Spectral Efficient CR Based 4G LTE-Advanced Network for Simultaneous Transmission Using Location Awareness

ISSN 2047-3338

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***Abstract*— Advance research shows that the resources allocated to radio channels, remains underused for explicit time span. With the rapid growth in the advancement of technology, demand of spectrum is increasing day by day. 4G LTE-Advanced, using MIMO and OFDMA techniques, is being capable of providing high data rate and minimum delay, but for the better efficiency and usage of wasted spectrum, Cognitive Radio (CR) is novel technology for spectrum regulation and management. Moreover, recognition of simultaneous transmission region is the serious issue. In this paper, we find out proportions of the simultaneous transmission region where a CR user will make an ad-hoc connection in the presence of infrastructure based network. Using location awareness, CR devices are capable of making spectrum fully efficient in terms of usage. Hence, efficiency of the spectrum can be improved. Using Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) Medium Access Control (MAC) protocol, we computed concurrent transmission probabilities for both uplink and downlink cases with throughput performance from Physical/MAC (PHY/MAC) layer prospective.**

***Index Terms*— 4G LTE-Advanced, MIMO, OFDMA, CR, CSMA/CA and PHY/MAC Protocol**

I. INTRODUCTION

THE future concept of the world is a network society with unlimited access and sharing of resources to everyone, everywhere, at any time. For this concept, technology is being improved day by day which will be helpful to accomplish future needs [1].

4G LTE (Long term Evolution) [2] with MIMO [3] and OFDM [4] technique, exceedingly speeds up the network`s capacity with enhanced user's experience. Moreover, for fully enhance features of 4G system, IMT advanced introduced by ITU-T, with advance technical specifications like carrier`s aggregation, relaying, multi-point transmission (LTE-Advanced) [5]. It is basically the extension in 3G with some features like minimum delay, high data rate and packet switched network. Technical requirements of LTE advanced are shown in Table I.

There is no wireless telecommunication without the use of spectrum [6]. With the advancement of 4G, we are being capable of having high data rate with minimum delay, but the use of spectrum is inefficient. There is huge popular demand of spectrum but there is unused spectrum as well. To overcome this wastage of spectrum, cognitive radio technology is being popular nowadays because it is not only radio technology but also has the capability to regulate and manage the spectrum.

TABLE I: TECHNICAL REQUIREMENTS OF LTE-ADVANCED NETWORK

No.	Technicalities	Requirements of 4G LTE-Advanced
1	Downlink	3 Gbps
2	Uplink	1.5 Gbps
3	Bandwidth	100 MHz
4	Latency	10 ms
5	Access Method	OFDMA
6	Propagation	MIMO

In wireless telecommunication, right of spectrum means license [7]. Licensee is primary user (PU), high-priority and licensed. Cognitive radio user is unlicensed or secondary user (SU). SU first sense the holes or unused spectrum and then employ it, as shown in Fig. 1. SU is intelligent enough that it can sense the spectrum very intelligently. The main objectives of the CR technology are improvement in utilization of Spectrum and to achieve high reliability in wireless telecommunication system. The main advantage of the CR technology is; it's aware from environment of surroundings and takes decision on basis of surrounding environment.

Hence, for establishing innocuous communication link, the requirements for CR user are:

1) Wideband Spectrum sensing [8]-[10].
2) Identify location and time of Primary User's spectrum utilization [11]-[14].
3) Accommodating transmission parameters and taking decision on the basis of surrounding environment [15]-[18].

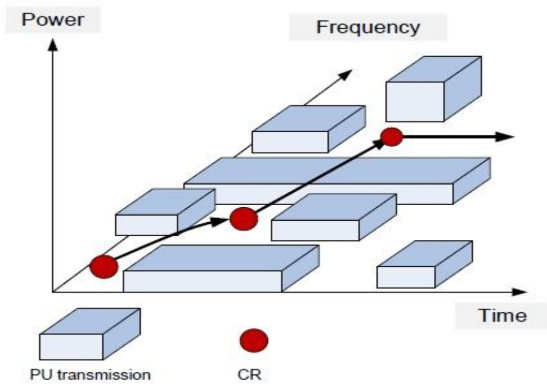

Fig. 1. Cognitive Radio (CR) concept

However, sensing wideband spectrum is a sophisticated process which needs advanced signal processing which is also very energy consuming [15]. In this scenario, CR users efficiently locate the free slots of spectrum without sensing wideband spectrum. Now, if a CR user knows the region, where it can concurrently transmit with primary user without creating any interference, then for detecting free spectrum holes, there is no need for a CR system to depend on wideband spectrum sensing which is time as well as energy consuming. Furthermore, concurrent transmission can enhance the overall throughput. In this sense, to identify interference free region will be of great importance rather than spectrum sensing for CR users.

Since wideband spectrum sensing methodology has following drawbacks:

- It requires advance signal processing methods which are very sophisticated and energy consuming.
- In WBSS, problems of hidden nodes and Shadowing effects need to resolve separately.

Now, rather we use or research on any another spectrum sensing technique, location awareness technique has significantly advantages over WBSS:

- CR devices can effectively locate the free spectrum holes without using wideband spectrum sensing.
- If the CR and the primary user are far away from each other, then both can simultaneously use the same spectrum without causing interference.
- If a CR user has knowledge about the region, where it can simultaneously transmit data with the primary user, a cognitive radio system doesn't need to depend on wideband spectrum sensing (WBSS), which is a sophisticated and also energy consuming process to identify the spectrum holes.
- No need for wideband spectrum sensing (WBSS).

Our main objective is to find out proportions of the simultaneous transmission region where a CR user will make an ad hoc connection in the presence of infrastructure based network. CR devices will use underutilized spectrum, hence, efficiency of the spectrum will be improved. For example students in a class want to share an important file with each other. So, they need to make an overlaying ad hoc network. Also let us suppose that their communicating devices access only licensed spectrum. Now of course, they all will not pay just for a short term data transfer. The solution is; to establish ad hoc link on the top of an infrastructure based link. This topology will bring a revolutionary change in the world of wireless telecommunications. Depending on carrier sense multiple access with collision avoidance (CSMA/CA) and medium access control (MAC) protocol, we find out improvement results in spectrum throughput for concurrent transmission.

Furthermore, identification of the concurrent transmission region is another major issue. Location awareness technique helps us to identify this opportunity so that CR user may not cause interference to already existed legacy wireless system.

The rest of the paper is organized as follows: section II, discusses the related research work. In section III, we present proposed system design. In section IV, we describe the simulations results in details. Section V, finally conclude this research and propose future work.

II. RELATED RESEARCH WORK

Cognitive radio, an approach towards implementation of Dynamic Spectrum Access (DSA) on Software Defined Radio (SDR). CR is an intelligent network consisting of Primary and Secondary users. Primary user (PU) is high-priority and licensed. Secondary user (SU) is unlicensed or also called Cognitive user. CR user first senses the holes or unused radio spectrum and then utilizes it [7].

Fig. 2 shows that six words reflect from the concept of Cognitive Radio which includes awareness, intelligence, learning, adaptiveness, reliability and efficiency [19]. The objective behind CR is the efficient utilization and management of radio spectrum, also the availability of reliable communication everywhere anytime.

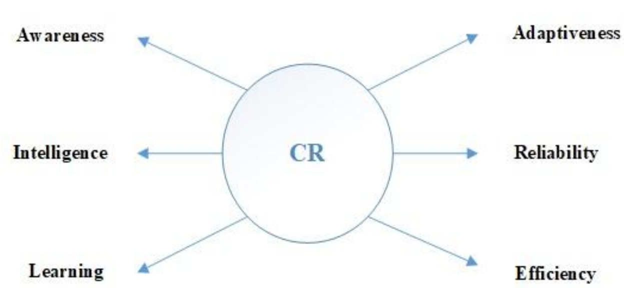

Fig. 2. Six words concept of CR

Quantitative research shows that more than 62% of the spectrum below 3Hz lies in the white space region which means wastage of the spectrum. This leads towards Opportunistic Spectrum Access (OSA). The concept of OSA is very simple but its implementation is not as easy as it requires advanced and complexed signal processing coupling with MAC protocols. Major disadvantage in the implementation of OSA network is its hardware requirement, also its energy inefficient [20].

Wideband spectrum sensing methodology is used to find out free spectrum holes. Again, as the wideband spectrum sensing requires advance signal processing methods, which are energy consuming as well as very complex, further, hidden nodes and shadowing effects are another problems which have to be resolved separately. Rather we use or research on any another spectrum sensing technique, in this thesis, focus of interest is;

Can CR devices effectively locate the free spectrum holes without using wideband spectrum sensing? If the CR and the primary user are far away from each other, then both can simultaneously use the same spectrum without causing interference. If a CR user have knowledge about the region, where it can simultaneously transmit data with the primary user, a Cognitive Radio system doesn't need to depend on wideband spectrum sensing (WBSS), which is a sophisticated and also energy consuming process to identify the spectrum holes.

The answer of all of the above questions is "YES". That means, there is no need of wideband spectrum sensing techniques. Furthermore, concurrent transmission can enhance the overall throughput. In this sense, to identify interference free region is of great importance rather than spectrum sensing for CR users. Location awareness technique incorporating with CR devices helps in finding the simultaneous transmission opportunity.

The overlaying ad-hoc network in the presence of primary connection is of great importance in terms of effectiveness and efficiency of the spectrum. The issues in the coexistence of ad-hoc based network in the presence of infrastructure-based network has already been discussed but in different scenarios. Their main concern was to incorporate the ad-hoc link with infrastructure-based network in order to increase the coverage area. But our focus is in overlapping of ad-hoc based network with infrastructure-based network, not in extending the coverage of the existing legacy network.

A. Integrated Cellular and Ad-hoc Relaying System (iCAR)

Integrated Cellular and Ad-hoc Relaying System (iCAR) architecture introduced in 2001 with the aim to increase the coverage area of the cell. Fig. 3 shows the basic system model of iCAR in which Mobile User 1 is communicating with BTS 1 through two Ad-Hoc relaying systems. Mobile User 1 may also communicate with Mobile User 2 through the BTS 1. The concept of iCAR is clear from the Fig. 3 that the cost of BTS 2 can be saved. The other advantage of this architecture includes load-balancing between two cells, reducing battery power of Mobile users and increasing transmission rate [21].

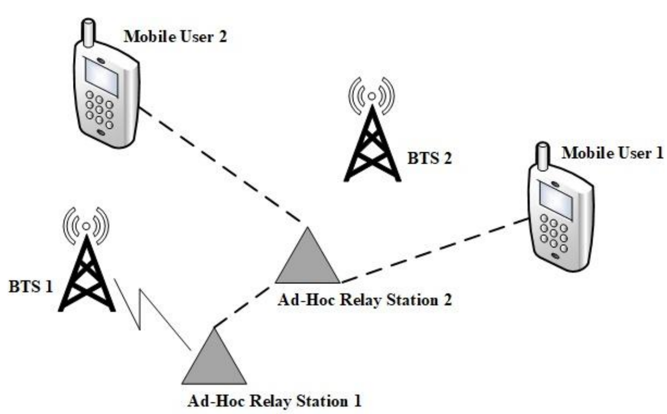

Fig. 3. Basic concept of iCAR

In this paper, the concept is to have overlaying CR-based network in the presence of infrastructure based ad-hoc network, rather than to increase the coverage area of ad-hoc network. Furthermore, simultaneous transmission results in improvement of spectrum throughput.

B. Location Awareness Engine (LAE)

Location awareness means to personify sense, learn, make a decision and get information about location. This term is widely used in positioning systems and location-based-services (LBS). Major applications of location awareness includes network optimization, environment identification etc. The need of location awareness in the cognitive radio networks leads to Location Awareness Engine (LAE). Location awareness with cognitive capabilities results autonomous and goal driven location aware system. The LAE model based on location and environment awareness in nature. Human beings and bats use location awareness concept for echolocation system and adaptation process respectively [22].

Cognitive radio with location awareness feature in the wireless network is the most promising technology from the last decade. Fig. 4 shows cognitive radio model with capabilities of location awareness, spectrum awareness and environment awareness. Cognitive engine plays major role of the proposed Location Awareness Engine (LAE) in order to fulfil required tasks. Handling spectrum related tasks (Frequency, Bandwidth) is the major responsibility of spectrum awareness engine. Similarly, paths related tasks are supervised by environment awareness engine. Location awareness engine is responsible for location information.

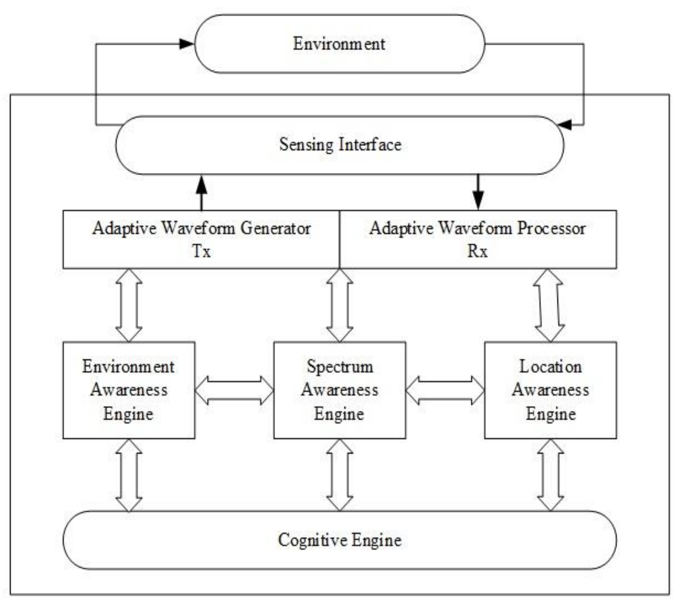

Fig. 4. LAE system model

Since, location awareness is the most advanced and influential feature of Cognitive Wireless Networks (CWN), so an architecture similar to location awareness engine also proposed in [23] with the idea of utilization of location awareness feature in location based applications. For this purpose, many examples related to location-assisted network optimization have been discussed in detail in order to reinforce the suggested model. Concluded results show that location awareness plays a fruitful role in CWN.

Location awareness feature of CR in my thesis is of great importance because if the CR user and Primary user knows region where both of them can transmit their data simultaneously. Location information helps in getting the region in order to increase the spectrum efficiency of CWN.

C. Throughput Performance of WLAN (IEEE 802.11)

In order to mitigate collisions between multiple users in shared medium, Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) Medium Access Control (MAC) protocol has been acquired. Since the demand of WLAN is increasing day by day, therefore investigation of throughput performance from Physical/MAC layer point of view is needed [24].

In recent years, research has been carried out to improve the performance of WLAN. From the CSMA/CA MAC protocol perspective, first idea of Dynamic Tunnelling algorithm proposed for traffic balancing. In addition, Out-of-Band signalling and Packet-Pipeline scheduling were also suggested to overcome the collision between users. Protocol overhead was reduced using frame-concatenation algorithm.

With the advancement of wireless technology like 4G LTE-Advanced with MIMO-OFDM, research on directional and smart antennas and their impact on throughput performance leads towards new direction. A complete analytical model with detailed simulation results in [24] is discussed. The results evaluated with practical directional antenna and capture effect and conclude that the throughput of CSMA/CA MAC protocol only relates to signal-to-interference ratio (SIR). Also throughput can be improved up to 10% by using directional antennas.

III. PROPOSED SYSTEM DESIGN

Fig. 5 shows the basic systematic model concept of infrastructure-based ad hoc network. From the Fig. 5, suppose that $\boldsymbol{MUE_a}$ & $\boldsymbol{MUE_b}$ establish a peer-to-peer ad-hoc connection and are positioned at $(\boldsymbol{l_1}, \boldsymbol{\theta_1})$ & $(\boldsymbol{l_2}, \boldsymbol{\theta_2})$ respectively. Furthermore, $\boldsymbol{MUE_c}$ is already connected via infrastructure based link positioned at $(\boldsymbol{l_3}, \boldsymbol{\theta_3})$. The area of the Base Station $(\boldsymbol{BS_z})$ is $\boldsymbol{\pi L^2}$. It is presumed that all three users are fixed.

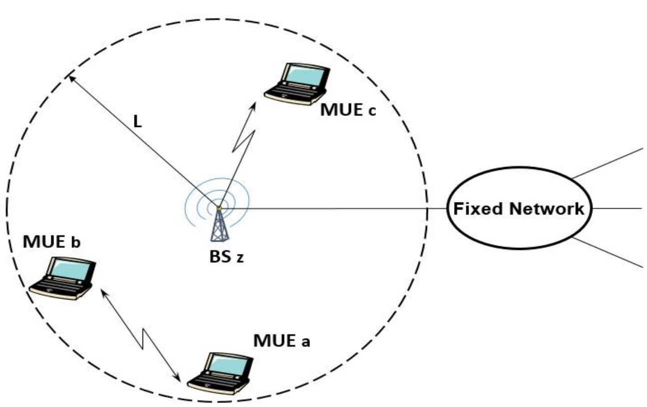

Fig. 5. A basic systematic model concept

As in case of CSMA with collision avoidance, many users try to get the channel, but only one mobile station can establish a link at one instant. Now, if a secondary user try to make a peer-to-peer ad-hoc connection in the same frequency region, it must ensure that;

1. Link quality of primary user cannot be dissipated.
2. Have to get channel (CSMA).

Let $\boldsymbol{SIR_{in}}$ & $\boldsymbol{SIR_{ad}}$ are the received signal to interference ratios, for infrastructure and ad-hoc based connections respectively. The simultaneous transmission probability $\boldsymbol{P_{ST}}$ for overlapped zone can be illustrated as:

$$\boldsymbol{P_{ST} = P\{(SIR_{in} > t_{in}) \cap (SIR_{ad} > t_{ad})\}} \quad \textbf{(1)}$$

Where $\boldsymbol{t_{in}}$ & $\boldsymbol{t_{ad}}$ are SIR thresholds. In order to get simultaneous transmission region, it's very important to find out $\boldsymbol{P_{ST}}$ for both infrastructure based connection and ad-hoc based connection. And CR device must have to shift on some other frequency, if link quality is not guaranteed.

Let us consider the concept of two-ray ground reflection, consisting of two paths (one is line of sight and the other is reflection from ground). So, we can calculate received power as,

$$\boldsymbol{P_r = \frac{P_t H_{bs}^2 H_{ms}^2 G_{bs} G_{ms} 10^{\frac{\varepsilon}{10}}}{R^{\alpha}}} \quad \textbf{(2)}$$

Where,

$\boldsymbol{P_r}$	=	Received power at mobile station
$\boldsymbol{P_t}$	=	Transmitted power at mobile station
$\boldsymbol{H_{bs}}$	=	Transmitted power at mobile station
$\boldsymbol{H_{ms}}$	=	Transmitted power at mobile station
$\boldsymbol{G_{bs}}$	=	Base Station Antenna Gain
$\boldsymbol{G_{ms}}$	=	Mobile Station Antenna Gain
$\boldsymbol{R}$	=	Distance between Transmitter & Receiver
$\boldsymbol{H_{ms}}$	=	Transmitted power at mobile station
$\boldsymbol{\alpha}$	=	Path Loss exponent
$\boldsymbol{10^{\frac{\varepsilon}{10}}}$	=	Shadowing component

IV. SIMULATION AND RESULTS

Fig. 5 depicts the systematic model topology which is under consideration, where Mobile User Equipment $\boldsymbol{MUE_a}$ & $\boldsymbol{MUE_b}$ are the CR based ad-hoc transmitter and receiver respectively whereas $\boldsymbol{MUE_c}$ is infrastructure based primary user. $\boldsymbol{L}$ is the radius of the base station $\boldsymbol{BS_z}$ in which $\boldsymbol{MUE_a}$ is distributed uniformly within the area of the base station. $(\boldsymbol{l_2}, -\frac{\pi}{2})$ & $(\boldsymbol{l_3}, \frac{\pi}{2})$ are the respective positions of $\boldsymbol{MUE_b}$ and $\boldsymbol{MUE_c}$ where $\boldsymbol{l_2}$ and $\boldsymbol{l_3}$ represents the distances between $\boldsymbol{BS_z}$ to $\boldsymbol{MUE_b}$ & $\boldsymbol{MUE_c}$ respectively.

Our main objective is to find out proportions of the simultaneous transmission region where a CR user will make an ad hoc connection in the presence of infrastructure based network. CR devices will use underutilized spectrum, hence, efficiency of the spectrum can be improved. This topology will bring a revolutionary change in the world of wireless telecommunications. Depending on carrier sense multiple access with collision avoidance (CSMA/CA) and medium access control (MAC) protocol, we computed probabilities for both uplink and downlink cases with the improvement results in spectrum throughput for concurrent transmission from PHY/MAC layer perspective.

We first analysed simultaneous transmission probabilities for both infrastructure-based link and CR-based ad-hoc link. Spectrum throughput performance is also evaluated by applying proposed system model. For this purpose, simulation is performed in MATLAB in order to proof improvement in spectral efficiency as well as to verify proposed analytical model. For the simulation purpose, location of the transmitter $\boldsymbol{MUE_a}$ is represented by 10,000 points, distributed uniformly within the area $\boldsymbol{\pi L^2}$. These points are calculated in order to calculate the simultaneous probability. The simultaneous transmission probability of $\boldsymbol{MUE_a}$ means that it can establish resistance-free connection with $\boldsymbol{MUE_b}$.

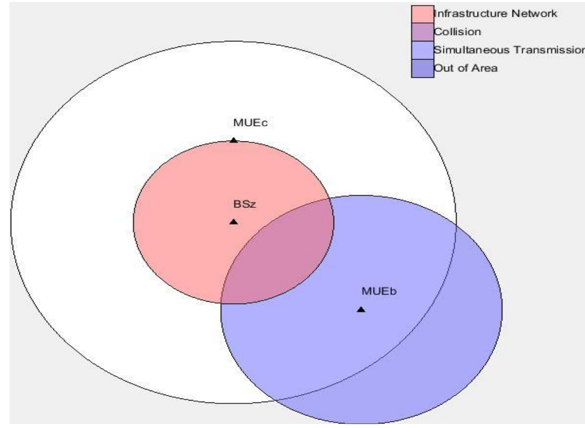

Fig. 6. Co-existence probabilities representation for uplink transmission

A. Uplink Simultaneous Transmission Probability

When primary user $\boldsymbol{MUE_c}$ sends data to base station ($\boldsymbol{BS_z}$), Signal to Interference Ratio (SIR) is known as Uplink SIR for infrastructure based network ($\boldsymbol{SIR_{in}}$) of $\boldsymbol{MUE_c}$ is calculated by computing the received powers $\boldsymbol{P_{cz}}$ & $\boldsymbol{P_{az}}$ at $\boldsymbol{BS_z}$ from $\boldsymbol{MUE_c}$ and $\boldsymbol{MUE_a}$ respectively. So, from Eq. **(2)**,

$$\boldsymbol{SIR_{in} = \left(\frac{l_1}{l_3}\right)^{\alpha} = P_{cz}/P_{az}} \quad \textbf{(3)}$$

Where,

$\boldsymbol{l_1}$ = Distance between MUE_a and BS_z

$\boldsymbol{l_3}$ = Distance between MUE_c and BS_z

Similarly, the SIR for a peer-to-peer ad-hoc link ($\boldsymbol{MUE_a}$ to $\boldsymbol{MUE_b}$) is calculated as:

$$\boldsymbol{SIR_{Adhoc} = P_{ab}/P_{cb} = \left(\frac{d_{bc}}{d_{ab}}\right)^{\alpha}} \quad \textbf{(4)}$$

Where,

$\boldsymbol{P_{ab}}$ = Received power on MUE_b from MUE_a

$\boldsymbol{P_{cb}}$ = Interference power on MUE_b from MUE_c

$\boldsymbol{d_{bc}}$ = Distance between MUE_b and MUE_c

$\boldsymbol{d_{ab}}$ = Distance between MUE_a and MUE_b

Substituting Eq. **(3)** & Eq. **(4)** into Eq. **(1)**, we get simultaneous transmission probability for uplink transmission:

$$\boldsymbol{P_{ST}^{Uplink} = P\left\{\left(l_3 t_{in}^{\frac{1}{\alpha}} < l_1 < L\right) \cap \left(d_{ab} < \frac{d_{bc}}{t_{ad}^{\frac{1}{\alpha}}}\right)\right\} \equiv A_{ST}^{Uplink}/\pi L^2}$$

In the Fig. 6, highlighted area with simultaneous transmission heading denotes A_{ST}^{Uplink} .

Fig. 7 shows the effect on simultaneous transmission probability for uplink case, as the Primary User $\boldsymbol{MUE_c}$ changes its location whereas the CR-based ad-hoc User $\boldsymbol{MUE_b}$ is fixed $(\boldsymbol{50}, -\frac{\pi}{2})$. Threshold values for $\boldsymbol{SIR}$ are zero or 3dB. Here the important point is the existence of optimum simultaneous transmission probability for uplink case. From the Fig. 7, it's to be noted that simultaneous transmission probability is 0.45 for $\boldsymbol{t_{in}}$ = 0 dB, at $\boldsymbol{l_3}$ = 40m. Also simultaneous transmission probability is 0.22 for $\boldsymbol{t_{in}}$ = 3 dB, at $\boldsymbol{l_3}$ = 26m. This means that; when primary user comes near to $\boldsymbol{BS_z}$, meanwhile closer to ad-hoc user, interference increases and therefore simultaneous transmission probability decreases. Similarly, when primary user moves away from the $\boldsymbol{BS_z}$, interference decreases because of weak signal, hence simultaneous transmission probability decreases. So, we can get optimum location of primary user in order to obtain finest simultaneous transmission probability for uplink case.

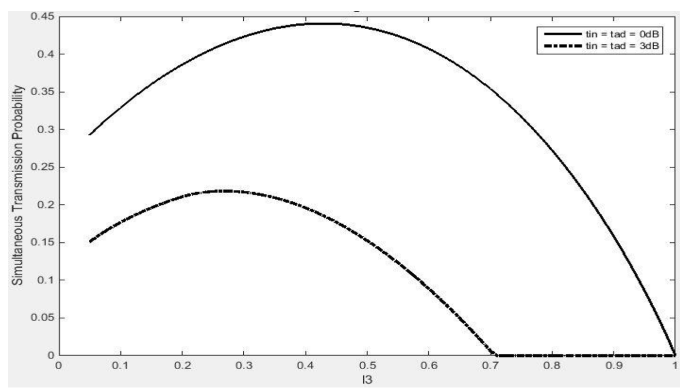

Fig. 7. Location of MUE_c versus Uplink Simultaneous Transmission Probability

Fig. 8 shows the effect on simultaneous transmission probability for uplink case as the CR-based ad-hoc User $\boldsymbol{MUE_b}$ changes its location whereas the primary user $\boldsymbol{MUE_c}$ is fixed $(\boldsymbol{50}, \frac{\pi}{2})$. The Fig. 8 clearly shows that when ad-hoc user moves away from $\boldsymbol{BS_z}$ (within the radius of the cell, 100m), interference from the primary user's link decreases, therefore the simultaneous transmission probability increases up to 5.0.

B. Downlink Simultaneous Transmission Probability

When Base Station ($\boldsymbol{BS_z}$) sends data to primary user $\boldsymbol{MUE_c}$, Signal to Interference Ratio (SIR) is known as Downlink SIR for infrastructure based network ($\boldsymbol{SIR_{in}}$) . From Eq. **2:**

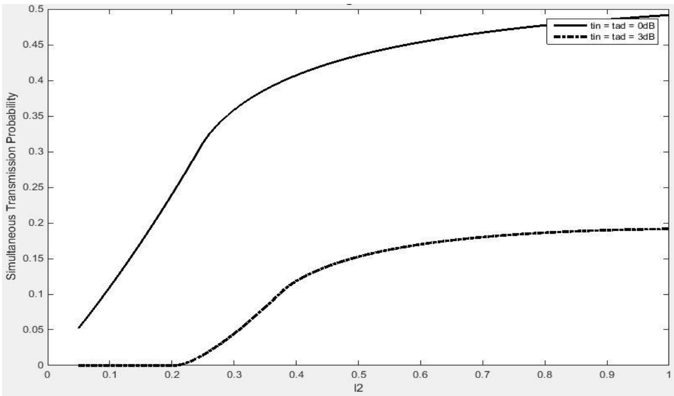

Fig. 8. Location of MUE_b versus uplink simultaneous transmission probability

$$SIR_{in} = \frac{P_{zc}}{P_{ac}} = \left(\frac{h_{bs}}{h_{mue}}\right)^2 \left(\frac{d_{ac}}{l_3}\right)^{\alpha} \quad \textbf{(5)}$$

Where,

P_{zc} = Received power on MUE_c from BS_z

P_{ac} = Received power on MUE_c from MUE_a

d_{ac} = Distance between MUE_a and MUE_c

Similarly, The SIR for peer-to-peer ad-hoc link (MUE_a to MUE_b) is expressed as:

$$SIR_{Adhoc} = \frac{P_{ab}}{P_{zb}} = \left(\frac{h_{mue}}{h_{bs}}\right)^2 \left(\frac{l_2}{d_{ab}}\right)^{\alpha} \quad \textbf{(6)}$$

Where,

P_{ab} = Received power on MUE_b from MUE_a

P_{zb} = Received power on MUE_b from BS_z

d_{ab} = Distance between MUE_a and MUE_b

Substituting Eq. **(5)** & Eq. **(6)** into Eq. **(1)**, we get simultaneous transmission probability for downlink transmission:

$$P_{ST}^{\text{Downlink}} = P\left\{\left(d_{ac} > l_3 {t'}_{in}^{\frac{1}{\alpha}}\right) \cap \left(d_{ab} < l_2 {t'}_{ad}^{\frac{1}{\alpha}}\right) \cap (l_1 < L)\right\} \equiv A_{ST}^{Downlink}/\pi L^2$$

Where,

$$t'_{in} = t_{in}.\left(\frac{h_{mue}^2}{h_{bs}^2}\right)$$

$$t'_{ad} = \left(\frac{1}{t_{ad}}\right).\left(\frac{h_{mue}^2}{h_{bs}^2}\right)$$

Fig. 9 shows representation of two cases for downlink simultaneous transmission probability. On the left side, when both intersection points of two circles made by MUE_c and MUE_b are within the range of Base Station (BS_z). On the right side, one intersection point is within the range of base station and the other is outside the range of base station. Here simulation is performed for both cases in order to verify proposed model and to proof improvement in spectral efficiency.

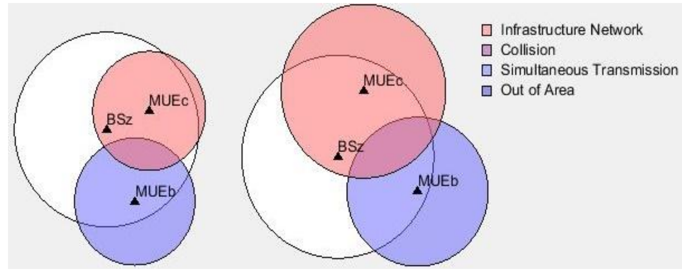

Fig. 9. Two cases representation for downlink simultaneous transmission probability

Fig. 10 shows the impact on simultaneous transmission probability for downlink case, when Primary User MUE_c changes its location whereas the CR-based ad-hoc User MUE_b is fixed $(50, -\frac{\pi}{2})$. Within the radius of the cell, 100m; the simultaneous transmission probability is constant i.e., 0.25 for $t_{in} = t_{ad}$ = 0 dB, as shown in the Fig. 10. The reason is the interference to the ad-hoc users is not depending on the primary user's location. For $t_{in} = t_{ad}$ = 3 dB, simultaneous transmission probability for downlink case decreases as so as primary user moves towards the boundary of the cell.

Fig. 11 shows the simultaneous transmission probability versus the location of ad-hoc user MUE_b. Simultaneous transmission probability for downlink case increases monotonically similar to the case shown in Fig. 8.

The difference between Fig. 11 and Fig. 8 is, uplink simultaneous transmission probability is 49% whereas downlink simultaneous transmission probability is 39%, because the interference to the ad-hoc user from the infrastructure based uplink transmission is weaker than that of from the downlink transmission.

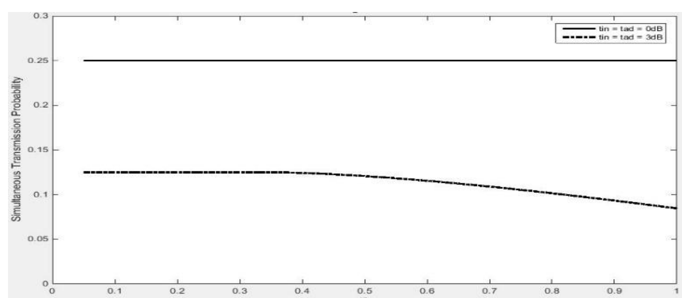

Fig. 10. Location of MUE_c versus downlink simultaneous transmission probability

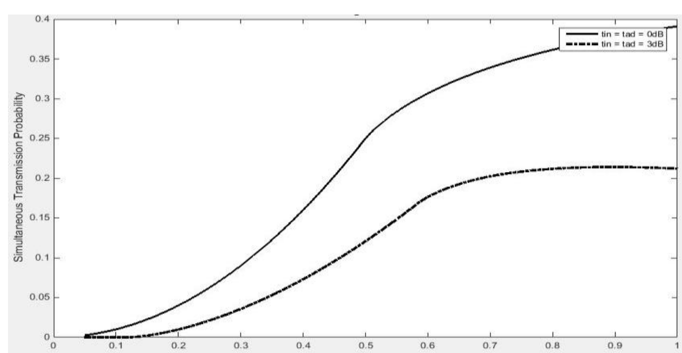

Fig. 11. Location of MUE_b versus downlink simultaneous transmission probability

C. Shadowing Effects on Simultaneous Transmission Reliability

Most of the research in the field of ad-hoc networks is ideal radio communication without assuming the impact of shadowing. Shadowing effects must be considered in realistic network environment. Shadowing is basically the deviation of the received signal power from the mean value, mostly caused by the obstacles. It is a random process and may vary with the geographical position or radio frequency [25].

Previously, we considered only path loss effect on simultaneous transmission probability. Although CR device is within the area $\boldsymbol{A_{ST}}$ but still peer-to-peer ad-hoc link may not be possible to simultaneously transmit data with primary user because of shadowing effect. So, it's very important and the need of the hour to find reliability of the CR based network when shadowing is considered.

Random variable with log normal distributed shadowing model can be used to investigate the reliability of the wireless network [26].

Suppose $\boldsymbol{\varepsilon_{ab}}$ be the Gaussian Random Variable (Zero Mean & $\boldsymbol{\sigma_{\varepsilon}}$ Standard Deviation) from user $\boldsymbol{a}$ to $\boldsymbol{b}$, then let us take $\boldsymbol{10^{\varepsilon_{ab}/10}}$ as shadowing component (propagation from $\boldsymbol{a}$ to $\boldsymbol{b}$), we can modify signal to interference ratios for infrastructure based connection and CR-based ad-hoc connection.

Uplink case:

$$\boldsymbol{SIR_{in}(\varepsilon_{cz}, \varepsilon_{az}) = \frac{10^{\varepsilon_{cz}/10}/l_3^{\alpha}}{10^{\varepsilon_{az}/10}/l_1^{\alpha}}}$$

$$\boldsymbol{SIR_{Adhoc}(\varepsilon_{ab}, \varepsilon_{cb}) = \frac{10^{\varepsilon_{ab}/10}/d_{ab}^{\alpha}}{10^{\varepsilon_{cb}/10}/d_{bc}^{\alpha}}}$$

Downlink case:

$$\boldsymbol{SIR_{in}(\varepsilon_{zc}, \varepsilon_{ac}) = \frac{10^{\varepsilon_{zc}/10}/l_3^{\alpha}}{10^{\varepsilon_{ac}/10}/d_{ac}^{\alpha}}}$$

$$\boldsymbol{SIR_{Adhoc}(\varepsilon_{ab}, \varepsilon_{zb}) = \frac{10^{\varepsilon_{ab}/10}/d_{ab}^{\alpha}}{10^{\varepsilon_{zb}/10}/l_2^{\alpha}}}$$

Where $\boldsymbol{\varepsilon_{cz}}$ in the uplink case is equivalent to $\boldsymbol{\varepsilon_{zc}}$ in the downlink case.

Reliability of the simultaneous transmission is the probability that a connection can be established successfully between CR device and Primary user in the presence of shadowing effect.

Fig. 12 and Fig. 13 both exemplify the simultaneous transmission reliability versus locations of $\boldsymbol{MUE_c}$ and $\boldsymbol{MUE_b}$ respectively, with two different standard deviations 1 dB and 6dB.

It is cleared from both of the above Fig. 12 and Fig. 13, that greater the shadowing standard deviation, lower the reliability for simultaneous transmission.

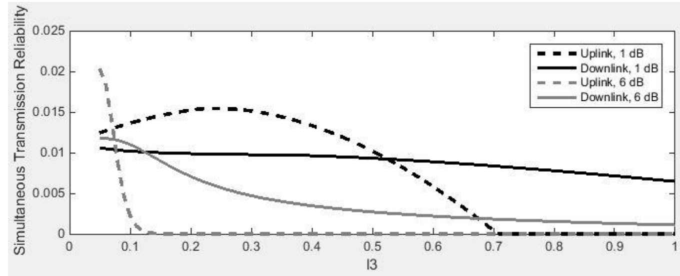

Fig. 12. Location of MUE_c versus simultaneous transmission reliability with shadowing effect

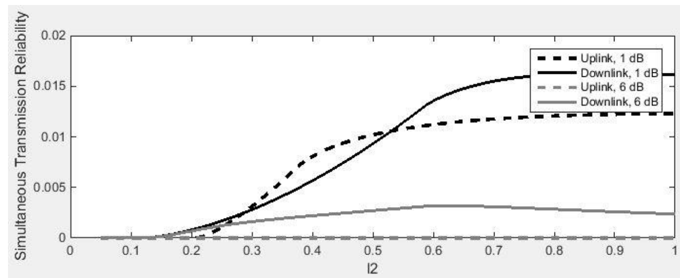

Fig. 13. Location of MUE_b versus simultaneous transmission reliability with shadowing effect

D. MAC Layer Analysis

From the viewpoint of MAC/PHY cross-layer, considered model of CR-based ad-hoc network in the presence of infrastructure based network, is studied in terms of its throughput. For this purpose, we considered both interferences either from ad-hoc link or from infrastructure link. CSMA/CA MAC protocol is used with binary exponential bac-off algorithm because of its highly usage in the field of computer networks. Also this algorithm is deployed in the world mostly where license free spectrum bands are used [27, 28].

In the presence of infrastructure based network, CSMA/CA MAC protocol is difficult to use in order to establish CR based ad-hoc connection because of Clear Channel Assessment (CCA) packets. CCA in the result of Received Signal Strength (RSS) from infrastructure based network disallow transmission. This limitation is removed using the information about location and channel station, in order to substitute RSS [29].

V. CONCLUSION AND FUTURE WORK

In this paper, we analysed simultaneous transmission area ($\boldsymbol{A_{ST}}$) which is interference-free region, where both infrastructure-based Primary Users and CR-based Ad-hoc Users can simultaneously transmit their data. We identified that once the location of nodes using location awareness feature of cognitive radio is known, simultaneous transmission area can easily be located. Major benefit of having simultaneous transmission area is spectrum efficiency in terms of throughput, as shown by our simulation/numerical results. Also we can diminish the use of time and energy consuming WBSS to some extent. Location awareness is important resource in the sense, a CR system create an opportunity for concurrent transmission in order to improve spectrum efficiency.

This work put some light to realize the importance of location awareness and simultaneous transmission opportunity. However, promising research topics needs to be examined like design of MAC protocol for simultaneous transmission, proficient appliance for exchanging location information between nodes, limit on the maximum number of simultaneous transmission ad-hoc links overlaying infrastructure-based network etc.

ACKNOWLEDGEMENT

Thanks to Almighty Allah with His blessings, our Teachers and our Parent’s supportive behaviour. Their love and encouragement always empower us and help us in going on. This research work was funded by Directorate of Research, University of Engineering and Technology, Lahore, Pakistan.

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