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ADAPTIVE POWER CONTROL BY USING THE RECEIVED SNR AS A PROXY FOR DISTANCE TO OPTIMIZE THE SPECTRUM USAGE IN A COGNITIVE RADIO SYSTEM

Rizwan Hussain

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Blekinge Institute of Technology
School of Engineering
Department of Applied Signal Processing
Supervisor: Maria Erman
Examiner: Dr. Jörgen Nordberg

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Abstract

In this thesis work we have proposed an Adaptive Power Transmission scheme for Cognitive Radio. The proposed scheme estimates the distance between the primary user and the Cognitive Radio, using the SNR as proxy for distance, also utilizing the information of IT (Interference Temperature). On the basis of these information the Cognitive radio adaptively changes its transmit power to prevent the primary user from harmful interference. The most challenging problem of cognitive radio is the interference which occurs when a cognitive radio accesses a licensed band but fails to notice the presence of the licensed user. Another challenge is to compute the correct distance between the cognitive radio and the primary user. To allow the cognitive radio to access the same spectrum band where the primary user is operating creates a problem, in such case; the cognitive radio may interfere with the primary system, hence degrading the quality of service for the primary receiver. The Primary goal of this work is to propose Adaptive power control based on the estimated distance R_{cr}^{pr} between the cognitive radio and primary user. We will discuss the transmit power being controlled on the basis of distance. But there is no such method to calculate the exact distance between the cognitive radio and the primary user, so that we interpret distance in terms of SNR. We will propose a method to make the CR so intelligent that it can determine the maximum level of the transmission power which does not cause any harmful interference to the primer user's quality of service.

Acknowledgements

In the name of ALLAH, the Beneficent, the Merciful. All praises to Allah who created me and granted me everything and give me ability to complete this task. Then I would like to express my deepest gratitude to my supervisors Maria Erman for her support, valuable advice and guidance throughout my thesis work. I am also thankful to BTH for providing me all the facilities and for being a part of such wonderful environment.

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Abbreviations:

RRC	Radio Resource Management
CR	Cognitive Radio
PRU	Primary User
SRU	Secondary User
CSI	Channel State Information
IT	Interference Temperature
2G	Second Generation

3G	Third Generations
3GPP	Third Generation Partnership Project
ARFCN	Absolute Radio Frequency Channel
BCCH	Broadcast Control Channel
BS	Base Station
BTS	Base Transceiver Station
CPICH	Common Pilot Channel
DAS	Distributed Antenna System
EMR	Electro-Magnetic Radiation
EU	Expansion Unit
FDMA	Frequency Division Multiple Access
GPRS	General Packet Radio Service
HSDPA	High Speed Downlink Packet Access
HSPA	High Speed Packet Access
HSUPA	High Speed Uplink Packet Access
ICNRP	International Commission on Non-Ionizing Radiation Protection

Chapter 1

Introduction

Due to the Speedy expansion of wireless applications in recent years, spectrum assets are facing massive demands. The radio spectrum is a limited resource, regulated by government agencies such as the Federal Communications Commission (FCC) in the United States. Within the current spectrum regulatory structure, many parts of the spectrum are entirely allocated to specific services and no violation from unlicensed users is legitimate. The spectrum scarcity problem is getting less of a problem due to the appearance of new wireless services. Luckily, the doubts about spectrum scarcity are being shattered by a recent review made by a Spectrum Policy Task Force (SPTF) within the FCC undertaken in New York City, reporting that the maximum total spectrum occupancy is only 13.1% from 30 MHz to 3 GHz. The electrifying results shed light on the problem of spectrum scarcity and inspired a new direction of possible solutions.

1.2 Previous Work & Thesis motivation:

To deal with the dispute between spectrum congestion and spectrum underutilization, a novel technology has been introduced recently which allows the unlicensed user to utilize licensed spectrum bands. [12], [13] by locating the spectrum holes with service given to these users through these spectrum holes. In this manner, the aim of this technology is to give a more efficient utilization of the spectrum. Cognitive radio provides some important metrics which includes spectrum sensing, transmit power control and dynamic frequency selection [14].From many challenging issues one of them is the interference which occurs when a cognitive radio aggressively increases its transmit power without notifying the presence of the primary user. To address this problem the cognitive radio is designed so that it can coexist with primary user without causing any harmful interference. There are different methods to control the interference one of them is to consider the choice of modulation format for the transmission of packets over selected spectrum gaps or holes. For this we strongly consider OFDM (orthogonal frequency division multiplexing) as a method of choice for the transmission of packets over a selected spectrum gaps or holes [1].A power control approach is presented for cognitive radio to avoid the harmful impact on the primary user's quality of servise.This power control approach is based on the location of primary user [4].

There are three main research areas in cognitive radio: spectrum sensing, Radio Resource Management, and Adaptive Transmission techniques [1].Spectrum sensing is for recognizing the ideal frequency or spectrum holes in time frequency space and region .The RRM (Radio Resource Management) is a set of MAC protocols that concurrently inform the predictable spectrum idleness to the BS (Base Station) and the MS (Mobile Station) when a fixed control channel for the CR systems does not exist. The wireless adaptive transmission is a technique that optimally transmits the data by adaptively adjusting the system parameters using the given sensing information and the CSI (Channel State Information) based on the IT (Interference Temperature) [5].

1.3 Thesis Problem formulation:

In this thesis work we propose an Adaptive power Transmission scheme for cognitive radio .The proposed scheme estimates the distance between the primary user and the cognitive radio using the SNR as proxy for distance, also utilizing the information of the IT (Interference Temperature).On the basis of this information, cognitive radio adaptively changes its transmit power to prevent the primary user from harmful interference. This power control method will allow the secondary users to aggressively increase their transmit power without affecting the quality of the service of the primary user.

The thesis work aims to:

- Propose Adaptive power P_{max}^{cr} to achieve maximum throughput for the CR user.
- Find the minimum value of $SINR_{min}^{pr}$ at the primary user to decode the signal accurately (as the minimum acceptable SINR at primary user).
- Find the exact distance between the CR and the primary user R_{cr}^{pr}.

1.4 Report Outline:

Chapter # 2: Gives a basic introduction to cognitive radio technology and its different issues.

Chapter # 3 : This chapter covers theory,the system model, and mathematical developments of the basic problems in cognitive radio like how to calculate the distance between the cognitive radio and the primary system; what interference temperature is and how we develop the IT model to mitigate the interferece at the primary user. A proposed power control algorithm is also included in this chapter. .

Chapter # 4: This chapter includes information on how the system works and some block diagrams are presented to develop the understanding of the system.

Chapter # 5: This chapter includes simulations and results,The environment of the simulation is Matlat

Chapter # 6 :Conclusion and future work.

Chapter 2

Introduction to Cognitive Radio

2.1 Introduction:

Due to the Speedy expansion of wireless applications in recent years, spectrum assets are facing massive demands. The radio spectrum is a limited resource, regulated by government agencies such as the Federal Communications Commission (FCC) in the United States. Within the current spectrum regulatory structure, many parts of the spectrum are entirely allocated to specific services and no violation from unlicensed users is legitimate. The spectrum scarcity problem is getting less of a problem due to the appearance of new wireless services. Luckily, the doubts about spectrum scarcity are being shattered by a recent review made by a Spectrum Policy Task Force (SPTF) within the FCC undertaken in New York City, reporting that the maximum total spectrum occupancy is only 13.1% from 30 MHz to 3 GHz. The electrifying results shed light on the problem of spectrum scarcity and inspired a new direction of possible solutions.

To solve the conflict between spectrum scarcity and spectrum under-utilization, cognitive radio [8], [9], including software-defined radio, has been proposed as the means to promote the spectrum utilization by allowing the secondary user (who is not being serviced) to access a spectrum hole unoccupied by the primary user at the right location and the time in question . As an intelligent wireless communication system, cognitive radio is aware of the radio frequency environment, selects the communication parameters (such as carrier frequency, bandwidth and transmission power) to optimize the spectrum usage and adapts its transmission and reception accordingly without disturbing the quality of service of the primary user. One of most vital issues of cognitive radio technology is spectrum sensing

2.2 Why Cognitive Radio:

Cognitive radio is emerging as a promising software defined radio technology in wireless communication for maximizing the use of limited resources of radio bandwidth .This software defined radio technology adapts the dynamic radio environment to maximize the utilization of the limited radio recourses .There are some reasons behind this technology which are mentioned below.

- Today's radio systems are not aware of their radio spectrum environment and operate in a specific frequency band.
- In some locations or at some times of the day, 70 percent of the allocated spectrum may be sitting idle.
- New bandwidth-intensive wireless services are being offered.
- Unlicensed users constrained to a few overloaded bands
- Increasing number of users.

This growth requires more spectral bandwidth to satisfy the user's demand The key feature of this technology is awareness of the radio environment. A good and clear definition of cognitive radio can be found in Simon Haykin's words [1].

"Cognitive radio is an intelligent wireless communication system that is sensitive of its neighboring environment (i.e., outside world), and uses the methodology of understanding-by-building to learn from the environment and adapt its internal states to statistical variations in the incoming RF stimuli by making corresponding changes in certain operating parameters (e.g., transmit-power, carrier-frequency, and modulation strategy) in real-time, with two primary objectives in mind.

- Exceedingly trustworthy communications whenever and wherever needed;
- Efficient utilization of the radio spectrum.[1]"

Smartness of cognitive radio technology can be illustrated in the cognitive cycle shown in figure 2.1.

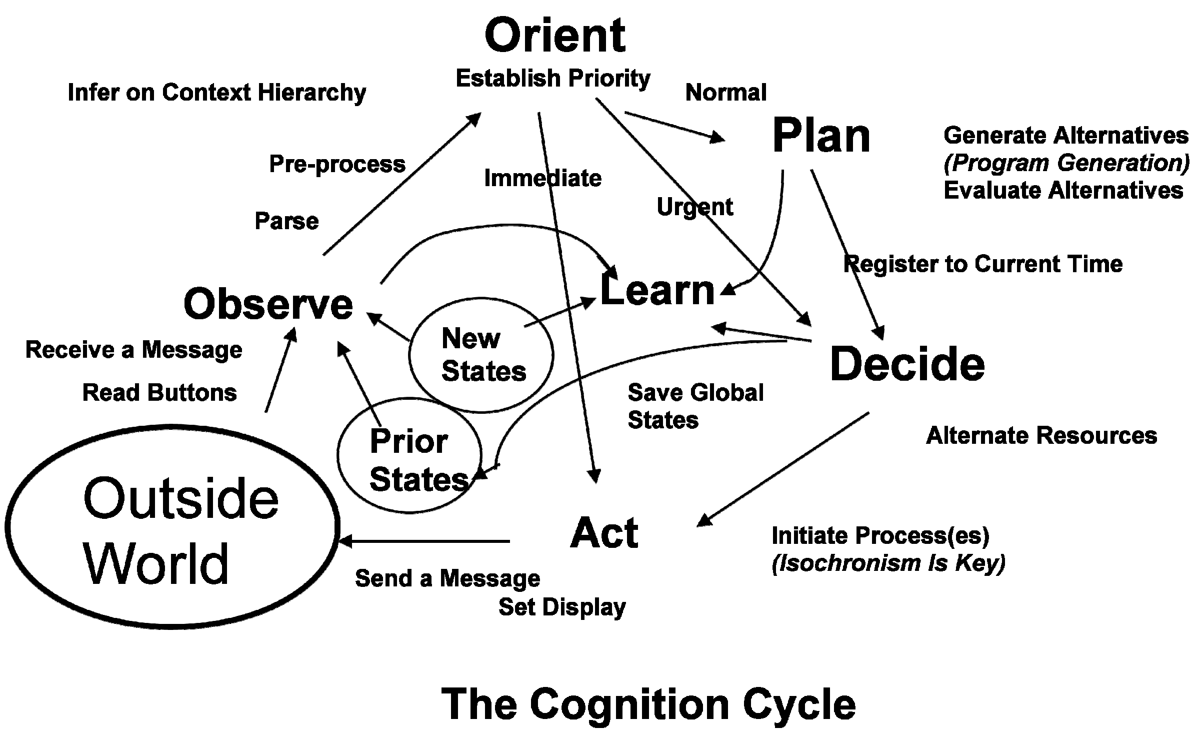
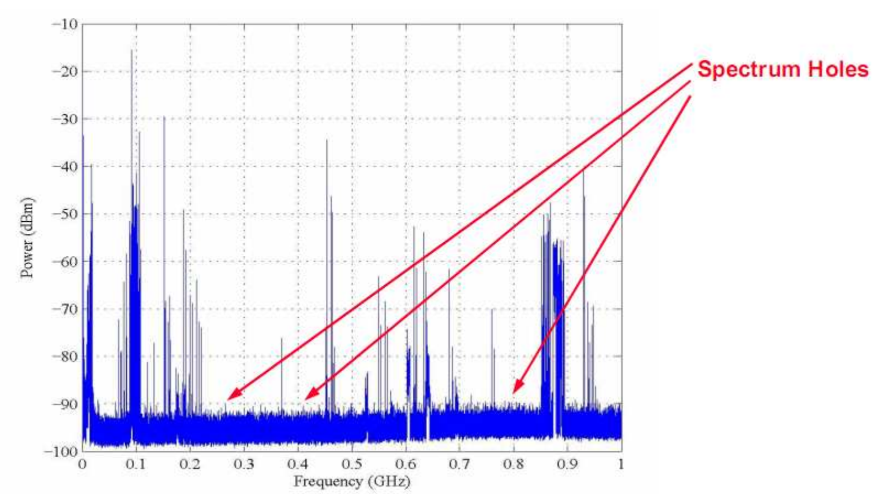


Figure 2.1: Cognitive Cycle showing the smartness of this technology, [2006 Josef Mitola].

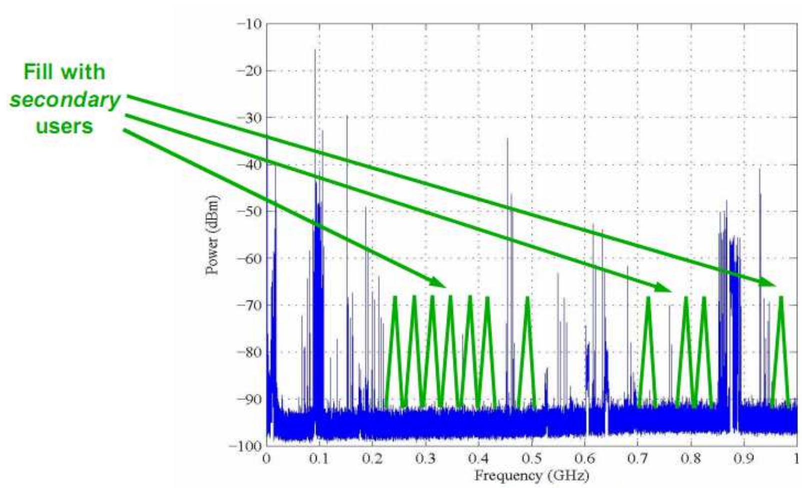
2.3 Vacant Frequency Bands (Spectrum holes):

Most of today's radio systems are not aware of their radio spectrum environment and operate in a specific frequency band using a specific spectrum access system. Investigations of spectrum utilization indicate that not all of the spectrum is used in space (geographic location) or time. A radio, therefore, that can sense and understand its local radio spectrum environment, to identify temporarily vacant spectrum and use it, has the potential to provide higher bandwidth services, increase spectrum efficiency and minimize the need for centralized spectrum management. This could be achieved by a radio that can make autonomous (and rapid) decisions about how it accesses the spectrum. Cognitive radios have the potential to do this. Cognitive radios have the potential to jump in and out of unused spectrum gaps to increase spectrum efficiency and provide wideband services. We can define spectrum holes as:

“A spectrum hole is a band of frequencies assigned to a primary user, but, at a particular time and specific geographic location, the band is not being utilized by that user.” [1]



Spectrum measurement across the 900 kHz –1 GHz band (Lawrence, KS, USA)



Spectrum measurement across the 900 kHz –1 GHz band (Lawrence, KS, USA)

Figure 2.2: Spectrum Measurement across the 900 kHz-1 GHz (Lawrence, KS, USA) (a) Frequency holes (b) Fill those holes with secondary user's data

2.4 Spectrum Sensing:

Spectrum sensing is a key factor in CR communications as it should be firstly performed before allowing unlicensed users to access a vacant licensed channel .This ensures the efficient utilization of the spectrum. There are many techniques to sense which channel of the primary system is in use or is vacant:

- **Energy Detection:** The energy detection method is optimal for detecting any unknown zero-mean constellation signals.
- **Match filter:** Match filter is an optimal method for detection of signals. match filter maximizes the signal to noise ratio of the received signal in the presence of AWGN.
- **Cyclostationary Detection:** If the signal of the primary system has cyclic characteristics, that signal can be detected at very low signal to noise ratio (SNR) by using a Cyclostationary detection technique.
- **Wavelet Detection:** Signal detection over wideband channels, the wavelet detection approach offers compensation in terms of implementation cost as well as flexibility in adapting to the dynamic spectrum as opposed to conventional use of multiple narrowband band pass filters (BPF) [10].

2.5 Interference Temperature:

The idea of interference temperature (IT) is impossible to tell apart to that of noise temperature. It is a measure of the power and bandwidth occupied by interference.

RF noise floor rise due to random appearance of new sources of interference such as out of sight terminals or CR (unlicensed user) causing a progressive destruction of quality of service. To guard against such a possibility, the FCC Spectrum Policy Task Force has recommended a paradigm shift in interference estimation. The proposal is based on a new metric called the IT model. The proposal is made with two key benefits:

a) "The interference temperature at a receiving antenna provides an accurate measure for the acceptable level of RF interference in the frequency band of interest; any transmission in that band is considered to be "harmful" if it would increase the noise floor above the interference-temperature limit.

b) A particular frequency band in which the interference temperature is not exceeded, that band could be made available to unlicensed users; the interference temperature limit would then serve as a "cap" placed on potential RF energy that could be introduced into that band".[1]

2.6 Dynamic Spectrum Management:

The priority of the CR system is to enhance the utility of the radio spectrum; to achieve this there are two main focus points:

1. Unoccupied sub-bands must coexist with the primary users and the secondary user.

2. Interference temperature (IT) at the receiver does not surpass an approved limit.

By keeping these two points in mind we can develop a working algorithm for the CR transmission:

1. If the wireless channel is sensed to be unused (i.e., a spectrum hole is available), the user can transmit its packets.
2. If the channel is sensed to be full of activity i.e., the spectrum hole has become occupied, the transmission of packets should be stopped and scheduled again depending on the results of the channel sensor.

3. In the same way, at every new interval of time, the user senses the channel and repeats the algorithm.

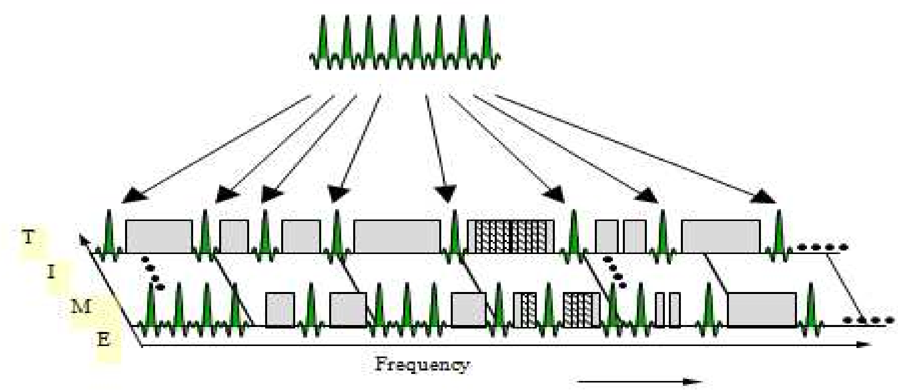


Figure 2.3: Dynamic Spectrum Access

2.7 Modulation Format:

Adaptive modulation is used in response to the quality of signal reception measured at the receiver; in effect, feedback is needed between each pair of the system, to make adaptive modulation to be feasible. The modulation order is changed according to the interference temperature at the primary user and the distance between the cognitive radio and the primary user. In this work we use four kinds of modulation

2.7.1 BPSK: Binary phase-shift keying

2.7.2 QPSK: Quadrature phase-shift keying (QPSK)

2.7.3 QAM: Quadrature Amplitude Modulation (8 bit and 64 bit)

Figure 2.4 shows that the power at the receiver is decreased by increasing the distance between the primary user and cognitive radio. Hence it is essential to adapt the adaptive modulation to protect the quality of service for the primary user. If the signal strength is becoming weakened the CR should send a request to increase the power or number of antennas at transmitter side because we know that we have to increase the diversity of the signal by increasing the number of antennas on transmitter side

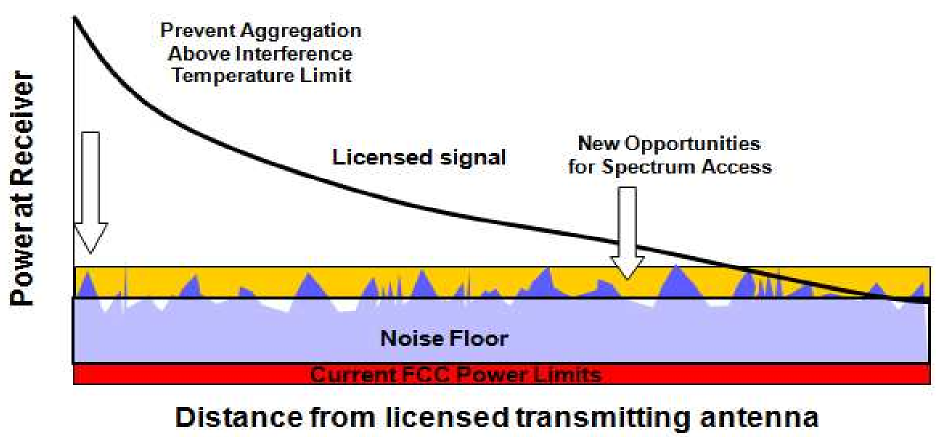


Figure 2.4: Relation of power at the CR receiver and the distance

Chapter 3

Problem Solution (Part1)

3.1 Hypothetical Approach:

The Primary goal of this work is to propose Adaptive power control based on estimated distance R_{cr}^{pr} between the cognitive radio and the primary user. We will discuss the transmit power being controlled on the basis of distance. However, there is no such method to calculate the exact distance between the cognitive radio and the primary user, in order that we may interpret the distance in terms of SNR. Our main goal is to make CR so intelligent that it can determine the maximum level of the transmission power which does not cause any harmful interference to the primer user's quality of service. To avoid the interference to the licensed users, the transmit power of the cognitive radio should be limited based on the locations of the licensed users. To achieve these goals we have to know about the distance between the cognitive radio and the primary user as well as the SINR (Signal to-Interference-and-Noise Ratio) at primary user. Let's make a hypothetical basis to approach a solution of the problem

Suppose

- P_{max}^{cr} is the maximum transmit power to achieve maximum throughput for the CR user.
- $SINR_{min}^{pr}$ is the minimum value of SINR at the primary user to decode the signal accurately (the minimum acceptable SINR at the primary user) .
- R_{cr}^{pr} is the distance between the CR and the primary user.

i.e.

$$P_{max}^{cr} = \begin{pmatrix} minimum\ value\ of\ SINR\ which \\ maintain\ the\ desired\ quality\ of \\ servise\ at\ primery\ user \end{pmatrix} * \begin{pmatrix} distance\ between\ CR\ and \\ primary\ user\ in\ terms \\ of\ SNR\ loss \end{pmatrix}$$

The propose power control scheme can determine the maximum power on the basis of SINR values at the primary user and distance between the cognitive radio and the primary user. We can say that the maximum transmit power P_{max}^{cr} of CR should be a function of $SINR_{min}^{pr}$ as well as R_{cr}^{pr}.Let's now discuss how we relate the distance with SNR loss and how we calculate the SINR(Signal to- Interference-and-Noise Ratio) at the primary user to avoid harmful interference.

3.2 System Model:

Let us consider a scenario in which there are three participants the transmitter, licensed and the unlicensed users. In this work we call the primary user as licensed and the secondary as the unlicensed user (cognitive radio) respectively. The system model of our interest is depicted in Figure3.1.The primary transmitter communicates with the primary user with a transmit power of $P_{pr}(f_c, B)$ and the primary transmitter communicates the secondary user (cognitive radio) with a transmit power of $P_{sc}(f_c, B)$. Here f_c and B denote the central carrier frequency and the bandwidth commonly used by the CR user and the primary user.

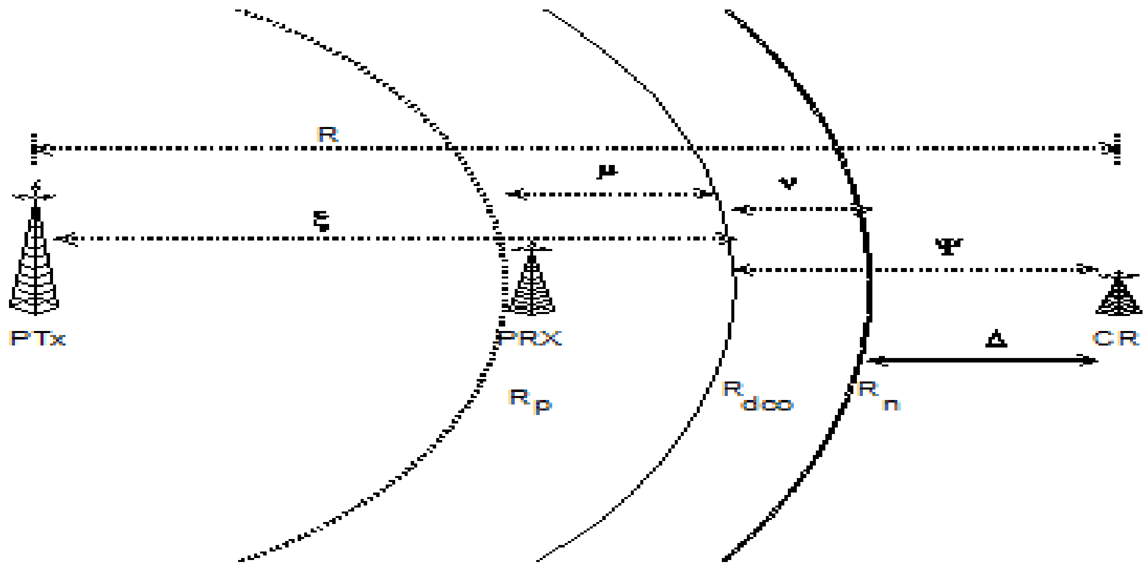


Figure 3.1: System model

Let us consider a high power transmit system within which priority based radial protection region are designed to provide the quality of service to the primary user in the presence of the cognitive radio (secondary user).Assume that the transmitter antenna is omnidirctional.

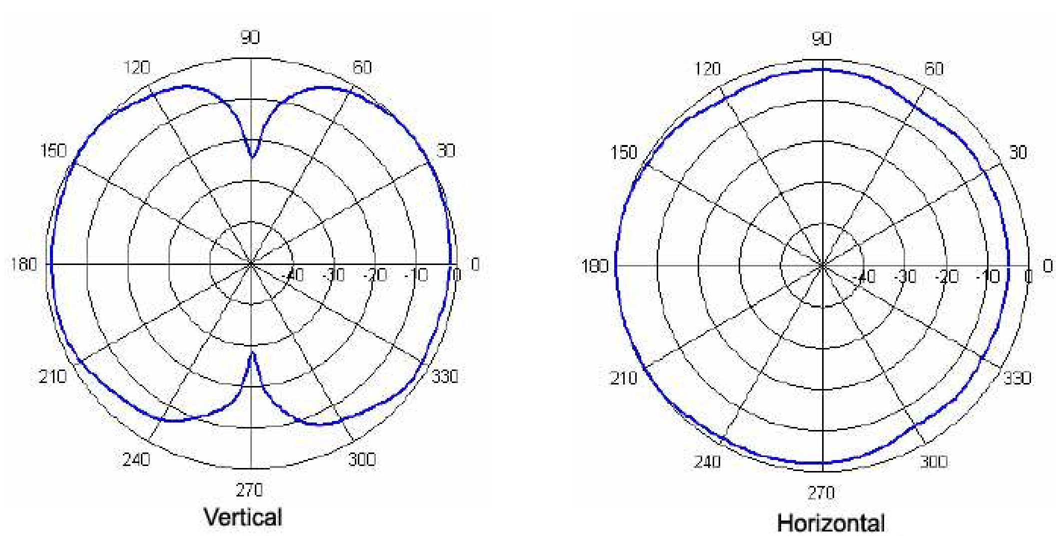


Figure3.2: Omni Directional Antenna Pattern 0

Let γ_{dco} be the minimum SNR required for the primary user to decode the signal successfully. This γ_{dco} occurs at a distance R_{dco} . R_P is the radial region where we provide the garnteed quality of service to the primary user called the protection region within which the signal-to-noise ratio (SNR) of decodebility occurs in the absence of interference to the primary receiver. At a distance greater than R_n the cognitive radio is allowed to transmit. Let's assume that the channel between two terminals is Rayleigh faded with distance-based PL (Path Loss) factor and AWGN (Additive White Gaussian Noise) without multipath fading. The propagation power attenuation is $Q_r = r^{-\alpha}$, where r is the any distance and α denotes the power loss exponent. Different path loss exponent's values according to different environments are given in table 3.1 [15].

Environment	*Path Loss Exponent α*
Free space	*2*
Urban area cellular radio	*2.7 to 3.5*
Shadowed urban cellular radio	*3 to 5*
In building line of sight	*1.6 to 1.8*
Obstructed in building	*4 to 6*
Obstructed in factories	*2 to 3*

Table 3.1: Typical PLS exponents values for different environments [6].

Since we are using locally measured SNR as a proxy for distance, it is convenient to represent R_{dco} , R_P, and R_n in terms of the SNR γ_{dco} , γ_p and γ_n respectively. We have to specify who is measuring SNR at each distance. Consider γ_{dco} and γ_p being measured by the primary user and γ_n measured by the cognitive radio. The primary system communicates with transmit power P_{pr} and the power of the noise is σ^2.

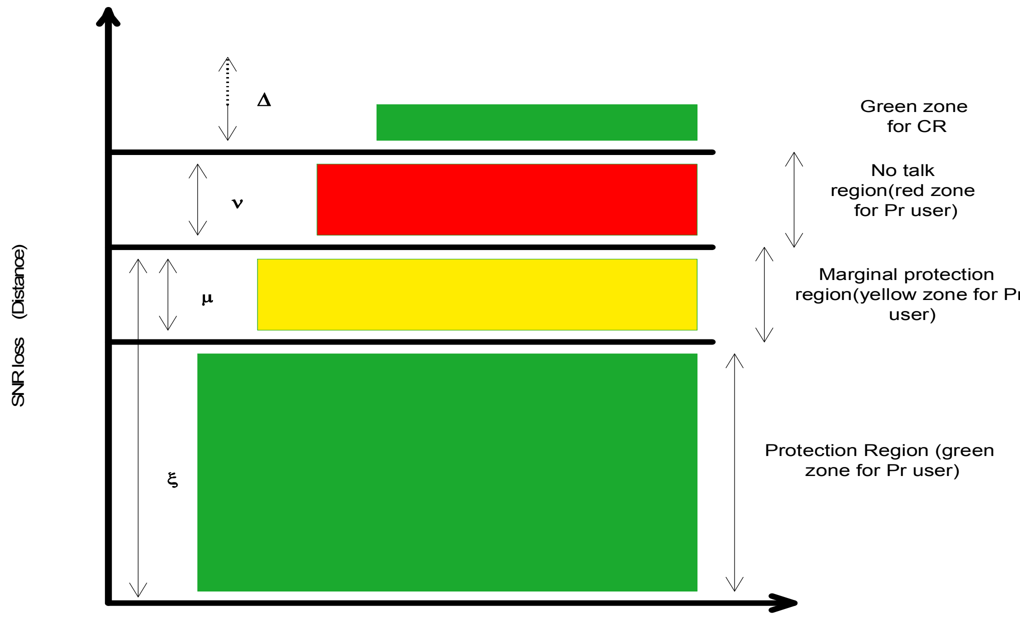


Figure 3.3: System model in terms of SNR loss

In figure3.2 ξ, μ, υ and Ψ are SNR losses due to their corresponding distances. We have divided our system into different zones depicted in figure3.2.The green zone shows the protection region where primary system should provide the guaranteed quality of service, with the separation of this region being equal to $S_1 = \xi + \mu$. The yellow zone shows the boundary of that region where the minimum SNR required for the primary user to decode the signal successfully; the separation of this region being $S_2 = \xi$ .The red zone is a red zone for both the primary user and the cognitive radio, where there is no guarantee for the primary user for good quality of service and the cognitive radio is not allowed to transmit. This region is called no talk region, with the separation of this region being $S_3 = \xi + \upsilon$.

3.3 Relation Establishment between SNR and Distance:

In wireless communication there is a strong relation between the SNR and distance (the distance between transmitter and receiver).There is no such method to find the exact distance of the receiver from transmitter. At receiver end we can easily get the value of the SNR so for the solution of this problem we can develop a relation between SNR and distance. To establish this relation let us consider a simple communication system with one transmitter T_x and one receiver R_x shown in figure.3.3

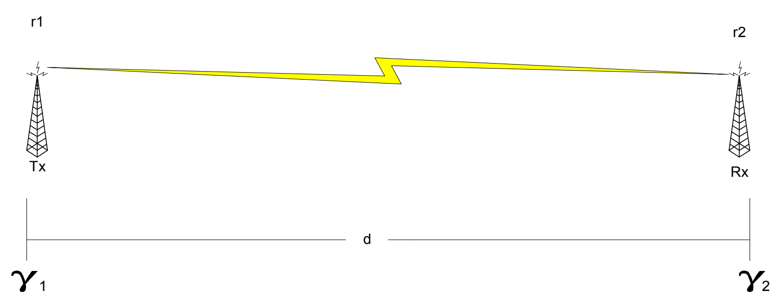


Figure 3.4: Simples Transreceiver System.

r_1 and r_2 represent the position of the transmitter and the receiver respectively, and d is the separation between the transmitter and the receiver. γ_1 is the SNR at r_1 and γ_1 is the SNR at r_2 .Let P be the transmit power of T_x and σ^2 is the noise power at R_x.Let assume that the channel between the two terminals is distance-based PL (Path Loss) factor and AWGN (Additive White Gaussian Noise) without the multipath fading. The propagation power attenuation is $Q_r = r^{-\alpha}$, where r is the distance and α denotes the power loss exponent, which is in the range of 2~6.α=2 corresponds to free space attenuation. Let ε represent the signal attenuation or the difference of SNR loss between the transmitter and the receiver. We can write

$$\varepsilon = \gamma_1 - \gamma_2 \qquad (1)$$

where $\gamma_1 = 10\log\left(\frac{P}{\sigma^2}\right)$

Path loss due to the distance d is [6]

$$Path\ loss = -10log(d^{-\alpha}) \quad (2)$$

$$= 10\log\left(\frac{P}{\sigma^2}\right) - 10\log(\gamma_2) \quad (3)$$

Comparing equation (1) and (2) we get

$$\gamma_2 = \left(\frac{P}{\sigma^2}d^{-\alpha}\right) \quad (4)$$

Hence equation (1) becomes

$$\varepsilon = 10\log\left(\frac{P}{\sigma^2}\right) - 10\log\left(\frac{P}{\sigma^2}d^{-\alpha}\right)$$

Where ε is the signal attenuation due to distance d. Equation (4) above shows the relation between the distance and the SNR.

3.4 Power Impact [$\mathbf{P_{pr}}(\boldsymbol{f_c},\boldsymbol{B})$]:

Consider from the system model, with $\mathrm{P_{pr}}(f_c,B)$ being the transmit power of the primary transmitter, where f_c and B denote the carrier frequency and the bandwidth. To calculate the impact of the primary transmitter's power at each radii of the mentioned regions of system i.e. The value of power at R_P, R_{dco} and R_n with $P_{pr}^{R_p}(f_c,B)$, $P_{pr}^{R_{dco}}(f_c,B)$ and $P_{pr}^{R_n}(f_c,B)$ respectively, from equation (4) we can write.

$$P_{pr}^{R_p}(f_c,B) = \mathrm{P_{pr}}(f_c,B)\ R_P^{-\alpha} \quad (5)$$

$$P_{pr}^{R_{dco}}(f_c,B) = \mathrm{P_{pr}}(f_c,B)\ R_{dco}^{-\alpha} \quad (6)$$

$$P_{pr}^{R_n}(f_c,B) = \mathrm{P_{pr}}(f_c,B)\ R_n^{-\alpha} \quad (7)$$

Where the above equations show the power at R_P, R_{dco} and R_n respectively.

3.5 Distance Relation with SNR loss:

Now we have to move towards an important issue, the direct relation of SNR loss and the distance between two points. From the system model we have to find the SNR loss between the transmitter and the CR (cognitive radio).Let δ be the SNR loss between the primary transmitter and the cognitive radio. From equation (3) we get:

$$\delta \;= 10 \log\left(\frac{\mathrm{P}_{\mathrm{pr}(f_c,B)}}{\sigma^2}\right) - \;10\log(\bar{\gamma}) \qquad (8)$$

Where $\bar{\gamma}$ denotes the average SNR at the cognitive radio. From the system model R is the separation between the primary transmitter and the cognitive radio, therefore

$$\delta \;= 10 \log\left(\frac{\mathrm{P}_{\mathrm{pr}}(f_c,B)}{\sigma^2}\right) - \;10\log\left(\frac{\mathrm{P}_{\mathrm{pr}}(f_c,B)R^{-\alpha}}{\sigma^2}\right)$$

After simplification we get

$$\mathrm{R} \;= \;\left(10^{\frac{\delta}{10}}\right)^{\frac{1}{\alpha}} \qquad (9)$$

Where δ is the SNR loss and R is the distance between the primary transmitter and the cognitive radio respectively. Equation (9) shows the direct relation between the distance and SNR loss. From equation (9) we can write

$$\delta = \;10\log\,(R^{\alpha})$$

$$\delta = \;-10\log\,(R^{-\alpha}) \qquad (10)$$

Equation (10) also shows the relation between the SNR loss and the distance R. Let us consider that ξ,μ,υ and Ψ as SNR losses due to their corresponding distances .From equation (v) we are able to write the relation between the distance and the SNR loss at each radii. Therefore

$$R_P = \left(10^{\frac{\xi+\mu}{10}}\right)^{\frac{1}{\alpha}} \tag{11}$$

$$R_{dco} = \left(10^{\frac{\xi}{10}}\right)^{\frac{1}{\alpha}} \tag{12}$$

$$R_n = \left(10^{\frac{\xi-\upsilon}{10}}\right)^{\frac{1}{\alpha}} \tag{13}$$

3.6 Power Impact [$\mathbf{P_{pr}}(\boldsymbol{f_c}, \boldsymbol{B})$] as SNR loss:

Above we have seen that the power impact of the primary transmitter on three different mentioned radii and the cognitive radio in terms of distance. We know that it is very difficult in wireless communication to know about distance i.e. we don't know the separation between the primary transmitter and the cognitive radio or the separation between the cognitive radio and the primary receiver (licensed user).It is easy to measure the SNR so we can represent power at each radii in terms of SNR loss. Comparing equation (5), (6), (7) and (11), (12), (13) therefore

$$P_{pr}^{R_p}(f_c, B) = \mathrm{P_{pr}}(f_c, B)\left(10^{\frac{\xi+\mu}{10}}\right)^{-1} \tag{14}$$

$$P_{pr}^{R_{dco}}(f_c, B) = \mathrm{P_{pr}}(f_c, B)\left(10^{\frac{\xi}{10}}\right)^{-1} \tag{15}$$

$$P_{pr}^{R_n}(f_c, B) = \mathrm{P_{pr}}(f_c, B)\left(10^{\frac{\xi-\upsilon}{10}}\right)^{-1} \tag{16}$$

3.7 Power Impact [$\mathbf{P_{cr}}(\boldsymbol{f_c}, \boldsymbol{B})$] as SNR loss:

Let us consider $\mathrm{P_{cr}}(f_c, B)$ being the transmitted power of the CR (cognitive radio).The impact of the CR transmitted power on every radii can be expressed as.

$$P_{cr}^{R_P}\ (f_c, B)\ \ =\ P_{cr}(f_c, B)\ \ (R - R_P\ )^{-\alpha} \qquad (17)$$

$$P_{cr}^{R_{dco}}(f_c, B)\ =\ P_{cr}(f_c, B)\ \ (R -\ R_{dco}\ )^{-\alpha} \qquad (18)$$

$$P_n^{R_n}\ \ (f_c, B)\ \ =\ P_{cr}(f_c, B)\ \ (R -\ R_n\ )^{-\alpha} \qquad (19)$$

Also

$$P_{cr}^{R_P}\ (f_c, B)\ = P_{cr}(f_c, B)\left(\left(10^{\frac{\delta}{10}}\right)^{\frac{1}{\alpha}} - \left(10^{\frac{\xi+\mu}{10}}\right)^{\frac{1}{\alpha}}\ \right)^{-\alpha} \qquad (20)$$

$$P_{cr}^{R_{dco}}\left(f_c, B\right) = P_{cr}(f_c, B)\left(\left(10^{\frac{\delta}{10}}\right)^{\frac{1}{\alpha}} - \left(10^{\frac{\xi}{10}}\right)^{\frac{1}{\alpha}}\ \right)^{-\alpha} \qquad (21)$$

$$P_n^{R_n}\ \left(f_c, B\right) = P_{cr}(f_c, B)\left(\left(10^{\frac{\delta}{10}}\right)^{\frac{1}{\alpha}} - \left(10^{\frac{\xi-\upsilon}{10}}\right)^{\frac{1}{\alpha}}\right)^{-\alpha} \qquad (22)$$

3.8 Distance between the CR and the Primary User:

Let us consider the primary system being located at the boundary of the protection region at a distance R_p from the primary transmitter and R_{cr}^{pr} from the cognitive radio, where $R_{cr}^{pr}\ = R\ -\ R_p$.

$$R_{cr}^{pr}\ \ = R\ -\ \ R_p \qquad (23)$$

From equation (9) and (11)

$$R_{cr}^{pr}\ \ = \left(10^{\frac{\delta}{10}}\right)^{\frac{1}{\alpha}} - \left(10^{\frac{\xi}{10}}\right)^{\frac{1}{\alpha}} \qquad (24)$$

Where $\delta =\ \xi + \Psi$ and further $\Psi = \upsilon + \Delta$

$$\delta =\ \xi + \upsilon + \Delta \qquad (25)$$

equation (24) becomes

$$R_{cr}^{pr}\ \ = \left(10^{\frac{\xi+\upsilon+\Delta}{10}}\right)^{\frac{1}{\alpha}} - \left(10^{\frac{\xi}{10}}\right)^{\frac{1}{\alpha}} \qquad (26)$$

where ξ, μ, υ and Ψ are all fixed and known values. Only Δ is an unknown quantity; hence we can say that the distance between the primary receiver and the cognitive radio is a function of Δ.

$$R_{cr}^{pr} = f(\Delta) \qquad (27)$$

3.9 Interference Temperature model (IT model):

The RF noise floor rises due to unpredictable appearances of new sources of interference like hidden terminals or CRs (unlicensed users) causing a progressive degradation of quality of service. To guard against such a possibility, the FCC Spectrum Policy Task Force has recommended a paradigm shift in interference assessment. The recommendation is based on a new metric called the interference temperature. The recommendation is made with two key benefits.

1) "The interference temperature at a receiving antenna provides an accurate measure for the acceptable level of RF interference in the frequency band of interest; any transmission in that band is considered to be "harmful" if it would increase the noise floor above the interference-temperature limit.

2) A particular frequency band in which the interference temperature is not exceeded, that band could be made available to unlicensed users; the interference-temperature limit would then serve as a "cap" placed on potential RF energy that could be introduced into that band".[1]

Measurements of power and bandwidth occupied by interference is called the interference temperature [5].Mathematically, we can write this expression as

$$T_I\,(f_c\,,B) = \frac{P_{av}\,(f_c,B)}{KB} \qquad (28)$$

where $P_{av}\,(f_c\,,B)$ is the average interference power in watts , f_c is the central frequency of the bandwidth B ,and K is the Boltzmann constant (K=1.38 * 10^{-23} joules/Kelvin). Let T_L be the maximum tolerable limit of interference to provide the guaranteed quality of service to the primary user. We should guarantee that the CR transmission power does not violate the interference temperature at the primary user

$$\mathrm{T_L(f_c\,,B)} = \frac{\mathrm{P_{av}\,(f_c,B)}}{\mathrm{KB}} \qquad (29)$$

Let us consider the primary user being located at R_p. To address the problem properly, the worst case scenario is discussed in this work where the primary receiver is located on the crossing point between the boundary of the protection region and the line from the primary transmitter to the cognitive radio. To allow the primary receiver to successfully decode the received signals from the primary transmitter in the presence of the cognitive radio, the signal-to-interference-plus-noise ratio (SINR) of the primary receiver should be guaranteed to be above a threshold of the decidability SNR γ_{dco} (in dB), i.e., SINR≥ γ_{dco}. [6] The average power at primary receiver is $\frac{P_{pr}^{'}(f_{c},B)}{P_{cr}^{'}(f_{c},B)+\sigma^2}$ hence:

$$\frac{P_{pr}^{'}(f_{c},B)}{P_{cr}^{'}(f_{c},B)+\sigma^2} \geq \text{SINR} = 10^{\frac{\gamma_{dco}}{10}} \qquad (30)$$

where $P_{pr}^{'}(f_{c},B)$ is the value of power due to the primary transmitter at the primary receiver. $P_{cr}^{'}(f_{c},B)$ is the value of power due to the cognitive radio at the primary receiver. Here f_c and B denote the carrier frequency and the bandwidth commonly used by the CR user and the primary user, since $P_{av}\left(f_{c},B\right)$ is the average interference power at the primary receiver. Neglecting intracell and intercell interference on the considered spectrum bands, and only considering the interference due to the cognitive radio's power plus noise power at the primary receiver we can write.

$$P_{av}\left(f_{c},B\right) = P_{cr}^{'}(f_{c},B) + \sigma^2$$

whereas minimum tolerable cognitive power at the primary receiver is (Note: cognitive transmit power creates interference at the primary receiver because they are using the same bandwidth and the same frequency)

$$P_{cr}^{'}(f_{c},B) \leq \left(10^{\frac{\mu}{10}} - 1\right)\sigma^2$$

$$P_{av}\left(f_{c},B\right) \cong \left(10^{\frac{\mu}{10}} - 1\right)\sigma^2 + \sigma^2$$

$$P_{av}\left(f_{c},B\right) \cong \sigma^2\left(\left(10^{\frac{\mu}{10}}-1\right)+1\right) \quad (31)$$

Therefore

$$T_L(f_c\,,\mathrm{B}) = \frac{\sigma^2\left(\left(10^{\frac{\mu}{10}}-1\right)+1\right)}{KB}$$

$$\mathrm{T_L(f_c\,,B)} = \frac{\sigma^2\left(\left(10^{\frac{\mu}{10}}-1\right)+1\right)}{\mathrm{KB}} \quad (32)$$

Also

$$\mathrm{T_I}\left(\mathrm{f_c},\mathrm{B}\right) = \frac{\mathrm{P_{av}}\left(\mathrm{f_c},\mathrm{B}\right)}{\mathrm{KB}} = \frac{\mathrm{P_{cr}^{Rp}}\left(\mathrm{f_c},\mathrm{B}\right)+\sigma^2}{\mathrm{KB}} \quad (33)$$

$$T_I\left(f_{c},B\right) = \frac{P_{cr}(f_c,B)\left(\left(10^{\frac{\delta}{10}}\right)^{\frac{1}{\alpha}}-\left(10^{\frac{\xi+\mu}{10}}\right)^{\frac{1}{\alpha}}\right)^{-\alpha}+\sigma^2}{KB} \quad (34)$$

The maximum transmission power of the CR without causing any interference on the primary user is derived from the following relationship [7]:

$$T_I\left(f_{c},B\right)+\frac{MP_{max}^{cr}}{KB} \leq T_L(f_c) \quad (35)$$

where M is the multiplicative attenuation due to fading and the path loss value between the CR and the primary user its is between 0~1.The idea is to not only put restriction on the transmit power of the CR but also to make it sense the interference temperature at the primary receiver. Interference temperature restricts the interference at the license receiver.

From the above expression P_{max}^{cr} is the maximum transmit power of CR

$$P_{max}^{cr} = \frac{KB}{M}\left(T_L(f_c)-T_I\left(f_{c},B\right)\right) \quad (36)$$

From equation (36) we can easily derive the expression of the minimum SINR (Signal to-Interference-and-Noise Ratio) at the primary receiver $SINR_{min}^{pr}$.

$$SINR_{min}^{pr} = \frac{Maximum\ transmit\ power\ of\ CR}{Average\ interference\ power}$$

$$SINR_{min}^{pr} = \frac{P_{max}^{cr}}{P_{av}\ (f_{c\ ,}B)}$$

$$SINR_{min}^{pr} = \frac{L\big(T_L(f_c) - T_I\ (f_{c\ ,}B)\big)}{MT_I\ (f_{c\ ,}B)}$$

Whereas L is similar as *M,* except it represents a multiplicative PL (path loss) between the CR transmitter and the receiver. If L and M are cancelled out, the above equation becomes

$$SINR_{min}^{pr} = \frac{\big(T_L(f_c) - T_I\ (f_{c\ ,}B)\big)}{T_I\ (f_{c\ ,}B)} \qquad (37)$$

Hence this is the minimum tolerable $SINR_{min}^{pr}$ at the primary receiver

3.10 Transmission Power Control:

We have derived the expression of the minimum tolerable interference at the primary user in terms of interference temperature and then in terms of SINR loss. (Signal to interference and noise ratio).Also we have developed a method to estimate the distance R_{cr}^{pr} between the cognitive radio and the primary user. Let us consider B to be the bandwidth, and K is the Boltzmann constant (K=1.38 * 10^{-23} joules/Kelvin) and $T_L(f_c)$ the maximum tolerable limit of interference to provide the guarantee quality of service to the primary user. Then we can write [7].

$$P_{max}^{cr} = BK\ T_L(f_c) * \left(\frac{R_{cr}^{pr}}{d_o}\right)^{\alpha} \qquad (38)$$

where d_o *is* the reference distance, normally assigned 1m .From equation (37) we have that.

$$SINR_{min}^{pr} = \frac{\left(T_L(f_c) - T_I\,(f_{c},B)\right)}{T_I\,(f_{c},B)}$$

After solving this equation for $T_L(f_c)$ we get

$$T_L(f_c) = T_I\,(f_{c},B)(SINR_{min}^{pr} + 1) \tag{39}$$

Putting the value of equation (26) and (39) into equation (38) we get

$$P_{max}^{cr} = BK\,T_I\,\left(f_{c},B\right)\left(SINR_{min}^{pr} + 1\right) * \left(\frac{\left(10^{\frac{\xi+\upsilon+\Delta}{10}}\right)^{\frac{1}{\alpha}} - \left(10^{\frac{\xi}{10}}\right)^{\frac{1}{\alpha}}}{d_o}\right)^{\alpha} \tag{40}$$

Putting the value of d_o and $T_I\,(f_{c},B)$ from equation (34) then equation (40) becomes

$$P_{max}^{cr} = \left(P_{cr}(f_{c},B)\left(\left(10^{\frac{\delta}{10}}\right)^{\frac{1}{\alpha}} - \left(10^{\frac{\xi+\mu}{10}}\right)^{\frac{1}{\alpha}}\right)^{-\alpha} + \sigma^2\right) * \left(SINR_{min}^{pr} + 1\right) * \left(\left(10^{\frac{\xi+\upsilon+\Delta}{10}}\right)^{\frac{1}{\alpha}}\left(10^{\frac{\xi}{10}}\right)^{\frac{1}{\alpha}}\right)^{\alpha} \tag{41}$$

Hence this is the proposed power control expression. The first part of the R.H.S shows the value of the interference power at the primary user; the second part shows the minimum tolerable SINR at the primary user, the third part shows the distance between the primary user and the cognitive radio. We can say that P_{max}^{cr} is the function of I (interference power at primary receiver), $SINR_{min}^{pr}$ and R_{cr}^{pr}.

$$P_{max}^{cr} = f\left(\mathrm{I}, SINR_{min}^{pr}, R_{cr}^{pr}\right)$$

Chapter 4

Problem Solution (Part2)

4.1The Proposed Adaptive Power transmission System:

We have proposed a power control approach in a cognitive radio system on the basis of received SNR, in order to mitigate the interference to the primary user due to the presence of the cognitive radio. This power control method will allow the secondary users to aggressively increase their transmit power without effecting the quality of the service of the Primary user (cognitive radio).A flow chart of this proposed scheme is shown below and an explanation of each step given below also

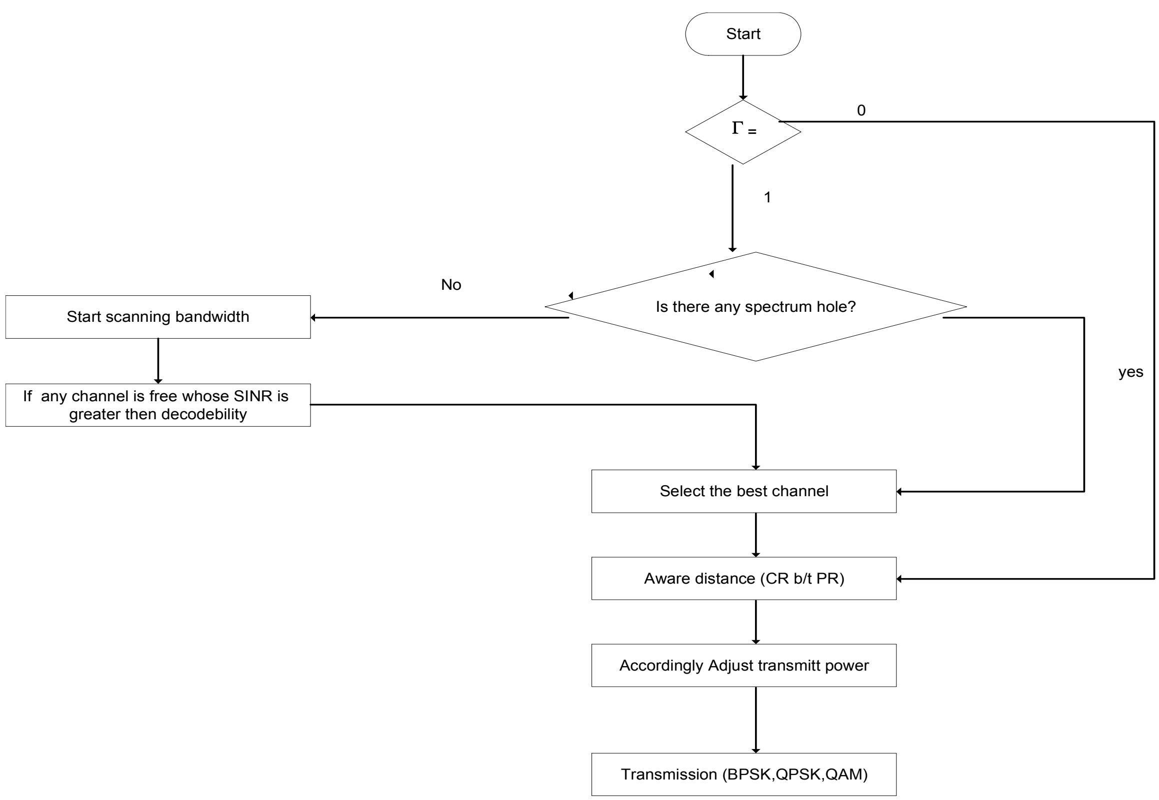


Figure 4.1: Flow chart for the proposed adaptive CR Power transmission scheme

4.2 Spectrum Sensing Procedure:

In order to detect the presence of the primary user signal, spectrum sensing is a fundamental element in cognitive radio communications as it should be firstly performed before allowing unlicensed users to access a vacant licensed channel or a spectrum hole. We can define spectrum hole as:

"A spectrum hole is a band of frequencies assigned to a primary user, but, at a particular time and specific geographic location, the band is not being utilized by that user."[1].

There is different kind of definitions but in the wireless world two cases can be distinguished. Case one: a particular band is considered vacant if a filtered radio signal that belongs to that band consists of noise. Second case: maybe that signal will consist of an unknown non-zero number of signals in addition to the noise. In this case we can't say that this band is vacant. These cases can be modeled as two possible hypotheses, $H0$ and $H1$:

$$H0: x(t) = n(t)$$

$$H1: x(t) = h\, s(t) + n(t)$$

Where $x(t)$ is the received signal at the cognitive radio, $s(t)$ is the transmitted signal from the primary transmitter, h denotes the Rayleigh fading channel coefficient and $n(t)$ is the zero-mean additive white Gaussian noise (AWGN). The energy of the received signal, denoted by E, is collected in a fixed bandwidth W and a time slot duration T and then compared with a pre-designed threshold Γ. let $\Gamma > 1$, then the cognitive radio assumes that the primary system is in operation, i.e., $H1$. Otherwise, it assumes $H0$. There is no doubt that this cognitive radio system depends mostly on the detector. If the detector detects properly and efficiently then we are able to provide a good quality of service to the primary user. If we detect wrong it will result in degradation of the quality of service of the primary user which will result in the collapse of the whole system.

However due to the uncertainty in the noise power, the quality of detection is degraded rapidly.

4.2.1Cyclostationary and Multi-cycles detector:

In order to detect the presence of the primary user signal, spectrum sensing is a fundamental requirement to achieve the goal of cognitive radio (CR). This ensures the efficient utilization of the spectrum. Cyclostationary detection is the preferred technique to detect the primary users receiving data within the communication range of a CR user at very low SNR. [2]

When a Cyclostationary model is selected for the searched signal, the detection problem of vacant bands in the spectrum is transformed to the following hypotheses, testing the problem on the received radio signal *x(t)*:[3]

- Under $H0$, *x(t)* is of stationary type and the band is regarded as free.
- Under H1, *x(t)* is of Cyclostationary type and the band is said to be occupied.

Here is the block diagram of a multicycle detector

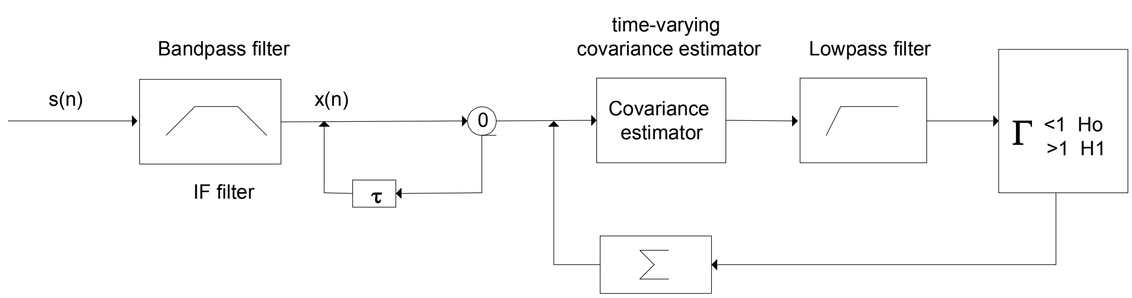


Figure 4.2: Block diagram of the multi-cycles detector

Block diagram of the *multi-cycles* detector describing the energy of the received signal, denoted by *E*, being collected in a fixed bandwidth *W* and a time slot duration T and then compared with a pre-designed threshold Γ. If $\Gamma > 1$, then the cognitive radio assumes that the primary system is in operation, i.e., $H1$. Otherwise, it assumes $H0$.

4.3 Spectrum Sensing key Metrics:

In order to detect the presence of the primary user signal, spectrum sensing is a fundamental element in cognitive radio communications as it should be firstly performed before allowing unlicensed users to access a vacant licensed channel. The spirit of spectrum sensing is testing a binary hypothesis problem:

H0: Primary user is absent (cognitive radio is free to communicate).
H1: Primary user is in operation (cognitive in not allowed to communicate).

The key metric in spectrum sensing are the probability of correct detectionP_d, probability of false alarm P_f and probability of miss P_m, which are given below respectively,

Pd = Probe {H1|H1} Probability of correct detection
Pf = Probe {H0|H0} Probability of false alarm
Pm = Probe {H0|H1} Probability of miss

Since we have developed the relation between SNR and the distance, let us plot the different probabilities against the different values of the SNR .

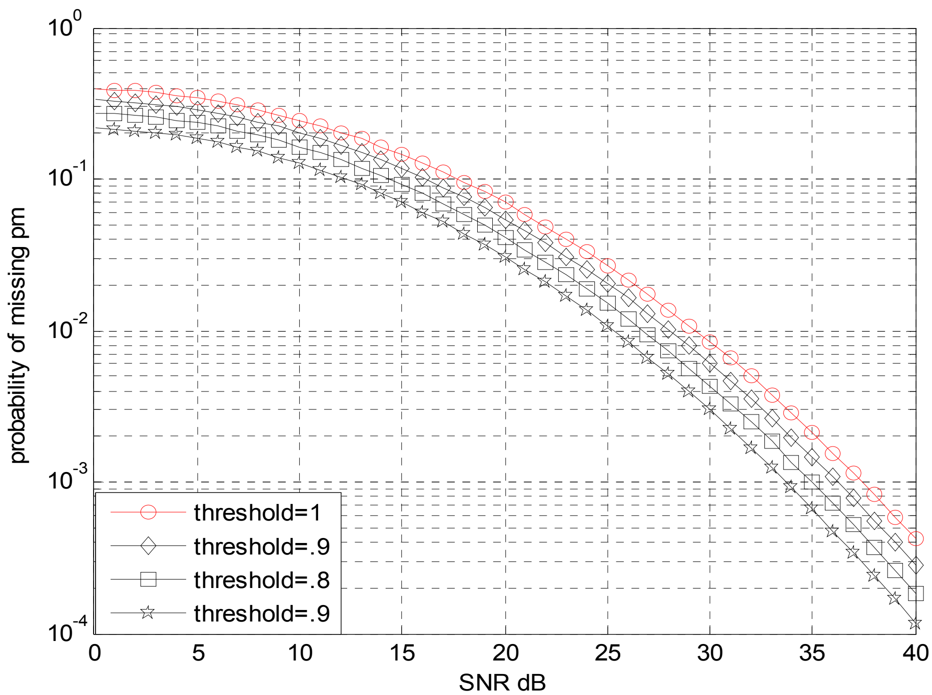


Figure4.3: Plot of the probability of the Miss Pm against SNR at different values of the threshold.

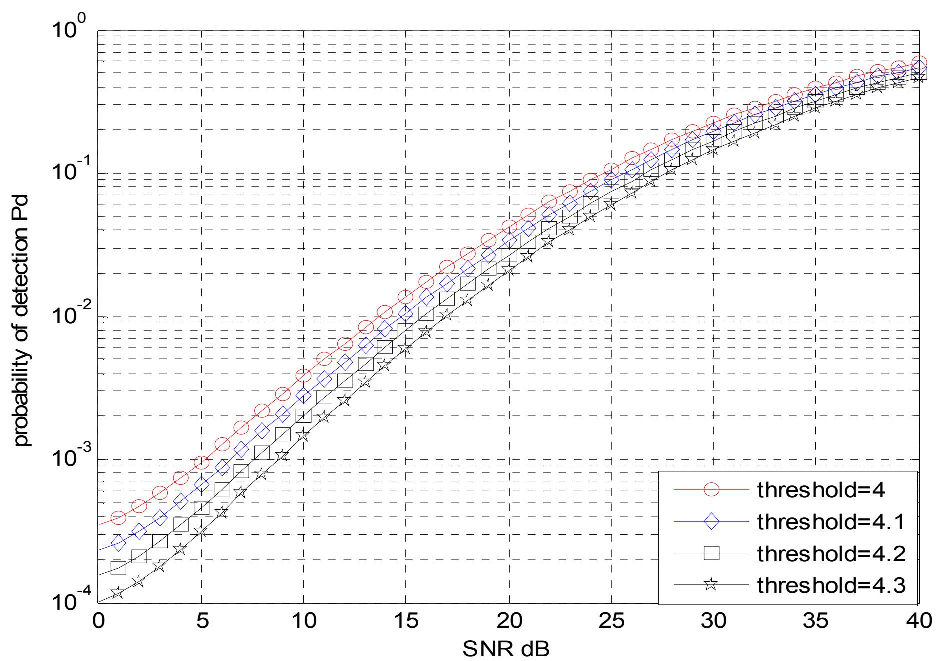


Figure4.4: Plot of the probability of the detection Pd against SNR at different values of the threshold

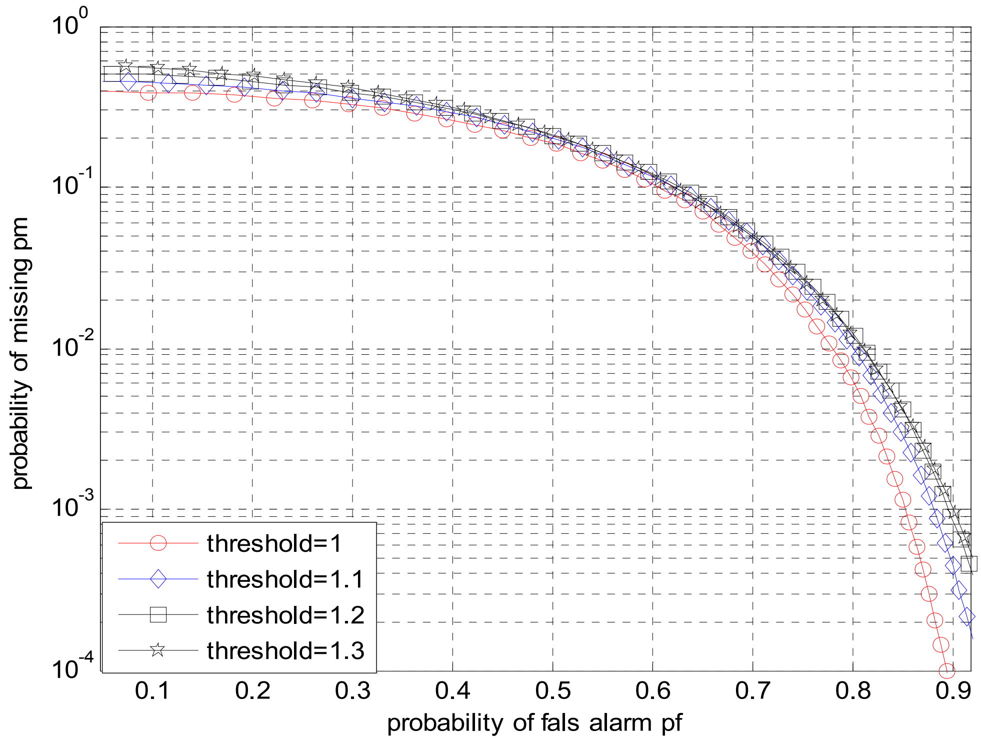


Figure 4.5: Plot of the probability of the Miss Pm probability of false alarm at different values of the threshold

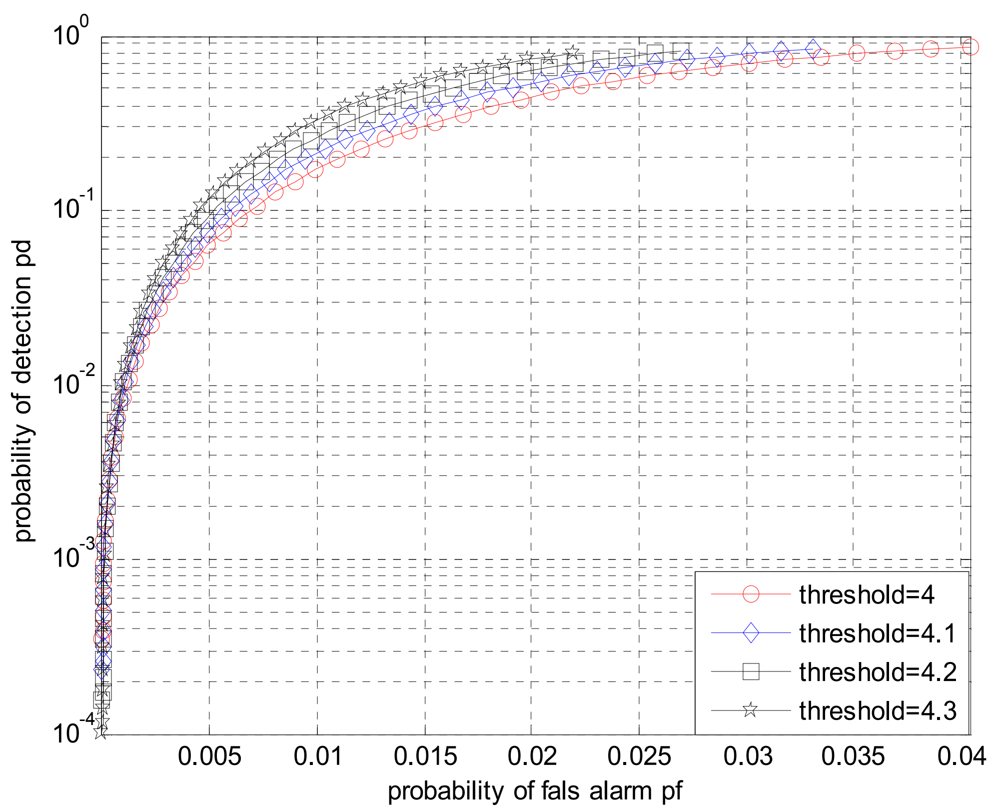


Figure 4.6: Probability of the detection Pd against the probability of false alarm at different values of the threshold.

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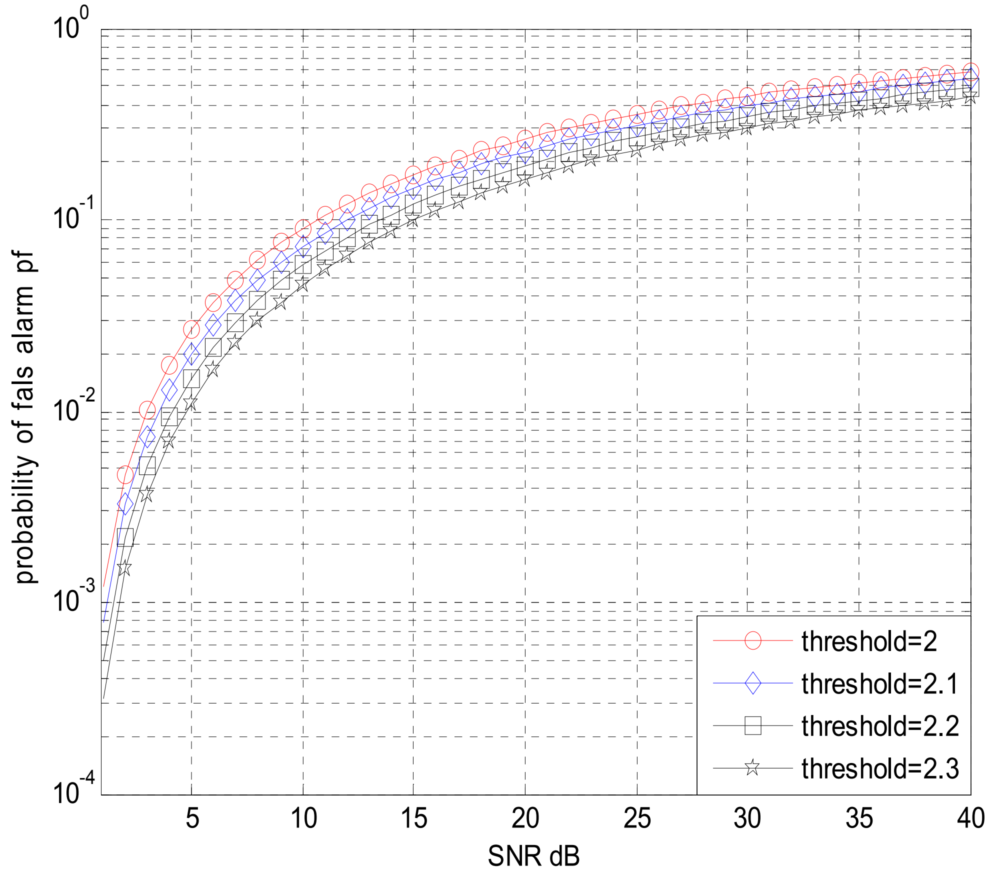

Figure 4.7: Plot of the probability of the false alarm Pf against SNR at different values of the threshold.

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It shows that when the average SNR decreases the probability of missing becomes bigger. For a specified average SNR, a larger *Pf* will result in the decrease of *Pm* because of the decrease of the threshold used in energy detection. From these results we can say that the probability of missing becomes bigger when the distance between the cognitive radio and the primary system is greater and vice versa. Since a small change in the threshold creates a big change in the corresponding probabilities, this shows how important the value of the threshold is.

4.4 Measurement of SINR at Primary User:

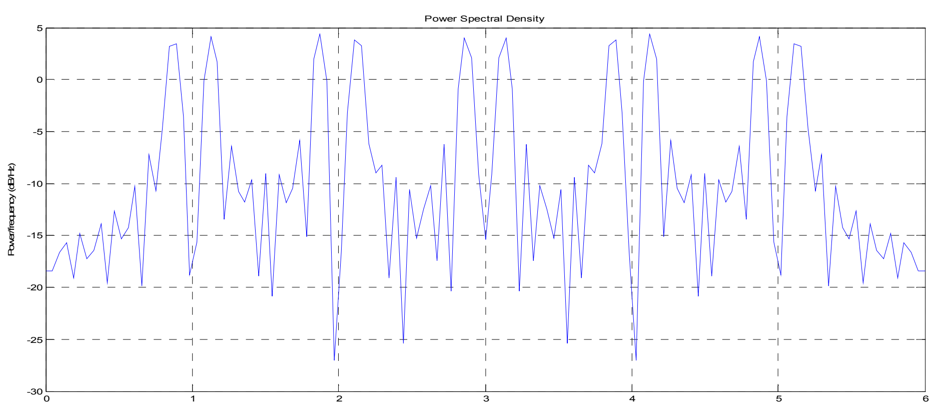
$\mathrm{SINR}_{\mathrm{min}}^{\mathrm{pr}}$ is measured by using the IT model explained above. "Measurements of power and bandwidth occupied by interference is called interference temperature"[5]. Since $\mathrm{SINR}_{\mathrm{min}}^{\mathrm{pr}}$ is the value of signal to interference and noise radio at the primary user we can find this value by using equation (37) which is

$$SINR_{min}^{pr} = \frac{\left(T_L(f_c) - T_I\,(f_c, B)\right)}{T_I\,(f_c, B)}$$

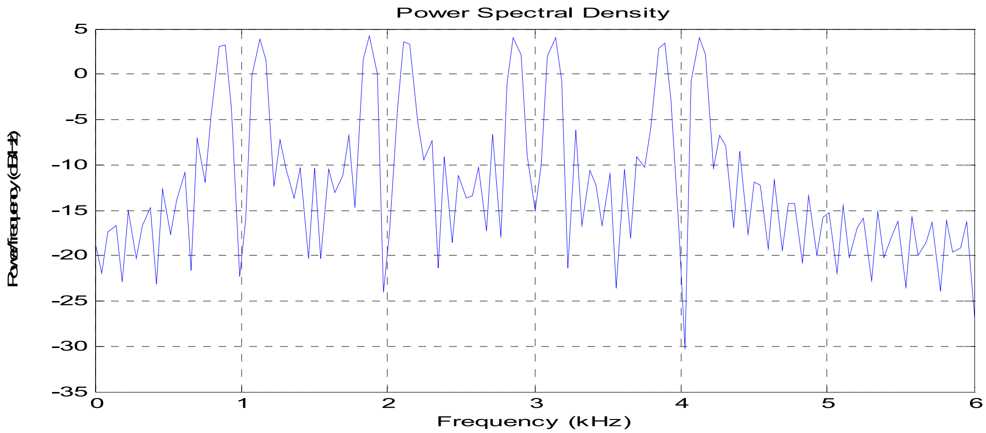
We can find the value of SINR at the primary user by using this equation and control our CR power.

4.5 Channel Selection for Transmission:

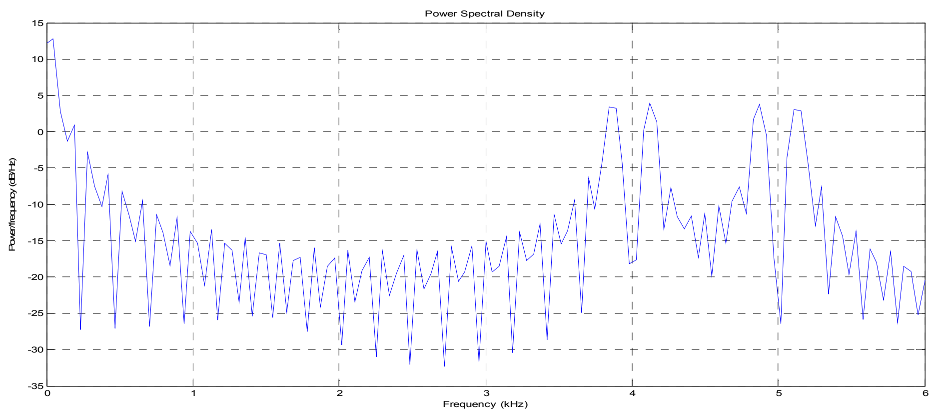
Let us divide our whole bandwidth B into a number of different channels, having the central frequency f_c .



(a)



(b)



(c)

Figure4.8: (a) Splitting the bandwidth into different channels with the bandwidth B and the central frequency .b) The Fifth channel is free for communication (c) The First three channels are free for communication

In figure 4.8 (a) there are five channels having their central frequencies at 1,2,3,4 and 5 each power peak being greater than 10dB, meaning that there is no empty frequency hole for the communication of the cognitive radio. In (b) and (c) the 5th and the first three channels are empty respectively; hence we can use these channels for cognitive radio communication.

The cyclostationary detection method, also called multi-cycles detection, was discussed above; we will apply these methods for the detection of the free channels within the given bandwidth. Hence the most suitable band for the CR user is supposed to be already selected by the spectrum sensing mechanism of the CR system in the given channel state. Note that the cognitive radio should use that channel which have the lowest IT value.

4.6 Awareness of Distance:

Our system should be aware of the distance between the primary user and the cognitive radio to communicate properly and to sense the state of the primary system efficiently. we can calculate the distance by using equation (26),i.e.:

$$R_{cr}^{pr} = \left(10^{\frac{\xi+\upsilon+\Delta}{10}}\right)^{\frac{1}{\alpha}} - \left(10^{\frac{\xi}{10}}\right)^{\frac{1}{\alpha}}$$

From this equation we can easily find the distance between the primary user and the cognitive radio. To control the power at the cognitive radio, it is essential to have the distance awareness at the cognitive radio.

4.7 Transmit Power Adjustment:

The proposed scheme controls the CR power adaptively by utilizing the information of the estimated distance R_{cr}^{pr} and the value of SINR at the primary user. The proposed scheme should maintain the SINR value which satisfies the target SER (symbol Error Rate) performance of the primary user. Hence, the maximum transmission power P_{max}^{cr} for the CR user and $SINR_{min}^{pr}$ which should provide for the incumbent user can be calculated by using the equation (41):

$$P_{max}^{cr} = \left(P_{cr}(f_c, B)\left(\left(10^{\frac{\delta}{10}}\right)^{\frac{1}{\alpha}} - \left(10^{\frac{\xi+\mu}{10}}\right)^{\frac{1}{\alpha}}\right)^{-\alpha} + \sigma^2\right)(SINR_{min}^{pr} + 1) * \left(\left(10^{\frac{\xi+\upsilon+\Delta}{10}}\right)^{\frac{1}{\alpha}} - \left(10^{\frac{\xi}{10}}\right)^{\frac{1}{\alpha}}\right)^{\alpha}$$

Hence this is the proposed power control expression. The first part of R.H.S shows the value of the interference power at the primary user; the second part shows the minimum tolerable SINR at the primary user; the third part shows the distance between the primary user and the cognitive radio. We can say that P_{max}^{cr} is a function of I (interference power at primary receiver), $SINR_{min}^{pr}$ and R_{cr}^{pr}.

$$P_{max}^{cr} = f\left(\mathrm{I}, SINR_{min}^{pr}, R_{cr}^{pr}\right)$$

4.8 Transmission:

On the basis of $SINR_{min}^{pr}$ and the R_{cr}^{pr} value, cognitive radio should adaptively change the modulation order to get the maximum throughput. Adaptive modulation is used in response to the quality of signal reception measured at the receiver; in effect, feedback is needed between each pair of the system, to make adaptive modulation feasible. The modulation order is changed according to the interference temperature at the primary user and the distance between the cognitive radio and the primary user. In this work we use four kinds of modulation: Binary phase-shift keying (BPSK), Quadrature phase-shift keying (QPSK) and Quadrature Amplitude Modulation (QAM).

Chapter 5

Simulations and Results

In this thesis work we propose a power control approach in cognitive radio system on the basis of the received SNR as a proxy for distance as well as the IT model, in order to mitigate the interference to the primary user due to the presence of cognitive radios. This power control method will allow the secondary users to aggressively increase their transmit power without affecting the quality of the service of the primary user. Rayleigh fading with the distance-based PL (Path Loss) factor and AWGN (Additive White Gaussian Noise) without the multipath fading, where the path loss exponent is 2 is used in all simulations.

Adaptive modulation is used in response to the quality of signal reception measured at the receiver; in effect, feedback is needed between each pair of the system, to make adaptive modulation feasible. The modulation order is changed according to the interference temperature at the primary user and the distance between the cognitive radio and primary user. In this work we use three kinds of modulation techniques:

- Binary phase-shift keying (BPSK)
- Quadrature phase-shift keying (QPSK)
- Quadrature Amplitude modulation (QAM)

5.1Procedure of simulation:

Our system works in a good procedural way. There are different steps involved in the simulation:

- The cognitive radio starts sensing its environment.
- If the primary user is silent, the cognitive radio starts communication with the target straight away.
- If not, then start scanning the channels to find the empty slot (channel) for communication.
- If yes, then use the best possible modulation scheme for communication to increase the throughput.
- Start communication with recommended transmit power.
- If the signal strength is becoming weekend, the CR should send a request to try and increase the power or number of the antennas at the transmitter side.
- If the signal strength is good, then start communication.

We are going to explain these steps. First the cognitive radio starts sensing its environment; if the primary system is not in work, then the cognitive radio should start its communication straight away. On the other hand, if the primary user is in working then the cognitive radio waits a while and start looking for frequency holes by utilizing the information of the SNIR at the primary user. If the cognitive radio is successful to find the vacant band, then communication can start and the power is adjusted on the basis of the distance between the primary user and the cognitive radio as well as the SINR value at the primary user. Adaptive modulation is used in response to the quality of the signal reception measured at the receiver. In this work we use three kinds of modulation (BPSK, QPSK, and QAM).

5.2 BPSK (Binary phase shift keying):

Figure 5.1 depicts the SEP (symbol error probability) performance of the cognitive radio user in accordance with SNR (signal to noise radio) for various values of the distance R, under the condition that the CR user uses the proposed scheme and the modulation scheme is BPSK. The channel between the cognitive radio and the Target is Rayleigh fading with distance-based PL (Path Loss) factor and AWGN (Additive White Gaussian Noise) without multipath fading where the path loss exponent is 2.

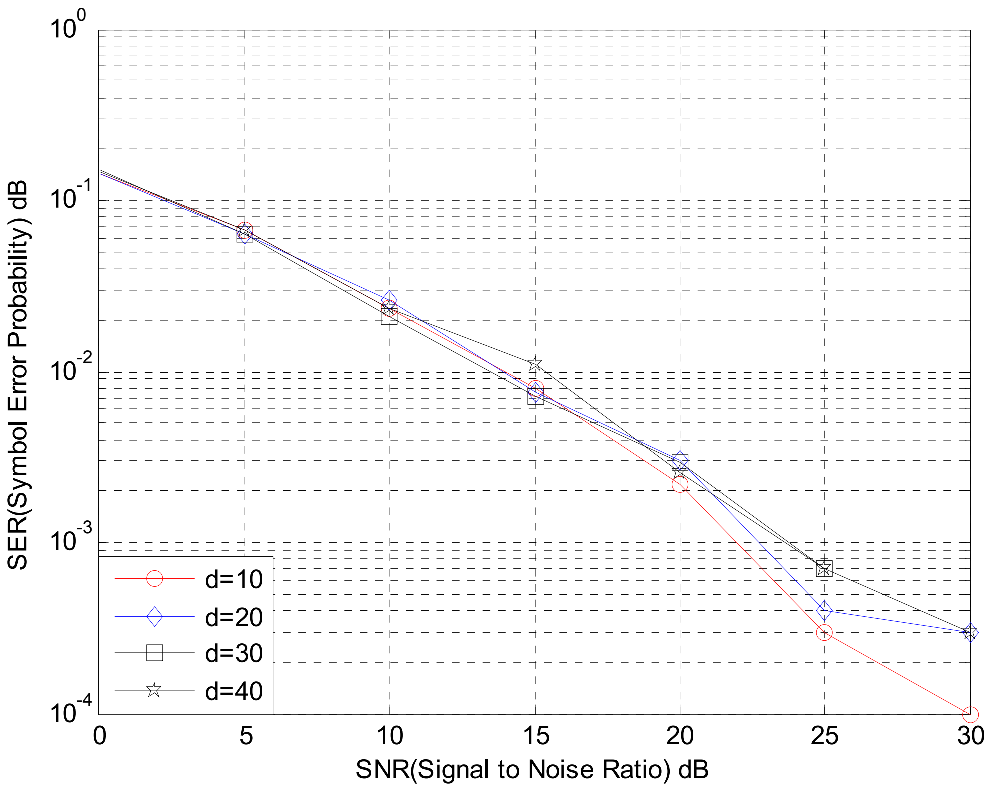


Figure5.1: Performance of the Cognitive Radio user in Accordance with the SNR (signal to noise ratio) for various values of the distance R using BPSK. The channel Rayleigh faded with a distance-based PL (Path Loss) factor and AWGN (Additive White Gaussian Noise) without multipath fading where path loss exponent is 2.

5.3 QPSK (Quadrature phase shift keying):

Figure 5.2 depicts the SEP (symbol error probability) performance of the primary user in accordance with the SNR (signal to noise radio) for various values of the distance R, under the condition that the CR user uses the proposed scheme and the modulation scheme is BPSK. The channel between the cognitive radio and target is Rayleigh fading with distance-based PL (Path Loss) factor and AWGN (Additive White Gaussian Noise) without the multipath fading where the path loss exponent is 2.

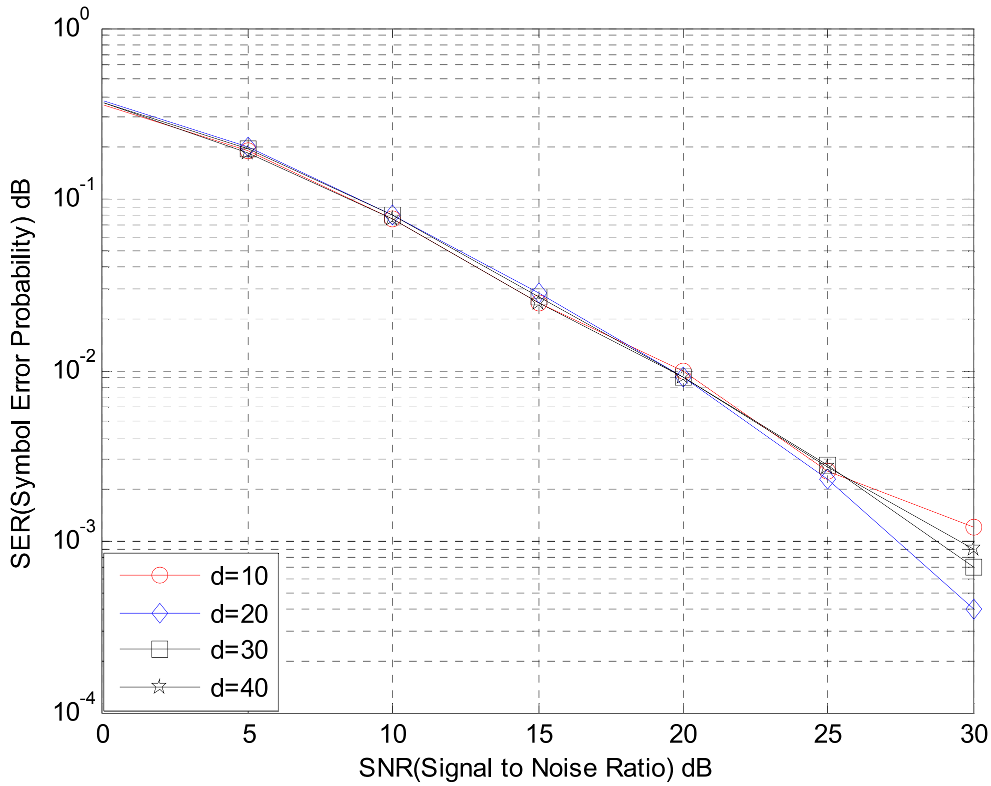
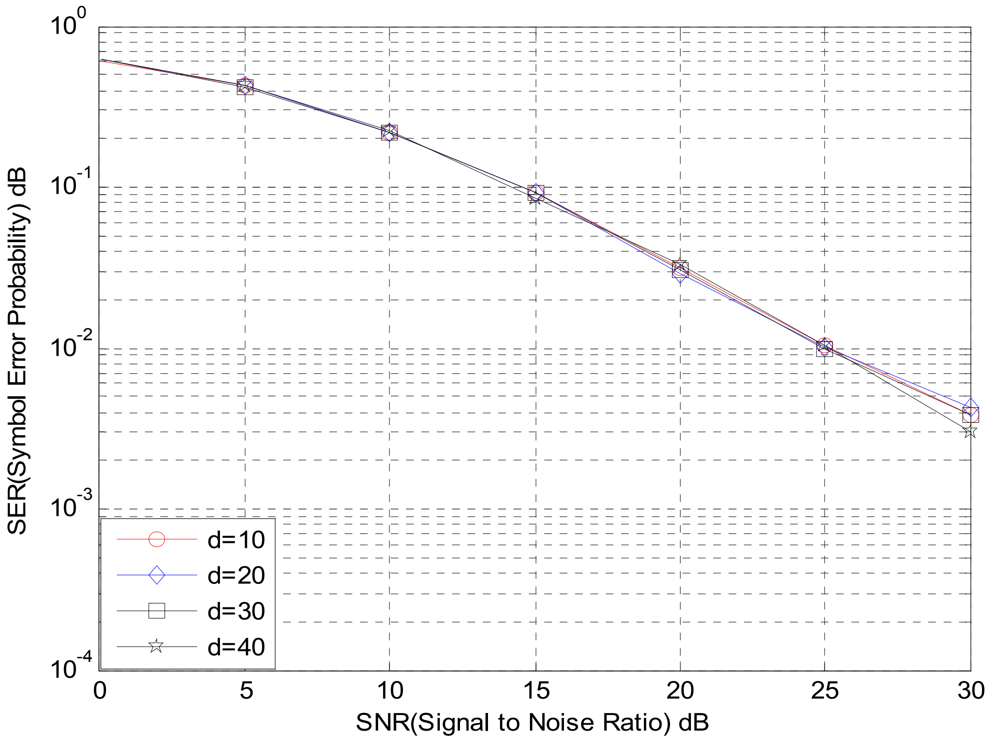


Figure5.2: Performance of the Cognitive Radio user in Accordance with the SNR (signal to noise ratio) for various values of the distance R Using QPSK The channel Rayleigh faded with a distance-based PL (Path Loss) factor and AWGN (Additive White Gaussian Noise) without multipath fading where path loss exponent is 2.

5.4 QAM (Quadrature Amplitude Modulation):

Figure 5.3 depicts the SEP (symbol error probability) performance of the Primary user in accordance with the SNR (signal to noise radio) for various values of the distance R, under the condition that the CR user uses the proposed scheme and the modulation scheme is BPSK. The channel Rayleigh faded with a distance-based PL (Path Loss) factor and AWGN (Additive White Gaussian Noise) without multipath fading where path loss exponent is 2.



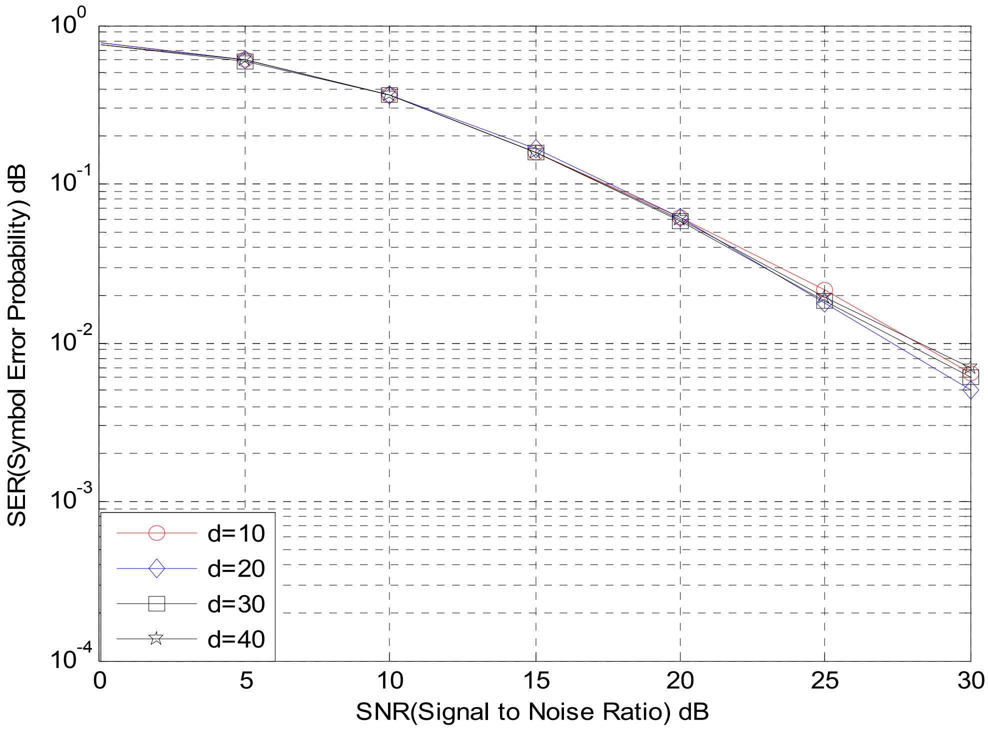


Figure5.3: Performance of the Cognitive Radio user in Accordance with the SNR (signal to noise ratio) for various values of the distance R Using QAM, The channel Rayleigh faded with a distance-based PL (Path Loss) factor and AWGN (Additive White Gaussian Noise) without multipath fading where path loss exponent is 2.

To allow the primary receiver to successfully decode the received signals from the primary transmitter in the presence of the cognitive radio, the signal-to-interference-plus-noise ratio (SINR) of the primary receiver should be guaranteed to be above a threshold of the decidability SNR (in dB), i.e., SINR≥ . [6] Average power at the primary receiver is $\frac{P'_{pr}(f_c,B)}{P'_{cr}(f_c,B)+\sigma^2}$, therefore from equation (30) we have that

$$\frac{P'_{pr}(f_c,B)}{P'_{cr}(f_c,B)+\sigma^2} \geq \text{SINR} = 10^{\frac{\gamma_{dco}}{10}}$$

The Cognitive radio should observe this value consistently.

5.5 QPSK (with and without Interference):

Figure 5.4 and 5.5 depicts the SEP (symbol error probability) performance of the primary user in the presence of the cognitive radio (with interference) and without cognitive radio (without interference) accordance with SNR (signal to noise ratio) for various values of the distance R , under the condition that the CR user uses the proposed scheme and the modulation scheme is BPSK. The channel is Rayleigh faded with the distance-based PL (Path Loss) factor and AWGN (Additive White Gaussian Noise) without multipath fading where the path loss exponent is 2.

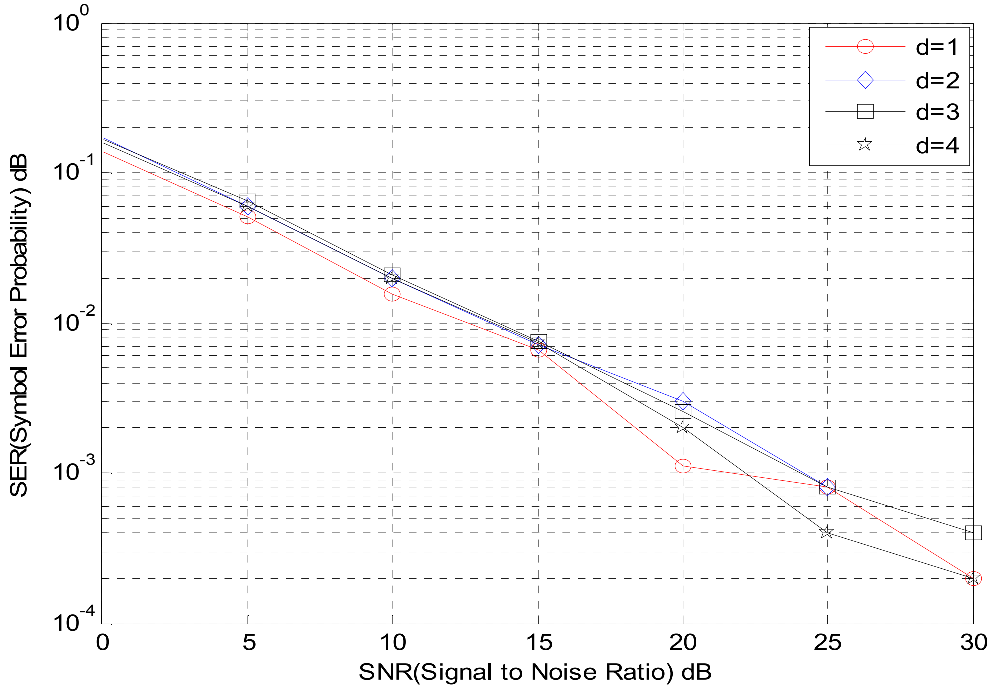


Figure5.4: (a) Performance of the Primary user in Accordance with the SNR (signal to noise ratio) for various values of the distance R Using QPSK, The channel Rayleigh faded with a distance-based PL (Path Loss) factor and AWGN (Additive White Gaussian Noise) without multipath fading where path loss exponent is 2.With Interference .

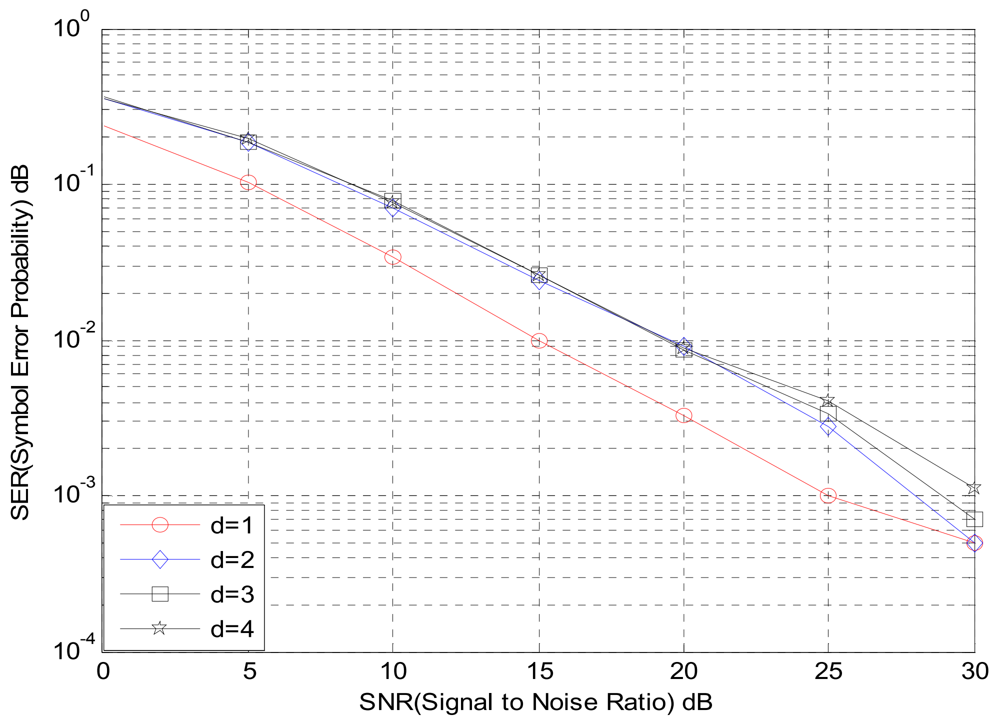
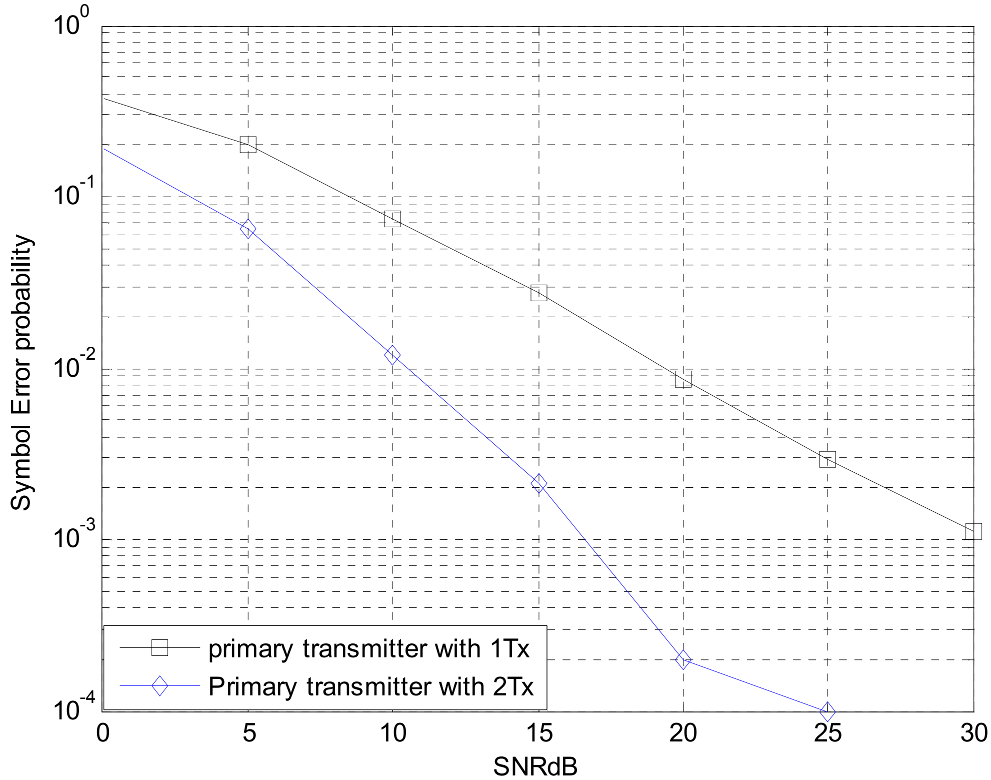


Figure5.4:(b) Performance of the Primary user in Accordance with the SNR (signal to noise ratio) for various values of the distance R Using QPSK .The channel Rayleigh faded with a distance-based PL (Path Loss) factor and AWGN (Additive White Gaussian Noise) without multipath fading where path loss exponent is 2..Without Interference

There is not much difference between these two results, i.e. the proposed scheme is very useful to avoid the primary user from harmful interference. Results show that we can provide service to the secondary user without sacrificing the quality of service of the primary user.

5.6 Signal Strength Problem:

Consider the scenario of the primary system not in work with the cognitive radio being free to utilize the primary user's bandwidth. We know that in the cognitive radio system there are many problems. One of them is the distance problem due to the signal strength is being more and more week. To improve the signal strength and quality, one possible way is to improve the diversity of signal by increasing the number of the antennas at the transmitter side. Hence if the signal strength at the cognitive radio is weak, then the cognitive radio should send a request to the transmitter side either increase the transmit power or increase the number of antennas on the transmitter side. In figure 5.6 and 5.7 some results are shown .From our result it is clear that when we increase the number of antennas on the transmitter side, the signal quality or diversity is improved significantly.



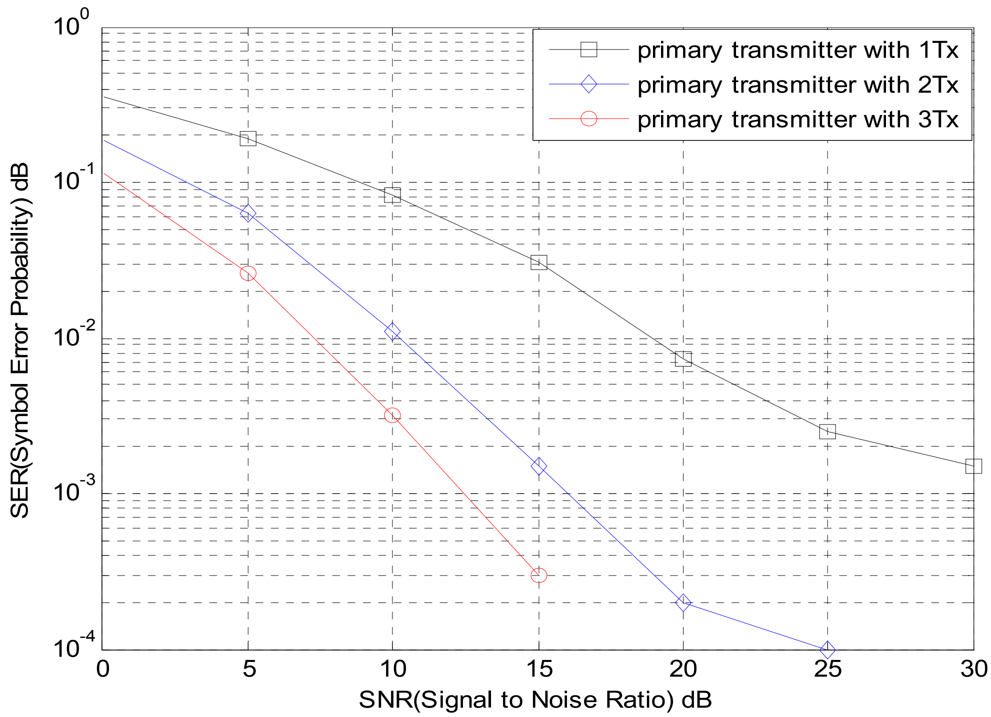


Figure 5.6 and 5.7 Depicts the SEP (symbol error probability) performance of the Cognitive Radio in accordance with the SNR (signal to noise ratio) at different values of antennas., under the condition that the CR user uses the proposed scheme and modulation scheme is QPSK. The channel is taken Rayleigh fading and the AWGN (Additive White Gaussian Noise).

Chapter 6
Conclusion and Future Work

6.1 Conclusion:

Cognitive Radio is an intelligent antenna that can sense the environment, adapts its way of communication to minimize the effects of interference at the primary user to maintain its quality of service. In this thesis work we have proposed *a power control approach which intelligently adjusts* the cognitive radio system's power without disturbing the quality of service of the primary user, in order to mitigate the interference at the primary user due to the presence of cognitive radios. This power control method will allow the secondary users to aggressively increase their transmit power without affecting the quality of the service of primary user.

Mathematically developed how a cognitive radio may calculate the estimated distance between the primary systems and the cognitive radio. Our proposed CR intelligent in that it can use adaptive modulation to get the maximum throughput. To avoid interference at the licensed users, the transmit power of the cognitive radio should be limited based on the locations of the licensed users and the value of SINR at the primary user. We proposed how to calculate distance between the cognitive radio and primary user as well as the SINR (Signal to- Interference-and-Noise Ratio) at primary user.

Furthermore, with our simulation we have shown how a cognitive radio senses its environment, i.e. if the primary system is not in work, and then the cognitive radio should start its communication straight away. On the other hand, if the primary user is transmitting, then the cognitive radio should wait for a while and start looking frequency holes by utilizing the information of SNIR at the primary user. If the cognitive radio is successful to find the vacant band, then communication may start and power adjusted on the basis of the distance between the primary user and the cognitive radio as well as the SINR value at the primary user. Adaptive modulation is used in response to the quality of the signal reception measured at the receiver. In this work we have use three kinds of modulation (BPSK, QPSK, QAM). Numerical results were presented to show that the projected approach can guarantee a dependable quality of service for the primary user in any location while enhancing the spectrum utilization greatly.

6.2 Future work:

We can increase the number of secondary users. In order to do this, we have to work more on the core issues related to cognitive radios' power control. There are different methods to control interference one of them is to consider the choice of the modulation format for the transmission of packets over selected spectrum gaps or holes. For this we strongly consider OFDM (orthogonal frequency division multiplexing) as a method of choice for future.

References:

[1] S. Haykin, Cognitive radio: Brain-empowered wireless communications, IEEE Journal on Selected Area in Communications 23 (5) (February 2005) 201–220.

[2] Mahapatra, R. Krusheel, M. "CycloStationary Detection for Cognitive Radio with Multiple Receivers "IEEE TRANS (Oct. 2008)

[3] Mohamed Ghozzi , Mischa Dohler , François Marx , Jacques Palicot "Cognitive radio: methods for the detection of free bands"

[4] N. Hoven and A. Sahai, "Power scaling for cognitive radio," in Proc.WCNC, Maui, Hawaii, USA, June 2005, vol. 1, pp. 250–255.

[5]T. Clancy and W. Arbaugh, "Measuring interference temperature," Proc. Virginia Tech. MPRG Symp. Wireless Personal Commun. (MPRG '06), Jun. 2006.

[6] Hamdi, K., Wei Zhang, Ben Letaief, K," Power Control in Cognitive Radio Systems Based on Spectrum Sensing Side Information," Communications, 2007. ICC '07. IEEE International Conference on 24-28 June 2007

[7] Minki Hong .,Jaewoon Kim, Hyunwook Kim, Yoan Shin ," An Adaptive Transmission Scheme for Cognitive Radio Systems Based on Interference Temperature Model"IEEE TRANS on 10-12 Jan. 2008.

[8] J. Mitola et al., “Cognitive radio: Making software radios more personal,”IEEE Pers. Commun., vol. 6, no. 4, pp. 13–18, Aug. 1999.

[9] J. Mitola, “Cognitive radio: An integrated agent architecture for software defined radio,” Doctor of Technology, Royal Inst. Technol. (KTH), Stockholm, Sweden, 2000.

[10]. Z. Tian and G. B. Giannakis, “A wavelet approach to wideband spectrum sensing for cognitive radios,” in Proc. Int. Conf. on Cognitive Radio Oriented Wireless Networks andCommunications (Greece), June 8–10, 2006.

[11] http://www.kathrein.de/en/mca/catalogues/download/99810844.pdf (03-01-2009)

[12] J. Mitola and G. Q. Maguire, “Cognitive radio: Making software radios more personal,” IEEE Pers. Commun., vol. 6, pp. 13–18, Aug. 1999.

[13] T. A. Weiss and F. K. Jondral, “Spectrum pooling: an innovative strategy for the enhancement of spectrum efficiency,” IEEE Commun. Mag., vol. 42, Mar. 2004, pp. S8–14.

[14] S. Haykin, “Cognitive radio: brain-empowered wireless communications,”IEEE J. Sel. Areas in Commun., vol. 23, pp. 201–220, Feb. 2005.