number of samples to L=900, as the detection PD=73% became later PD=80% at L=1000 samples, and therefore. The detection decreases with increasing noise uncertainty coefficient, but increases with increasing dynamic coefficient as well as number of samples observed.

4.4.2 Simulation Performance of CR with Effect Noise Uncertainty Factor at Activity Period and Discussion

Figure (4.12) corresponds to Fig. (4.4) in some form, where the relationship between the period of the main user activity and the PD is represented. But, in the current analysis and simulations, the noise uncertainty factor is included in the detection equation. The parameters were selected according to the requirements of the analysis and tested as follows:

Table 4.7: Detector parameters when there is an uncertainty factor.

Parameters	Values
Number of samples	1000
Noise Uncertainty factor	1.01
Dynamic coefficient	1.02
Activity period	0.5 ,0.6 ,0.7
Number of iteration	1000

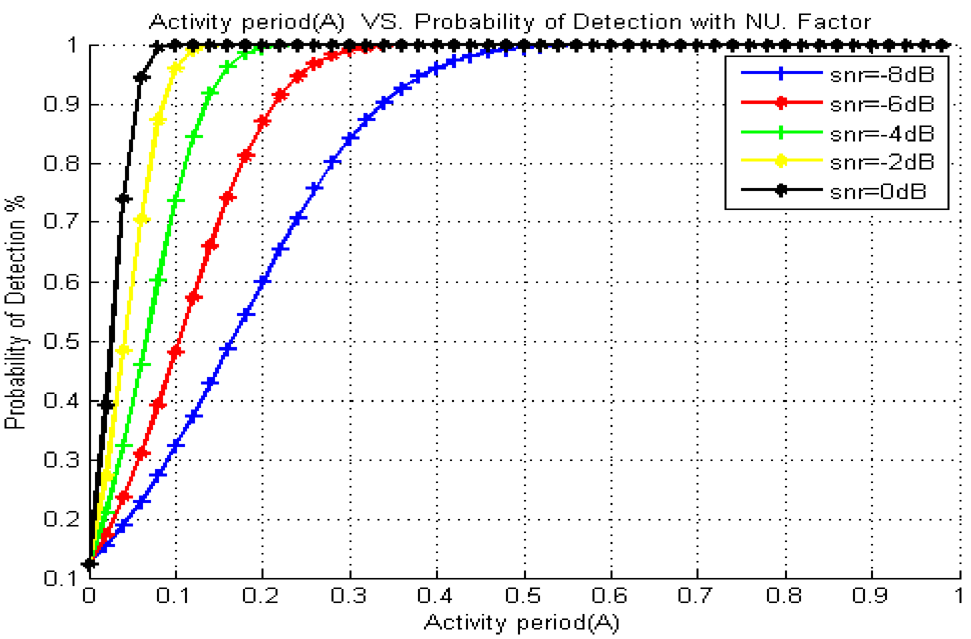

Fig.4.12. Effect of Noise Uncertainty coefficient (p) on the Probability of Detection with varying SNR values and L=1000.

In figure (4.4), it seems that the value of PD=99% at SNR=-2dB when A=0.1 and the number of samples L=1000, while the ratio is lower when the noise factor P is greater than one, as it became PD=94% instead of PD=99% at

SNR=-2dB. The percentage decreased by 5% when using the same values for other parameters, as well as the dynamic factor d, which is the greater than in both formats.

4.4.3 Simulation Performance of ED with Effect NU on the Detection and Discussion

The new formula includes a noise uncertainty coefficient within the detection pattern. The results are shown in Fig. (4.13). Although the same message length L=1000 samples is assumed in Fig. (4.10), yet the detection ratio is affected by the presence of this factor, as it is also noticed that the detection ratio decreases with an increase in the ratio of the noise factor. It has been assumed than P is greater than one , so that the detector is more realistic and practical.

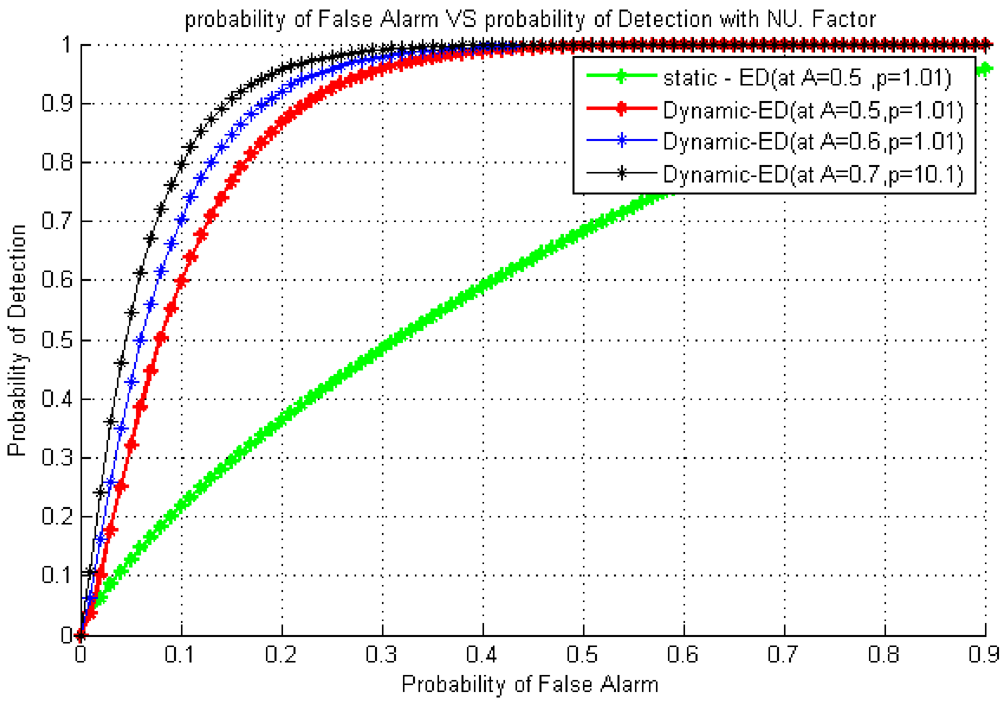

Fig. 4.13: Effect of Noise Uncertainty Factor (NU) with dynamic threshold and varying (*A*) values on ROC detection at L=1000 for CR system.

The simulation was achieved via the Additive White Gaussian Noise channel with the number of samples during the detection period at L=1000 and the signal-to-noise ratio being (-12dB).

In the first case, the ratio of detection has become PD=21% approximately at PF=0.1 when the activity period A=0.5 and the dynamic factor d=1. The ratio of detection, on the other hand, increases with the increase in the dynamic factor to d=1.02 to become PD=60% at the same probability ratio of the Activity period (A=0.5). In the second case, an increase in the detection ratio was noticed, as it became PD=80% with an increase in the probability ratio of Activity period (A=0.7), where the detection increased by 10%, at PD=60% and A=0.6, although the dynamic factor remained the same (d=1.02) for both. It turns out that the detection increases with two factors: the dynamic factor (d) and the Activity period factor (A).

4.4.4 Simulation Performance of ED with Effect NU on the SNR

Figure (4.14) shows a graph of the PD versus SNR with the presence of the noise uncertainty coefficient and the number of repetitions N=1000 at PF=0.1, and the number of samples L=1000. According to the graphic shown below, the detection ratio decreased with the presence of the noise factor along with the signal, as this factor increases with the decrease in detection and vice versa. The simulation was done based on the parameter values in Table (4.7) above.

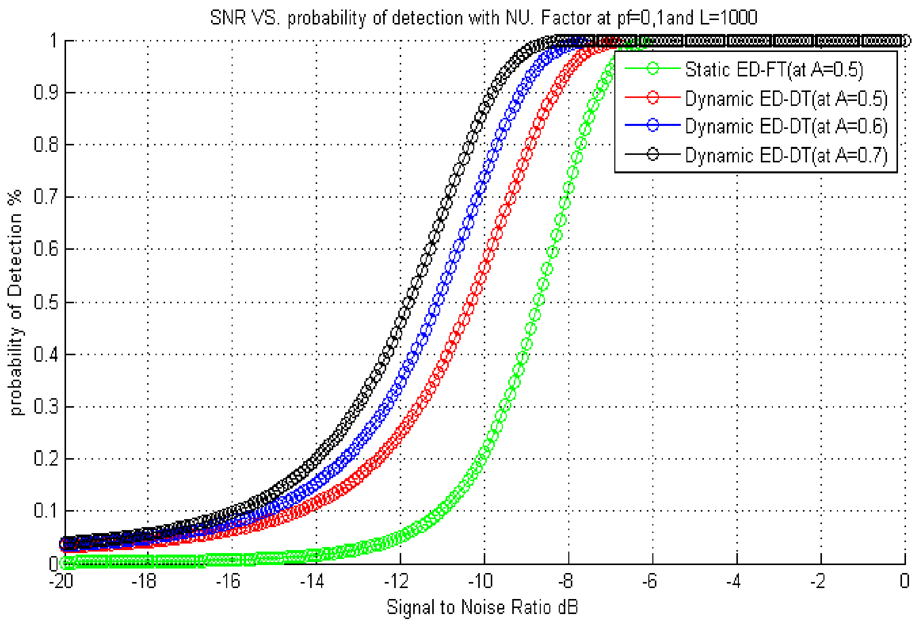

Fig. 4.14 Effect of Noise Uncertainty factor (NU) and relation between SNR and PD with different *A* at message L=1000 and PF =0.1.

This figure represents a positive correlation between the PD (PD) and the signal-to-noise ratio(SNR), where the PD increases with an increase (SNR).

It is noted that when using the Fixed threshold (λ), it is obtained PD=90% at SNR=-7dB and for an Activity period (A=0.5dB) while this ratio (i.e. PD=90%) can be obtained at (SNR=-8.4dB) when using the dynamic threshold at the same Activity period(A). In the other case, the detection increases with the increase in the Activity period, as When the activity period (A=0.6) can be obtained (PD=90%) at (SNR=-9.5dB) approximately, while (PD=90%) can be obtained at (SNR=-10dB) and for a period of Activity (A=0.7). It appears that the detection improves with the increase in Activity period.

Although the signal detection improves with an increase of the period of PU activity and dynamic coefficient, yet it decreases with the increase in noise factor.

CHAPTER FIVE

CONCLUSIONS

5.1 Conclusion

This thesis presents a study of the performance of the radio spectrum sensing through the CR system, where work has been done to detect PU by using the energy-sensing schemes to sensing the spectrum holes. Detection schemes, such as; A scheme of using a dynamic threshold instead of a static threshold for the dynamic PU detection. This scenario is the most realistic approach for PU detection because it always has the freedom to use its assigned channels in the spectrum. In this scheme, the noise uncertainty factor (i.e. p=1) is neglected. The effect of the dynamic threshold on the detection results is studied, as well as the movement of the PU interaction with the detection, and its effect. The other scheme of the detection takes into account the fluctuation of the noise uncertainty factor (p>1) .

The results with the proposed detection algorithms is indicate a positive relationship between the PU Activity(A) and the dynamic threshold factor with percentage of the detection , as the detection improves significantly when there is a slight change in the value of the dynamic threshold factor and the increase in the PU activity gives positive change in the detecting performance also. and as well as, dynamic factor(d) solves the problem of noise uncertainty, as the conventional detection is less than (30%), while it becomes within limits(80%) with dynamic detection with there is fluctuation in the noise level (p>1), and also the detection ratio in conventional detection is less than (40%) when (PF=0.1) And (SNR=-12dB) while improving to become (90%) with dynamic detection.

The results show a clear improvement in dynamic detection performance using a dynamic threshold compared to conventional detection using a static threshold For dynamic PU detection as well as in case of noise fluctuation.

5.2 Future Works

Based on this work and summaries of the some that has previously been conducted in this field, we conclude that there are still many, many scenarios and experiences through which the detection process can be improved. Some suggestions and principles for future research are as follows:

1. Through the existing simulation results, it is possible to work on implementing them by applying the algorithms practically.
2. In this work, these algorithms were used to detect one PU. To enhance detection schemes, a group of PUs can be used to increase the reliability of the detection algorithm.
3. The proposed detection has been applied to an AWGN channel, it could be tried on other channels.
4. The proposed detection algorithms can be implemented on one of the other detection methods and compared with the results of the energy detector used in this thesis, probably better detection results may be obtained.

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الخلاصة

تقدم هذه الرسالة دراسة لأداء استشعار الطيف الراديوي من خلال نظام CR ، حيث تم العمل على الكشف عن PU باستخدام مخططات استشعار الطاقة وذلك لأستشعار ثقوب الطيف. مخططات الكشف ، مثل ؛ مخطط استخدام عتبة ديناميكية بدلاً من عتبة ثابتة لاكتشاف PU الديناميكي. هذا السيناريو هو النهج الأكثر واقعية لاكتشاف PU لأنه يتمتع دائمًا بحرية استخدام القنوات المخصصة له في الطيف. في هذا المخطط ، تم إهمال عامل عدم التأكد من الضوضاء (أي p = 1). تمت دراسة تأثير العتبة الديناميكية على نتائج الكشف وكذلك تفاعل حركة المستخدم الأولي وتأثيره على الكشف. يأخذ المخطط الآخر للكشف في الاعتبار تذبذب عامل عدم التيقن من الضوضاء (p> 1). تشير النتائج باستخدام خوارزميات الكشف المقترحة إلى وجود علاقة إيجابية مترابطة بين نشاط المستخدم الأولي (A) وعامل الحد الديناميكي مع النسبة المئوية للكشف ، حيث يتحسن الاكتشاف بشكل كبير عندما يكون هناك تغيير طفيف في قيمة عامل الحد الديناميكي زيادة نشاط PU تؤدي الى تغيير إيجابي ملحوظ في أداء الكشف أيضا. وكذلك العامل الديناميكي (d) يحل مشكلة عدم التأكد من الضوضاء حيث أن الكشف التقليدي أقل من (30٪) بينما يصبح ضمن حدود (80٪) مع الكشف الديناميكي مع وجود تذبذب في مستوى الضوضاء (p> 1) وكذلك نسبة الكشف في الكشف التقليدي أقل من (40٪) عند (PF = 0.1) و (- = SNR 12dB) مع التحسن لتصبح (90٪) بالكشف الديناميكي.

تظهر النتائج تحسنًا واضحًا في أداء الكشف الديناميكي باستخدام عتبة ديناميكية مقارنة بالكشف التقليدي باستخدام عتبة ثابتة لاكتشاف PU الديناميكي وكذلك في حالة تذبذب الضوضاء.

هورية العراق

وزارة التعليم العالي والبحث العلمي

جامعة الفرات الاوسط التقنية

الكلية التقنية الهندسية _ نجف

تحسين أداء الكشف لحركة المستخدم الاساسي شبكات الراديو الأدراكية

رسالة مقدمة الى

قسم هندسة تقنيات الاتصالات

جزء من متطلبات نيل درجة الماجستير في هندسة الاتصالات

تقدم بها

الطالب: عقيل حسن حميد

بكالوريوس في هندسة الاتصالات

بإشراف

أ.م.د. بشار جبار حمزة **أ.م.د. وسن كاظم سعد**

تموز / ٢٠٢٠