



Sudan University of Science and Technology
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School of Electronics Engineering

**Comparative of Spectrum of spectrum sensing
Techniques Energy Detection and matched filter**

مقارنة بين حساسات الطيف (كاشف الطاقة وكاشف المرشح)

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Degree of B.Sc. (Honors) in Electronics Engineering*

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قال تعالى:

﴿قَالُوا سُبْحَانَكَ لَا عِلْمَ لَنَا إِلَّا مَا عَلَّمْتَنَا إِنَّكَ أَنْتَ الْعَلِيمُ الْحَكِيمُ﴾^١

صدق الله العظيم

Dedication

To

The guide of our life...

Prophet Mohammed "Sala allah alihi wa salm"

The reason of our existence...

Our family.

Our colleges...

Sudan University of Science and Technology...

School of Electronic Engineering ...

We Dedicate Our Effort...

Acknowledgements

we grateful to the creator who taught the names to Adam and gave human being authority to pass beyond the zones of heavens and earth, without his blessing and mercy, this project would not have been possible

We also owe our deepest gratitude to our families for their constant support and encouragement. It is my pleasure to thank all those who made this project possible. We heartily thankful to my supervisor Dr Sami H.O. Salih.

Lastly, I offer our regards to all of those who supported our in any respect during the completion of the project.

Abstract

The growing demand of wireless applications has put a lot of constraints on the usage of available radio spectrum which is limited and precious resource. Cognitive radio is a promising technology which provides a novel way to improve utilization efficiency of available electromagnetic spectrum.

Spectrum sensing is a technique in which the surrounding radio environment is sensed in order to determine the presence or absence of the licensed user in the licensed band. It enables the CR to get an overview on the radio environment usage and in determining the spectrum holes .spectrum sensing consider is main function in cognitive radio.

In this project, studied of some spectrum sensing techniques and analyses performance Energy detector and matched filter in detection probability and false alarm probability their relationships. Used this parameters for performance evaluation between them and design simulation in different scenarios and select best environment when combination of two technique.

المستخلص

مع تنامي و زيادة الطلب علي التطبيقات اللاسلكية نتيجة لذلك يتم حجز معظم الطيف الراديوي المتوفر .واقترح لحل المشكلة باستخدام الراديو الإدراكي .هو تكنولوجيا تزيد من كفاءة استخدام الطيف الراديوي .

تقوم تقنية حساسات الطيف بتحسس البيئة وتقرر حضور أو غياب المستخدم الأساسي المسموح له استخدام النطاق وتعتبر حساسات الطيف أهم وحده من مكونات الراديو الإدراكي.

في هذا المشروع يتم تحليل طريقة عمل كشف طاقة وكشف المرشح و حساب احتمالية اكتشاف الصحيح والإنذار الخطأ في نفس السيناريو.

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LIST OF Symbol

A	threshold.
P_d	probability of detection.
P_{fa}	probability of False alarm.
$P_{D.M.F.D}$	probability of detection of matched filter detection
$P_{F.M. F.D}$	probability of false alarm of matched filter detection
N	number of sample.
Γ	signal to noise ratio SNR.
$Q(.)$	the Gaussian complementary distribution function.
$W[n]$	additive white Gaussian.
$X[n]$	signal samples.
H_0	signal absent
H_1	signal present

ABBREVIATIONS

CR	Cognitive Radio
CDMA	Code <i>Division Multiplexing Access</i>
DARPA	Defiance Advanced Research Project Agency
<i>ED</i>	<i>Energy Detection</i>
EDGE	Enhanced Data rates for GSM Evolution,
FCC	Federal Communications Commission
GSM	Global System for Mobile communications
IEEE	Institute of Electrical and Electronics Engineers
LO	<i>Local Oscillator</i>
MBMS	Multimedia Broadcast and Multicast Services
<i>MFD</i>	<i>Matched Filter Detection</i>
MMITS	modular Multifunction Information Transfer Systems
OFDMA	Orthogonal Frequency Division Multiplexing Access
PU	Primary Users
PDA's	personal digital assistants
<i>QOS</i>	<i>Quality of Service</i>
<i>RF</i>	<i>Radio Frequency</i>
SDR	Software Defined Radio
SS	Spectrum Sensing
SU	Secondary Users
SNR	<i>Signal to Noise Ratio</i>
TDMA	<i>Time Division Multiplexing Access</i>

WiMAX	Worldwide Interoperability for Microwave Access
WCMA	wide band code <i>Division Multiplexing Access</i>

CHAPTER ONE

INTRODACTION

1.intrudocion

1.1 preface:

With the development of a host of new and ever expanding wireless applications and services, spectrum resources are facing huge demands.. As day passes demand for spectrum are expected to increasing rapidly and it would get in future. As more and more technologies are moving towards fully wireless system.[1]

Most of the primary spectrum is already assigned, so it becomes very difficult to find spectrum for either new services or expanding existing services.

Recently there has been great interest in re-evaluating the spectrum usage policy. One way to increase the utilization of spectrum is by building smarter radios that can detect temporal and spatial “holes” in the spectrum These radios have been termed Cognitive Radio (CR).[2]

Cognitive radio is a novel technology which improves the spectrum utilization by allowing secondary user to borrow unused radio spectrum from primary licensed users or to share the spectrum with the primary users. As an intelligent wireless communication system, cognitive radio is aware of the radio frequency environment, selects the communication parameters (such as carrier frequency, modulation type, bandwidth and transmission power) to optimize the spectrum usage and adapts its transmission and reception accordingly.[3].

Cognitive Radio (CR) technology have been proposed since it represents one of the most promising solution for the improvement of the resource utilization. From a technical point of view, CR draws upon the concept of Software Defined Radio (SDR), enhancing its .

reconfigurability and multi-standard management with self-adaptation capabilities to dynamic environments . In cognitive radio terminology, *primary users* can be defined as the users who have higher priority or legacy rights on the usage of a specific part of the spectrum. On the other hand, *secondary users*, which have lower priority, exploit this spectrum in such a way that they do not cause interference to primary users. Therefore, secondary users need to have cognitive radio capabilities, such as sensing the spectrum reliably to check whether it is being used by a primary user and to change the radio parameters to exploit the unused part of the spectrum.[4]

spectrum sensing by far is the most important component for the establishment of cognitive radio. Spectrum sensing is the task of obtaining awareness about the spectrum usage and existence of primary users in a geographical area.

Spectrum sensing is the ability to measure, sense and be aware of the parameters related to the radio channel characteristics, availability of spectrum and transmit power, interference and noise, radio's operating environment, user requirements and applications, available networks (infrastructures) and nodes, local policies and other operating restrictions[5].

we present signal detection techniques for spectrum sensing by categorizing into three follow.

- **Primary transmitter detection:**
- **Primary receiver detection:**
- **Interference temperature management**

1.2 Problem Statement:

Different Spectrum sensing techniques have been use to detect the presence of the primary users. Each of them comes with pros and cons.

The purpose of the project is to evaluate matched-filter and energy detection as spectrum sensing techniques used in cognitive radio network in terms of probability of false alarm and probability of detection.

1.3 Proposed solution:

A test-bed is to be developed to evaluate the performance of energy detection and matched filter detection.

Different scenarios are used to.

1.4 methodology:

evaluate the performance of energy detection and matched filter detection. Make designed and simulated of them in MATLAB® software. MATLAB® offers an easy interactive environment and fast mathematical algorithms. It allows matrix handling, plotting of functions and data, and algorithm implementations.

1.5 Thesis Outline:

In the Chapter Two, introduces background information related to the real-time implementation, which provides and explanation of the concept of software defined radio system and concept of cognitive radio and its basic properties are introduced.

The third This chapter also includes the details of spectrum sense (SS) algorithms used in this implementation.

The sensing algorithms are explained with analytical models and the analytical performance of different sensing algorithms is also briefly discussed.

The fourth chapter provides the implementation details of ED based SS and MFD. It provides the detailed information about how the transmitter and receiver are implemented, with graphs and instructions., result of implementation of matched filter an energy detection and shown in figures. Evaluate simulation results providing SNR versus detection probability, in order to show the detection performance with different SNR values.

The last chapter provides a brief conclusion based on the measurements results provided in Chapter 4, as well as a discussion about possible future improvements of the implementation and future research topics.

CHAPTER TWO

COGNITIVE RADION NETWORK

2.cognitive radio network

2.1 background:

The chapter parameters encompasses the background work of software defined radio , cognitive radio and cognitive radio network .

2.2.1 Software Defined Radio (SDR):

SDR is defined as “radio in which the radio frequency (RF) operating including, but not limited to, frequency range, modulation type, or output power can be set or altered by software, and/or the technique by which this is achieve.[6]

SDR IS collection of hardware and software technologies that enable reconfigurable system architectures for wireless networks and user terminals. Through programmatic reconfiguration, radio hardware can be reset over time to perform varying functions. This sets the stage for common platform technologies supporting varied infrastructure services, and would enable better scalability, reusability, interoperability, and portability of platforms and waveforms.

SDR may provide flexible ,upgradeable and longer lifetime radio equipment for military and for civilian wireless communication infrastructure.

SDR represents a very flexible and general radio platform that is capable of operating with many different bandwidths over a wide range of frequencies and using many different modulation and waveform formats. As a result, SDR can support multiple standards, i.e., GSM, EDGE, WCDMA, CDMA2000, Wi-Fi, WIMAX and multiple access technologies such as Time Division Multiple Access (TDMA) Orthogonal Frequency Division Multiple Access (OFDMA).

SDR is used to minimize hardware requirements; it gives user a cheaper and reliable solution. But it will not take into account spectrum availability. Cognitive Radio (CR) is newer version of SDR in which all the transmitter parameters change like SDR but it will also change the parameters according to the spectrum availability.[7]

2.2.2 background of SDR:

The term "software radio" was coined in 1984 by a team at the Garland, Texas Division of E-Systems Inc. (now Raytheon) to refer to a digital baseband receiver and published in their E-Team company newsletter. A 'Software Radio Proof-of-Concept' laboratory was developed there that popularized Software Radio within various government agencies. This 1984 Software Radio was a digital baseband receiver that provided programmable interference cancellation and demodulation for broadband signals, typically with thousands of adaptive filter taps, using multiple array processors accessing shared memory.[8]

In 1991, Joe Mitola independently reinvented the term software radio for a plan to build a GSM base station that would combine Ferdensi's digital receiver with E-Systems Melpar's digitally controlled communications jammers for a true software-based transceiver. E-Systems Melpar sold the software radio idea to the US Air Force few months after the National Tele systems Conference 1992, in an E-Systems corporate program review, a VP of E-Systems Garland Division objected to Melpar's (Mitola's) use of the term "software radio" without credit to Garland. Alan Jackson, Melpar VP of marketing at that time asked the Garland VP if their laboratory or devices included transmitters. The Garland VP said "No, of course not — ours is a software radio receiver". Al replied "Then it's a digital receiver but without a

transmitter, it's not a software radio." Corporate leadership agreed with Al, so the publication stood. Many amateur radio operators and HF radio engineers had realized the value of digitizing HF at RF and of processing it with Texas Instruments TI C30 digital signal processors (DSPs) and their precursors during the 1980s and early 1990s. Radio engineers at Roke Manor in the UK and at an organization in Germany had recognized the benefits of ADC at the RF in parallel, so success has many fathers. Mitola's publication of software radio in the IEEE opened the concept to the broad community of radio engineers. His landmark May 1995 special issue of the IEEE Communications Magazine with the cover "Software Radio" was widely regarded as watershed event with thousands of academic citations. Mitola's was introduced by Joao da Silva in 1997 at the First International Conference on Software Radio as "godfather" of software radio in no small part for his willingness to share such a valuable technology "in the public interest."

The term "software defined radio" was coined in 1995 by Stephen Blust, who published a request for information from Bell South Wireless at the first meeting of the Modular Multifunction Information Transfer Systems (MMITS) forum in 1996

2.2.3benefits of SDR technology:

- New features and capabilities to be added to existing infrastructure without requiring major new capital expenditures allows service providers to quasi-future proof their networks.
- The logistical support and operating expenditure can be reduced significantly with the use of a common radio platform for multiple markets.

- Remote software downloads through which capacity can be increased, capability upgrades can be activated and new revenue generating features can be inserted.
- A family of radio products to be implemented using a common platform architecture allows new products to be faster introduced into the market.
 - Software to be reused across radio products reduces development costs dramatically.
 - Remote reprogramming allows ‘bug fixes’ to occur while a radio is in service, whereas the time and costs associated with the operation and maintenance can be reduced.
- Reduce costs in providing end users with access to ubiquitous wireless communications.[9]

2.3 Cognitive Radio (CR):

Cognitive Radio (CR) is a form of wireless communication in which a transceiver can intelligently detect the spectrum band in which channels are in use and which are not, and can then instantaneously move to vacant channels thus avoiding occupied ones. This optimizes the use of available radio-frequency (RF) spectrum whilst reducing interference to other users. The main objectives for cognitive radio are highly reliable communication wherever and whenever needed, and efficient utilization of the radio frequency spectrum

The idea behind cognitive radio was first presented by Joseph Mitola at the Defense Advanced Research Project Agency (DARPA) in the United States . Radio spectrum is a natural resource, the exploitation of which is licensed by government. In November 2002, the Federal Communications Commission (FCC) published a report by the spectrum-policy task force , which showed that radio spectrum is

extremely underutilized. Cognitive Radio offers a novel technique of solving this underutilization problem.

Cognitive radio: A radio or system that senses its operational electromagnetic environment and can dynamically and autonomously adjust its radio operating parameters to modify system operation, such as maximize throughput, interference, facilitate interoperability, access secondary markets". In a cognitive radio system a primary system operated in the licensed band has the highest priority to use that frequency band (e.g. 3G/4G cellular, digital TV broadcast) . Other unlicensed users/systems can neither interfere with the primary system in an Intolerable way nor occupy the license band.[10]

Cognitive modules in the transmitter and receiver must work in a harmonious manner which is achieved via a feedback channel connecting them. Receiver is enabled to convey information on the performance of the forward link to the transmitter. Thus CR by necessity is an example of a feedback communication system[11].

2.3.1 Back ground of CR:

The concept of cognitive radio was first proposed by Joseph Mitola's III in a seminar at KTH (the Royal Institute of Technology in Stockholm) in 1998 and published in an article by Mitola and Gerald Q. Maguire, Jr. in 1999. It was a novel approach in wireless communications, which Mitola later described as:

The point in which wireless personal digital assistants (PDAs) and the related networks are sufficiently computationally intelligent about radio resources and related computer-to-computer communications to detect user communications needs as a function of use context, and to

provide radio resources and wireless services most appropriate to those needs.

Cognitive radio is considered as a goal towards which a software - defined radio platform should evolve: a fully reconfigurable wireless transceiver which automatically adapts its communication parameters to network and user demands.

Traditional regulatory structures have been built for an analog model and are not optimized for cognitive radio. Regulatory bodies in the world (including the Federal Communications Commission in the United States and OFCOM in the United Kingdom) as well as different independent measurement campaigns found that most radio frequency spectrum was inefficiently utilized. Cellular network bands are overloaded in most parts of the world, but other frequency bands (such as military, amateur radio and paging frequencies) are insufficiently utilized. Independent studies performed in some countries confirmed that observation, and concluded that spectrum utilization depends on time and place. Moreover, fixed spectrum allocation prevents rarely used frequencies (those assigned to specific services) from being used, even when any unlicensed users would not cause noticeable interference to the assigned service. Regulatory bodies in the world have been considering whether to allow unlicensed users in licensed bands if they would not cause any interference to licensed users. These initiatives have focused cognitive-radio research on dynamic spectrum access.[7]

2.3.2 Main Functions :

2.3.2.1. Spectrum Sensing: this is a fundamental function in CR to enable cognitive radio users (CRs) to detect the underutilized spectrum of primary systems and improve overall spectrum efficiency.

2.3.2.2 Spectrum Management: functions are required for CR to achieve user's communication needs by capturing the best available spectrum; CR should decide on the best spectrum band and the channels within it to meet the QOS requirements over all available spectrum channels

2.3.2.3. Spectrum Mobility: this is the process whereby cognitive radio users change their frequency of operation. Cognitive radio networks aim to use the spectrum dynamically by allocating the radio terminals to operate in the greatest available frequency channels

2.3.2.4. Spectrum Sharing: this is one of the main challenges in open spectrum usage, providing efficient and fair dynamic spectrum allocation methods to distribute the unoccupied spectrum of primary users to the competitive secondary users .

2.3.3 cognitive cycle:

The cognitive cycle consists of three main mechanisms: (a) sensing the Radio Frequency (RF) spectrum; (b) cognition / management, and (c) control

2.3.3.1. Spectrum Sensing:

- Detection of unused spectrum bands or estimation of the total interference in the radio environment.
- Estimation of channel state information (Signal to Noise Ratio (SNR)).
- Expectation of channel capacity for use by the transmitter.

2.3.3.2. Cognition / Management:

- Spectrum management which controls opportunistic spectrum access.
- Traffic shaping.
- Routing.
- Provisioning Quality of Service (QOS).

2.3.3.3. Control action

- Adaptive coding and modulation.
- Control of transmission power.
- Control of transmission rate.

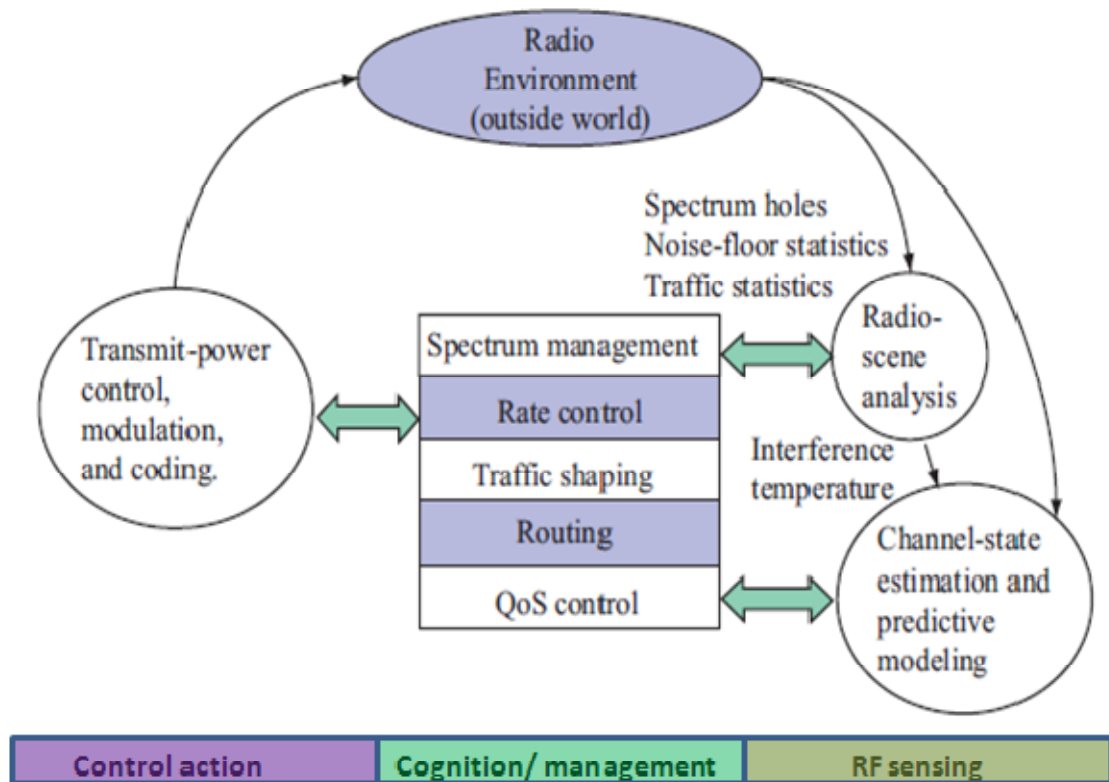


Figure 2-1: Fundamental Cognitive Cycle

-+

2.3.4 Cognitive Radio key benefit:

Cognitive Radio offers optimal diversity (in frequency, power, modulation, coding, space, time, polarization and so on) which leads to:

2.3.4.1 Spectrum Efficiency- This will allow future demand for spectrum to be met and is the basic purpose of implementing CR.

2.3.4.2 Higher bandwidth services- Demand of MBMS is constantly on the rise which will be facilitated by the implementation of CR.

2.3.4.3 Graceful Degradation of Services - When conditions are not ideal, a graceful degradation of service is provided, as opposed to the less desirable complete and sudden loss of service. This feature of CR is very important in providing services to the users. This feature of CR is very important in providing services to the users especially when they are mobile and the base stations in contact are constantly changing.

2.3.4.4 Improved Quality of Service (QoS) (latency, data rate, cost etc) - Suitability, availability and reliability of wireless services will improve from the user's perspective.

2.3.4.5 Commercial Exploitation- CR promotes spectrum liberalization (makes it much easier to trade spectrum between users). Indeed, a business case may exist for becoming a spectrum broker, whereby a third party manages the trade between supplier and demander and receives a commission.

2.3.4.6 Benefits to the Service Provider- More customers in the market and/or increased information transfer rates to existing customers. More players can come in the market.

2.3.4.7 Future-proofed product- A CR is able to change to services, protocols, modulation, spectrum etc. without the need for a user and/or manufacturer to upgrade to a new device.

2.3.4.8 Common hardware platform- Manufacturers will gain from economies of scale because they no longer need to build numerous hardware variants, instead using a single common platform to run a wide range of software. This also assists in rapid service deployment.

2.3.4.9 Flexible regulation-By using a form of policy database, regulation could be changed relatively quickly as and when required, easing the burden on regulators.

2.3.4.10 Benefits to the Licensee- CR can pave the way for spectrum trading, where licensees would be allowed to lease a portion of their spectrum rights to third parties on a temporal, spatial or other appropriate basis to recoup some of the expense of its 24hr-a-day license and even make money.[12]

2.3.5 Drawbacks of CR:

- Security
- Loss of control
- Regulatory concerns
- Fear of undesirable adaptations
- Significant research has remains to be done to realize commercially practical cognitive radio. [13]

Table.2.1. Comparison between Cognitive Radios with SDR

Conventional Radio	Software Defined Radio	Cognitive Radio
1. Traditional RF design	Conventional Radio + Software Architecture	SDR + Intelligence
2. Traditional baseband design	Reconfigurability	Reconfigurability + Awareness

2.4 Cognitive Radio Network (CRN):

During the last years there have been significant advancements in hardware technology, enabling engineers to build radios that can understand their environment and dynamically alter their transmission parameters (e.g., transmission frequency, modulation type etc.). One would have expected that such developments would have lead to large scale cognitive radio network deployments. However, this is not the case, and even a prototype large-scale deployment is yet to appear. The majority of the work in this area is theoretical and makes a number of assumptions that may not hold in practice. Even though these studies are arguably important and can provide scientific insights, they are not the best avenues to drive practical implementation and eventually commercial adoption and success. As we will elaborate in the following sections, specific assumptions that are prevalent in the literature can either expose the primary receiver to harmful interference or limit the performance of a CR network. Much of the existing literature focuses on the detection of signals at a given location from a single primary transmitter using threshold schemes. If the received signal from this primary transmitter is below a predefined threshold, the band is declared to be vacant.

2.4.1 SPECTRUM SENSING IN COGNITIVE RADIO NETWORK:

Key factors of the CRN are the cognitive capability, sensing, availability of spectrum and transmission power, bandwidth, modulation techniques, learn, and awareness of radio environment and characteristics of the channel, user requirements and applications,

available networks (infrastructures) and nodes, local policies and other operating restrictions. In the spectrum sensing, the radio scene and thereby estimating the power spectra of incoming RF stimuli

2.4.2 Classifying of the spectrum :

- **Black Space:**

Spectrum bands which are engaged by PUs (high-power local interferers) some of the time.

- **Grey Space:**

Spectrum bands which are partially engaged by PUs (low-power interferers).

- **White Space or Spectrum Hole:**

Spectrum bands which are not occupied by any PUs, and free of RF interferers excluding the ambient noise.

Spectrum sensing is a useful concept for discovering spectrum opportunities for secondary spectrum usage in real-time. Main objective of the sensing is the identification of unused spectrum (detection of spectrum holes) or to detect the primary user's transmission. When any two users want to communicate, then transmitter and receiver are responsible for sensing operation; following operations are performed by them:

- Source and destination choose a set of channels to sense.
- Source and destination estimate channel availability.
- Channel filtering is performed, and a communication path is set up

we present signal detection techniques for spectrum sensing by categorizing into three follow.

- **Primary transmitter detection:** Detection of primary users/signal is performed based on the received signal at CR user-receiver. This approach includes matched filter (MF) detection , energy based detection Cyclostationarity based detection
- **Primary receiver detection:** In this method ,spectrum opportunities are detected based on primary user receiver's local oscillator leakage power
- **Interference temperature management:** the secondary users coexist with primary users and are allowed to transmit with low power and restricted by the interference temperature level so as not to cause harmful interference to primary user[14]

CHAPTER THREE

SPECTRUM SENSING TECHNIQUES

3 .spectrum sensing techniques

3.1Background:

In this chapter classified of most popular spectrum sensing techniques

And methedoledegy of theme

3.2 SPECTRUM SENSING:

Cognitive radio (CR) technology solves the issue of spectrum underutilization in wireless communication better way. Cognitive radios are designed in order to provide highly reliable communication for all users of the network, wherever and whenever needed and to facilitate effective utilization of the radio spectrum to its maximum extent .show relatively low utilization of the licensed spectrum which is mainly due to inefficient fixed frequency allocations rather than any physical shortage of the spectrum This observation has lead the regulatory bodies to search a method where secondary (unlicensed) systems are allowed to opportunistically utilize the unused licensed bands commonly called them as white space CR network can change its transmitter parameters based on interaction with environment in which it operates. Cognitive radio includes four major functional blocks: spectrum management, spectrum sharing, spectrum sensing and spectrum mobility

A major challenge in cognitive radio is that the secondary users need to detect the presence of primary users in a licensed spectrum and come out of the frequency band as quickly as possible if the corresponding primary radio emerges in order to avoid interference to primary users.

This method is called spectrum sensing. Spectrum sensing and estimation is the fast and major step to implement CR system.[10]

The most popular spectrum sensing techniques are classified under three major categories primary transmitter detection, primary receiver detection and Interference based detection as shown in Fig 3.1 of the spectrum.

3.3 SPECTRUM SENSING TECHNIQUES

Recently, there is a great concern about the spectrum sensing to make more effective interactivity between the cognitive radio and the environment[11] spectrum sensing have number of techniques developed for detecting whether the primary user is present in a particular frequency band.

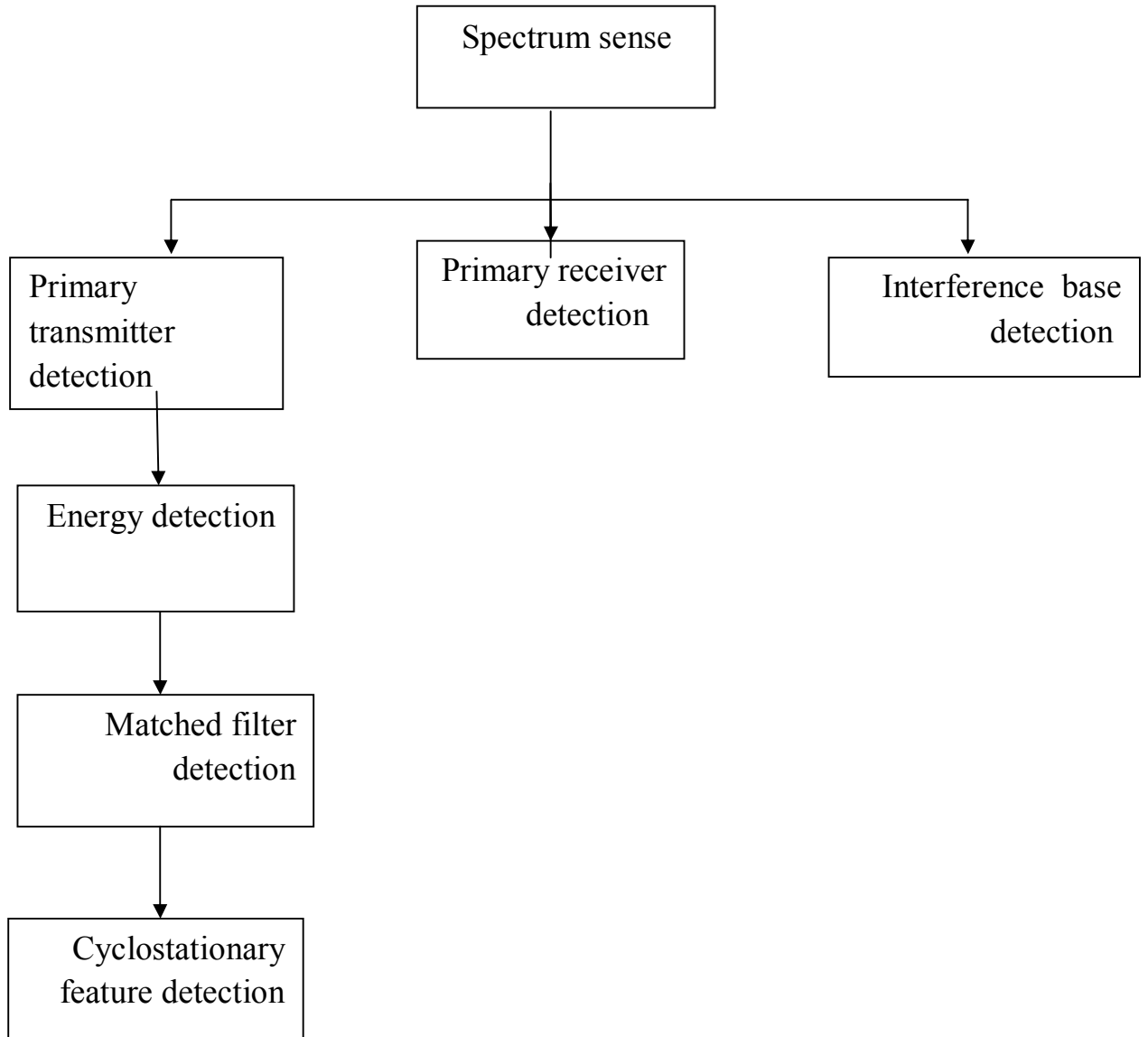


FIG 3.1 Classification of spectrum sensing techniques

3.3.1 Primary Transmitter Detection :

In this detection method, CR users sense the radio environment in order to detect the presence of PU signal. Since the CR users have no prior information regarding the PU signal type and characteristics so, it has to distinguish between the noise and the PU signal. It is the most widely used method since it directly gives an idea regarding the usage pattern of a given radio spectrum. CR uses binary hypothesis problem

formulation for detecting the PU signal against the noise. The binary hypothesis problem is described in details in subsequent section.

The primary detection can be performed by various methods, out of which there are three popular methods, (a) Energy detection method, (b) Matched Filter detection method and (c) Feature based Detection method.[12]

3.3.1.1 Energy Detection Method:

It is a blind detection scheme and optimal detection method when the primary user signal is unknown. It is the most widely used method for the detection of PU signal since, it doesn't require any *a priori* information. In this method, the energy of the received signal is calculated which is compared against some given threshold to determine the presence or absence of PU signal.[12]

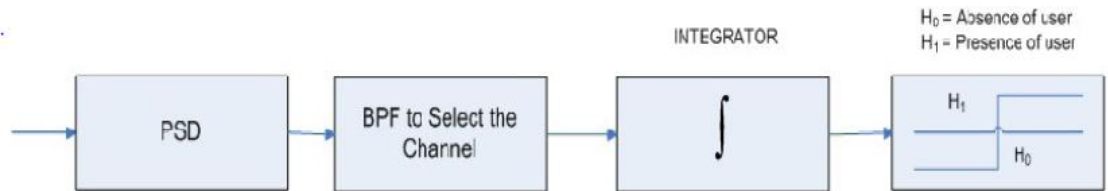


Fig 3.2 The block diagram of energy detection

In this scheme, signal is allowed through band pass filter of the bandwidth W and is integrated over time interval. The outcome from the integrator block is then compared to a pre calculated threshold. This comparison is used to find the existence or absence of the primary user. The threshold value of energy detection can be fixed or variable based on the channel conditions and threshold value depends on SNR ratio

Although energy detection can be implemented without any *a priori* knowledge of the primary user signal, the technique has some problems. Firstly, it can only detect the signal of the primary user if the

detected energy is greater than the threshold. The choice of the threshold level is not straight-forward, since it is highly susceptible to the changing background noise and interference, especially. A second difficulty is that the energy approach cannot distinguish the primary user from other secondary users sharing the same channel.[13].

3.3.1.2 Matched Filter Detection :

When the transmitted signal is known, the optimum spectrum detection technique is the matched filter detector. He uses a priori knowledge of the received signal, such as frequency, bandwidth, modulation type, pulse shaping, etc.[13]

A matched filter is a linear filter designed to provide the maximum signal-to noise ratio at its output for a given transmitted waveform[11]

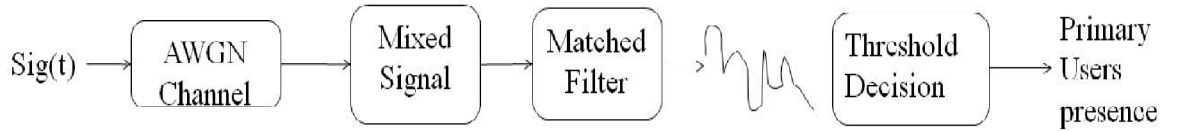


FIG 3.3 matched filter block

Here the transmitted signal is allowed through the channel where the additive white Gaussian noise is getting added to the signal and outputted the mixed signal. The matched filter is getting this mixed signal as input. The impulse response convolved with the matched filter input and the matched filter output is then compared with the threshold for primary user detection. The threshold of a signal, determined with the impulse response of the matched filter and the matched filter output is then compared with the threshold for primary user detection.

An advantage of the MF is that it requires less time to achieve detection; however, false detection occurs when incorrect information concerning the transmitted signal is available at the SU end [14].

Its main drawback lies in a *priori* knowledge requirement for its implementation. CR has limited information regarding the signal structure of the PU.[12]

And other drawback comes in demodulation process which requires perfect timing, carrier synchronization, etc. which requires a dedicated receiver for different PU signals, which increases complexity of the system. [12]

3.3.1.3 Cyclostationarity Feature Detection

Cyclostationarity feature detection needs high computation complexity, the best detection point is determined through simulation analysis on When signals exhibit statistical attributes, autocorrelation that change periodically with time, there are termed Cyclostationarity Features (CF) . Usually, wireless transmissions present Cyclostationarity features depending on their data rate, modulation type, and carrier frequency. Most communication signals can be modeled as Cyclostationary, since there exhibit underlying periodicities in their signal structures Cyclostationary feature detection.

(CFD) is a method that applies Cyclostationary features to detect a signal. The identification of a unique set of characteristics particular to a radio signal for a wireless access system can be used to detect the system based on its Cyclostationarity features. These features have periodic statistics and spectral correlation not obtained with interference signals or stationary noise. Thus exploiting this periodicity in the received primary signal to identify the presence of primary users makes this

method possess a high noise immunity compared to other spectrum sensing methods.[14] In this technique, CR user uses the periodic feature of the modulated signal in order to discriminate the PU signal from the noise. It is a complex method among the three techniques.[12]

different detection points, and then we intend combination detection method using multiple detection points to obtain better performance. Output validate the effectiveness of the suggested method Cyclostationarity feature detection can be able to have high detection probability under low SNR, actually, it requires high computation complexity. Using of the licensed users prior knowledge like properties of signal, we only makes detections in some specific frequencies and cycle frequencies, and multiple combine detection points to increase the performance further.[10]

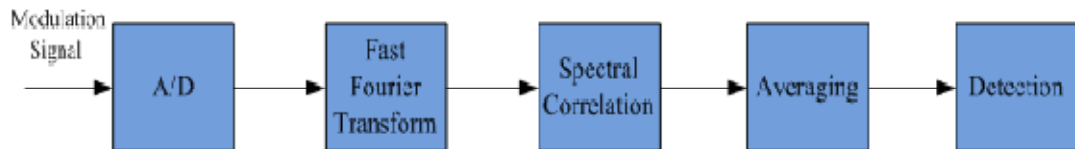


Fig 3.4 Implementation Cyclostationarity.

This technique is more effective in an environment where the levels of noise are uncertain. The noise uncertainty is because of the spectral correlation function of the AWGN channel is zero due to the stationary property[10]

3.3.1.2 Limitations of Transmitter Detection :

There are two limitations of transmitter detection, Receiver uncertainty problem and shadowing problem [2]. First, in transmitter detection cognitive radio users have information only about primary

transmitter and it has no information about primary receiver. So cognitive radio can identify receiver through weak transmitted signals. This sort of problem is called receiver uncertainty problem. Moreover transmitter detection faces the hidden node problem that limits its usability. Secondly, shadowing causes cognitive radio transmitter unable to detect the transmitter of primary user.

3.3.2 primary Receiver Detection:

Now we need such spectrum sensing techniques which are able to remove transmitter detection. To remove receiver's uncertainty, we have to design techniques which we have some information about primary receiver. The makers of transmitter detection techniques state that we have available the information of primary receiver.

The detection of weak signals from primary transmitter where it was that the problems becomes very difficult when there is uncertainty in the receiver noise variance. Then new spectrum sensing techniques are introduced in which we will get information about receiver from its own architecture.[5]

the basic idea in this approach is to detect primary user-receivers, which are within the communication range of CR system users. In general, primary receiver emits the local oscillator (LO) leakage power from its RF front-end while receiving the data from primary transmitter. Using that leakage power, one can detect the primary signal as in . Wild and Ramchandran have proposed a new CR architecture consisting of sensors to detect the LO leakage, and those sensors communicate the spectrum usage to the CR system. We note that this approach does not introduce any modification to primary user devices however the CR system need to be equipped with sensor and communication capability to detect the primary receiver LO leakage power, and report to the CR

transmitter. Using received information from sensors; the CR transmitters will identify the spectrum opportunities for given time and location to transmit their data.[4]

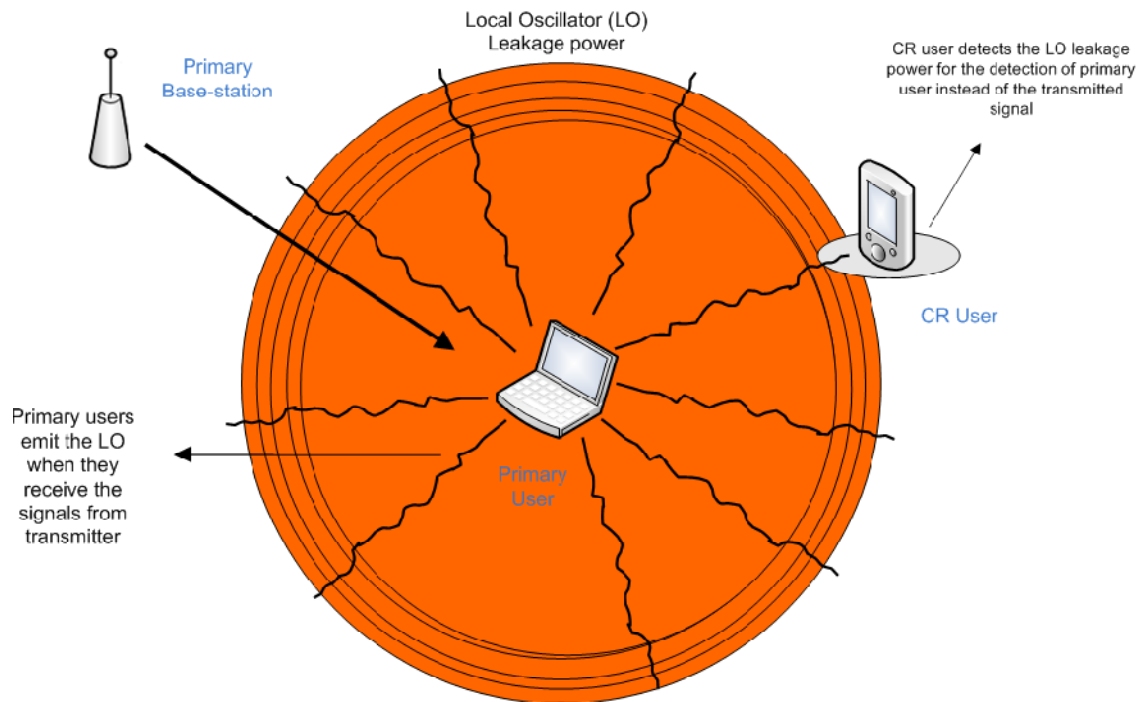


Figure 3 .3 primary receiver detection

3.3.3 Interference Temperature Management:

Unlike the primary receiver detection, the basic idea behind the interference temperature management is to set up an upper interference limit for given frequency band in specific geographic location such that the CR users are not allowed to cause harmful interference while using the specific band in specific area. Typically, CR user transmitters control their interference by regulating their transmission power (their out of band emissions) based on their locations with respect to primary users. This method basically concentrates on measuring interference at the receiver.

The operating principle of this method is like an UWB technology where the CR users are allowed to coexist and transmit simultaneously with primary users using low transmit power that is restricted by the interference temperature level so as not to cause harmful interference to primary users[15]

An illustration of the interference temperature model is shown in Figure 3.5 above. The SU may exploit the channel if the detected primary signal level is below the interference temperature limit. More so, if the power of transmission of an SU stays below the interference gap, it may utilize any frequency parameter of its choice. With this approach, it is hypothesized that the SUs will be allowed to transmit concurrently with the Pus under stringent interference avoidance constraints; wherein it is categorized as a spectrum underlay scheme. [16]

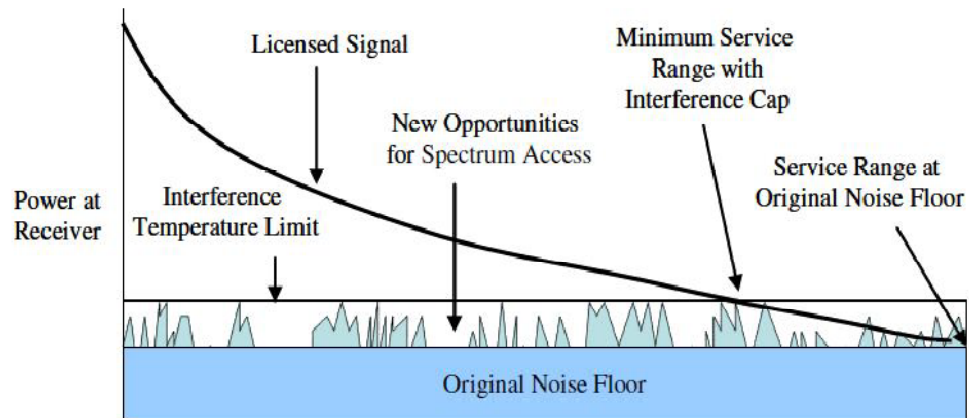


Figure 3.5: Interference temperature model

This is a disadvantage of the approach secondary CR users cannot transmit their data with higher power because of imposed low transmit power and interference temperature limit even if the licensed system is completely idle for given time and location.

Table 3.1 *Comparison between spectrum sensing technique*

Technique parameter	Primary Transmitter			Primary Receiver	Interference Temperature
	Energy detection	Matched filter	Feature detection		
Complexity	Less	Fair	High	Fair	Less
Primary signal Properties	Not required	Required	Requires Cyclostationary signal	Not required	Not require
Noise effect	Sensitive	Less effect	Not effect	Noise temperature	Sensitive
Accuracy of performance	Less	Fair	High	High	Fair
Time of detection	high	Less	Very high	Not need	less
Weak point	Uncertainty in noise power	Dedicated receiver for every primary user	Consumes more computational power	Secondary user use low power Transmitter	Some time not reliable
Strong Point	Simplicity	Fast decision	Robustness	More efficiency to use spectrum	Good alternative when primary transmitter faraway

CHAPTER FOUR

MATCHED FILTER & ENERGY DETECTION

4. Matched filter & energy detection

4.1 background :

In this chapter the mathematical model along with the techniques used in the code is illustrated. The results are included and it is consist of a comparison between matched and energy detection.

4.1 Energy Detection :

The simplest detection technique for spectrum sensing is Energy Detection. energy detector measures the energy received from primary user during the observation interval. If energy is less then certain threshold value then it declares it as spectrum hole.

Let $r(t)$ is the received signal which we have to pass from energy detector. [18].

The ED is set to be the Blind signal detector because it ignores the structure of the signal. It estimates the presence of the signal by comparing the energy received with a known threshold derived from the statistics of the noise. Analytically, signal detection can be reduced to a simple identification problem, formalized as a hypothesis test it can consider a complex baseband equivalent of the energy detector.

The detection is the test of the following two hypo-theses:

H_0 : $Y[n] = W[n]$ signal absent

H_1 : $Y[n] = X[n] + W[n]$ signal present

$n=1, \dots, N$; where N is observation interval

The noise samples $W[n]$ are assumed to be additive white Gaussian (AWGN) with zero mean and noise variance σ^2 . In the absence of coherent detection, the signal samples $X[n]$ can also be modeled as

Gaussian random process with variance σ^2 signal detector a decision rule can be stated as,

$$H_0 \quad \text{if } \hat{\epsilon} < \lambda$$

$$H_1 \quad \text{if } \hat{\epsilon} > \lambda$$

Where $\hat{\epsilon} = E | y(n) |^2$ the estimated energy of the received signal.
 λ = threshold.

The performance of the energy detector is calculated by P_d and P_{fa} given[0568]

$$P_d = Q \left(\frac{\lambda - N(1+\gamma)}{2\sqrt{N}} \right)$$

$$P_{fa} = Q \left(\frac{\lambda - N}{2\sqrt{N}} \right)$$

Where σ_n^2 the variance of the noise and Q is the Q-function, defined as;

$$Q(t) = \frac{1}{\sqrt{2\pi}} \int_t^{\infty} e^{-\tau^2/2} d\tau$$

N = number of sample

4.2 Matched Filter Detection (MFD) :

A matched filter successfully requires demodulation of the signal to detect primary users . That is, the CR needs a prior knowledge of the primary user signal, such as modulation type, bandwidth and pulse shaping. This data can be pre-stored in the CR memory.[12]

Let us assume $\text{sig}(t)$ be the transmitted signal, $w(t)$ is the channel noise, $\text{sig}(t) + w(t)$ will be the received signal, which is given as the input to the matched filter and $\text{sig}_0(t)+w_0(t)$ be the output of the filter. Let the impulse response of matched filter's be $h(t)$.

Here the transmitted signal is allowed through the channel where the additive white Gaussian noise is getting added to the signal and outputted the mixed signal. The matched filter is getting this mixed signal as input. The impulse response convolved with the matched filter input and the matched filter output is then compared with the threshold for primary user detection. The threshold of a signal, determined with the impulse response of the matched filter and the matched filter output is then compared with the threshold for primary user detection. The threshold of a signal, determined by two possible ways has been mentioned here. One way is to find the energy of the signal and make it to half, fix it as a threshold. Another way is to calculate the standard deviation of the signal by computing the mean and use it as threshold. Of the two methods, the first one is theoretically proved to be optimal. .

Once the threshold is fixed, presence of signal is determined based on the following decision rule.

$\text{rx}_d(t) > \lambda$: signal present

$\text{rx}_d(t) < \lambda$: signal absent

Here $\text{rx}_d(t)$ is the matched filter output given by

$$r_{xd}(T) = s_{ig0}(T) + w_0(T)$$

From eqn.(2)

$$r_{xd}(T) = E + w_0(T)$$

Matched Filter Detector

$$T_{MFD} = \sum_{n=0}^{N-1} z(n) * x(n), \text{ where } z(n) = 2\sqrt{P_s}\cos(2\pi f_0 n)$$

$$E = \sum_{n=0}^{N-1} z(n)^2$$

$$P_{D,A.M.F.D} = Q\left(\frac{T_{MFD} - E}{\sigma_W \sqrt{E}}\right)$$

$$P_{F,A.M.F.D} = Q\left(\frac{T_{MFD}}{\sigma_W \sqrt{E}}\right)$$

Where $Q(\cdot)$ is the Gaussian complementary distribution function.

4.3 Simulation Result and Discussion

In this section, through simulations, the capability of an energy detector and matched filter applied to a secondary user for spectrum sensing is evaluated. All simulations in his work is executed using MATLAB2 version R2012a.

test between energy detection and matched filter

The following paragraph represents probability of false alarm x axis and in y axis the probability of detection is represented

show fig 4.1 low SNR -10dB,energy detection is begin with high probability of detection(0.7210) and matched filter is begin with low probability of detection(0.0220) in low false alarm (.01)

In false alarm (.05) ED probability=(.98) and MF probability(.6640) .

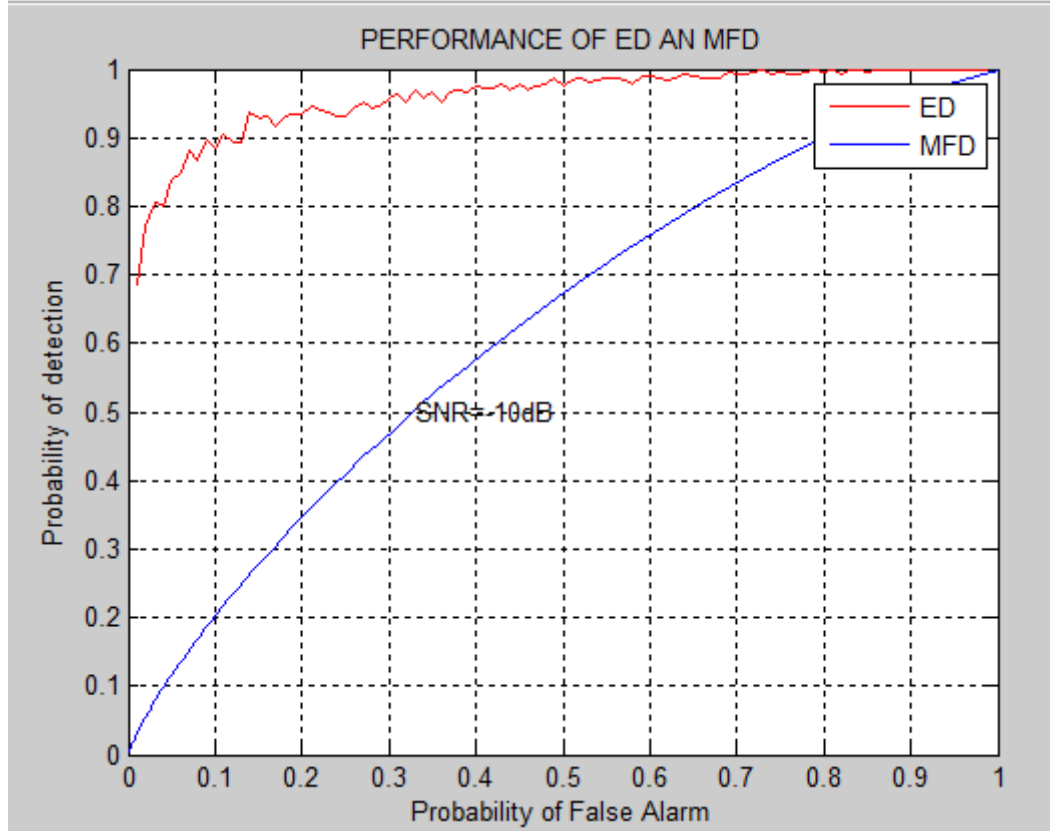


Fig 4.3 performance of ED and MFD, at fixed SNR of -10dB

In fig 4.2 When decrease low SNR to -15dB,energy detection is begin with probability of detection(.1840) and matched filter is begin with probability of detection(0.014) in low false alarm (.01)

In false alarm (.05) ED probability=(.7660) and MFD probability(.5990)
. Observed that ED probability is decrease when decreased SNR and MFD probability have lower effect

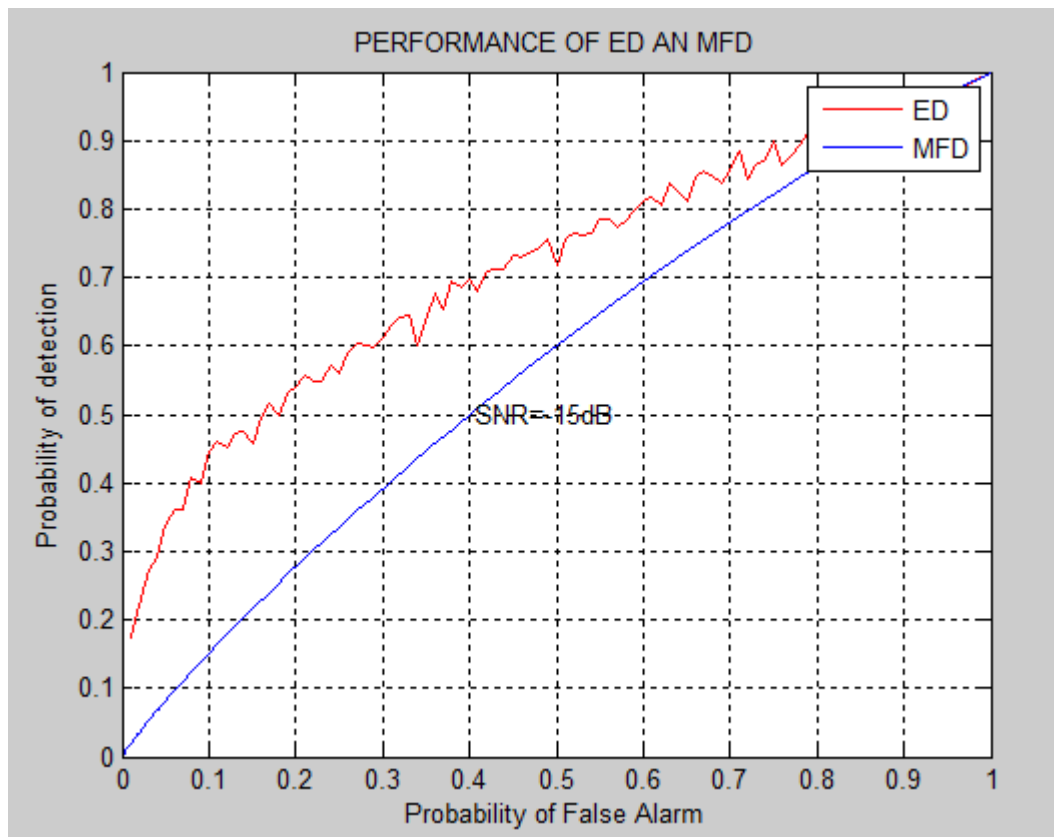


Fig 4.2 performance of ED and MFD, at fixed SNR of -15dB

fig 4.3 At low SNR to -20dB,energy detection is begin with probability of detection(0.073) and matched filter is begin with probability of detection(0.01) in low false alarm (.01)

In false alarm (.05) ED probability=(.555) and MFD probability(.584)
 . Observed that ED probability is decrease when decreased SNR and MFD probability have lower effect

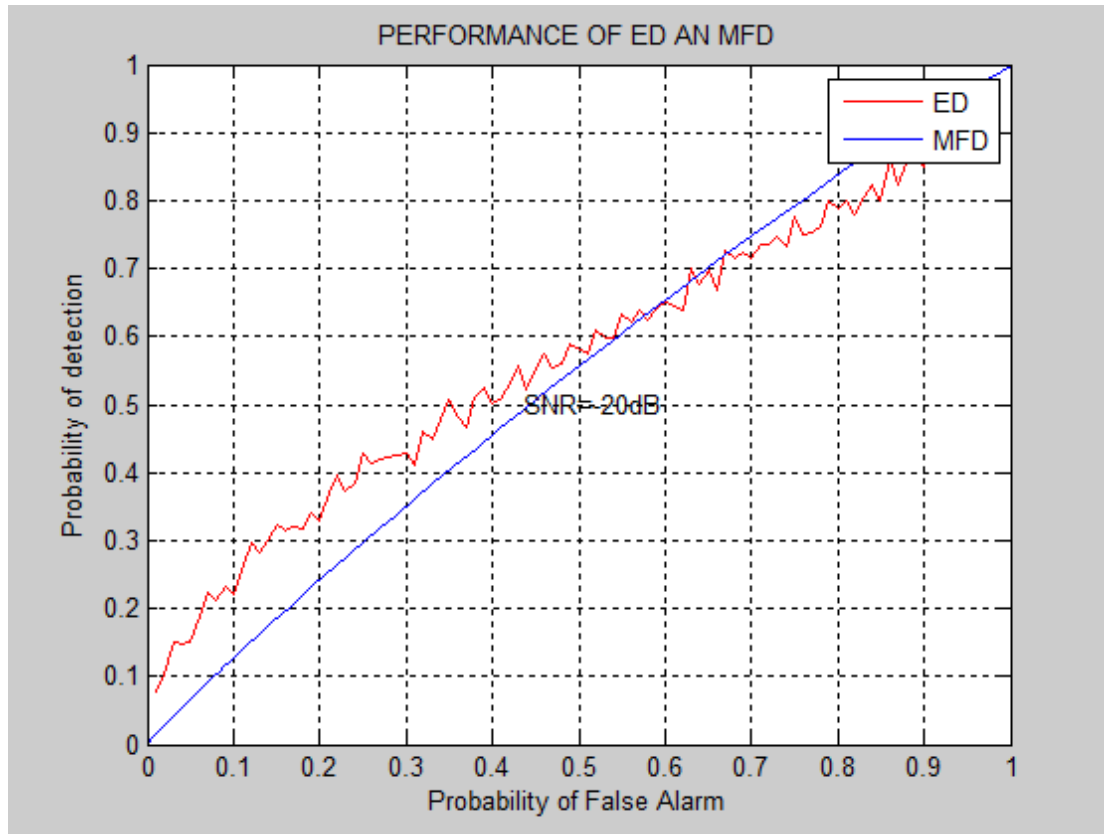


Fig 4.2 performance of ED and MFD, at fixed SNR of -20dB

From the all graph it was found that energy detection not work efficiency in low SNR and matched filter more efficiency and Robustness.

When was false alarm fixed at(0 .5) in different SNR the performance of detection in ED is more sensitivity with value of SNR and MFD is the performance of detection change in small scale .

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5. Conclusion and recommendation

5.1 Conclusion

This work introduced the implement spectrum sensing methods in cognitive radio systems by deriving decision rules for detecting .and to evaluate matched-filter and energy detection as spectrum sensing techniques used in cognitive radio network in terms of probability of false alarm and probability of detection for a specific SNR.

And as conclusion The energy detection method is a less computational complex technique but performs poorly at low SNR conditions the matched filter was found best performances than the energy detection and we found optimum SNR use for both as shown in chapter four results.

5.2 Recommendation

Using other parameters for evaluated

Use other simulation programs to insure of the results.

Use fixed points rather than using random generators..

Hybrid sensing approach can be implemented in first use the feature s
match filter detection and feature of energy detection technique .

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Appendix A:

```
axis ([0 1 0 1]);
clc , clear, close all
L = 1000;
snr_dB = -10; % SNR in decibels
snr = 10.^(snr_dB./10); % Linear Value of SNR
Pf = 0.01:0.01:0.99; % Pf = Probability of False Alarm
%% Simulation to plot Probability of Detection (Pd) vs.
Probability of False Alarm (Pf)
for m = 1:length(Pf)
    m
    i = 0;
    for kk=1:1000 % Number of Monte Carlo Simulations
        n = randn(1,L); %AWGN noise with mean 0 and variance 1
        s = sqrt(snr).*randn(1,L); % Real valued Gaussina Primary User
Signal
        y = s + n; % Received signal at SU
        energy = abs(y).^2; % Energy of received signal over N samples
        energy_fin =(1/L).*sum(energy); % Test Statistic for the energy
detection
        thresh(m) = (qfuncinv(Pf(m))./sqrt(L))+ 1 ;% Theoretical value
of Threshold, refer, Sensing Throughput Tradeoff in Cognitive
Radio, Y. C. Liang
        if(energy_fin >= thresh(m)) % Check whether the received energy
is greater than threshold, if so, increment Pd (Probability of
detection) counter by 1
            i = i+1;
        end
    end
    Pd(m) = i/kk;
end

gg=Pd;
for i=1:1:length(gg)-1
    cc(i)=gg(i);
end

plot(Pf, Pd, 'R');
hold on
%% Theroretical ecpression of Probability of Detection; refer
above reference.
figure(1)
thresh = (qfuncinv(Pf)./sqrt(L))+ 1;
Pd_the = qfunc(((thresh - (snr + 1)).*sqrt(L))./(sqrt(2).*(snr +
1)));
%plot(Pf, Pd_the, 'r')
hold on

%%%%%%%%%%%%%%

%clc,clear
```

```

% fix the random number generator
rstream = RandStream.create('mt19937ar','seed',2009);

Ntrial = 1e3;           % number of Monte-Carlo trials
snrdb = -10;            % SNR in dB
snr = db2pow(snrdb);    % SNR in linear scale
spower = 1;            % signal power is 1
npower = spower/snr;    % noise power
namp = sqrt(npower/2);  % noise amplitude in each channel
s = ones(1,Ntrial);    % signal
n = namp*(randn(rstream,1,Ntrial)+1i*randn(rstream,1,Ntrial)); %
noise
Pf = 0.01:0.1:0.99;
x = s + n;
mf = 1;

y = mf'*x; % apply the matched filter

z = real(y);
for m = 1:length(Pf)-1

Pfa(m) = Pf(m);
snrthreshold(m) = db2pow(npwgntthresh(Pfa(m), 1,'coherent'));
mfgain = mf'*mf;
% To match the equation in the text above
% npower - N
% mfgain - M
% snrthreshold - SNR
threshold(m) = sqrt(npower*mfgain*snrthreshold(m));

Pd1(m) = sum(z>threshold(m))/Ntrial;
Pfa(m) = sum(z>threshold(m))/Ntrial
end
x = n;
y = mf'*x;
z = real(y);

rocsnr(snrdb','SignalType','NonfluctuatingCoherent','MinPfa',1e-
3);

pp_energy=max(Pf)
pp_matchfilter=max(snrdb)

Diffrent_Curve_Value=gg(1)

%percentage=Diffrent_Curve_Value*100/1

diff=cc-Pfa;
%maximum_diff=max(diff)
for i=1:1:length(diff)

```

```
diff_per(i)=diff(i)*100/max(diff);  
end
```

```
L=cc-Pd1;
```

```
SS=sum(L)/length(L);
```

```
SS
```

```
x=0:length(cc)-1;
```

```
figure(5)  
plot (x,cc)  
axis ([0 1 0 1 ]);  
hold on
```

```
ddd=(cc)-(Pfa)*2*1;  
ddd=max(ddd)
```

```
for i=1:1:length(cc)
```

```
    fff=cc(i)-Pfa(i);
```

```
    if fff~=ddd  
        cc(i)  
        Pfa(i)  
        break  
    end
```

```
end
```