Energy Detection in Cognitive Radio Network (CRN) under Rayleigh Nakagami-*m* Fading Channels

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APPROVAL

The Research Project Report “Energy Detection in Cognitive radio network (CRN) under Rayleigh Nakagami-*m* fading channels” submitted by Shirin Akter (SID # 2013-2-98-001) and Mohammad Hossain (SID # 2013-2-98-005), to the Department of Electronics & Communications Engineering, East West University, has been accepted as satisfactory for the partial fulfillment of the requirements for the degree of Masters of Science in Telecommunications Engineering and approved as to its style and contents.

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DECLARATION

We, hereby, declare that the work presented in this Research Project is the outcome of the investigation performed by us under the supervision of Dr. M. Ruhul Amin, Professor, Department of Electronics & Communications Engineering, East West University and Dr. Md. Imdadul Islam, Professor (Adjunct), Department of Electronics & Communications Engineering, East West University. We also declare that no part of this Research Project and there of has been or is being submitted elsewhere for the award of any degree or diploma.

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Terms and Abbreviations

PD►	Probability of Detection
PFA►	Probability of False Alarm
AWGN►	Additive White Gaussain Noise
CR►	Cognitive Radio
CRN►	Cognitive Radio Network
GSM►	Global System For Mobile Communication
BTS►	Base Transceiver Station
PU►	Primary User
SU►	Secondary User
MU►	Malicious User
AP►	Access Point
FCC►	Federal Communications Commission
SFA►	Spatial False Alarm
ED►	Energy Detection
SNR►	Signal to Noise Ratio
UWB►	Ultra -wideband
WRAN►	Wireless Regional Area Network
WLAN►	Wireless Local Area Network
UHF►	Ultra –High Frequency
VHF►	Very –High Frequency
WNAN►	Wireless Network After Next
PRNs►	Primary Radio Networks

ABSTRACTS

The performance of a Cognitive radio network depends on, how successfully the Secondary User (SU) can detect the present of Primary User (PU) and recognize the false alarm arises from interferences. In this research project, we determine the profile of probability of detection and probability of false alarm of a Secondary User under Rayleigh and Nakagami-*m* fading channels. Here, we use the combination of fading and Additive White Gaussian Noise (AWGN) as the impairments of the signal. We detect both the above parameters analytically and verified by Monte Carlo Simulation. The analytical and simulation results are found very closed to each other.

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CHAPTER: 1

INTRODUCTION

Chapter: 1 Introduction

Cognitive radio is radio in which communication systems are aware of their internal state and environment, such as location and utilization on RF frequency spectrum at that location. They can make decisions about their radio operating behavior by mapping that information against predefined objectives. Cognitive radio is further defined by many to utilize Software Defined Radio, Adaptive Radio, and other technologies to automatically adjust its behavior or operations to achieve desired objectives. The utilization of these elements is critical in allowing end-users to make optimal use of available frequency spectrum and wireless networks with a common set of radio hardware. This will reduce cost to the end-user while allowing him or her to communicate with whomever they need whenever they need to and in whatever manner is appropriate.

Cognitive radio is defined as software defined radio which is aware of its environment, learns from and has the ability to change its parameters according to these changes in its environment and the networks requirements [1]. The concept of cognitive radio has been introduced to alleviate the spectrum under-utilization problem of wireless communications. One of the most challenging tasks in cognitive radio networks is spectrum sensing, which is required to opportunistically access the idle radio spectrum.

Existing spectrum sensing techniques can be divided into three types [2]: energy detection, matched filter detection and cyclostationary detection. Among them, energy detection has been widely applied since it does not require any a priori knowledge of primary signals and has much lower complexity than the other two schemes. The radio channel is characterized by two types of fading effects: large scale fading and small-scale fading [3], [4]. Small-scale fading models include the well known Rayleigh, Rice, and Nakagami-m [5]-[6] distributions. For large scale fading conditions, it is widely accepted that the probability density function (PDF) of the fading envelopes can be modeled by the well-known lognormal distribution [7], [8]. Due to the several multipaths fading, a cognitive radio may fail to notice the presence of the PU and then will access the licensed channel and cause interference to the PU. To combat these impacts, cooperative spectrum sensing schemes have been proposed to obtain the spatial diversity in multiuser CR networks [9-11]. The performance of single CR user based spectrum sensing in fading channels such as Rayleigh, Nakagami, Weibull has been studied in [12]. The performance of cooperative spectrum sensing with censoring of cognitive radios in Rayleigh fading channel has been evaluated in [13-15]. Cooperative spectrum sensing improves the detection performance. All CR users sense the PU individually and send their sensing information in the form of 1-bit binary decisions (1 or 0) to Fusion center (FC). The hard decision combining rule (OR, AND, and MAJORITY rule) is performed at FC using a counting rule to make the final decision regarding whether the primary user present or not [16]-[18]. Cooperative spectrum sensing has been addressed in [19-22]. However, the existed works examined the additive white Gaussian noise (AWGN) channel and the Rayleigh fading channel.

The entire project work is organized as:

Chapter- 2 provides detail analytical model of detection of signal of cognitive radio network along with of simulation.

Chapter-3 provides the result based on analytical model of previous chapter

Chapter-4 Finally concludes entire analysis.

CHAPTER: 1

COGNITIVE RADIO NETWORK

1.1 Cognitive Radio Definition

The idea of cognitive radio has been first introduced by (Mitola and Maguire, 1999)[23]. It is defined as software defined radio which is aware of its environment, learns from and has the ability to change its parameters according to these changes in its environment and the network requirements (Haykin, 2005)[24]. The name cognitive radio as we use today refers mostly to spectrum aware communication systems. The need for the cognitive radio emerged from the fact that current frequency allocations (with fixed spectrum assignment policy) show that the radio spectrum is highly occupied, i.e. spectrum is a scarce resource, however, it is highly underutilized (i.e., spectrum is not used effectively). (Licensed) and secondary (unlicensed-cognitive) users, secondary users continuously check the frequency bands to determine if there is a primary user transmitting, if not, the band is available and the secondary user can start transmitting its own data. These spectrum holes can occur in two ways, in time or in space. When a primary user is not transmitting at a given time, then there’s a temporal spectrum hole, if, a primary user is transmitting in a certain portion of the spectrum at a given time but it is too far away from the secondary user so that the secondary user can reuse the frequency, then a spatial spectrum hole exists.

In general the cognitive radio may be expected to look at parameters such as channel occupancy, free channels, the type of data to be transmitted and the modulation types that may be used. It must also look at the regulatory requirements. In some instances knowledge of geography and this may alter what it may be allowed to do. In some instances it may be necessary to use a software defined radio, so that it can reconfigure itself to meet the achieve the optimal transmission technology for a given set of parameters. Accordingly Cognitive radio technology and software defined radio are often tightly linked.

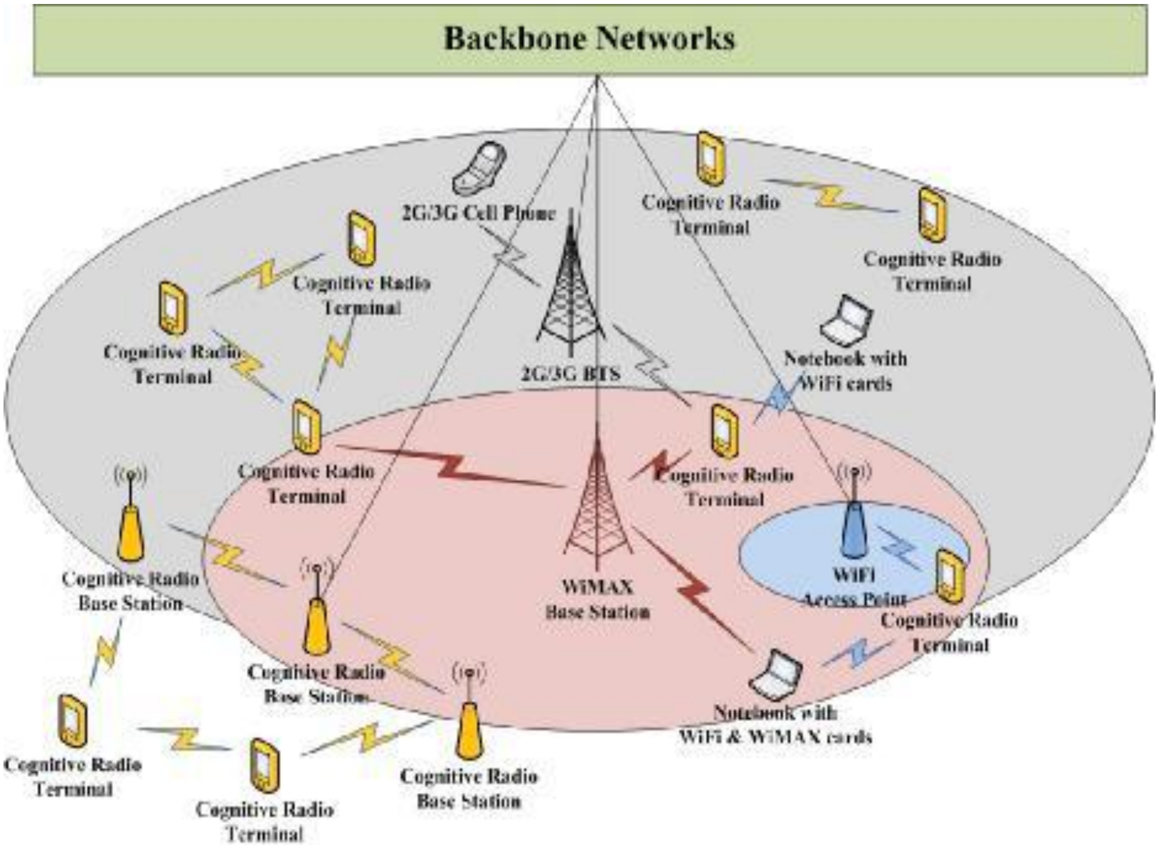


Figure 1: Ubiquitous Cognitive Radio Heterogeneous

Cognitive radio technology could also facilitate interoperability among different communication systems in which frequency bands and/or transmission formats differ [26].

1.2 TERMINAL CAPABILITY OF COGNITIVE RADIO NETWORKS

The capabilities of cognitive radios as nodes of CRN can be classified according to their functionalities. A cognitive radio shall sense the environment (cognitive capability), analyze and learn sensed information (self-organized capability) and adapt to the environment (reconfigurable capabilities).

1.2.1 Cognitive Capability

1.2.1.1 Spectrum Sensing

A cognitive radio can sense spectrum and detect “spectrum holes” which are those frequency bands not used by the licensed users or having limited interference with them.

1.2.1.2 Spectrum Sharing

A cognitive radio could incorporate a mechanism that would enable sharing of spectrum under the terms of an agreement between a licensee and a third party. Parties may eventually be able to negotiate for spectrum use on an ad hoc or real-time basis, without the need for prior agreements between all parties.

1.2.1.3 Location Identification

The ability to determine its location and the location of other transmitters, and then select the appropriate operating parameters such as the power and frequency allowed at its location. In bands such as those used for satellite downlinks that are receive-only and do not transmit a signal, location technology may be an appropriate method of avoiding interference because sensing technology would not be able to identify the locations of nearby receivers.

1.2.1.4 Network/System Discovery

For a cognitive radio terminal to determine the best way to communicate, it shall first discover available networks around it. These networks are reachable either via directed one hop communication or via multi-hop relay nodes. For example, when a cognitive radio terminal has to make a phone call, it shall discover if there is GSM BTSs or WiFi APs nearby. If there is no directed communication link between the terminal and the BTSs/APs but through other cognitive radio terminals some access networks are reachable, it can still make a call in this circumstance. The ability to discovery one hop or multi-hop away access networks is important.

1.2.1.5 Service Discovery

Service discovery usually accompanies with network/system discovery. Network or system operators provide their services through their access networks. A cognitive radio terminal shall find appropriate services to fulfill its demands.

1.3 Reconfigurable Capability

1.3.1 Frequency Agility

It is the ability of a radio to change its operating frequency. This ability usually combines with a method to dynamically select the appropriate operating frequency based on the sensing of signals from other transmitters or on some other method.

1.3.2 Dynamic Frequency Selection

It is defined in the rules as a mechanism that dynamically detects signals from other radio frequency systems and avoids co-channel operation with those systems. The methods that a device could use to decide when to change frequency or polarization could include spectrum sensing, geographic location monitoring, or an instruction from a network or another device.

1.3.4 Adaptive Modulation/Coding

Adaptive modulation techniques can modify transmission characteristics and waveforms to provide opportunities for improved spectrum access and more intensive use of spectrum while “working around” other signals that are present. A cognitive radio could select the appropriate modulation type for use with a particular transmission system to permit interoperability between systems.

1.3.5 Transmit Power Control

Transmit power control is a feature that enables a device to dynamically switch between several transmission power levels in the data transmission process. It allows transmission at the allowable limits when necessary, but reduces the transmitter power to a lower level to allow greater sharing of spectrum when higher power operation is not necessary.

1.3.6 Dynamic System/Network Access

For a cognitive radio terminal to access multiple communication systems/networks which run different protocols, the ability to reconfigure it self to be compatible with these systems is necessary.

1.4 Self-Organized Capability

1.4.1 Spectrum/Radio Resource Management

To efficiently manage and organize spectrum holes information among cognitive radios, good spectrum management scheme is necessary.

1.4.2 Mobility and Connection Management

Due to the heterogeneity of CRNs, routing and topology information is more and more complex. Good mobility and connection management can help neighborhood discovery, detect available Internet access and support vertical handoffs, which help cognitive radios to select route and networks.

1.4.3 Trust/Security Management

Since CRNs are heterogeneous networks in nature, various heterogeneities (e.g. wireless access technologies, system/network operators) introduce lots of security issues. Trust is thus a prerequisite for securing operations in CRNs.

1.5 Cognitive Radio Characteristics

CR has two important characteristic concepts should be featured [29]:

1.5.1 Cognitive capability

The cognitive capability of a CR is a process of observing the outside environment in order to find unused radio spectrum and determine appropriate communication parameters to adapt to the dynamic radio environment. Metola first who explain the cognitive capability in term of the cognitive cycle during which "a cognitive radio continually observes the environment, orients itself, creates plans, decides, and then acts", as shown in figure

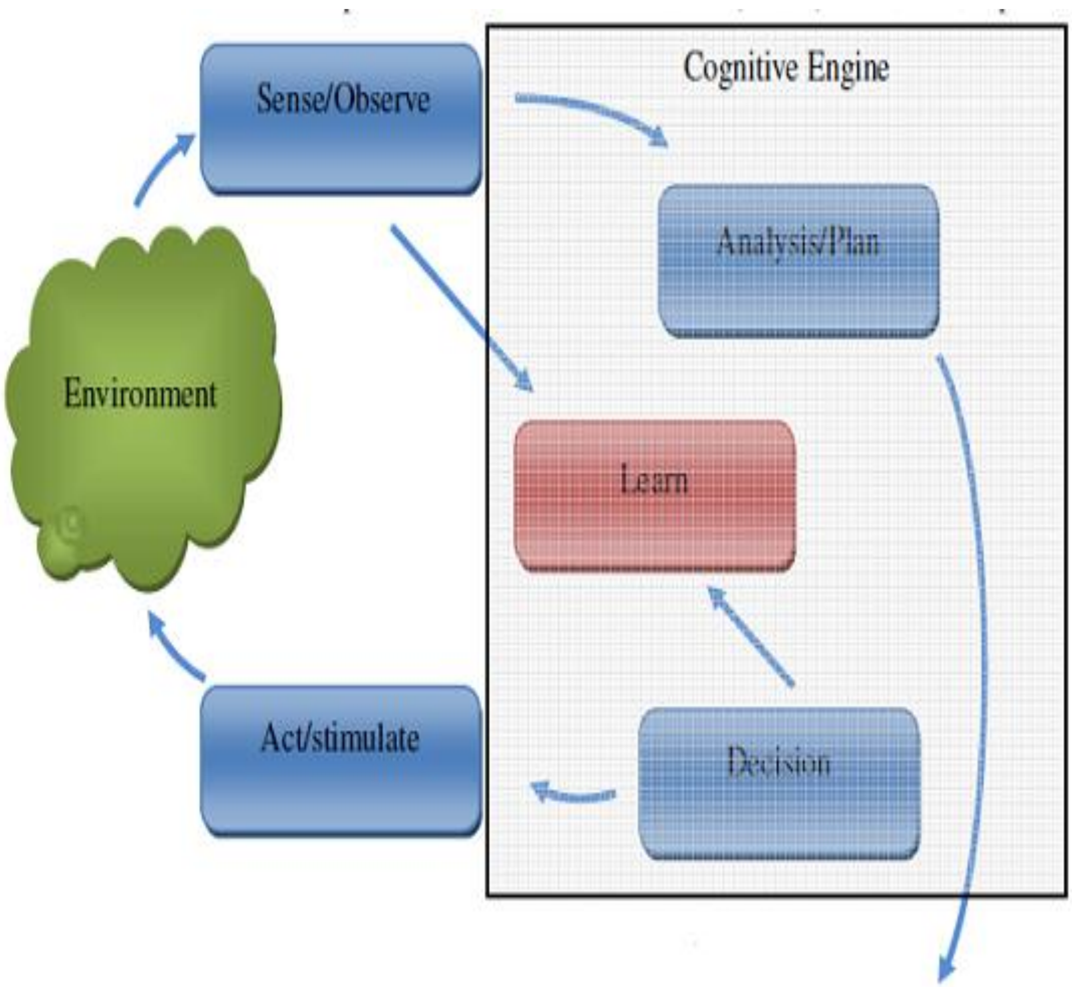


Figure 2: Simplified Cognitive Cycle

The process of sensing the outside world determines the presence of spectrum hole. The Observations taken by the sensing will be supply into plan cycle processes in which further used, but they also supply to learn module to learn and remember. The learning allows the system to learn from the experiences. The analysis process is responsible for generating and analyzing work streams which may be taken, i.e. determines data rate, bandwidth, frequency, power, modulation, etc. At the decision stage of the cycle, the CR is chosen appropriate spectrum band for transmission of the signal. The analysis, decision and learn modules compose the inner part of the system, the intelligence that governs the entire CR: the Cognitive Engine. We consider a cognitive engine (similar to a human brain) to enable intelligence in the radio device. Finally the decision is put into action and the operation of the cognitive radio is actually influenced. The sensing (or observation) and action modules represent the interfaces of the CR with the real world. Similar cycles are used to describe the operation of cognitive radio by [30,31,32].

1.5.2 Re-configurability

Re-configurability shows the radio capability to change the functions according to enclosing i.e. Cognitive radio can change the radio frequency, transmission power, modulation scheme, Communication protocol in order to reach the optimal working [33,30,34].

1.5.3 Intelligence and flexibility

Work is under way to determine the best methods of developing a radio communications system that would be able to full-fill the requirements for a CR system. Although the level of processing required may not be fully understood yet, it is clear that a significant level of processing will be needed. The radio will need to determine the occupancy of the available spectrum, and then decide the best power level, mode of transmission and other necessary characteristics. Additionally the radio will need to be able to judge the level of interference it may cause to other users. This is an equally important requirement for the radio communications system if it is to operate effectively and be allowed access to bands that might otherwise be barred.

1.6 Standardization and Applications of Cognitive Radio

The radio spectrum allowed for television (TV) broadcasting (e.g., 54–806 MHz in US) is allocated for different TV operators. In the TV band, the frequencies not being used by operators are called white spaces. White spaces may include guard bands; free frequencies due to analog TV to digital TV switchover (e.g., 698–806 MHz in US), and free TV bands created when traffic in digital TV is low and can be compressed into fewer TV bands. Since the use of white spaces by unlicensed users is allowed by the FCC, the IEEE 802.22 standard has been released with medium access control and physical layer specifications for a wireless regional area network (WRAN).

Cognitive Radio Networking and Opportunistic Spectrum Access can be used in different applications. In what follows, we briefly discuss those applications that can benefit from the research conducted in this project work.

1.6.1 Cognitive Mesh Networks

Multi-hop wireless mesh networks have recently gained significant popularity as a cost-effective solution for last-mile Internet access. Traditional wireless mesh network are challenged by the scarcity of the wireless bandwidth needed to meet the high-speed requirements of existing wireless applications. Opportunistic Spectrum Access can be used to alleviate the bandwidth scarcity problem of mesh networks by allowing the mesh nodes to dynamically explore any available spectral opportunities. Such cognitive mesh networks are meant be used to provide broadband access to rural, tribal, and other under-resourced regions [35].

1.6.2 Public Safety Networks

Public safety networks are another type of networks that can exploit Cognitive Radio Networking. Public safety networks are used for communications among police officers and fire and paramedic personnel. Such networks are also challenged by the limited amount of allocated spectrum. Even with the recent extensions of the allocated public safety spectrum bands, the public safety personnel do not have the technology to dynamically operate across the different spectrum segments. Recall that public safety licensees have a wide variety of bands available (VHF-Low, VHF-Hi, 220MHz, UHF below 800, UHF-800, etc.). The cognitive radio technology can offer public safety networks more bandwidth through Opportunistic Spectrum Access. Furthermore, a public safety CRN can provide a substantial communication improvement by allowing the interpretability across different public safety services while smartly adapting to the high peak-to-average nature of the traffic carried out by such networks [36].

1.6.3 Disaster Relief and Emergency Networks

Natural disasters such as hurricanes, earthquakes, wild fires, or other unpredictable phenomena usually cause the communications infrastructure to collapse. For example, some base stations of cellular networks can fall, the connectivity between sensor nodes and the sink node in static wireless sensor networks can be lost, existing Wireless Local Area Networks (WLANs) can be damaged, etc. This results in a set of partially or fully damaged coexistent networks that were previously deployed and then became disconnected. Meanwhile, there is an urgent need for a means of communications to help the rescue teams to facilitate organized help, rehabilitation efforts, and to locate the disaster survivors. CRNs can be used for such emergency networks (e.g., see [37] and references therein). The use of Opportunistic Spectrum Access in disaster relief networks can provide a significant amount of bandwidth that can handle the expected huge amount of voice, video, and other critical and time-sensitive traffic. It is worth mentioning that WLANs were used in the relief References 19 of the Haiti earthquake. However, the communication over such a network was unreliable and suffered significant delays [38].

1.6.4 Battlefield Military Networks

Unfortunately, the recent advances in wireless technologies made the job of communication jamming and/or hacking much easier. Consequently, achieving reliable and secure communications in modern battlefields has become a more challenging task. Recall that a battlefield communication network provides the only means of immunizations between soldiers, armed vehicles, and other units in the battlefield amongst themselves as well as with the headquarters. This implies that such networks do not only require significant amount of bandwidth, but also mandate secure and reliable communications to carry vital information. The cognitive radio is the key enabling technology for realizing such densely deployed networks which use distributed Opportunistic Spectrum Access strategies to fulfill the bandwidth and reliability needs. Note that, the dynamic nature of OSA makes the ability to track and jam a communication more difficult. Thus motivated, DARPA initiated the Wireless Network after Next (WNaN) program aiming at creating a flexible architecture for military communications [40]. The main goal of the WNAN program is to develop a low-cost handheld cognitive radio terminal that is capable of selecting its own frequencies and forming a dense network within a large battlefield area.

1.6.5 Leased Networks

All of the aforementioned CRN applications have the secondary users exploiting the resources of the primary networks without being beneficial to the primary networks in any way. However, a primary network can benefit from leasing a fraction of its licensed spectrum to secondary operators adopting cognitive radio technology to opportunistically access the spectrum. The entrance of the secondary operator to the market of the incumbent primary network can increase the revenue of the primary licensed operator [39].

1.7 Challenges in cognitive radios and networks

The cognitive radio has no sense of sight, which severely limits the ability to detect the environment. This can lead to the hidden terminal problem where the sensing secondary user is unaware of the presence of a primary user because it cannot reliably detect its presence. A PU terminal and a SU terminal can be separated by some physical obstacle opaque to radio signals. They can also be out-of-range of each other so that the reliable sensing of primary transmission becomes impossible. Two such terminals are said to be hidden from each other [Tobagi 1975]. [41]

One example of hidden terminal problem is a digital TV, which lies at the cell edge where the power of received signal can be barely above the sensitivity of the receiver [Krenik 2005][43]. If the CR is not capable of detecting TV signal, it can start to use the spectrum and interfere with the signal the digital TV is trying to decode. This problem can be avoided if the sensitivity of CR outperforms primary user receiver by a large margin [Čabrić 2004], [Krenik 2005][42].

The hidden terminal problem is also present in WLAN systems, which operate on open bands. In WLANs based on the IEEE 802.11 standard, the problem is tackled by using carrier sense multiple accesses with collision avoidance (CSMA/CA) scheme as the multiple access method. In CSMA/CA a station wishing to transmit first listens to the channel and only transmits if the channel is sensed “idle”. If the channel is sensed busy before transmission, the transmission is deferred for a random interval, which reduces the probability of collisions on the channel.

In a non-cooperative game, the hidden terminal problem can cause unpredictable moves and thus lead to a bad situation. Cooperation and distributed methods help to avoid hidden terminal problem and thus reduce interference to the primary system. Access point (AP) is needed in an ad hoc wireless network to realize control-theoretic cooperation between secondary users. Spectrum sensing information of the nodes will be handled and combined in the access point [Weiss 2004] [44]. Based on that information the occupancy vector is defined and distributed to the nodes in the network. Occupancy vector can be a simple binary vector in which 1 refers to the channel in use and 0 for a free channel. In a four-channel system where only the second channel is free, the occupancy vector is 1011.It is not adequate to determine whether a band is free. The cognitive radio must also estimate the amount of interference and noise that would exist in the free sub-band to make sure that the transmission power of the cognitive radio does not violate the interference limit of the system. The complexity of the cognitive radio is an important aspect. The benefits from the use of cognitive capability must exceed the cost of introducing the cognitive ness, which inherently adds to the complexity of the system.

The cognitive radio must be capable of operating over wide bandwidths because the spectrum holes can be spread over large bandwidths. The cognitive radio must be able to sense wide bandwidths as well as transmit on wide range of bandwidth, which places challenges on the antenna design. In particular, the transmission may be spread to several narrow sub-bands and the emission to adjacent bands which are used by the primary users must be avoided.

In a cognitive network information is exchanged between the nodes. The amount of control information is an important issue since the transmission of the control information can become the bottleneck if the amount of control information is large. In an ad hoc network of cognitive radios, all control information is sent over the wireless links resulting in significant traffic amounts if not properly planned. The emergent behavior apparent in the cognitive network due to the adaptations in the time varying operating environment is a key issue. When sets of adaptive equipments are connected, the uncontrolled adaptations can lead to fundamental problems. Emergent behavior in cognitive radios can be classified into:

1. Positive emergent behavior, which is characterized by order, and
2. Negative emergent behavior, which is characterized by disorder (e.g. traffic jams and Chaotic behavior).

It is important to be able to detect negative emergent behavior, which is difficult. In positive emergent behavior predictability is easier.

The last Decade has witnessed the increasing popularity of wireless services. In fact, recent measurements by Federal Communications Commission (FCC) have shown that 70% of the allocated spectrum in US is not utilized. CR is a kind of intelligent wireless device, which is able to adjust its transmission parameters, such as transmit power and transmission frequency band, based on the environment. In a CR network, ordinary wireless devices are referred to as primary users (PUs), and CRs are referred to as secondary users (SUs). CR is defined as an intelligent wireless communication system that provides more efficient communication by allowing secondary users to utilize the unused spectrum segments. The core technology behind spectrum reuse is cognitive radio, which consists of three essential components:

- **Spectrum sensing:** The secondary users are required to sense the radio spectrum environment within their operating range to detect the frequency bands that are not occupied by primary users.

- Dynamic spectrum management: Cognitive radio networks are required to dynamically select the best available bands for communications.

- Adaptive communications: A cognitive radio device can comfit its transmission parameters to opportunistically make best use of the ever-changing available spectrum [45,46,51].

Typically, the performance of spectrum sensing is evaluated with the probability of detection and probability of false alarm. From the primary user's point of view, the probability of detection is critical as it determines how often primary user is susceptible to potential interference from the cognitive radio system. This is because the time of failures in detecting the presence of primary user depends on the probability of detection. Therefore, we are interested in the probability of detection as a measure for spectrum sensing performance. In this model, the SU first sense the frequency band allocated to the PU to detect the state of the PU and then adapts its transmitting power according to the detection result. If the PU is inactive, the SU allocates the transmit power based on its own benefit to achieve a higher transmission rate. If the PU is active, the SU transmits with a lower power to avoid causing harmful interference to the PU. In cognitive radio networks, the criterion considered so far is in terms of protecting the primary user, i.e., maximizing the probability of detection under the constraint of probability of false alarm. Detection of primary user by the secondary system is critical in a cognitive radio environment. However this is rendered difficult due to the challenges in accurate and reliable sensing of the wireless environment. Secondary users might experience losses due to multipath fading, shadowing, and building penetration which can result in an incorrect judgment of the wireless environment, which can in turn cause interference at the licensed primary user by the secondary transmission [45].

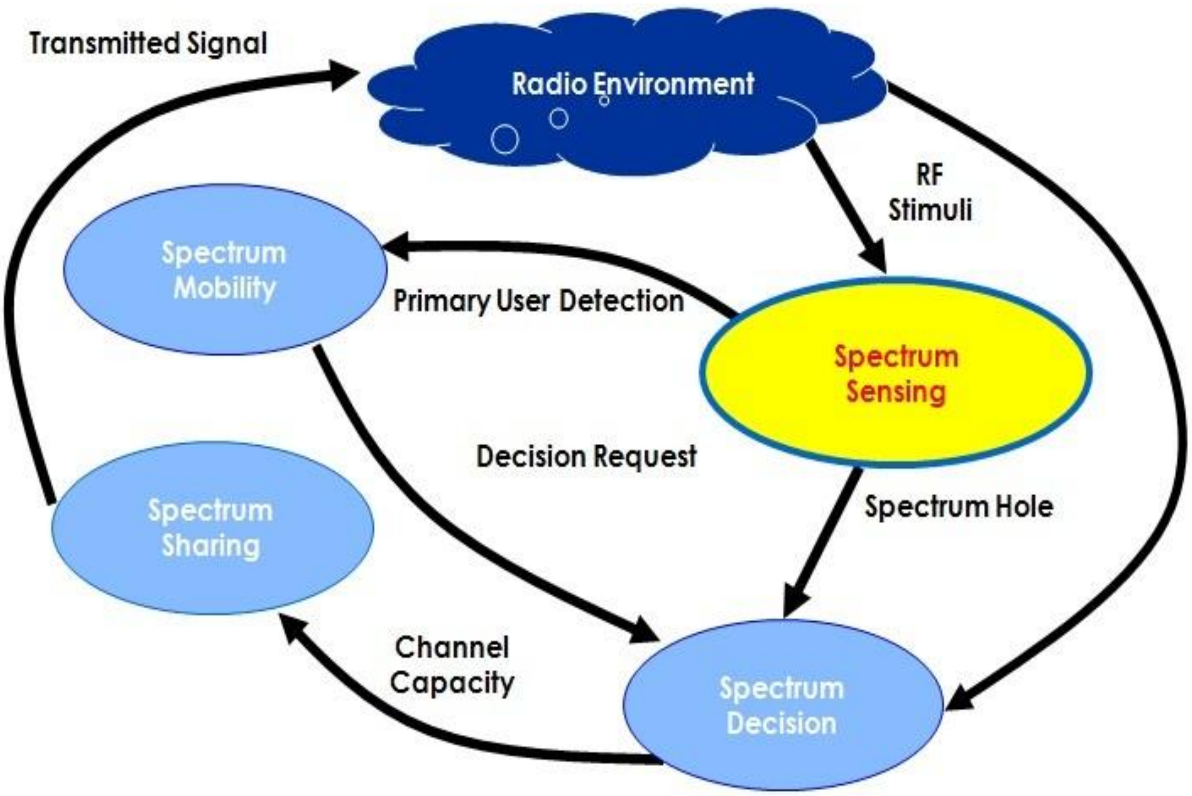


Figure 3: Basic Cognitive Radio Cycle

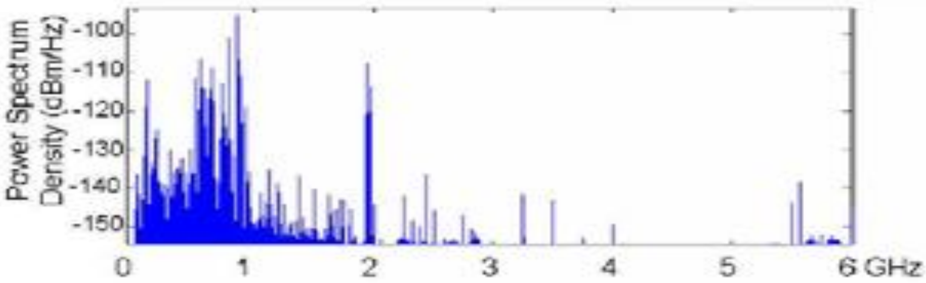


Figure 4: Measurement of Spectrum Utilization (0-6 GHz)

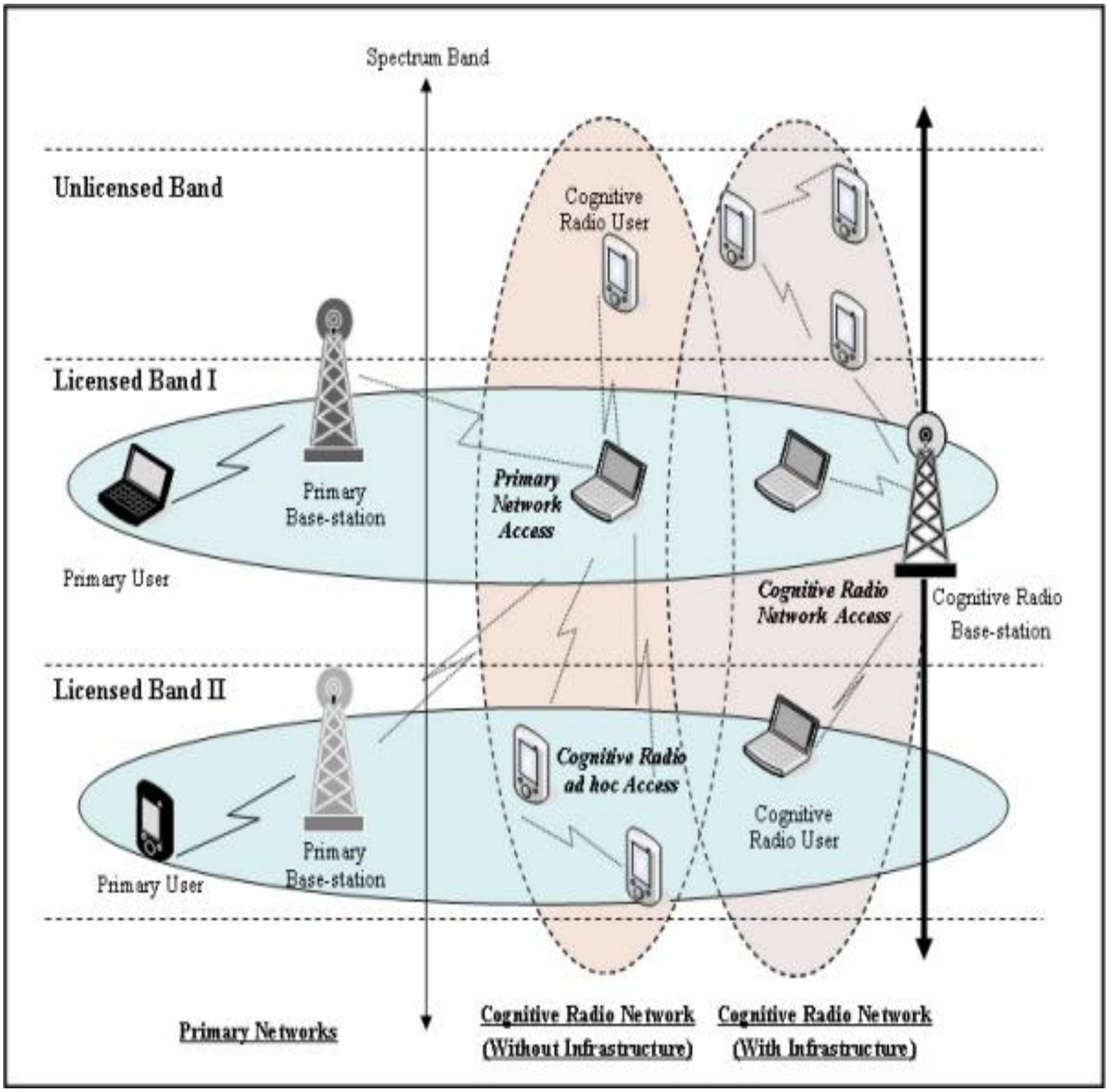


Figure 5.1: Cognitive Radio Network Architectures

The Figure-3 is basic cognitive radio cycle. It shows cognitive radio operations as spectrum sensing, analysis, decision and utilization.

Figure- 4 indicates the spectrum usage. As is clear from the Fig. that from 0-6GHZ bands only a part of the band is used efficiently and the rest part is useless or not allocated. To make better use of this band is the only purpose of CR technology.

Table 1: Percentage usage of (0-6) GHZ band.

Freq(GHz)	**0-1**	**1-2**	**2-3**	**3-4**	**4-5**	**5-6**
Utilization(%)	**54.4**	**35.1**	**7.6**	**0.25**	**0.128**	**4.6**

0 1 2 3 4 5 6 7 8 9

Time (min)

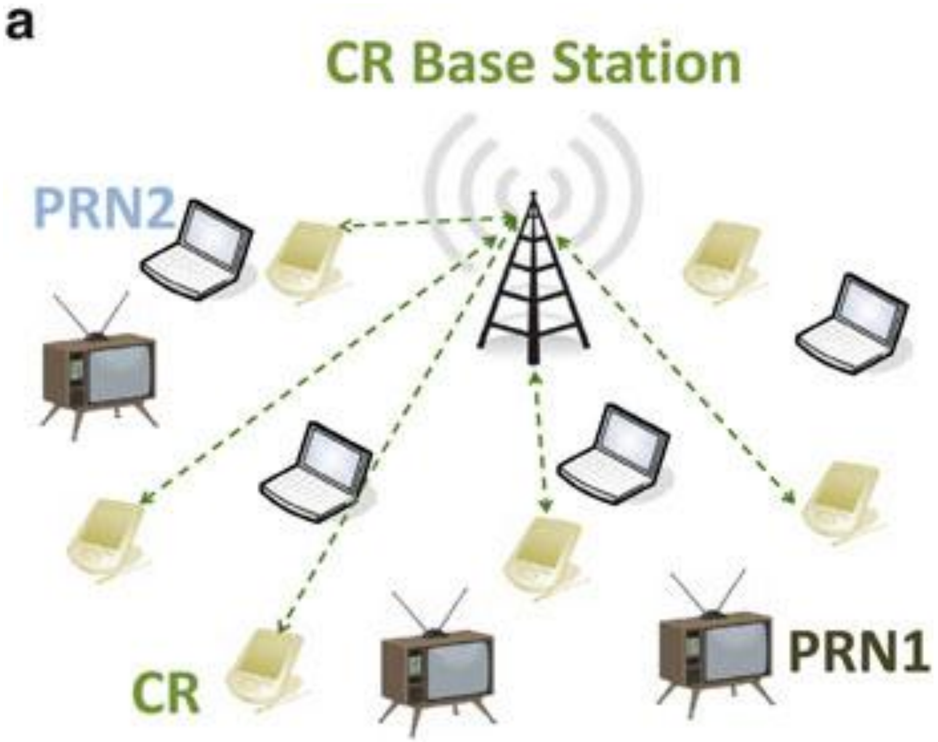
Table: 1 shows the percentage usage of the band. As we can see that up to 3 GHZ band is used but after that the band is partially used. To maximize this usage the concept of CR came into existence.

1.7.1 Cognitive Radio Network Architectures

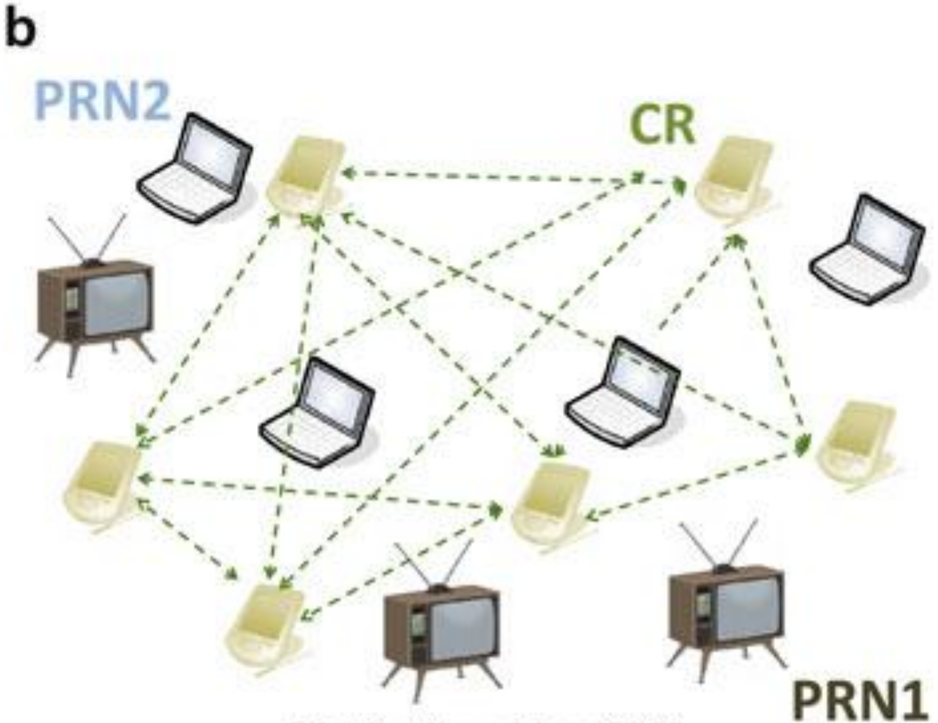
A typical CRN environment consists of a number of Primary Radio Networks (PRNs) that coexist within the same geographical area of a single CRN (also referred to as the secondary network). A primary network is an existing network that is licensed to operate in a certain spectrum band. Hence, a primary network is also referred to as a licensed network. Primary networks can either be based on a centralized infrastructure or distributed ad-hoc in nature. The users of a primary network can only access the spectrum licensed to this particular network. Primary users have priority with respect to spectrum access and operate, as they are the sole users of their licensed spectrum. Hence, primary users do not provide any type of cooperation with the secondary network. PRNs are non-intrusive and the secondary users should not affect the transmissions of the primary users. Therefore, the primary networks define upper bounds on the CRN activities in their licensed bands, typically in terms of maximum power levels, to guarantee the promised performance level to their legitimate users. On the other hand, the CRN is not licensed to operate in a predefined band. Spectrum access for the CRN is achieved in an opportunistic manner that allows the secondary users to opportunistically access the entire spectrum available to all of the geographically collocated PRNs. Recall that the cognitive users can also exploit the unlicensed spectrum. This is referred to as spectrum heterogeneity of CRNs [52, 53]. When operating in a licensed band, the CRN transmissions must adhere to the constraints imposed by its primary owner. A CRN can either be centralized infrastructure-based network or a distributed ad-hoc network as shown in Fig. 2.2

1.7.2 Centralized Cognitive Radio Networks

Centralized CRNs are infrastructure-based networks in which cognitive radio base stations control and coordinate the transmission activities of the secondary cognitive radio users as shown in Fig. 5.1a. The cognitive radio base stations control the secondary transmissions over both the licensed and unlicensed bands by collecting all the spectrum-related information from the cognitive radio users. Based on the collected information, the base stations take global spectrum access decisions for all nodes. An example centralized infrastructure-based CRN is the IEEE 802.22 network model. The IEEE 802.22 is the first worldwide standard for CRNs [54]. The IEEE 802.22 standard defines the specifications of a point-to-multipoint communication scheme over the unused television (TV) bands in which a base station manages cognitive radio users within 33 km radius using a centralized spectrum database. Other examples include the European Dynamic Radio for IP services in Vehicular Environment (DRIVE) [29] and Spectrum Efficient Uni-cast and Multi-cast Services Over Dynamic Radio Network in Vehicular Environments



Centralized infrastructure-based CRN.



Distribution ad-hoc CRN.

Figure 5.2: Classified Cognitive Radio Network Architectures

(Overdrive) [55] Projects. These projects have a centralized entity that coordinates the dynamic utilization of the temporal and spatial spectral opportunities. Centralized Infrastructure-based CRNs are beyond the scope of this book.

1.7.3 Distributed Cognitive Radio Networks

Alternatively, CRNs can also have the cognitive nodes communicating with each other via ad-hoc point-to-point connections over either the licensed or the unlicensed bands as shown in Fig. 5.2b. While alleviating the infrastructure cost, such infrastructure less CRNs have increased networking complexity. In the absence

of a controlling centralized entity, cognitive radio nodes in a distributed CRN jointly coordinate their spectrum access decisions to share the available spectral opportunities. Thus, global mechanisms such as network-wide synchronization might be needed for spectrum access coordination. In addition, distributed cooperative detection and communication techniques are used to improve the overall network performance. Example distributed CRNs include, the peer-to-peer mode of DARPA's next Generation (XG) dynamic access network [31,32], DARPA's Wireless Network after Next (WNAN) military test bed [40], the Nautilus distributed 2.4 Cognitive Radio Network Applications 17 scalable and efficient coordination project for open spectrum ad-hoc network [56, 57], and the cognitive radio approach for usage of virtual unlicensed bands (CORVUS) [58]. This book targets Opportunistic Spectrum Access in distributed CRNs. Our goal is to alleviate the network-wide coordination overhead by omitting inter-flow communications in such a network model.

1.7.4 Cognitive radio Acceptance

With wire-less and radio communications becoming far more widely used, and the current levels of growth looking to increase, ideas such as cognitive radio will become more important. Some areas of the spectrum are very heavily used while others are relatively free. Additionally the ability to change modes, frequencies and power levels will not only make communication possible for the cognitive radio system itself, but should also reduce the overall levels of interference to other users. This is because the most spectrum or interference efficient modes can be chosen by the cognitive radio system. In view of the possibility of CR radio communications systems utilizing the spectrum more efficiently some regulatory bodies such as the FCC in the USA and Ofcom in the UK are looking favorably at the idea of cognitive radio. When the idea becomes a reality it would enable greater efficient use of the radio spectrum, which is not an infinite resource as it once was considered. Accordingly the way may be opened from this viewpoint to assist the development of cognitive radio communications technology.

Cognitive radio is a powerful concept on its own. However under some circumstances it is possible to build a network of radios - nodes by linking several cognitive radio nodes. In this way several elements of the performance can be considerably enhanced.

In many instances a single cognitive radio will communicate with several non-cognitive radio stations as in the case of a femtocell, which requires cognitive functionality to set itself up, and then communicate with non-cognitive cell-phones. In other cases, several cognitive radios will be able to form a network and act as an overall cognitive radio network. This scenario has many advantages in terms of improving the performance of the overall network well beyond that of the individual elements.

1.7.5 Cognitive radio network advantages

The use of a cognitive radio network provides a number of advantages compared to cognitive radios operating purely autonomously:

Improved spectrum sensing: By using cognitive radio networks, it is possible to gain significant advantages in terms of spectrum sensing.

Improved coverage: By setting up cognitive radio network, it is possible to relay data from one node to the next. In this way power levels can be reduced and performance maintained.

1.7.5.1 Spectrum Sensing

Spectrum sensing is one of the key enabling functions in CR networks that are used to explore vacant spectrum opportunities and to avoid interference with the PUs. The two main approaches for spectrum sensing techniques for CR networks are primary transmitter detection and primary receiver detection. The primary transmitter detection is based through the local observations of CR users. The primary receiver detection aims at finding the PUs that are receiving data within the communication range of a CR user. In this approach, the main objective is to find the sensing that minimizes the missed detection probability, i.e. determining the spectrum to be unoccupied when there is an active PU, and conversely, the false alarm probability, i.e. incorrectly inferring the presence of a PU in a vacant spectrum band. Several spectrum sensing methods have been proposed which require some knowledge of the potential interferer, including matched filter detection for specific systems and cyclostationary detectors for known modulations based on spectral correlation theory developed by Gardner. These methods will be helpful for detecting known primary systems. [59,60]. Cognitive networks, which consist of two types of users:

1.7.5.2 Primary Users (PU):

These wireless devices are the primary license-holders of the spectrum band of interest. In general, they have priority access to the spectrum, and subject to certain Quality of Service (QoS) constraints, which must be guaranteed.

1.7.5.3 Secondary Users (SU):

These users may access the spectrum, which is licensed to the primary users. They are thus secondary users of the wireless spectrum, and are often envisioned to be cognitive radios. For the rest of this chapter, we will assume the secondary users are cognitive radios (and the primary users are not) and will use the terms interchangeably. These cognitive users employ their “cognitive” abilities to communicate while ensuring the communication of the primary users is kept at an acceptable level1.

1.7.5.4 Malicious User (MU):

In Cognitive radio network there is a set of secondary users in a system and in the same system there is also a subset of illegal users. If these subset users generate enough power to the secondary user locations which may look like that a primary transmission is occurring. Then according to the rules the secondary users vacate the spectrum. Then the subset users will use those spectrums for their own. These subset bad secondary users are called “malicious users”. A number of good users can lose their access to the network for these types of incidents. All these happen for the malicious users. This occurrence provides poor usage of spectrum to the authorized users and at the same time the malicious users get unfair advantage

1.8 Spatial False Alarm (SFA):

In cognitive radio, secondary user (SU) performs spectrum sensing with a certain sensing range. It is widely considered that a SU is permitted to utilize the primary channel if no primary user (PU) transmits data inside its sensing range. However, it is observed that a busy PU outside the sensing range still can be detected by SU. As a result, the SU misinterprets that this busy PU is inside its sensing range, and hereby loses opportunity to utilize the primary channel. This new sensing issue is termed as Spatial False Alarm (SFA) problem [59].

1.8.1 Spectrum Sensing Techniques

Spectrum sensing techniques include energy detection, matched filter, cyclostationary feature detection, and eigenvalue detection.

1.8.1.1 Energy detection:

This measures the energy of the received signal within the pre-defined bandwidth and time period. The measured energy is then compared with a threshold to determine the status (presence/ absence) of the transmitted signal. Not requiring channel gains and other parameter estimates, the energy detector is a low-cost option. However, it performs poorly under high noise uncertainty and background interference [26].

1.8.1.2 Matched filter:

This detector requires perfect knowledge of the transmitted signal and the channel responses for its coherent processing at the demodulator. The matched filter is the optimal detector of maximizing the signal-to-noise ratio (SNR) in the presence of additive noise. Since it requires the perfect knowledge of the channel response, its performance degrades dramatically when there is lack of channel knowledge due to rapid changes of the channel conditions [27, 28].

1.8.1.3 Cyclostationary feature detection:

If periodicity properties are introduced intentionally to the modulated signals, the statistical parameters of received signal such as mean and autocorrelation may vary periodically. Such periodicity of statistical properties is used in the cyclostationary detection. Cyclostationary properties of the received signal may be extracted by its input-output spectral correlation density. The signal absence status can be identified easily, because the noise signal does not have cyclostationary properties. While this detector is able to distinguish among the primary user signals, secondary user signals, or interference. it needs high sampling rate and a large number of samples, and thus increases computational complexity as well [29–32].

1.8.1.4 Eigenvalue detection:

The ratio of the maximum (or the average) eigenvalue to the minimum eigenvalue of the covariance matrix of the received signal vector is compared with a threshold to detect the absence or the presence of the primary signal. However, if the correlation of the primary signal samples is zero (e.g., primary signal appears as white noise), eigenvalue detection may fail - a very rare event. This detector has the advantage of not requiring the knowledge of the primary signal and the propagation channel conditions. The main drawback is the computational effort to compute covariance matrix and eigenvalue decomposition. The threshold selection is challenging as well [33–35].

1.9 Probability of Detection (PD)

The probability of detection is the time during which the PU (licensed) is detected. The throughput of system depends upon Pd. If the sensing time is increased then PU can make better use of its spectrum and the limit is decided that SU can’t interfere during that much of time. More the spectrum sensing more PUs will be detected and lesser will be the interference because PU can make best use of their priority right. Secondary users might experience losses due to multipath fading, shadowing, and building penetration which can result in an incorrect judgment of the wireless environment, which can in turn cause interference at the licensed primary user by the secondary transmission. This raises the necessity for the cognitive radio to be highly robust to channel impairments and also to be able to detect extremely low power signals. These stringent requirements pose a lot of challenges for the deployment of CR networks [47,49].

1.9.1 Probability of False Alarm (PFA)

Probability of the sensing algorithm mistakenly detecting the presence of PUs while they are inactive. Low probability of false alarm should be targeted to offer more chances for SUs to use the sensed spectrum. The lower the probability of false alarm, the more chances the channel can be reused when it is available, thus the higher the achievable throughput for the secondary network. From the secondary user's perspective, however, the lower the probability of false alarm, there are more chances for which the secondary users can use the frequency bands when they are available. Obviously, for a good detection algorithm, the probability of detection should be as high as possible while the probability of false alarm should be as low as possible. [47,50]

1.9.2 Energy Detector (ED)

The PU transmission to the CU is treated as a deterministic signal with unknown parameters. In such situations, ED is an appropriate mechanism to determine the presence of that unknown deterministic signal (Urkowitz, 1967)[61]. Modeling of primary transmissions as a signal with unknown parameters is particularly important when considering the security threats face by PUs by exposing information to CUs. Without obtaining unwanted and unauthorized information, ED measures the energy content of the received signal over a period of time and tries to decide on the existence of primary transmission. Since, only the content of energy of the waveform matters, and not its shape or other parameters, this technique is simple in structure and can be applied to detect any form of deterministic signals of any overlaying technologies.

However, to meet specific detection probability, O (1/SNR2) samples are required (Tandra and Sahai, 2008)[62]. This is a consequence non-coherent processing of ED. In addition, there are drawbacks of ED that cause to diminish its simplicity in implementation and are listed below (Cabric et al., 2004)[63].

1. The energy threshold used for detection at the detector is highly susceptible to unknown or varying noise power levels and threshold values should be adjusted adaptively.
2. Under frequency selective fading, deciding energy threshold value is difficult with channel notches and sophisticated mechanism should be employed.
3. To work with spread spectrum signals like direct sequence and frequency hopping, more complicated signal processing algorithms are required.
4. The ED cannot differentiate between modulated signals, noise and interference and hence, cannot benefit from interference cancellation techniques.

However, ED finds wide range of applications in cognitive radio and ultra wide-band systems and provides a versatile method, which can be used in many overlaying technologies. Further, ED is optimum to detect a signal with known power (Ganesan and Li, 2007b)[64]. Therefore, researchers are particularly interested in this technique and we will also model our systems based on energy detection as the primary detection mechanism.

In this thesis, we will not consider matched filter detection, cyclostationary feature detection and other methods proposed for detection of spectrum holes.

1.9.3 Energy Detector Applications

The first cognitive radio standard IEEE 802.22 specifies two stage incumbent sensing,

1. Fast sensing
2. Fine sensing

Where energy detection is one of the promising methods in the first stage (Cordeiro and Birru, 2006)[65]. Further, the energy detector is simple in structure, operates with less priority knowledge and does not exploit unauthorized details of primary transmissions thus providing inherent security to PUs. Capability to detect any shape of signal waveforms makes it possible to apply in wide variety of applications over many different technologies.

In developing ultra low power communication systems, Ultra-Wideband (UWB) is a key technology. Research works are underway for low power and low complex receiver realizations, which utilize energy detection approaches (Steiner and Wittneben, 2007)[66].

1.9.4 Spectrum Sensing via Energy Detection

An energy detector is a device that may decide whether the transmitted signal is absent or present in the noisy environment. Energy detector does not require any prior knowledge of the transmitted signal (e.g., phase, shape, frequency). The conventional energy detector measures the energy of the received signal over specified time duration and bandwidth. The energy is then compared with an appropriately selected threshold to determine the presence or the absence of an unknown signal.

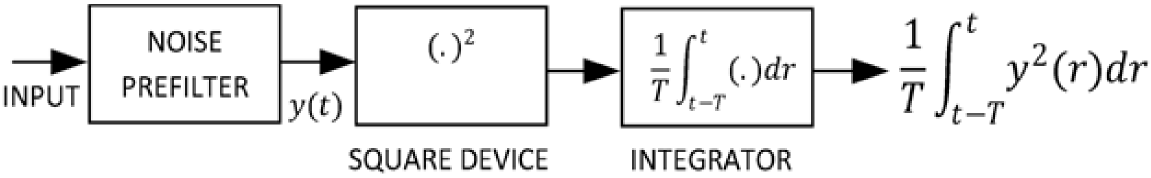


Figure 6: Energy Detector

Two models of energy detector can be considered in time-domain implementations:

1. Analog energy detector, which is illustrated in Fig. 7.1(a), is considered in [48]. It consists of a pre-filter followed by a square-law device and a finite time integrator. The pre-filter limits the noise bandwidth and normalizes the noise variance. The output of the integrator is proportional to the energy of the received signal of the square law device.

2. Digital energy detector is shown in Fig. 7.2(b). It consists of a low pass noise pre-filter which limits the noise and adjacent signal bandwidths, an analog-to-digital converter (ADC), which converts continuous signals to discrete digital signal samples, and a square law device followed by an integrator. The digital implementation is usually used at the experimental tested.

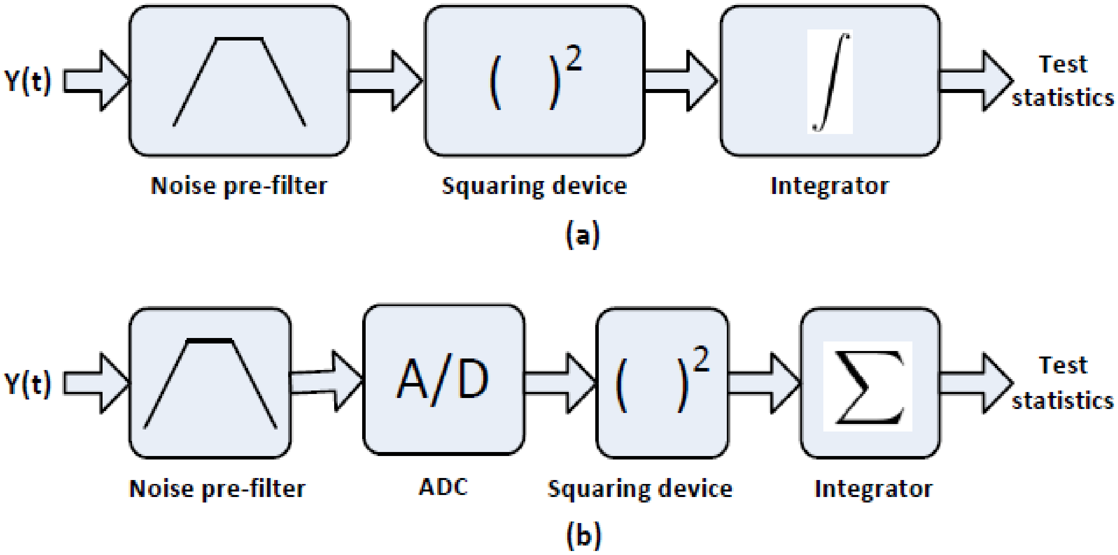


Figure 7: The conventional energy detectors: (a) analog and (b) digital

The integrator output of any architecture is called decision statistic or test statistic. The test statistic is finally compared at the threshold device followed by decision device to make the final decision of the presence/absence of transmitted signal. The test statistic may not always be the integrator output, but it can be any function, which is monotonic with the integrator output

1.9.5 Wireless Channel

The propagation of radio signals significantly affected by the physical channel in several ways. Some of the main channel effects can be described by path loss, slow fading, fast fading, Doppler, delay and angle spreads as follows.

- Fast Fading - Caused by multipath propagation. Rapid fluctuations are observed in the received signal amplitude.
- Path Loss - Caused by many factors including antenna, filter and propagation losses.
- Depends heavily on the propagation medium and the wireless environment.
- Slow Fading - Caused by shadowing effects due to mountains, buildings etc.
- Doppler Spread - Also known as time-selective fading.
- Delay Spread - Also known as frequency-selective fading.
- Angle Spread - Also known as or space-selective fading.

In this research, spectrum sensing is discussed over fast fading channels such as Additive White Gaussian Noise Channel, Rayleigh and Nakagami-m. Other important effects such as frequency selective, time selective and slow fading effects are out of the scope of this research study.

1.9.6 Additive White Gaussian Noise Channel

The additive white Gaussian noise (AWGN) channel is the simplest wireless channel model, which does not account inevitable fading effects. In this case, the energy detector has to decide on the existence of signal s (t) based on the decision variable under noise uncertainty. In addition, in energy detection, the signal is modeled as an unknown deterministic and hence detector cannot benefit from interference cancellation techniques. Therefore, modeling the channel as AWGN includes the interference.

1.9.7 Rayleigh Fading Channels

When information is transmitted in an environment with obstacles (Non Line-of-sight - NLOS), more than one transmission paths will appear as result of the reflection(s). The receiver will then have to process a signal, which is a superposition of several different transmission paths. If there exists a large number of transmission paths may be modeled as statistically independent; the central limit theorem will give the channel the statistical characteristics of a Rayleigh Distribution [67]. (Figure: 8)

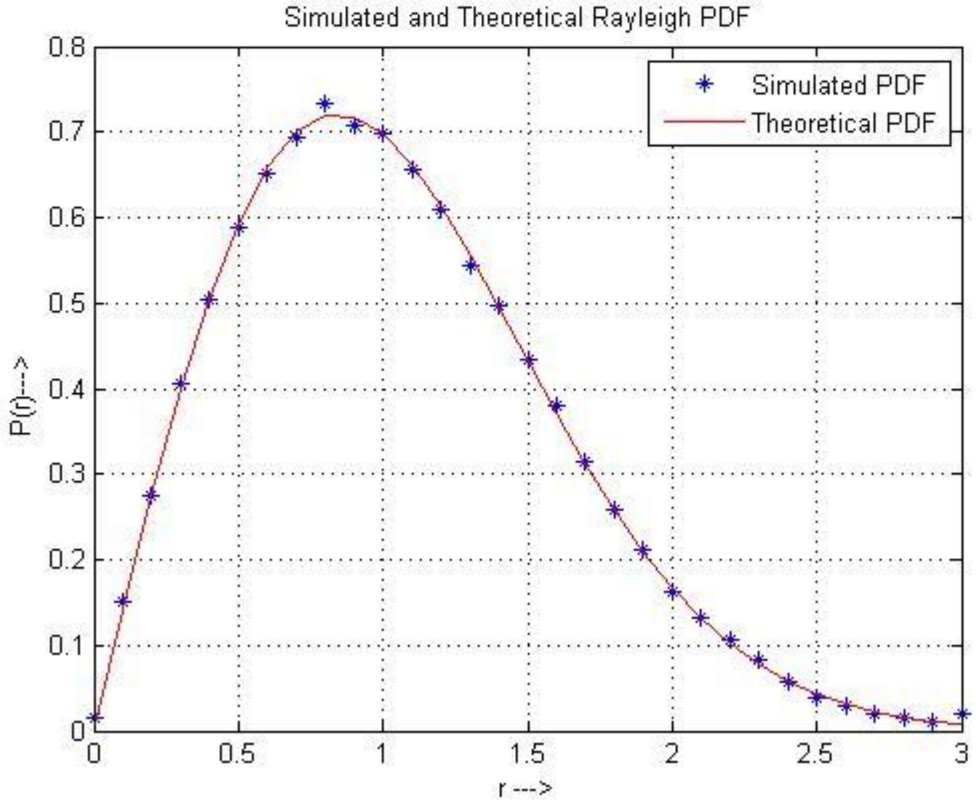


Figure 8: Rayleigh Fading Channel

1.9.8 Nakagami Fading Channel

Although Rayleigh and Ricean distributions are the most popular distributions to model fading channels, some experimental data does not fit well into neither of these distributions. Thus, a more general fading distribution was developed whose parameters can be adjusted to fit a variety of empirical measurements [68]. This distribution is called the Nakagami fading distribution. The Nakagami distribution was introduced by Nakagami in the early 1940’s to characterize rapid fading in long distance HF channels [69].

It is possible to describe both Rayleigh and Rician fading with the help of a single model using the Nakagami distribution. The Nakagami m-distribution is used in communication systems characterize the statistics of signal transmitted through multipath fading channels. The Nakagami distribution is often used for the following reasons. First, the Nakagami distribution can model fading conditions that are either more or less severe than Rayleigh fading. When $m = 1$, the Nakagami distribution becomes the Rayleigh distribution, when $m = 1/2$, it becomes a one-sided Gaussian distribution, and when $m = \infty$ the distribution becomes an impulse (no fading). Second, the Ricean distribution can be closely approximated by using the following relation between the Ricean factor K and the Nakagami shape factor m [69].

CHAPTER: 2

SYSTEM MODEL

2.1 Analytical Model

Now consider the more general signal detection problem

$$H_0 : x[n] = w[n] \qquad \text{n=0, 1 ………..}N\text{-1}$$

$$H_1 : x[n] = A + w[n] \qquad \text{n=0, 1………… }N\text{-1}$$

Where the signal is s[n] = A for $A > 0$ and w[n] is WGN with variance σ^2. The previous example is just a special case where $A = 1$, $N = 1$ and $\sigma^2{}_{=1}$. Also note that the current problem is actually a test of the mean of a multivariate Gaussain PDF. This is because under H_0, $x \sim N\ (0,\ \sigma^2\ I)$ while under H_1, x $\sim N\ (A1,\ \sigma^2\ I)$, where 1 is the vector of all ones. Hence we have equivalently

$$H_0 : \mu = 0$$

$$H_1 : \mu = A1$$

We will often use this parameter test of the PDF interpretation in describing a single detection problem. Now the NP detector decides H_1 if

$$\frac{\dfrac{1}{\left(2\pi\sigma^2\right)^{\frac{N}{2}}}\exp\left[-\dfrac{1}{2\sigma^2}\sum_{n=0}^{N-1}(x[n]-A)^{2}\right]}{\dfrac{1}{\left(2\pi\sigma^2\right)^{\frac{N}{2}}}\exp\left[-\dfrac{1}{2\sigma^2}\sum_{n=0}^{N-1}x^2[n]^{2}\right]} > \gamma$$

Taking the logarithm of both sides results in

$$-\frac{1}{2\sigma^2}\left(-2A\sum_{n=0}^{N-1}x\ [n]\ + NA^2\right) > \ln\gamma$$

which simplifies to

$$\frac{A}{\sigma^2}\sum_{n=0}^{N-1} x\ [n]\ > \ln\gamma + \frac{NA^2}{2\sigma^2}$$

Since $A > 0$, we have finally

$$\frac{1}{N}\left[\sum_{n=0}^{N-1} x[n] > \frac{\sigma^2}{NA}\right]\ln\gamma + \frac{A}{2} = \gamma \tag{3.5}$$

The NP detector compares the sample mean $x = \sum_{n=0}^{N-1} x\ [n]$ to a threshold γ'. This is intuitively reasonable since χ may be thought of as an estimate of A. If the estimate is large and positive, then the signal is probably present. How large the estimate must be before we are willing to declare that a signal is present depends upon our concern that noise only may cause a large estimate. To avoid this possibility we adjust γ' to control P_{FA} with larger threshold values reducing P_{FA} (as well as P_D).

To determine the detection performance we first note that the test statistic $\boldsymbol{T(x) = (\frac{1}{N})\sum_{n=0}^{N-1} x[n]}$ is Gaussian under each hypothesis. The means and variances are

$$ET(x);H_0 = E\left(\frac{1}{N}\right)\sum_{n=0}^{N-1} w[n]\ = \frac{1}{N}\sum_{n=0}^{N-1} E(w[n])$$

$$= 0$$

Similarly, $ET(x);H_1 = A$ and

$$\operatorname{var}(T(x);H_0) = \operatorname{var}\left(\frac{1}{N}\sum_{n=0}^{N-1} w[n]\right) = \frac{1}{N^2}\sum_{n=0}^{N-1}\operatorname{var}(w[n])\ = \frac{\sigma^2}{N}$$

Similarly, $\mathrm{var}\left(T(x);H_1\right)$ $=\sigma^2/\mathrm{N}$ where we have noted that the noise samples are uncorrelated, Thus

$$\mathrm{T}\ (\mathrm{x}) \sim \begin{cases} N\left(0, \dfrac{\sigma^2}{N}\right) \text{ under } H_0 \\ N\left(A, \dfrac{\sigma^2}{N}\right) \text{ under } H_1 \end{cases}$$

We have then

$$P_{FA} = \Pr\{T(x) > \gamma'; H_0\}$$
$$= Q\left(\frac{\gamma'}{\sqrt{\sigma^2 / N}}\right) \tag{3.6}$$

and Probability Detection,

$$P_D = \Pr\{T(x) > \gamma;' H_1\}$$
$$= Q\left(\frac{\gamma' - A}{\sqrt{\sigma^2 / N}}\right) \tag{3.7}$$

We can relate P_D to P_{FA} more directly by noting that the Q function is monotonically decreasing since 1-Q is a CDF, which monotonically increasing. Thus Q has an inverse that we denote as Q^{-1}. As a result, the threshold is found from (3.6) as

$$\gamma' = \sqrt{\frac{\sigma^2}{N} Q^{-1}};\left(P_{FA}\right)$$

Probability Detection,

$$P_D = Q\left(\frac{\sqrt{\frac{\sigma^2}{N}}Q^{-1}\left(P_{FA}\right) - A}{\sqrt{\frac{\sigma^2}{N}}}\right)$$

$$= Q\left(Q^{-1}\left(P_{FA}\right) - \sqrt{\frac{NA^2}{\sigma^2}}\right) \tag{3.8}$$

The average probability of detection under Nakagami-*m* fading is given by:

$$P_{d_{Nak}} = \int_0^{\alpha} P_d\left(\gamma\right) f_{Nak}\left(\gamma\right) d\gamma$$

Where $f_{Nak}(\gamma)$ is the probability density function of the instantaneous signal to noise ratio at the fusion center, γ.

The fusion center decision probabilities under soft decision fusion are therefore well approximated by:

$$P_f \approx Q\left(\frac{\gamma - Mn}{\sqrt{2Mn}}\right),$$

$$P_d\left(\gamma\right) \approx Q\left(\frac{\gamma - M\left(n+\gamma\right)}{\sqrt{2M\left(n+2\gamma\right)}}\right)$$

.

2.2 Simulation Model

1. Generate N = 50 random variable x_j with mean and variance σ^2 follows Gaussian PDF. Taking the mean of x_j i,e $T(i) = \frac{1}{N}\sum_{j=1}^{N} x_j$.
2. Generate M = 10,000 mean symbols $T(i)$; i = 1, 2, 3, 4……………10,000.
3. Evaluate maximum and minimum value of $T(i)$ denoted as $\gamma_{\max}$ and $\gamma_{\min}$. The interval of SNR will be $\frac{\gamma_{\max} - \gamma_{\min}}{N_\delta}$, where N_δ is selected as the number of SNR points on P_D vs SNR curve.

4. Let us model the channel of "Rayleigh Channel" symbols period of t' and Doppler Shift D as:

   Channel = Rayleigh (t' , D).
5. The Fading signal will be:

   F_{ad} = filter (Channel, *T);*

   where *T* is a vector whose elements are mentioned in Step-1.
6. Let us count the number of event for which $T > \gamma(i)$; where the maximum, minimum and interval of γ is shown in Step-3. If the. is $N_c(i)$ then the probability of Detection P_D will be $\frac{N_c(i)}{M}$.
7. The theoretical value of P_D is $\int_{\gamma_{\min}}^{\gamma_{\max}} \frac{1}{2} erf_c\left(\gamma / \sqrt{2\sigma^2 lN}\right) e^{-\gamma/\gamma_{av}} d\gamma$ where γ_{av} in above equation if the γ of Step-6.
8. Let us compare the result of Step-6 and Step-7 and absorbed the confidence level of Simulations.

CHAPTER: 3

RESULTS

3.1 Results and Discussion

This chapter provides the results based on the system model of Chapter-3. Fig-3.1 shows the variations of probability of false alarm against threshold SNR in dB for pure AWGN channel. It is visualized that the P_f decays with increase in SNR at the same time P_f also decreases with increase in the number of Samples considered for detection. Here, we can consider the number of samples $N = 5$, 10 and 20 and the range of SNR -8 dB to 6 dB. The P_f fall below 8% at SNR of 0, 1.66 and 3.33 dB for $N = 20$, 10 and 5 respectively.

Fig-3.2 shows the variations of Probability of Detection P_D against threshold SNR in dB for pure AWGN channel. The probability of detector P_D remains approximately constant till SNR of 0 dB and beyond that P_D falls exponentially. Now, we have to find an optimum solutions so that $P_f \leq 0.08$ and $P_D \geq 0.8$. Comparing fig 3.1 & 3.2, we found SNR of 0, 1.66 & 3.33 dB to satisfy above condition.

Fig-3.3 shows the variations of probability of false alarm against threshold SNR in dB for Rayleigh, Nakagami-*m* and pure AWGN channel. From the profile of P_f of fading channel we found that P_f is maximum for Rayleigh fading case and minimum for AWGN channel and Nakagami-*m* channel provides an intermediate result since Nakagami-*m* fading channel provides strongly direct link where the Rayleigh fading channel does not have any direct path.

Similarly the variation of probability of detection is plotted against threshold SNR in dB for Rayleigh, Nakagami-*m* and pure AWGN channel shows in Fig 3.4. Now, we have to find the optimum solution like before to satisfy the condition of $P_f \leq 0.08$ and $P_D \geq 0.8$. For Nakagami-*m* fading case SNR = 0 dB provides above result but for Rayleigh fading case SNR ≥ 2.8 dB for $P_f \leq 0.08$ and $P_D \geq 0.8$. Therefore, received SNR requirement is grater for Rayleigh fading channel compared to Nakagami-*m* fading case.

In Fig 3.5., Finally, we compare the analytical and simulation of probability of detection against SNR for Rayleigh fading channel. The error between analytical and simulation result is found < 5% hence the simulation proves 95% confidence level.

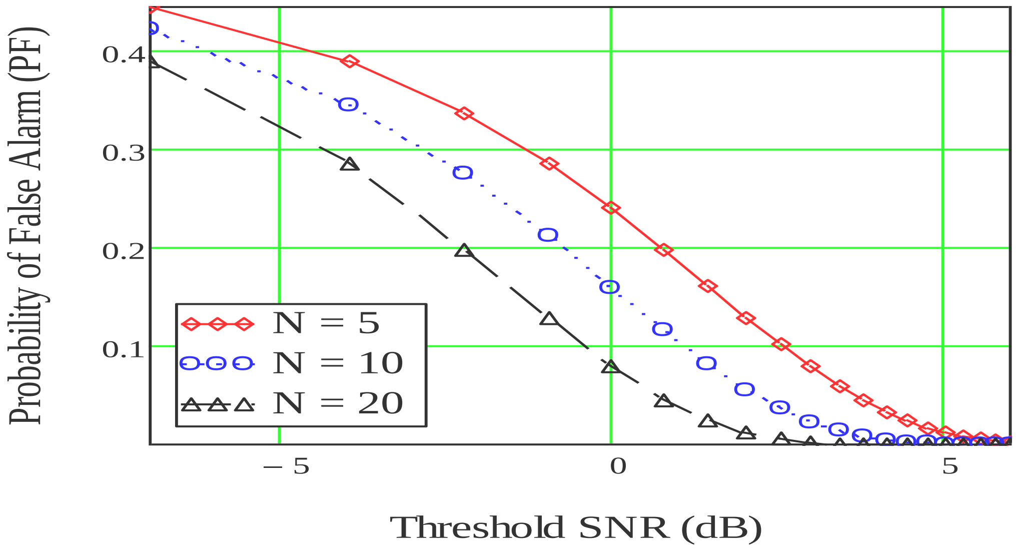


Figure 3.1: Variation of probability of false alarm against SNR taking the number of sample parameter for pure AWAN channel.

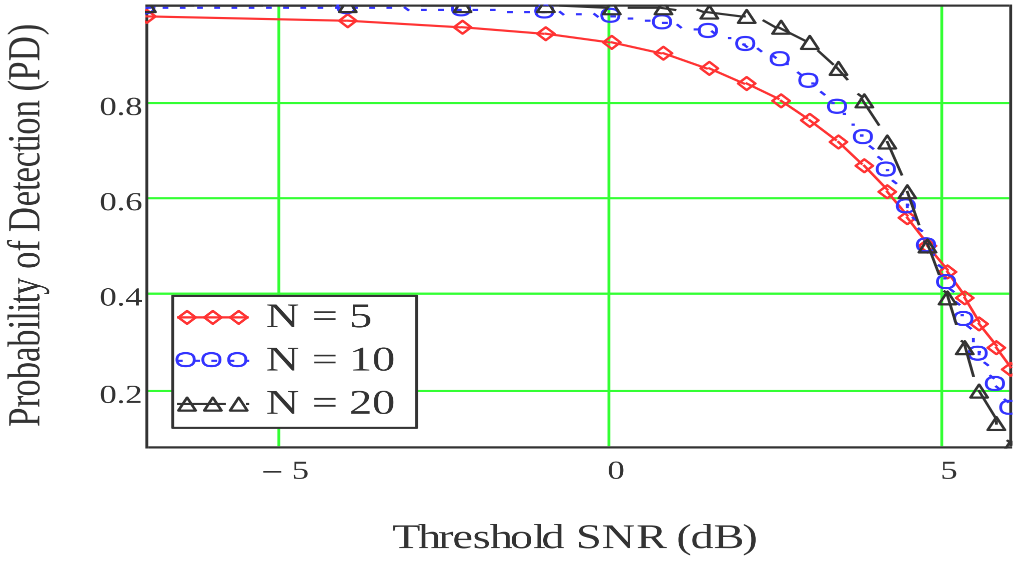


Figure 3.2: Variation of Probability of Detection against SNR taking the number of sample parameter for pure AWGN channel.

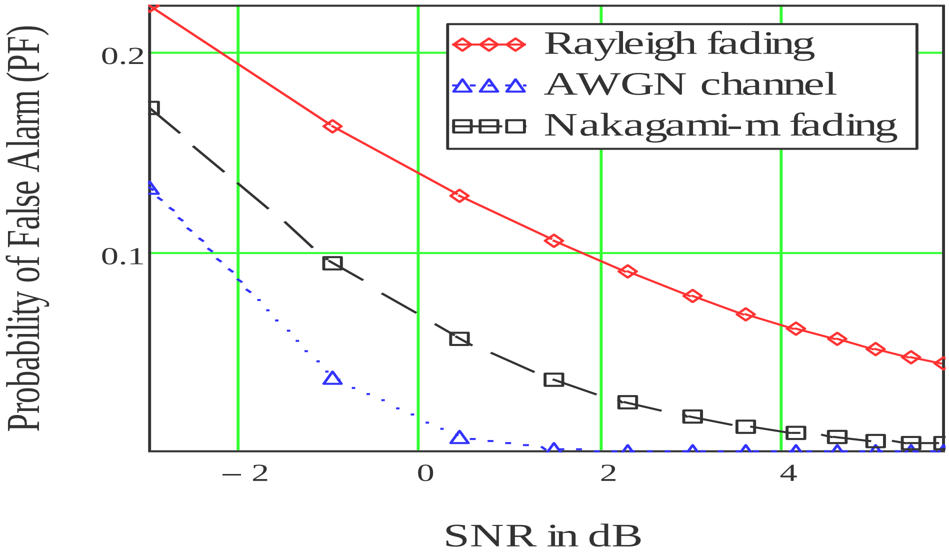


Figure 3.3: Variation of probability of False Alarm against SNR for Rayleigh, Nakagami-*m* and pure AWGN channel.

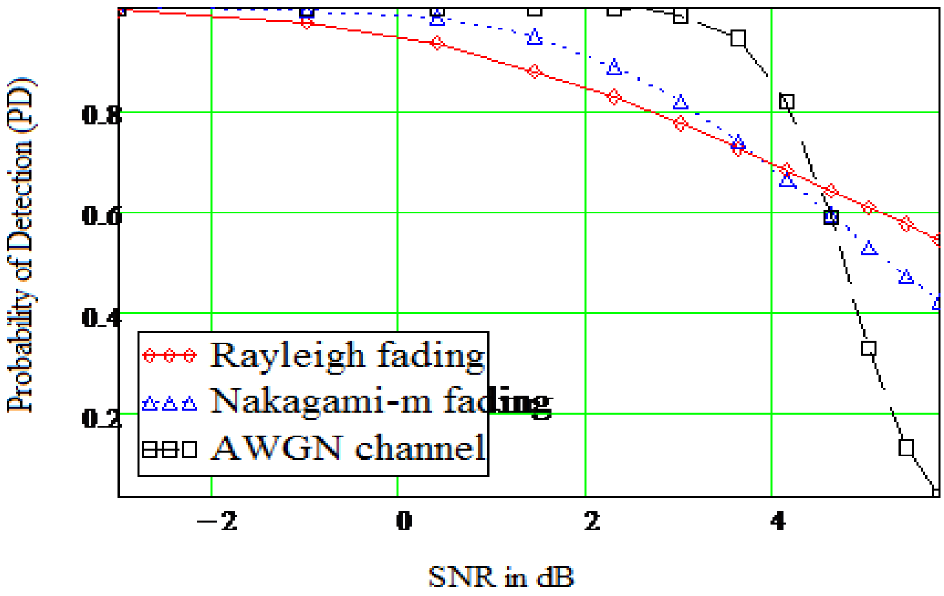


Figure 3.4: Variation of Probability of Detection against SNR for Rayleigh, Nakagami-*m* and pure AWGN channel.

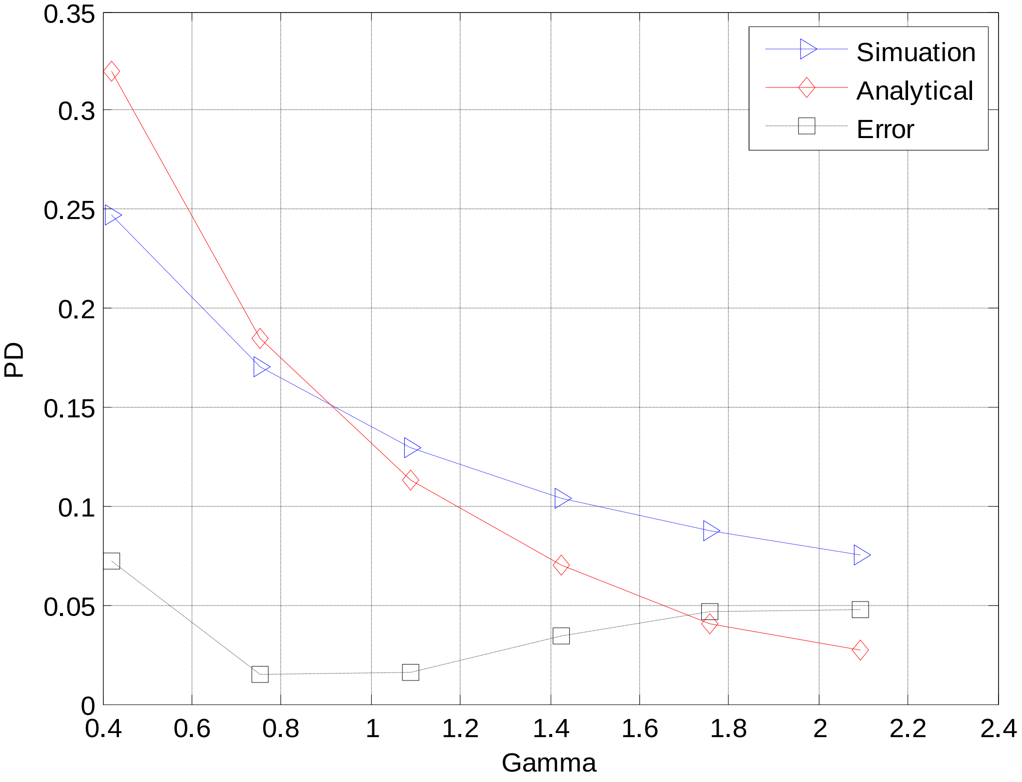


Figure 3.5: Comparison of simulation and analytical P_D under Rayleigh fading channel

CHAPTER: 4

CONCLUSION

CONCLUSTION

In this research project work, we evaluate the performance of cognitive radio network based on probability of detection and probability of false alarm. The received SNR is evaluated to provide $P_f \leq 8\%$ and $P_d \geq 80\%$ for Rayleigh and Nakagami-*m* fading channel. The analytical and simulation results are compared which provides 95% confidence level. The above work can be extended for chi-squired PDF where random variables are the square sum of Gaussian random variable, even for the case of weighted sum of random variable signal. Another further work can be inclusion of malicious user and observed of its impact on network performance.

CHAPTER: 5

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