Impact of Location Awareness on Concurrent Transmissions of the Ad Hoc Cognitive Networks

Thesis submitted to the faculty of Engineering in partial fulfillment of requirements for the Degree of MS Electronic Engineering

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1. Telecommunication systems
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بسم الله الرحمن الرحيم

In the name of Allah, the most Beneficent
and the most Merciful

Approval Certificate

It is certified that this thesis work entitled, "Impact of Location Awareness on Concurrent Transmissions of the Ad Hoc Cognitive Networks" was carried out by "Muhammad Adeel Altaf" having Reg. # 294-FET/MSEE/F-12 under my supervision and in my opinion this piece of thesis work fulfills all requirement and is in scope for the degree of MS (Electronic Engineering).

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Originality Declaration

It is certified that research work titled "Impact of Location Awareness on Concurrent Transmissions of the Ad Hoc Cognitive Networks" is carryout by me. For any assessment, the work has not presented anywhere else. The materials coated from different sources in this work are acknowledged properly.

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Acknowledgements

For all the blessings I am very thankful to Almighty Allah. No one is able to accomplish any kind of task without the support and blessing of Allah Almighty. Whenever I need the support and courage, I found my family's support there that is why I feel grateful for their supportive behavior. Their love and encouragement always empower me and help me in going on. I am very thankful to my supervision Dr. Adnan Umar. With his supportive supervision, determination and plenty of knowledge he delivered me, I become able to complete my thesis. This thesis work is complete due to his help and guidance, which he provided me throughout of this challenging work.

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Abstract

Cognitive radio (CR) can identify the opportunity of reusing the frequency spectrum of other wireless systems through wideband spectrum sensing. To save time and energy of wideband spectrum, we investigate to what extent a CR system incorporating the location awareness capability can establish a scanning-free region where a peer-to-peer ad hoc network can overlay on an infrastructure-based network. Based on the carrier sense multiple access with collision avoidance (CSMA/CA) medium access control (MAC) protocol, the concurrent transmission probability of a peer-to-peer connection and an infrastructure-based connection is computed.

Chapter 1

A Brief Introduction of Cognitive and Software Defined Radios

1 Introduction

Wireless communication is one of the most important type of communication. In our daily life, its presence and importance is evident. Wireless communication should advance, as its usage is increasing day-by-day. The whole world is accelerating towards the future in which communication will be efficient, easy and cheap. So in order to move parallel, wireless communication must advance with same pace. Radio spectrum (RF) is a range of those frequencies in which electromagnetic waves can be radiated. This range of frequencies used for communications and ranges from 3 Hz to 300GHz.

The RF band commonly divided into two different bands namely as licensed and unlicensed band. The license is most commonly supply by authorized body for country or some region. The institute named as International Telecommunication Union (ITU) has established some rules for RF band licensing. The authorized body of country is responsible for ensuring the implementation of ITU rules within country. Licensed users mostly have interference problem as other unlicensed users are trying to get access to that licensed band. The License contains a list of band of frequencies (depending upon the demand), a geographical region and allowable operational factors. Unlicensed bands are free for all i.e. every user can utilize this band but one must ensure that the rules finalized by ITU are obeyed to avoid interference.

A new domain emerges when FCC came to know about these spectrum holes that the licensed spectrum is being underutilized and it is not completely occupied all the time and hence FCC opened a new horizon named IEEE 802.11. . The charter of IEEE 802.22, "the Working Group on Wireless Regional Area Networks (WRANs), under the PAR approved by the IEEE-SA Standards Board is to develop a standard for a Cognitive Radio-based PHY/MAC/air – interface.

1.1 Cognitive Radios

1.1.1 Definition

Cognitive radio (CR) is an intelligent communication system based on wireless that uses the approach of learning from the environment and adjusts itself to statistical deviations in the environment by making changes to its internal parameters. All this is done in real time.CR keeps two things in mind; efficient utilization of spectrum and reliable communication.

In Cognitive radio, a transceiver can cleverly detect which communication channels are being used and which are not, and quickly move into free channels while staying away from involved ones. Federal Communications Commission (FCC) defines CR as "A radio that has ability of sensing electromagnetic operational environment and can dynamically and autonomously adjust its radio operating parameters to modify system operation".

1.1.2 Explanation

Cognitive radio (CR) has pulled a lot of attention of both industrial and the scholarly world because spectrum without license become gathered while some of licensed spectrums are not completely utilized [1, 2]. Incorporating with the Federal Communication Council (FCC), DARPA (Defense Advanced Research Projects Agency) additionally launches the next generation (XG) communication technique. This technique used by the military and emergency applications to create access techniques named opportunistic spectrum [3, 4].

Cognitive Radio (CR) is a technology that is handling scarceness and rising demand of wireless spectrum. By utilizing the location awareness and spectrum information of primary users CR provides secondary users (SUs) an access to the licensed spectrum bands and keep off the SUs interference with PUs. For doing so and protecting PUs different strategies and transmission power may be adapted by the SUs.

In current legacy system for securing a harmless communication link CR user [5] is required to:

1. Sensing wideband spectrum [6],
2. Identification of the PU's spectrum consumption as far as location and time [7,8]
3. Understand the opportunity of spectrum sharing of band for both PUs and SUs under adjustment of the parameters of transmission [9], [10].

CR users can easily recognize an availability of spectrum holes without utilizing the sensing technique named wideband spectrum sensing. Responsively, when the primary user of legacy system is far away from secondary one then both secondary user (CR) and the primary user transmit information with each other without any interference.

For the detection of spectrum holes, dependency on energy and time consuming wideband spectrum sensing technique approaches to zero if CR has location awareness for transmitting the data concurrently with primary user. Furthermore, it is obvious that overall throughput can be upgrade through concurrent transmission. This makes clear that priority of transmission opportunity over the spectrum sensing is higher for CR user. Moreover, Cognitive radio ad hoc networks (CRAHNs) are considered the networking technology of next generation. The most essential aspect of research is reliability in the area of CRAHNs.

The aimed routing mechanism is examined in MATLAB simulator. The known factors relevant to wireless network transceiver and used radio signals frequency. Figure 1.1 shows the Cognitive Radio block diagram.

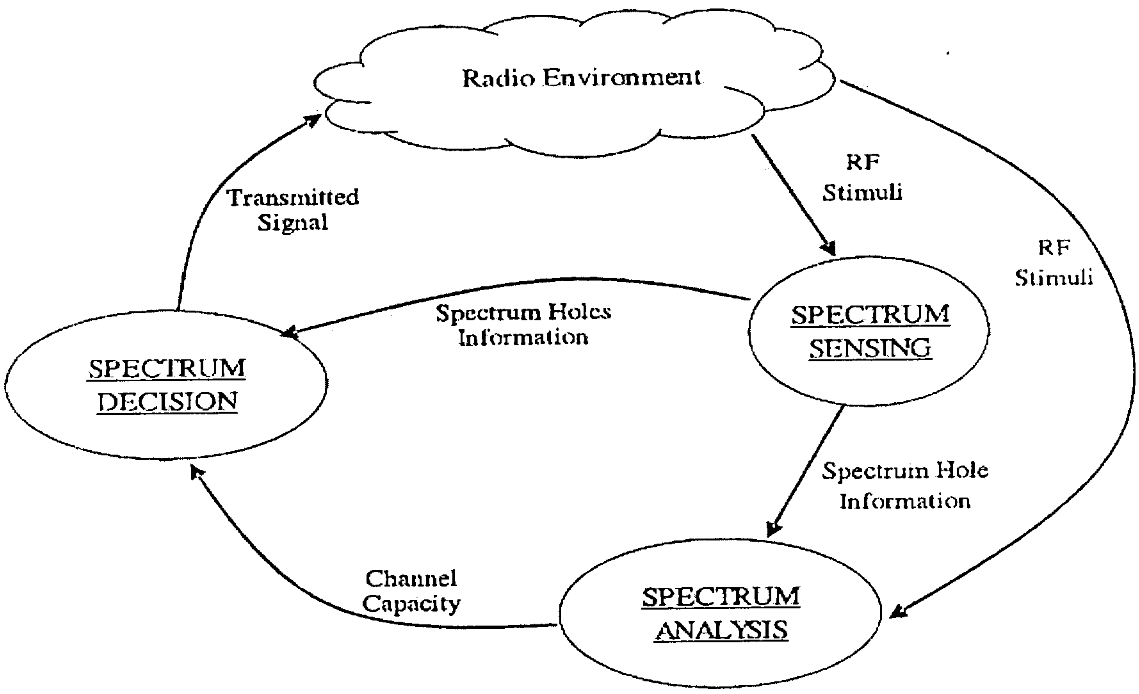

Fig 1.1: Cognitive Radio Block Diagram

1.2 Software Defined Radios

Software Defined Radio (SDR), as the name indicates, is the radio in which different parameters of the radio e.g., modulation scheme, transmitting power, channel encoding-decoding and encryption can be altered using a computer program or software. SDR hardware is the very general one. No changes in the hardware are required to alter the modulation scheme, transmitting power, channel encoding-decoding, encryption and other blocks in a communication system.

Haykin is a person who first introduces the basic concept of cognitive radar for environment awareness having cognition cycle. This was initially introduced for detection of bat under echolocation system. Below figure 1.2 shows the SDR block diagram.

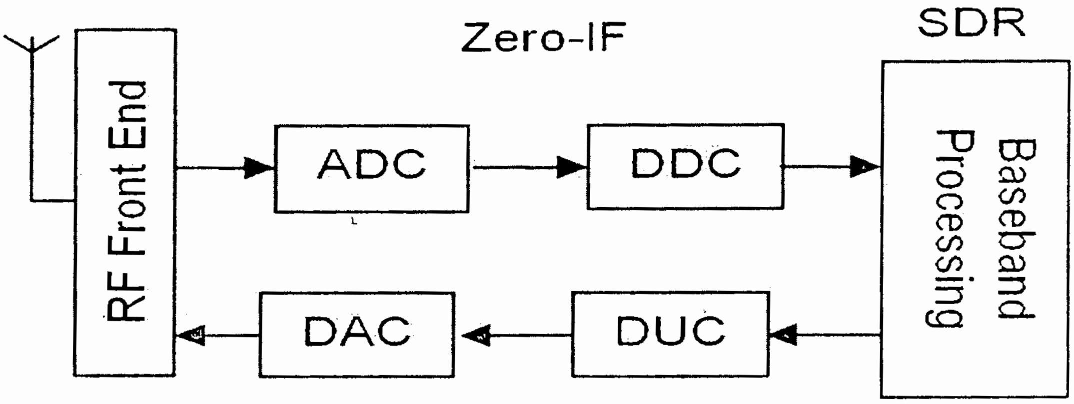

Fig 1.2: SDR Block Diagram

There are three main sections; RF, IF and the baseband section. In RF section, the analogue front end converts the RF band to IF band. The wide-band converter converts analogue to digital or digital to analog communication. In digital IF and baseband sections there are configurable parameters, which can be altered in the software. SDR does not have to sense the spectrum.

So it is different from the CR. CR is the comprehensive version of SDR which has added spectrum sensing capability

1.3 Task Implementation

1.3.1 Problem Statement

In different research works it is demonstrated that for some certain time periods the resource of radio channel remains underutilized where the demand for the spectrum usage is increasing. However, for maximum utilization of spectrum, it is required that spectrum should be managed in a proper manner. Moreover, the concurrent transmission region identification is a major concern means the region in which users of the legacy systems will not cause the interference with the CR users.

1.3.2 Proposed Solution

Instead of using another efficient spectrum sensing technique, we aim at location awareness technique in order to provide the assistance for CR users for identification of opportunity of concurrent transmission. The particular aim of this research work is to determine the exact dimension of region of concurrent transmission where CR devices can create an overlaying ad hoc network on the top of an infrastructure based legacy system. We will examine the overall improvement coming from concurrent transmissions based on the carrier sense multiple access with collision avoidance (CSMA/CA) medium access control (MAC) protocol.

1.4 Thesis organization

In second chapter, some essential techniques of spectrum sensing are discussed in detail. Comparative analysis of all techniques is carried out and conclusion is made through comparative results. In third chapter, main discussion is on, system model and wideband spectrum sensing. In fourth chapter, analyze coexistence probability of both the infrastructure and ad hoc connections, which are simultaneously sharing the same frequency spectrum.

In fifth chapter, the numerical results shown and discussed, and after conclusion is made through results and discussion, and at the end future recommendation is suggested.

Chapter 2

A Brief Introduction of Spectrum Sensing Techniques

2.1 Spectrum Sensing

Many techniques of spectrum sensing are in literature which sense the spectrum hole in the absence and presence of primary user. CR has to perform this task very accurately as to keep the interference with the PUs communication below a safe limit. High precision of Cognitive Radio in spectrum sensing will result in precise spectrum holes' allocation but the complexity is also an issue.

2.1.1 Techniques of Spectrum Sensing

Many techniques of spectrum sensing are in literature, which sense the spectrum hole. The most important sensing techniques are as follows:

I. Signal Processing Technique
II. Cooperative Sensing Technique

The techniques of signal processing are further categories into

i. Detection of matched filter
ii. Detection of energy
iii. Detection of cyclo-stationary characteristics

Similarly, the techniques of cooperative sensing are further categories into

i. Spectrum sensing in centralized manner
ii. Spectrum sensing in decentralized manner
iii. Spectrum sensing in hybrid manner

The figure 2.1 shows the different important sensing techniques

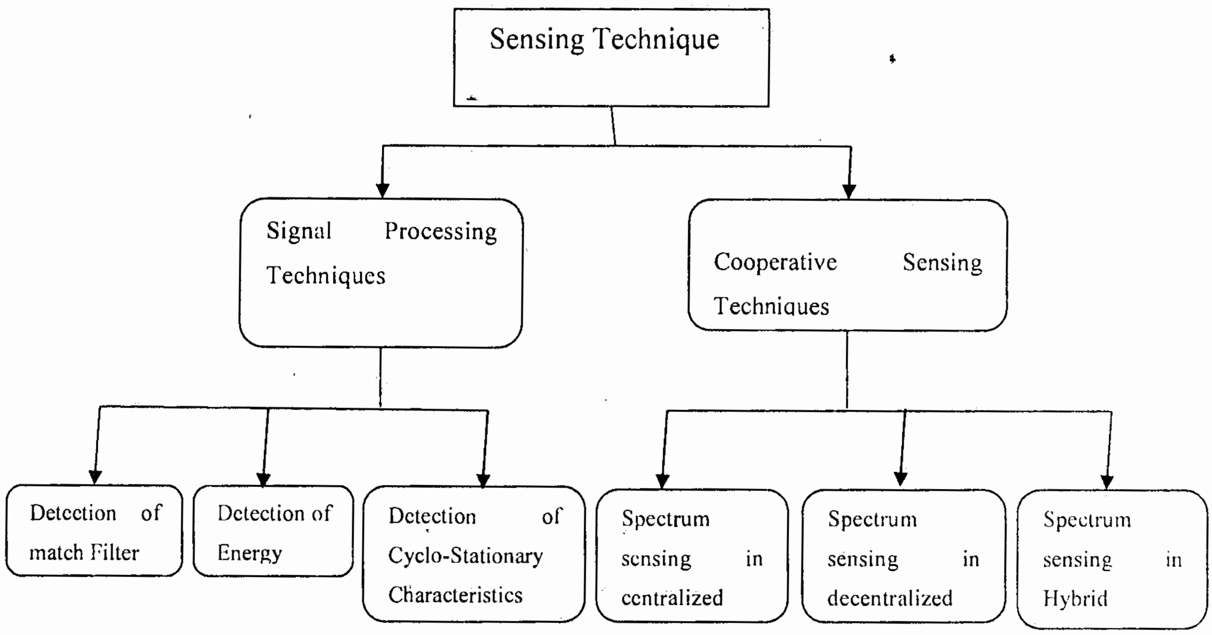

Fig 2.1: Sensing Techniques Categories

2.2 Signal Processing Techniques

2.2.1 Detection of Matched Filter

Matched filter detector is a coherent detector and we should have the prior knowledge of the primary signal. If the necessary parameters are not true, then its performance is very poor. Matched filter is a linear type of filter and it maximizes the Signal-to-Noise ratio (SNR) at the sampling points. Its impulse response, which is conjugated time-reversed form of the reference signal, is convolved with the received signal.

The basic advantage of this filter technique is that, CR performs its function at remit time where it utilizes few received samples. By this way the number of samples of signals and SNR are reduced, and other advantage of filtering is that we can accomplish a certain probability of midsection. CR consumes power and has high complexity and accurate information about target users. However, its drawback is that CR requires a devoted receiver.

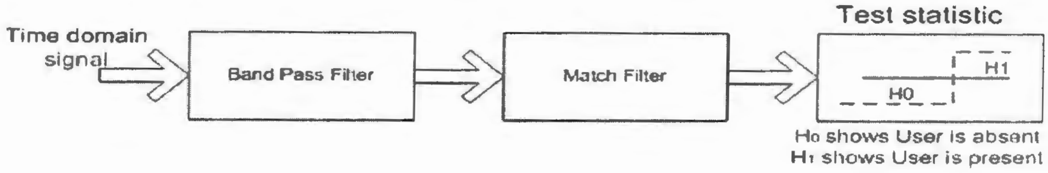

Fig 2.2: Detection of Matched Filter Block Diagram

In this method at first stage for measuring the energy with relevant band, the samples of input signal passes from band pass filter. After that the match filter, having impulse response related to reference signal, is convolved with results of band pass filter. At final stage for primary user detection, the result of matched filter is compare with threshold.

2.2.2 Energy Detection

In this detection of energy, the signal detects on the bases of sensed energy. Even this system does not require the signals of primary user and its simplicity make it prominent. The low precision is main drawback of this method. Another weakness of this method is that it does not have an ability to detect the signals of secondary user from the primary user signals. Locating of the wideband spectrum signals is difficult and therefore at low or small SNR it has poor and hapless execution.

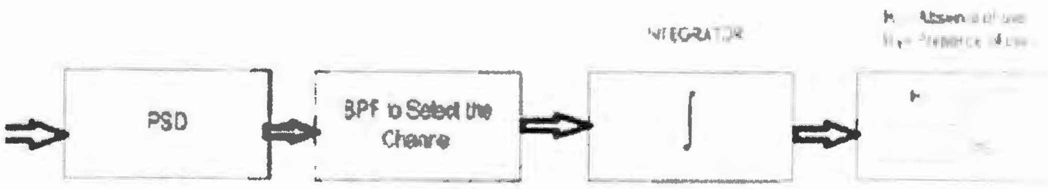

Fig 2.3: Detection of Energy Block Diagram

The figure 2.3 shows the step-by-step detection of energy process. It shows that initially the signal passes through the band pass filter whose bandwidth is W and integration is applied in term of small interval of times. After that the results of integrator are compared with preset threshold. The purpose of this comparison is to find out either the primary user is present or not. The threshold value used for comparison may be either changeable or fixed depends on the channel consideration.

In this process the estimation of signal presence is find out by means of received energy comparison with threshold value.

2.2.3 Detection of cyclo-stationary characteristics

For finding the primary user's presence, this method uses the received signal information. The information mostly required for this purpose is spreading code, sinusoidal waves, cyclic prefix and pulse trains of receiving signal.

The main benefit of this process is that, its performance is good even for the region having low SNR and also for noise uncertainties. The most prominent defect of this method is its high time taking of sensing as well as computational complexity.

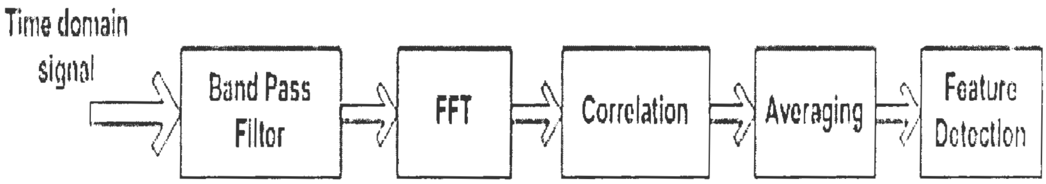

Fig2.4: Block Diagram of Detection of cyclo-stationary characteristics

Identification of received signals in primary signals presence it is not good for the periodicity of modulated signals couple with sine wave career mode, cyclic prefixes, sequences of hopping etc. The received signals have the periodicity therefore it exhibits the statistics which are in periodic form and have noise free spectral correlation.

2.3 Cooperative Sensing Techniques

Mostly the cooperative sensing techniques are further categories as following

i) Spectrum Sensing with Centralized Cooperation

ii) Spectrum Sensing with Decentralized Cooperation

iii) Spectrum Sensing Hybrid Cooperation

2.3.1 Spectrum Sensing with Centralized Cooperation

In this technique, every wireless sensor of CR performs the task of finding the existence of primary user in a channel by using the spectrum sensing technique. In this centralized technique, a centralized cooperator exists and all CR wireless sensors are required to send their decisions to that centralized cooperator. The centralized cooperator is called as collector, server or cluster head. For finding the existence of primary user, the centralized cooperator uses all received information from CR sensors for final decision.

2.3.2 Spectrum Sensing with Decentralized Cooperation

In this technique, there is no need of controller or central cooperator. In this sensing method the wireless sensors form number of clusters and each cluster get sensing information locally and share this information with other clusters of that channel or network. Therefore, its functioning is considered as decentralized. This technique requires high processing and large storage capacity for record maintenance.

2.3.3 Spectrum Sensing Hybrid Cooperation

In this technique, the sharing of information between sensors is in decentralized manner. In other words, it can be defined that the cluster head may be required by centralized cooperator for sharing information of the channel.

2.4 Comparison

After all the pros and Cons of distinctive spectrum sensing techniques and difficulty in their operations, and number of issues to be faced in signal and energy detection. Among all of these methods, the most common issue of all the techniques is energy detection due to the signals strength complexities. In most methods of energy detection, the user not bothering as happened in matched filter, about the primary user's information and in other different methods.

Chapter 3

Wideband Spectrum Sensing

3.1 Introduction of Wideband Spectrum Sensing

In this Wideband Spectrum Sensing (WBSS), signal processing methods are energy consuming and very complex, moreover, it is also required to handle the shadowing effects and hidden nodes problems. Instead of making some other effective spectrum sensing method, in this thesis work, focusing on challenging but key issue, that is, without sensing a wideband spectrum, the users will easily access the spectrum holes. When the secondary user is far away from primary user (PU) then PU can transmit data concurrently without creating any interference between primary user and CR network. For the concurrent data transmission between the primary user and the CR network zone, if the CR devices have knowledge of desired transmission region then the CR system does not require the time and energy consuming WBSS. Therefore, the concurrent transmission identification opportunity has much more presidency than the spectrum sensing and have high throughput as well.

In this work, the effort is done for concurrent transmission identification by using the location awareness methodology. The particular objective of this work is to give a new dimension to the region of concurrent transmission, in this region where CR devices have an opportunity to establish an overlaying ad hoc network over an infrastructure-based legacy system.
This overlaying ad hoc network is an essential part for CR devices due to reusing of the underuse spectrum and it also enhance the frequency band proficiency significantly.

For achieving the extended coverage region for the infrastructure-based networks, the concept of combining the links such as infrastructure based link with ad hoc link introduces [11, 12], this concept shows that the area covered by infrastructure-based network can never coincide with the ad hoc network coverage zone.

The figure 3.1 shows the basic model for the hybrid infrastructure-based/ad hoc network. The figure shows the legacy system having peer-to-peer CR users within its coverage zone.

It is recommended that the access-point AP must switched between the mode of ad hoc and infrastructure system for improving the throughput of WLAN [13] in dynamic manner. In their suggested scenario, ad hoc connections are made by CR users in a distributed manner.

3.2 System Model

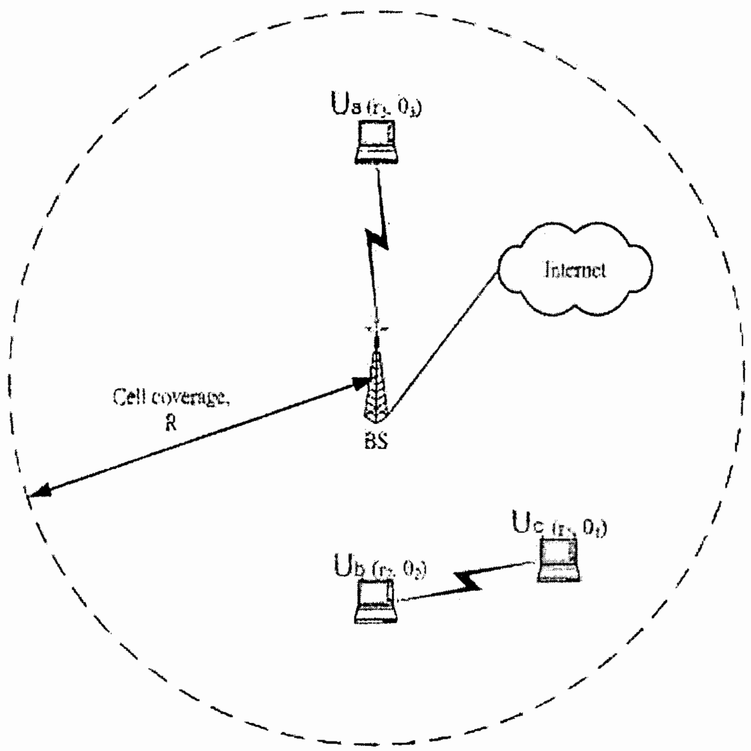

Fig 3.1: Basic Model for the Hybrid Infrastructure-based/Ad hoc Network

The figure 3.1 shows the basic model for the hybrid infrastructure-based ad hoc network, which comprise of three users named as U_a, U_b, and U_c, from these three users one of them is primary user (U_a) and two others are secondary users (U_b, U_c). It's presumed that the two secondary users are trying to establish the peer-to-peer link, however, the primary user has already established its link with base station (B_s). The B_s have coverage zone of πR^2 and its users

U_a, U_b, and U_c are at (r_3, θ_3), (r_2, θ_2) and (r_1, θ_1) respectively. Moreover, all users must strict to their position.

Either by the use of the BS_s signal strengths or GPS, the CR devices can find out their relative or absolute position in coverage zone of network [14, 15, 16].

By using the geographical routing protocols, each CR device broadcast its location information [17]. The geographical and position routing is difficult & the wastage of time and energy so there is no need to work anymore for every data transmission. The position and geographical routing protocols only activates when some new nodes want to join or leave its position. Moreover, information of position may also be stored in device with the upper layer's assistance. Therefore, it is accepted that the additional memory space and energy utilization is require for location and position information, which is comparatively small, instead of spectrum sensing technique for every transmission [18].

At any instant, multi-users try to contend the channel and under such scenario only single mobile station, which is present within the BS coverage zone be capable to establish the infrastructure-based communication link, which based on protocol known as CSMA/CA MAC protocol.

If the secondary user wants to establish the connection on the primary user's frequency, it required to make sure that it never degrades the present infrastructure-based link and also needed to win the possible contend from other secondary users for availing the frequency.

Let suppose a legacy system has a primary user and number of secondary users having alike transmit power. CR is capable enough to entertain just one secondary user after winning contend for establishing the link.

The received SIR (signal to interference ratio) for ad hoc link is represented by SIR_n and for infrastructure-based link is represented by SIR_m. For the overlapped coverage zone of CR based ad hoc link and infrastructure-based link, the coexistence probability (P_{CT}) also known as concurrent transmission probability is given as

$$P_{CT} = P\{(SIR_m > x_m) \cap (SIR_n > x_n)\} \tag{3.1}$$

Here x_n defines the required threshold for ad hoc link and x_m defines the required threshold for the infrastructure-based link. The calculation of the coexistence for ad hoc link and infrastructure-based link is necessary for finding the concurrent transmission zone. The CR devices are required to sense some other frequency and shift to it when the primary user link quality cannot ensure.

Suppose a two-ray ground reflection model, which have receiver and transmitter with two paths for transmission [19]. One is ground reflected and other is of line-of-sight type. Therefore, the received power is given as

$$P_r = \frac{P_t h_{bs}^2 h_{ms}^2 G_{bs} G_{ms} 10^{\frac{\varepsilon}{10}}}{r^{\alpha}} \quad (3.2)$$

Here received power is represented by P_r and transmitted power is represented as P_t. Moreover, the B_s antenna height is represented by h_{bs} and mobile station antenna height is represented as h_{ms}, the B_s antenna gain is represented by G_{bs} and mobile station antenna gain is represented as G_{ms}, the distance from transmitter to receiver is represented by r , the distributed log-normalized shadowing component is represented by $10^{\frac{\varepsilon}{10}}$ and path loss exponent by α.

3.3 Analysis of Signal-to-Interference Ratio

3.3.1 Analysis of SIR for Uplink

For case of uplink, by transferring the data from primary user (U_a) to B_s, the SIR of uplink for primary user (U_a) is represented by SIR_m^u , and the received power from U_a is P_{30} and received power from U_c is P_{10}. From equation 3.1we get

$$SIR_m^{(u)} = \left(\frac{r_1}{r_3}\right)^{\alpha} = P_{30}/P_{10} \quad (3.3)$$

Here r_1 represents distance from U_a to B_s and r_3 represents the distance from U_c to B_s. However, for the peer-to-peer ad hoc link between $U_b$and U_c the SIR is given as

$$SIR_n = \frac{P_{12}}{P_{32}} = \left(\frac{d_{23}}{d_{12}}\right)^{\alpha} \quad (3.4)$$

Here power received at U_b from U_c is represented as P_{12} and the interference power $P_{32}$from U_a, the distance from the U_c to U_b is represented by d_{12} and the distance from the U_a to U_b is represented by d_{32}. Where the $P_{ct}^{(u)}$ for uplink can be given by eq. 3.5 which we get by putting equations 3.3 and 3.4 in equation 3.1

$$P_{ct}^{(u)} = P\{(r_3 x_m^{\frac{1}{\alpha}} < r_1 < R) \cap (d_{12} < \frac{d_{23}}{x_n^{\frac{1}{\alpha}}})\} \triangleq R_{ct}^{(u)}/\pi R^2 \qquad (3.5)$$

Note that $R_{ct}^{(u)}$ shows the concurrent transmission region, for the scenario in which the U_c establish the connection without interrupting the uplink signal between U_a and B_s to U_b. It is clear from figure 3.2 that the donut-shaped region is form with $(r_3 x_m^{\frac{1}{\alpha}} < r_1 < R)$ condition, this type of region is formed with combination of two circles having radii R and $r_3 x_m^{\frac{1}{\alpha}}$, centered at B_s. The circular area of region having radius $d_{23}/x_n^{\frac{1}{\alpha}}$ centered at U_b is concede with $(d_{12} < d_{23}/x_n^{\frac{1}{\alpha}})$ condition. The $R_{CT}^{(u)}$ is given by eq. 3.6

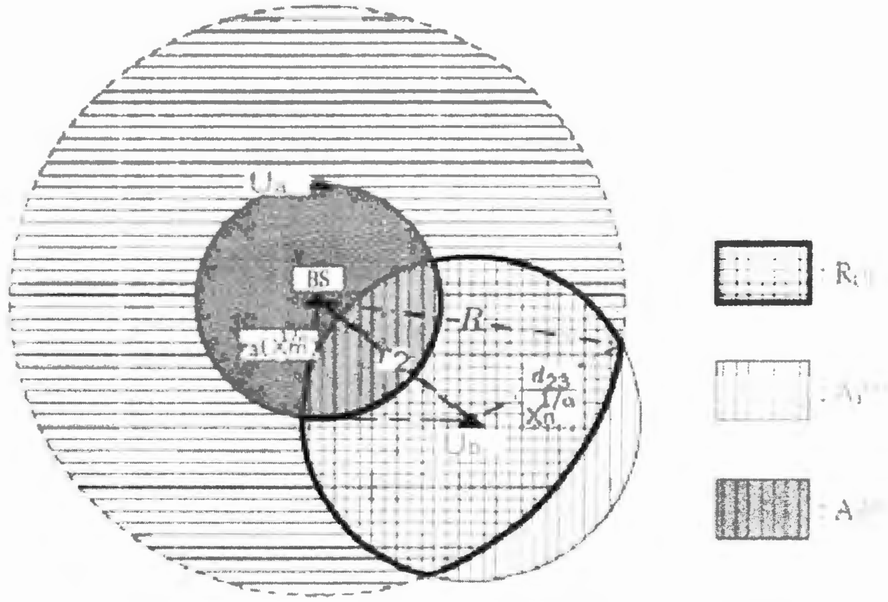

Fig 3.2: Physical Model for Coexistence Probability of Uplink Transmission

From the figure, the region $R_{CT}^{(u)}$ can be computed as:

$$R_{CT}^{(u)} = \left(\frac{d_{23}}{x_n^{\frac{1}{\alpha}}}\right)^2 - A_1 - A_2 \qquad (3.6)$$

Where $A_1$and A_2 are given by equations 3.7 and 3.8 respectively

$$A_1 = \left(\frac{d_{23}}{x_n^{\frac{1}{\alpha}}}\right)^2 (\pi - \theta') - R^2\theta + 2\Delta \quad (3.7)$$

$$A_2 = \left(\frac{d_{23}}{x_n^{\frac{1}{\alpha}}}\right)^2 \Phi - \left(r_3 x_m^{\frac{1}{\alpha}}\right)^2 \Phi' - 2\Delta' \quad (3.8)$$

3.3.2 Analysis of SIR for Downlink

For case of downlink, by transferring the data from B_s to primary user (U_a), the SIR for downlink is represented by $SIR_m^{(d)}$. From equation 3.2 we get

$$SIR_m^{(d)} = \frac{P_{03}}{P_{13}} = \left(\frac{h_{bs}}{h_{ms}}\right)^2 \left(\frac{d_{13}}{r_3}\right)^\alpha \quad (3.9)$$

Here the power received by U_a from $B_s$is represented by P_{03}, and $U_a$receive the power from U_c is represented by P_{13}. The distance from U_c to $U_a$is represented by d_{13}. The termsh_{ms}, $h_{bs}and$ $r_3$are same as defined for equations 3.2 and 3.3. However, for the ad hoc link between $U_b$and U_c the SIR is given as

$$SIR_n = \frac{P_{12}}{P_{02}} = \left(\frac{h_{ms}}{h_{bs}}\right)^2 \left(\frac{r_2}{d_{12}}\right)^\alpha \quad (3.10)$$

Here the power received by U_b from $U_a$is represented by P_{12}, and U_b receive the power from B_s is represented by P_{02}. The distance from $B_s$to U_b is represented by r_2, where the terms h_{bs}, d_{12} and h_{ms} are same as defined for equations 3.2 and 3.4. Where the $P_{ct}^{(d)}$for downlink transmission can be given by eq. 3.11 which we get by putting equations 3.9 and 3.10 in equation 3.1

$$P_{CT}^{(d)} = P\{(d_{13} > r_3 x'^{\frac{1}{\alpha}}_m) \cap (d_{12} < r_2 x'^{\frac{1}{\alpha}}_n) \cap (r_1 < R)\} \triangleq \frac{R_{CT}^{(d)}}{\pi R^2} \quad (3.11)$$

Where $x'_m = x_m \cdot \left(\frac{h_{ms}^2}{h_{bs}^2}\right)$ and $x'_n = \left(\frac{1}{x_n}\right) \cdot \left(\frac{h_{ms}^2}{h_{bs}^2}\right)$

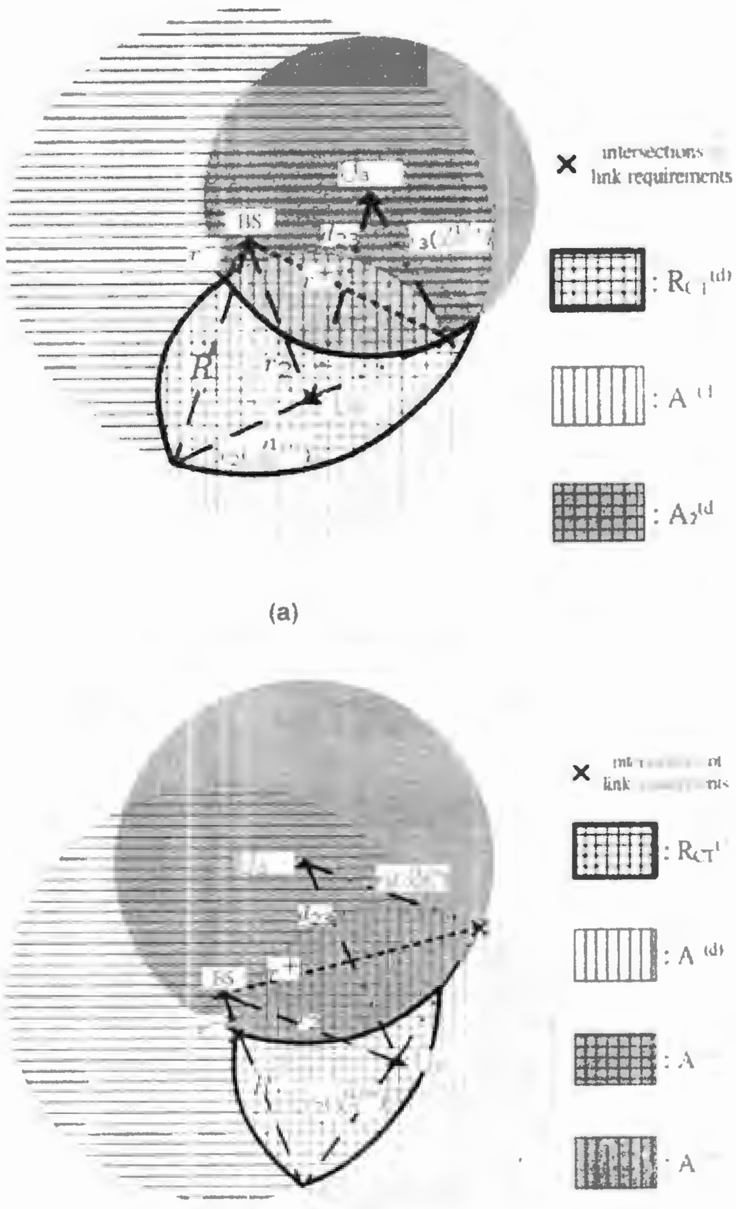

Fig 3.3: Model for Area of R_{CT} for Downlink (**a**) For condition: $max(r^+, r^-) \leq R$(**b**) For condition: $max(r^+, r^-) > R$

The region which is outside of the circle, whose center is at U_a with radius $r_3 x'^{\frac{1}{\alpha}}_m$, is due to result of $(d_{13} > r_3 x'^{\frac{1}{\alpha}}_m)$. Where the region inside of circle whose center is at U_b with radius $r_2 x'^{\frac{1}{\alpha}}_n$, is due to the result of $(d_{12} < r_2 x'^{\frac{1}{\alpha}}_m)$.

If it is assumed that U_c is distributed uniformly within cell, R then $r_1 = R$. By calculating the $R^{(d)}_{CT}$ area, the coexistence probability can easily be computed with it. The distances between the point of intersection of two circles having radii of $r_2 x'^{\frac{1}{\alpha}}_n$ and $r_3 x'^{\frac{1}{\alpha}}_m$, and AP are given as r^- and r^+.

Chapter 4

Coexistence of Infrastructure Link with Multiple Ad hoc Connections

4.1 Introduction

After assessing the ad hoc link's and infrastructure link's concurrent transmission probability that what number of a secondary users can be able in establishing a simultaneous ad hoc links along with primary user. Its recommended that in the existence of infrastructure transmission, the CR devices must make some ad hoc links rather than counting the maximum number of ad hoc links. The procedure for establishing such ad hoc links is defined as:

Assume a network in which the both primary user as well as the secondary users are hardly fixed or cannot move and the CR device follow the routing mechanism in order to get its neighbors and receiver's location and then established coexistence ad hock links with infrastructure in meanwhile. Before establishing another ad hoc connection, the device remembers all current transmitter's location by overhearing all channels.

The R_{CT} concurrent transmission zone is being assess by the newly entered CR device having the information of location. The device may face some interference either from any currently existence ad hoc link or from any infrastructure link.

Let q represents the primary user, m represents the new ad hoc link transmitter and receiver of such a new link is represented by n, where the previously present ad hoc link is represented by O.

By following the procedures by which the equation 3.5 derived for uplink infrastructure case, these three conditions are as follows:

$$r_m \geq \left(\frac{1}{\frac{1}{x_m}\left(\frac{1}{r_q}\right)^{\alpha} - \Sigma_k\left(\frac{1}{r_o}\right)^{\alpha}} \right)^{\frac{1}{\alpha}} \quad (4.1)$$

$$d_{mn} \leq \left(\frac{1}{x_n\left(\left(\frac{1}{d_{qn}}\right)^{\alpha} + \Sigma_k\left(\frac{1}{d_{on}}\right)^{\alpha}\right)} \right)^{\frac{1}{\alpha}} \quad (4.2)$$

$$r_m \leq R (4.3)$$

By following the procedures by which the equation 3.5 derived for downlink case, these three conditions are as follows:

$$d_{mq} \geq \left(\frac{1}{\frac{1}{x_m}\left(\frac{1}{r_q}\right)^{\alpha} - \Sigma_k\left(\frac{1}{d_{oq}}\right)^{\alpha}} \right)^{\frac{1}{\alpha}} \quad (4.4)$$

$$d_{mj} \leq \left(\frac{1}{x_n\left(\left(\frac{1}{r_n}\right)^{\alpha} + \Sigma_k\left(\frac{1}{d_{on}}\right)^{\alpha}\right)} \right)^{\frac{1}{\alpha}} \quad (4.5)$$

$$r_m \leq R \quad (4.6)$$

Since the concurrent transmission regions $R_{CT}^{(u)}$ and $R_{CT}^{(d)}$ are known, the CR device can focus whether CR transmit information simultaneously both with the infrastructure link and with other ad hoc connections of the primary and other secondary CR users.

4.2 Effects of Shadowing

Previously the discussion was limited to the path loss effects of concurrent transmission probability of a CR network. In existence of infrastructure link of primary user, the existence of peer-to-peer ad hoc link cannot be possible because of shadowing.

Therefore, it is very necessary to find out the reliable way for concurrent transmission for hybrid network in the existence of shadowing. Mostly the random variable lognormal distributed is used for the demonstration or modeling of the shadowing [20]. From the users i to j, the shadowing component represents as $10^{\varepsilon_{ij}/10}$in the propagation path where the Gaussian random variable having σ_ε as standard deviation and zero mean is represented as ε_{ij}.Thus, for both ad hoc link and infrastructure link having the modified downlink SIRs and uplink SIRs is given as:

4.2.1 SIR for case of Uplink

$$SIR_m^{(u)}(\varepsilon_{30}, \varepsilon_{10}) = \frac{10^{\varepsilon_{30}/10}/r_3^\alpha}{10^{\varepsilon_{10}/10}/r_1^\alpha} \quad (4.7)$$

$$SIR_n^{(u)}(\varepsilon_{12}, \varepsilon_{32}) = \frac{10^{\varepsilon_{12}/10}/d_{12}^\alpha}{10^{\varepsilon_{32}/10}/d_{23}^\alpha} \quad (4.8)$$

4.2.2 SIR for Case of Downlink

$$SIR_m^{(d)}(\varepsilon_{03}, \varepsilon_{13}) = \frac{10^{\varepsilon_{03}/10}/r_3^\alpha}{10^{\varepsilon_{13}/10}/d_{13}^\alpha} \quad (4.9)$$

$$SIR_n^{(d)}(\varepsilon_{12}, \varepsilon_{02}) = \frac{10^{\varepsilon_{12}/10}/d_{12}^\alpha}{10^{\varepsilon_{02}/10}/r_2^\alpha} \quad (4.10)$$

The point to be noted is B_s is represented by 0, and in case of uplink the equation 4.8 have ε_{30} which is equivalent to ε_{03} of equation 4.9 of downlink.

4.3 Analysis of MAC Layer

By considering the PHY/MAC cross-layer, the performance of Hybrid network is checked in term of throughput. In MAC layer, the fundamental task is incorporation of the interference from the ad hoc link and the infrastructure link into the throughput evaluation model.

For this work, the CSMA/CA MAC protocol with an algorithm named as binary exponential back-off algorithm is used in the several license-exempt frequency bands for its deployment.

On the other hand, for establishing the secure ad hoc link in CR network the CSMA/CA MAC protocol may not requ`ire because in the existence of infrastructure link the transmission may forbid by assessing the received signal (RSS) strength in clear channel assessment (CCA).
The constraint is removed with the utilization of the information of channel station and location, by substituting RSS estimation for CCA in conventional CSMA/CA MAC protocol. Therefore, the previously present primary infrastructure link does not harm by the new connection once the secure ad hoc connection can easily establish by CR device.

Chapter 5

Discussion on Simulation Results and Conclusion

5.1 Discussion on Simulation Results

First of all, the discussion is carried out for investigation of the concurrent transmission probability of networks such as overlaying CR-based ad hoc network and infrastructure-based network. For the evaluation in the hybrid network in term of throughput performance, the suggested analytical cross-layer model is applied.

The network topology is shown in chapter 3 in figure 3.1. The figure shows that network have CR based ad hoc receiver $U_b$at location$\left(r_2, {}^{-\pi}/_2\right)$, infrastructure-based primary user U_c at location $\left(r_3, {}^{\pi}/_2\right)$ and transmitter U_a. Here the distance from $B_s$to U_b is represented as r_2 and the distance from $B_s$to $U_a$is represented as r_3. However, the distribution of U_c is uniformly within the cell having the radius R of 100m.
Moreover, for checking out the performance in term of concurrent transmission probability P_{CT} the simulation of the suggested analytical model is performed. The locations where the existence of ad hoc transmitter U_c is possible, are represented by the 10^4 points distributed uniformly within πR^2 region for this simulation. When nearby the infrastructure link that is $B_s$toU_a, the U_c form the ad hoc link with U_b. For this case the number of points are counted for the computation of the P_{CT}.

5.2 Uplink Concurrent Transmission Probability

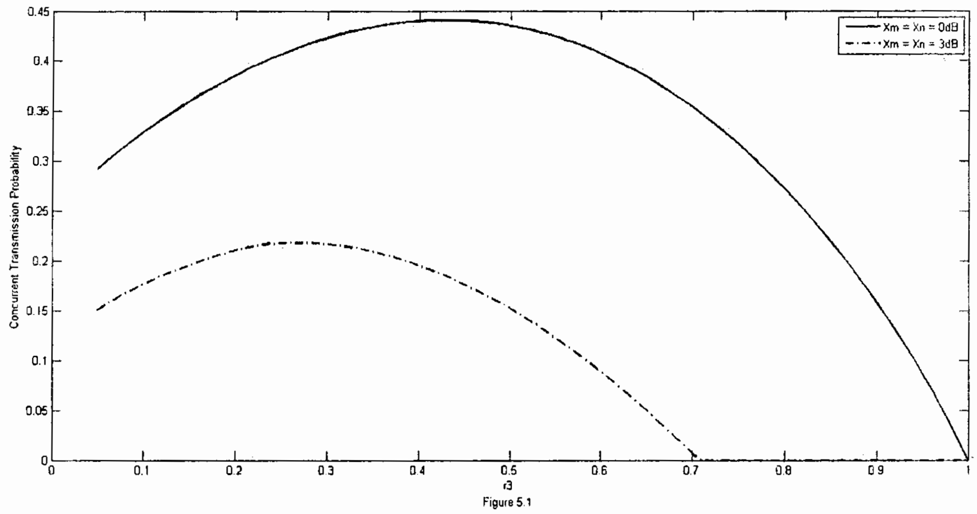

Fig 5.1: Location of the Users of Infrastructure Uplink versus Concurrent Transmission Probability

For the noise power N_o having value of $-90\ dBm$ and transmission power P_t having value of $20\ dBm$, the effects on the uplink concurrent transmission probability due to primary user's location are shown in figure 5.1, where the expected SIR threshold may either be $3\ dB$ or $0\ dB$. For the distance r_3 which is from U_a (primary user) to B_s, the existing concurrent transmission probability is optimum. From the observation it is noted that when the value of x_m is $0\ dB$, at position or location $r_3 = 40m$ the maximum value of $P_{CT}^{(u)} = 0.45$, however, when the value of x_m is $3dB$, at position or location $r_3 = 26m$ the maximum value of $P_{CT}^{(u)} = 0.22$.

In the situation, when the primary user U_a comes near to B_s, it also approaches to ad hoc receiver decreasing $P_{CT}^{(u)}$ & causing high interference. So, when U_a moves away from the B_s, the signal strength becomes weak therefore, the value of the uplink SIR reduces and it produces the small value of $P_{CT}^{(u)}$. Therefore, maximizing the uplink $P_{CT}^{(u)}$ helps in receiving the optimum location of U_a.

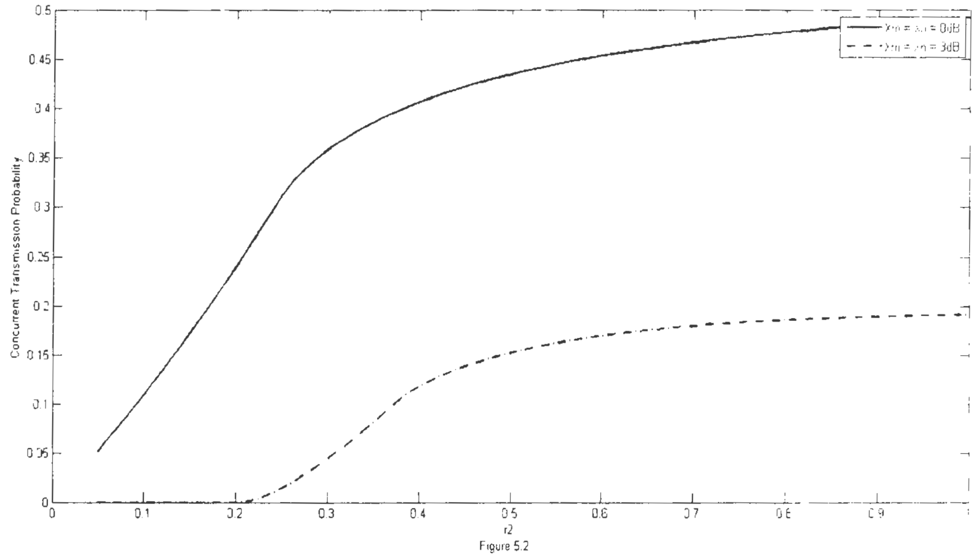

Fig 5.2: Location of the ad hoc Receiver versus Concurrent Transmission Probability

The effect on uplink $P_{CT}^{(u)}$ due to the U_b's location is shown in figure 5.2. The figure shows that in the situation, when the ad hoc CR-user moves off from B_s, the interference from infrastructure link to ad hoc link decreases and due to this reason the steady increase occurs in $P_{CT}^{(u)}$ and this increase is in range of 10% to 50%.

5.3 Downlink Concurrent Transmission Probability

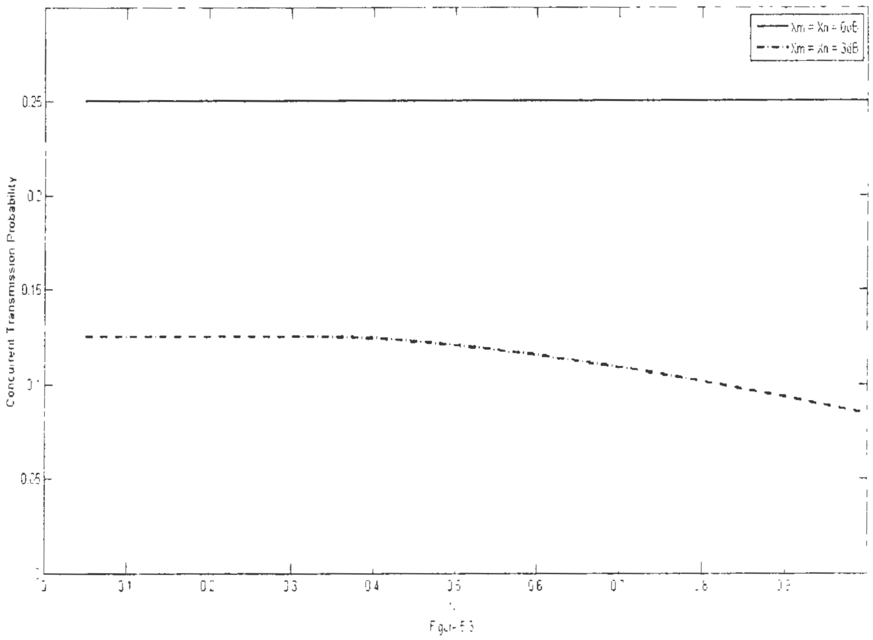

Fig 5.3: Impact on the Downlink $P_{CT}^{(d)}$ due to Location of U_a

When the location of U_b is $(50, {}^{-\pi}/_2)$, the downlink $P_{CT}^{(d)}$ against U_a distance r_3 to B_s is shown is figure 5.3. In the range of distance $r_3 \leq 100m$, for the requirement of $SIR, x_m = x_n = 0\ dB$. $P_{CT}^{(d)} = 25\%$ is constant. All this happens due to interference whose transmission is from B_s to ad hoc users is independent of U_a locations. Although when value of r_3 increases, the larger requirement of $SIR, x_m = x_n = 3\ dB$ produces the lower and reducing value of downlink $P_{CT}^{(d)}$.

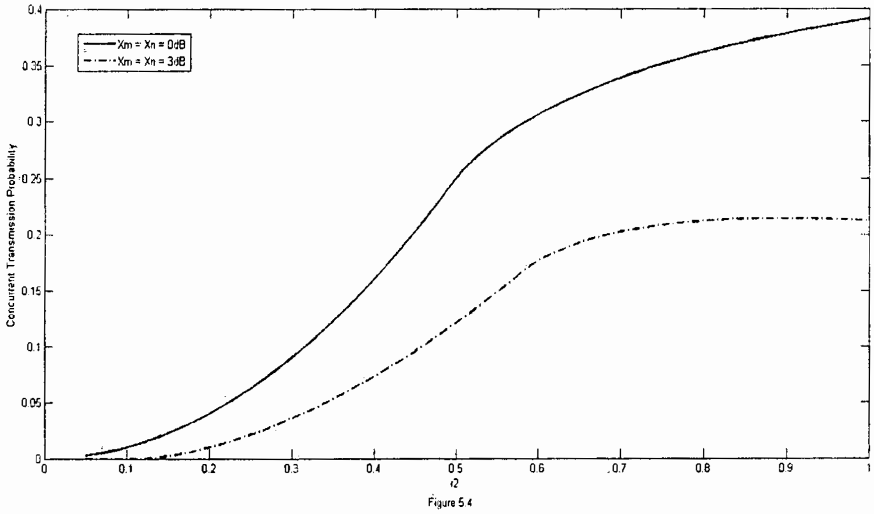

Fig 5.4: Impact on the Downlink $P_{CT}^{(d)}$ due to Location of Receiver U_b

The impact on the downlink $P_{CT}^{(d)}$ due to location of ad hoc receiver U_b is shown in figure 5.4. The comparison of figure 5.4 with figure 5.2 shows that when the ad hoc user U_b moves off from the B_s due to this, the steady increase occurs in $P_{CT}^{(d)}$ as similar $P_{CT}^{(u)}$ increases. However, increase in uplink $P_{CT}^{(u)}$ is greater as compared to $P_{CT}^{(d)}$. For $x_m = x_n = 0\ dB$ and r2 = 100 m, $P_{CT}^{u} = 49$ percent and $P_{CT}^{d} = 39$ percent, respectively. This all happens due to the interference from infrastructure uplink transmission to the ad hoc user is much weaker than the interference from downlink transmission to the ad hoc user.

5.4 Reliability of Concurrent Transmission in the Presence of Shadowing

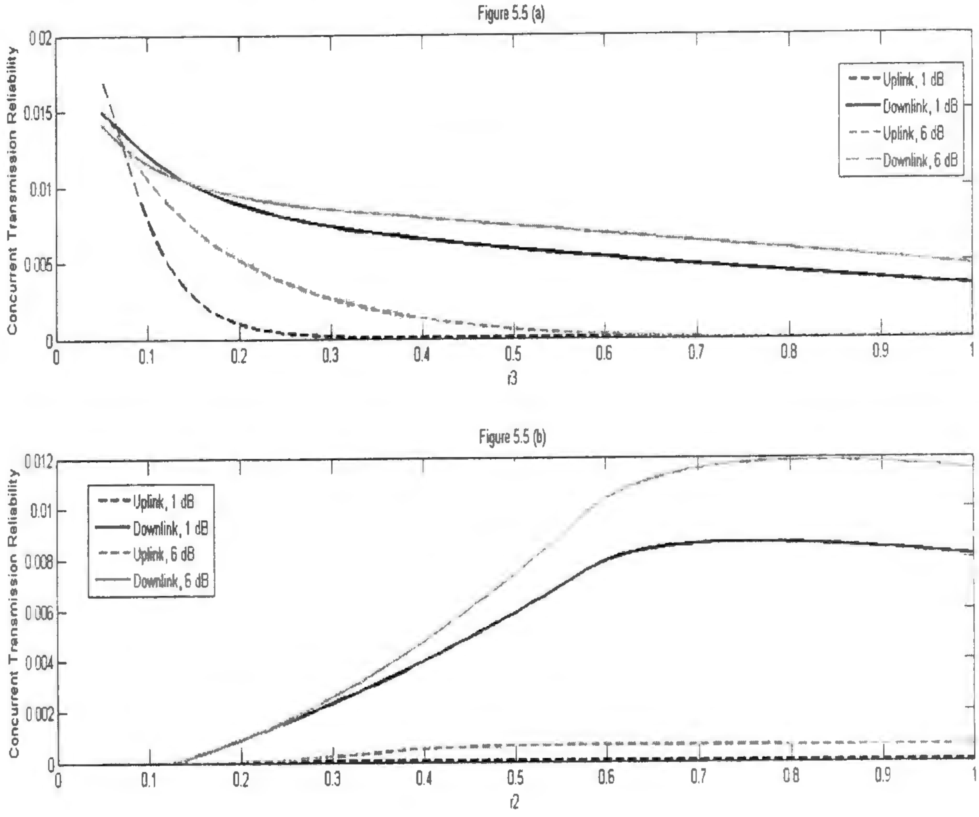

Fig 5.5: The Location of **(a)**$U_a$versus Concurrent Transmission and **(b)**U_b versus Concurrent Transmission

The concurrent transmission's reliability having the standard deviations of shadowing against distance r_3 and distance r_2 are shown in figures 5.5(a) and 5.5(b) respectively. It can be seen by anyone that for the both uplink transmission and downlink transmission the reliability decreases with the increase of shadowing variance. This can be more cleared by looking at the figure 5.5(a) and 5.5(b) for values $\sigma_\varepsilon = 1\,dB$ and $\sigma_\varepsilon = 6\,dB$.

From the figure 5.5(a) it is seen that when the distance r_3 of primary user to B_s is in between the 0m to 100m range, for the $\sigma_\varepsilon = 1$ dB the value of $F_{CT}^{(d)}$ decreases from 0.015 to 0.005 for σ_ε=1dB, & 0.014 to 0.0075 for σ_ε=6dB. Although, at cell edge, the downlink transmission and uplink transmission's reliability for primary user's reduce due to the fact of weak RSS and shadowing.

Therefore, the signal strength for the uplink is much weaker than from signal strength of downlink. Moreover, comparing the sensitivity of shadowing effects for both uplink and downlink concurrent transmission reliability it is found that uplink concurrent transmission reliability is more sensitive when the U_a located at the cell edge position.

From figure 5.5 (b) shows the shadowing graph, it is clear that, for both uplink and downlink concurrent transmission reliability increases when the receiver $U_b$moves towards the cell edge. For σ_ε=6dB, ${F_{CT}}^{(u)}$ slightly increases & ${F_{CT}}^{(d)}$ increases from 0 to 0.012 respectively. For σ_ε=1dB, ${F_{CT}}^{(d)}$increases from 0 to 0.008 & ${F_{CT}}^{(u)}$ slightly increases as r_2 increases to 100m.

It is also clear that when the ad hoc user moves away from the B_s, the weak interference recorded for U_a to ad hoc user. The increase is noted in concurrent transmission reliability where for distance $r_2 > 30m$ the shadowing effect is constant for both $\sigma_\varepsilon = 1$ dB and also for distance $r_2 > 60m$ for $\sigma_\varepsilon = 6$ dB.

5.5 Conclusion and the Idea for Future Research

5.5.1 Conclusion

Here in this work, we conclude that the R_{CT} critical region is identified in which data can transfer simultaneously without any interference by the overlaying secondary users and primary user.

The concurrent transmission area can be easily located if information of the other nodes location is available.

From the numerical data of uplink, it can be demonstrated that for 1 dB standard deviation of shadowing, the concurrent transmission region might be 45% of the cell region having the reliability of 90% and for 6 dB of standard deviation of shadowing, the concurrent transmission region might be 45% of the cell region having the reliability of 60%.

It can also be demonstrated that the time and energy consuming WBSS process decreases in dramatic manner if the identification of such an opportunity for concurrent transmission is obtained first. The location awareness also helps the CR to identify the opportunity by means of primary user's spectrum within the spatial domain instead in the time domain.

5.5.2 Idea for Future Research

For the research, there are many topics that follow mechanism of exchange of location information efficiently and Concurrent transmission designing of MAC protocol. For the further exploration, we can also add CR networks which is using spectrum sensing for ad hoc networks, the location awareness technique can be applied by mean of multiband joint detection technique for the better throughput.

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