INVESTIGATION OF THE EFFECT OF DIRECTIONAL ANTENNAS USED IN COGNITIVE RADIO AD-HOC NETWORKS (CRAHN)

Thesis submitted in fulfillment of the requirement for the degree of

BACHELOR OF TECHNOLOGY

IN

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DECLARATION BY THE SCHOLAR

I hereby declare that the work reported in the B.Tech thesis entitled **"Investigation of the effect of directional antennas used in cognitive radio ad-hoc networks"** submitted at **Jaypee University of Information Technology, Waknaghat, India** is an authentic record of our work carried under the supervision of **Dr. Ashwani Sharma (Assistant Professor (Senior Grade))** and **Dr. Shweta Pandit (Assistant Professor (Senior Grade))** was our co-supervisor**.** We have not submitted this work elsewhere for any other degree or diploma.

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CERTIFICATE

This is to certify that the work reported in the B.Tech project report entitled **"Investigation of the effect of directional antennas used in cognitive radio ad-hoc networks"** which is being submitted by **Shagun Malhotra and Abhishek Rana** in fulfillment for the award of Bachelor of Technology in Electronics and Communication Engineering by the Jaypee University of Information Technology, is the record of candidate's own work carried out by him/her under my supervision. This work is original and has not been submitted partially or fully anywhere else for any other degree or diploma.

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ABBREVIATIONS

This section includes the abbreviations that are used in the report.

PU	Primary User
SU	Secondary User
CR	Cognitive Radio
CRN	Cognitive Radio Network
DIR-CRAHN	Directional antenna- Cognitive Radio Ad Hoc Network.
SDR	Software Defined Radio
CRAHN	Cognitive Radio Ad Hoc Network.
RF	Radio Frequency
SPT	Spectrum Policy Task Force
WANET	Wireless Ad Hoc Network
UCA	Uniform Circular Array
ULA	Uniform Linear Array
VSWR	Voltage Standing Wave Ratio
HPBW	Half power bandwidth

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ABSTRACT

The project is aimed towards finding the effect of directional antenna on the cognitive radio ad-hoc network and compare the results with omni directional antenna. Basically two types directional antenna were used, Uniform Circular Array (UCA) and Uniform Linear Array (ULA). We have also simulated the directivity of UCA and ULA. Results of UCA and ULA like gain and half power bandwidth have been used in finding out the probability of channel availability and probability of connectivity for ULA and UCA for different number of array antenna elements. Our project has delivered important conclusions like which antenna is better in terms of probability of connectivity of nodes and the probability of resource available like channel availability in cognitive radio ad-hoc network. Our future work is to modify our current network model and making it more practical by introducing side lobes in the beam formation of directional antenna and investigating the effect of those side lobes like whether we can make use of those side lobes in enhancing the connectivity of our network or we have to reduce it in order to enhance the gain of the main beam of our directional antenna.

CHAPTER 1
INTRODUCTION AND PRIOR WORK

1.1 Cognitive radio

Cognitive radio (CR) is an intelligent device as, cognitive itself means intelligence, which knows its surroundings and can learn from its surroundings. It is a form of wireless communication system in which it can intelligently detect which frequency channels are free and which are not, and can opportunistically move into an empty channel while avoiding b. This optimizes the use of available radio-frequency (RF) spectrum.

The Cognitive Radio uses robust radio technology which means that the communication device supervises and customize its own performance i.e. cognitive radio is familiar with its RF environment.

The cognitive radio is simply Artificial Intelligence + Software Defined Radio (SDR). SDR is a reconfigurable device which implements mixers, filters, amplifiers, modulators-demodulators, filters etc. using the software on embedded systems or computers instead of their hardware implementation which is done traditionally.

1.2 Ad- hoc Networks

Ad- hoc network is not dependent on an antecedent infrastructure, such as routers in wired networks or access points in managed (infrastructure) wireless networks.

In Ad-hoc networks, each participating node in the network forwards data packets to and from each other rather than leaning on an antecedent infrastructure like a base station or access point. For example Bluetooth in the mobile phones.

1.3 Antenna

Antennas are one of the most important components of the communication system. An antenna can be defined as a means for radiating or receiving radio waves.

An antenna provides or acts as an interface between the electric currents in the devices and the RF electromagnetic waves traveling in the space.

Here we are discussing two types of antennas namely Omnidirectional and directional antennas.

1.3.1 Omnidirectional Antennas

An omnidirectional antenna is an antenna device that is capable of receiving and transmitting radio frequency (RF) electromagnetic radiations in all directions equally in one plane. This type of antenna radiates in the horizontal plane only.

1.3.2 Directional antenna

An antenna which emits or collects high power in particular direction because of which performance increases and interference from unwanted sources is reduced is known as directional antenna.

In this project, the directional antennas like uniform linear and circular array are discussed in chapter 3, in the section 3.4 array antennas and the radiation pattern of these two directional antennae using Matlab is also shown in the same section.

1.4 Beamforming

Beamforming is a phenomenon for interference cancellation i.e. to isolate the signal of the desired user from interference and noise and is achieved by combining elements in an antenna array in such a way that signals at particular angles experience constructive interference while others experience destructive interference.

1.5 Objective

Investigation of the effect of directional antennas used in cognitive radio ad-hoc networks

This project deals with the investigation of the effect of directional antennas, to enhance connectivity of CRAHNs. In cognitive radio, there is a primary user, which is allocated to a fixed amount of spectrum for communication, and a secondary or cognitive user which do not have a spectrum. The cognitive radio aims to provide spectrum to the unlicensed secondary user opportunistically using Dynamic Spectrum Allocation (DSA).

As today's world is utilizing the frequency spectrum using the Fixed Spectrum Allocation (FSA) scheme, in which a fixed spectrum is allocated to each user. Due to this FSA, sometimes and somewhere this spectrum remains underutilized. Also due to increasing number of users this spectrum is getting scarce. That's why cognitive radio is introduced, it uses DSA to increase the efficiency of frequency spectrum allocation. The key terms related to the Cognitive radio (CR) are discussed in chapter 2.

The major challenges here are the connectivity of secondary users in the network, the spectrum mobility if the PU again initiates the data transfer and the neighboring node discovery.

For the neighboring node discovery and connectivity, we are using the antennas, which are discussed in chapter 3. As the omnidirectional antennas radiate equally in all directions this may cause interference to the other nodes both PUs and SUs in the network, so the connectivity between the nodes may get affected badly. So, we are making the use of directional antennas, that radiates in particular directions only, so we have mentioned two directional antenna schemes i.e. Uniform Circular Array and Uniform Linear Array in chapter 3 and we will further make their use to solve these issues.

So, the next 2 chapters deals with the cognitive radio and antennas respectively.

1.6 Flow Graph

Flow graph of the work that we have done

1. Studied basics of cognitive radio.
2. Gained a very basic knowledge of antennas
3. Chose a base paper(IEEE Transaction) and studied it
4. Studied some more papers to gain knowledge and idea for proceeding further in our work.
5. Studied the beamforming by uniform circular array and uniform linear array and compared the result.
6. Composed our model to study the effect of omnidirectional antenna in cognitive radio ad-hoc network
7. Modified the model for directional antenna.
8. Compared the results of both omnidirectional and directional antenna to see which one is better in performance.

1.7 Literature review

[1]. Georgiou Orestiset. al. (2015) We have studied the result of multihop connectivity of networks with directional antennas mentioned in reference [1]. Random beamforming strategies have been considered in which nodes have the freedom of choosing the direction of radiation at random i.e. no prior information is there about the location of nodes in wireless sensor network. According to a general mathematical framework [1], we saw that they have taken into account metrics like antenna directivity G, node density ρ, pathloss exponent 'η', and have accordingly got the result which clearly shows that random beamforming method can significantly enhance multihop coverage, reachability etc. and can also minimize the hop distance between nodes, hence improving end-to-end delay and signaling overheads.

[2]. Wang Yuanyuanet. al. (2016) In this paper, the author has tried to analyze the local connectivity as well as overall connectivity of a network in which primary and secondary users are equipped with directional antennas. The author has also made a theoretical framework of node isolation and overall connectivity of directional cognitive radio ad-hoc network. They have produced results which show that DIR-CRAHNs have higher connectivity than OMNI-CRAHNs.[6]

[3]. Bettstetter Christianet. al. (2005) In this paper the author has tried to analyze the effect of beamforming antennas on the topological connectivity of multihop WSN. Metric chose for analyzing the connectivity of the network, percentage of nodes that are connected by multihopping. In the paper, it was proved that a network where randomized beamforming is used there is significant improve in the connectivity of nodes as compared to omni-directional antenna.

[4]. Zhou Xiangyunet. al. (2009) In this paper, the author has presented an analytical model for finding the impact of beamforming and shadowing on the connectivity of wireless ad-hoc sensor network. Two main schemes of beamforming are discussed. First is random beamforming, where each node of the network selects a main beam direction without the help of any other node, and second is center-directed beamforming, where each node points its main beam toward the geographical center of the network.

CHAPTER 2
INTRODUCTION TO COGNITIVE RADIO

2.1 Introduction

Cognitive radio is a new system for designing wireless communication systems which aim to enhance the utilization of the radio frequency (RF) spectrum. The inspiration behind cognitive radio is the shortage of the available frequency spectrum, rising demand, due to hike in wireless applications in mobile communication. The maximum part of available radio spectrum is already allocated to pre-existing wireless systems and only a little part of it now can be used by new wireless applications. According to the research done by the Spectrum Policy Task Force (SPTF) of the Federal Communications Commission (FCC) we came to know that only a few frequency bands are heavily used by licensed users, but in comparison to that humongous part of frequency bands are mostly unused in certain locations and at particular times respectively. For example, spectrum assigned to mobile networks in India has the maximum usage during office hours but it is mostly free from midnight to early morning. Similarly, spectrum bands allocated to TV Broadcasts are highly underutilized in the rural areas in India. The limitations in accessing the spectrum due to the static spectrum licensing scheme are:

- When a spectrum is allocated for a particular use, it can not be used for any other purpose.
- Spectrum licensed is allocated to a specific user or wireless service provider in a larger region.
- One can not obtain a license for small spectrum band to use for the short time period in a certain area.
- Unlicensed users can’t access the spectrum

Figure 2.1 is showing spectrum holes and how cognitive user shifts from one frequency to other when the primary user starts accessing the network.

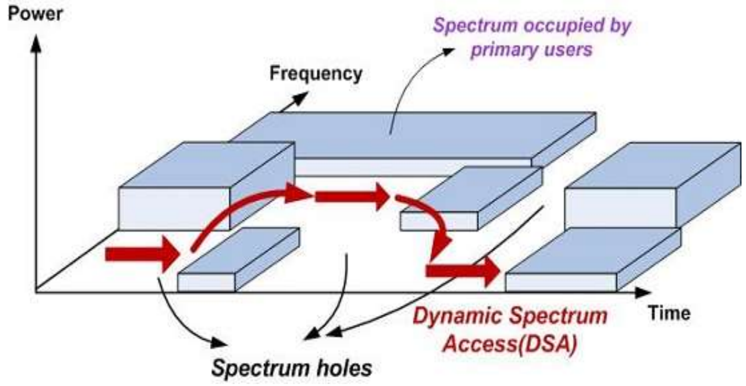

Figure 2.1. Spectrum hole (or spectrum opportunity) [5]

2.1.1 Software-defined radio

A software defined radio is a reconfigurable wireless communication system which uses software controlled signal processing algorithms to dynamically control the parameters of transmission such as operating frequency bands, protocol etc. It is an important component to set up cognitive radio system. The basic SDR Transceiver system is shown in fig.2.2,

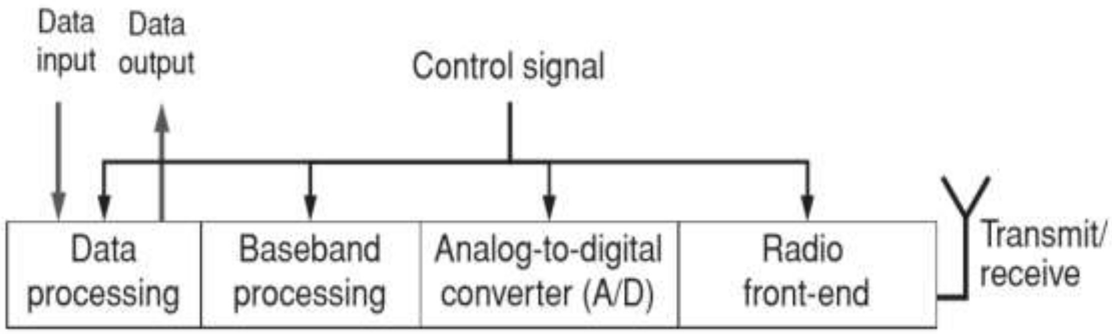

Figure 2.2. SDR Transceiver [6]

The main functions of SDR are as follows in Table 2.1:

Table 2.1. Functions of SDR

Function	Support	Example
Multiband Operations	Wireless data transmission over different frequency spectrum	ISM band, Tv band, Cellular band
Multistandard Support	Different standards, different air interfaces within the same standard	Wi-Max, WCDMA, CDMA2000, GSM, Wifi, IEEE 802.11a/b/g/n, in WiFi standard
Multiservice Support	Multiple services	Broadband wireless internet access or cellular telephony
Multichannel Support	Simultaneously operates on multiple frequency bands	Transmitting and receiving data at the same time

2.2 Cognitive radio features and capabilities

Cognitive radio is a smart wireless communication system to which its surrounding environment is known. Cognitive radio judges the network conditions and accordingly takes the decision and adjusts the communication parameters. Also learning from these adoptions, it can take decisions in a real-time manner. The two main objectives of cognitive radio are: (1) to achieve a wireless communication system on which one can rely and is efficient, and (2) to enhance the useage of the frequency spectrum.

2.2.1 Functions of cognitive radio

The main functions of cognitive radio are as follows:

Spectrum sensing: It detects the status of the spectrum and the activity of the licensed users by regularly sensing the target frequency band and also helps us to access spectrum by determining the factors like transmitting power and access duration. It merely creates any interference to the licensed user transmitting at that instance.

Two types of spectrum sensing are: -

1. Centralized spectrum sensing

2. Distributed spectrum sensing

Centralized spectrum sensing has a sensing controller that can be an access point or base station which senses the target frequency band, collects the sensing information and then shares it with other secondary nodes in the system. In this case complexity of user terminals is decreased as sensing functions has already been performed by the sensing controller. The drawback of this technique is that, here sensing controller might not be able to sense unlicensed users at the edge of the cell, reason being it suffering from location diversity. **In distributed spectrum sensing**, all secondary nodes i.e. unlicensed users individually perform spectrum sensing, and the sensing results obtained when are used by individual cognitive radio users is known as non-cooperative sensing and when shared among other users also is known as cooperative sensing. In cooperative sensing there is large communication and processing overhead, but it is more accurate way of spectrum sensing compare to that of non-cooperative sensing.

Spectrum management: According to user communication requirements unlicensed user has to choose the best spectrum on the basis service quality and availability of frequency channel for data transmission so as not to create any kind of interference to the licensed user. The main functions of spectrum management are given as:-

Spectrum analysis: Data is collected after spectrum sensing and is then examined to acquire information about the availability duration of spectrum holes, how much interference is there and also the probability of collision with primary users because of error in sensing. After this the decision is made to optimize the spectrum access.

Spectrum access: In accordance to above decision, the cognitive users now can access the spectrum holes.

Spectrum mobility: Spectrum mobility means changing the operating frequency band of cognitive radio users. When a licensed user suddenly comes and starts communicating on the radio channel which is currently being used by an unlicensed user, the unlicensed user has to shift to the spectrum band which is free at that time. This is also known as spectrum handoff. After the spectrum handoff we have to make sure that there come no issues with cognitive user transmission when shifted to new frequency band.

2.3 Cognitive Radio Ad-Hoc Network

In a wireless ad-hoc network (WANET) there is no centralized access point of the system and it has no predefined infrastructure, that is why it is known as an ad-hoc network.

Cognitive Radio Ad-Hoc Network (CRAHNs) has come into existence in recent times. The difference to traditional ad- hoc network is that there is machine learning involved in CRAHNs. We have shown the CRAHN by using user nodes communication channel in fig.3.3. The advantages of ad-hoc networks are

- less transmit power required (for longer battery life)
- easy and fast to deploy
- Independent of the infrastructure
- Higher frequency reuse for higher capacity

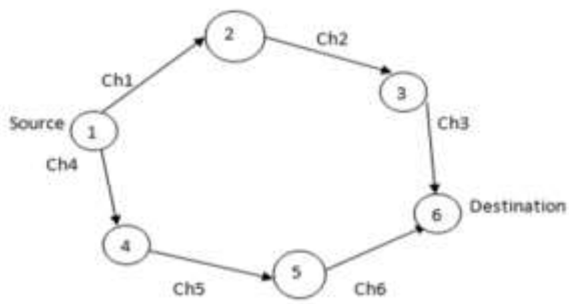

Figure.2.3. Cognitive radio ad-hoc network [7]

2.3.1 Comparison between CRN's and CRAHN's

Here we are going to discuss, differences and similarities of *Ad Hoc* CRN's, and CRN's mentioned in Table 2.2.

Table 2.2. Comparison between ad-hoc CRN's and CRN's [8]

Factor	**Ad-Hoc CRN's**	**CRN's**
Wireless medium	Licensed spectrum bands (Data channels)	Licensed spectrum bands (Data channels) Licensed or ISM band (control channel)
Availability	Under development	Not readily available (under conceptual phase)
Identification	Unique ID by its MAC address	Not unique
Hardware constraint	*Intelligent ad hoc mobile device with cognition capability*	Intelligent, cognition capabilities, small, moderate processing capacity, moderate memory capacity
Traffic	Random	One to many, many to one, many to many
Bandwidth deficient	yes	yes
Communication Range	Long	Short (intelligently controllable)
Standards	Not yet defined	Not yet defined
Topology changes	Frequent	Less frequent
Failure rate	Low	Moderate
Communication	Broadcast	Point to point
Fault tolerance	Less critical points of failure	High fault tolerance required
Population of nodes	Sparsely populated	Densely populated
Interaction	Close to humans e.g. laptops, PDAs, mobile radio terminals, *etc*	Focus on interaction with the environment
Data-centric	Generally address-centric networking	Generally data-centric

Seamless operation	Depends on the PUs	Depends on the PUs
Suitable for	Where ISM band is overcrowded	Where ISM band is overcrowded
Multichannel	Required	Required
Routing	All in all	Broadcast/Echo from/to sink
Application specific	Generally not	yes
Self-organization	Cognitive decision support system	Cognitive decision support system
Multi-hop communication	often	often
Mobility	Often (MANET)	Less mobile or stationary
In-network processing	Supposed to deliver bits from one endto the other	Expected to provide information on the other end, but not necessarily original bits
Energy conservation	concern	Highly concern
Whitespace utilization concern	yes	yes

2.4 Comparison between omnidirectional and directional antennas

An omnidirectional antenna is one that radiates and receives energy equally in all directions, i.e. having a coverage area of 360 degrees whereas the antenna that focuses energy in a particular direction is known as a directional antenna.

Table 2.3. Comparison between the omnidirectional and directional antenna

Omnidirectional antenna	Directional antenna
1. Omni antennas are very easy to install.	1.Installation of the directional antenna is a challenging task as the direction antenna array should be facing must be the direction where we want the desired coverage.
2. It has large horizontal coverage.	2. You cannot cover the large area reason being it having less angular coverage.
3. It can be used for long-distance communication.	3. Directional antennas can divert RF energy to farthest distance in a particular direction.

2.4.1 Effect of omnidirectional and directional antennas on cognitive radio ad-hoc networks

As omnidirectional antenna has a coverage of 360 degrees because of which it causes a great amount of interference to all other nodes present in the network whereas the directional antenna has limited number of main beams so causing less interference to other nodes [see the results in chapter 3].

2.4.1.1 Connectivity

Network connectivity is a kind of metric which tells how well the nodes in the network with each other.

Channel availability: It is a metric which tells how many channels are available for secondary users data transmission out of the total channel available for data transmission for primary users.

CHAPTER 3
ANTENNAS: OMNI AND DIRECTIONAL

3.1 Introduction

This chapter involves discussion of the Antennas, here, firstly a very brief introduction about the antennas is given and transitional structure of the general antenna is shown. The next section shows some antenna properties like antenna radiation efficiency, directivity, antenna gain etc. A brief introduction to dipole antennas, followed by radiation pattern of Hertzian dipole antenna is given, and finally in the last section the array antennas like ULA, UCA are discussed along with their radiation patterns.

Antenna means sail yard which helps in spreading the sails of a boat or yatch. In analogous to that an antenna in communication field, supports and spreads the 'wireless communication' with the help of electromagnetic waves, on space as a channel.

Antenna is the mid-transitional structure between the source and the receiver. This guiding device is used as transmitting and receiving device for the electromagnetic waves.

A general antenna as a transition structure is shown in figure 3.1

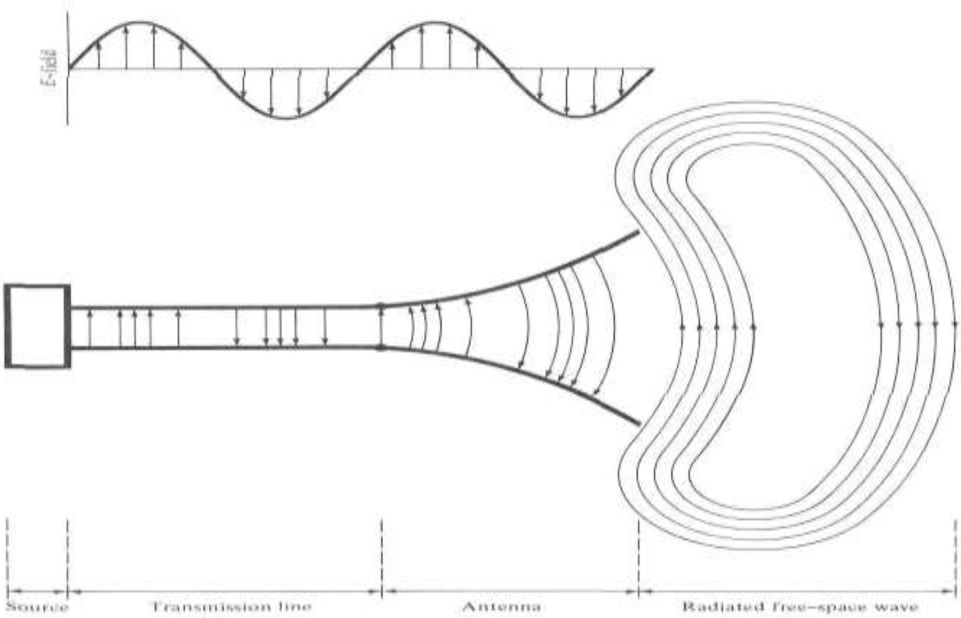

Figure 3.1. A general antenna as a transition [9]

3.2 Properties of antennas

In antennas radiation field is linked to current flowing in wires at wide range of frequencies ranging from lower audio through the upper range infrared region. Aperture antennas have the ability of linking radiation fields to materials which can operate in all the frequency regimes for eg.X ray ultraviolet, infrared, far infrared etc.

3.2.1 Input Impedance (Z_{in})

The input impedance of antenna controls the amplitude of current due to applied voltage at the input side.
For e.g. if the impedance of antenna is 5Ω then for a input voltage of 2V the amplitude of the current will be 0.4 A.

Generally Z_{in}=Real + j*Imaginary.

This impedance could be purely real as mentioned above which implies that voltage and current are in phase, if Z_{in} is purely imaginary then voltage leads the current by 90° in phase.

3.2.2 VSWR

VSWR stands for Voltage Standing Wave Ratio, VSWR is a real number which tells how precisely the impedance of the antenna is matched to the transmission line, and it is the ratio of peak amplitude of standing wave to that of its minimum amplitude.
If there will be a load mismatch between the transmission line and antenna then the power will be reflected back by the antenna and this will interfere with the forward power to the antenna and thus will create *standing voltage waves.*

$$\mathbf{VSWR} = \frac{\mathbf{Vmax}}{Vmin} \geq 1$$

VSWR=1 implies no mismatch i.e. antenna is perfectly matched to the transmission line. Higher values indicate impedance mismatch.

3.2.3 Reflection Coefficient (┌)

The ratio of amplitudes of reflected and forward voltages is the voltage reflection coefficient.

$$\textbf{VSWR}=\frac{\mathbf{Vmax}}{\boldsymbol{Vmin}}=\frac{\mathbf{1+|\Gamma|}}{\mathbf{1-|\Gamma|}}$$

As the Γ increases the ratio V_{max} to V_{min} becomes larger i.e. if ratio is 1, then there will be no Standing waves. If this ratio is infinite (i.e. $\frac{\mathrm{Vmax}}{Vmin}=\infty$) then Γ = 1 i.e. all the power will be reflected.

3.2.4 Antenna Radiation Efficiency (η)

The antenna efficiency also known as *radiation efficiency* is the ratio of the power radiated by the antenna to that of power input to the antenna.

If P_T is the input power to the antenna (transmitter) and P_{TR} will be radiation power then the radiation efficiency will be $\boldsymbol{\eta}=\frac{\mathbf{PTR}}{\mathbf{PT}}\leq \mathbf{1}$.

Typically, is close to unity for most of the antennas. In ideal conditions, the power is to be radiated particularly in the desired direction, but in reality some part of it is radiated instead to the side into *sidelobes*, and to the backward 2π steradians in the form of *back lobes.*

3.2.5 Antenna Directivity

Antenna directivity (θ, φ)is the ability of an antenna to radiate energy in a intended direction and is defined as the ratio of power actually transmitted in a particular direction to that which would be transmitted had the power P_{TR} been radiated isotropically. Therefore, directivity is sometimes referred to "directivity over isotropic".

Here the direction is specified in spherical coordinates (θ , φ) , where θ is the elevation angle or altitude above a specified reference plane and φ is the azimuth angle ,it is angle between the projection of the antenna in a given direction onto the specified reference plane and a specified reference direction (such as north or east) in that plane with specified sign such as clockwise or counterclockwise.

The directivity is defined as:

$$\mathbf{D(\theta,\ \varphi)}=\frac{\mathbf{P(\theta,\varphi)}}{\mathbf{(PTR/4\pi)}}$$

Where P(θ, φ) (watts/steradian) integrated over 4π steradians equals to P_{TR}. Therefore

$$\int_{4\pi} D\ d\,\Omega=4\pi.$$

3.2.6 Antenna Gain

A more common characterization is *antenna gain* G(θ, **φ**), which is the ratio of the power actually transmitted in the direction θ, **φ** to that which would be radiated if the entire available transmitter power P_T were radiated isotropically. That is:

$$G(\theta, \varphi) = \eta_A \ D(\theta, \varphi) = \eta_A \ \frac{P(\theta,\varphi)}{(PTR/4\pi)}$$

Where η_A is the constant dimensionless factor independent of θ, **φ** known as Antenna efficiency factor ($0 \leq \eta_A \leq 1$), $\eta_A = 1$ implies a lossless antenna. Sometimes the term "gain over isotropic" is used to facilitate memorization of the definition.

3.3 Dipole antenna

Now we are going to emphasize on dipolar ***or doublet antenna***[12]. A dipole antenna in telecommunication is the simplest and most widely used antenna. The dipole belongs to the class of antennas producing a radiation pattern similar to that of an elementary electric dipole with a structure which is radiating and supporting a line current which is so energized that the current has only one node at each end. Dipole antenna usually comprises of two conductive elements which are totally identical like metal rods or wires, which are generally symmetrical in nature. Current which is driving from the transmitter is applied,and for the case of receiving antennas the output signal to the receiver is taken, between the two halves of the antenna. Each side of the feed line to the receiver or transmitter is connected to one of the conductors which is in contrasts to a monopole antenna, which consists of a single conductor with only a side of the feed line connected to it, and the other side connected to a type of ground.

A basic layout of half wavelength dipolar antenna is shown in figure 3.2.

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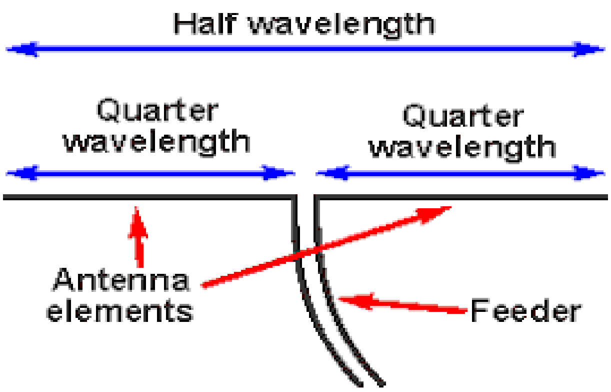

Figure 3.2. A dipolar antenna [10].

One of the very common example of a dipole antenna is the "Rabbit Ears" television antenna generally found over the broadcast television sets shown in figure 4.3.

Figure 3.3. A typical rabbit antenna [11].

3.3.1 Hertzian Dipole Antenna

Hertzian electric dipole is an elementary source of infinitesimal length and consisting of a time-harmonic electric current element of specified direction.

First of all just consider two spherical conductors, whose size is small,connected by a wire. Suppose that electric charge flows back and forth periodically in between the spheres. Let q(t) be the *instantaneous* charge on one of the conductors. As the system has zero net charge, hence the charge on the other conductor is –q(t). Let, $q(t)=q_0\sin(\omega t)$.

Our expectations is that the oscillating current flowing in the wire which is connecting the two spheres, to produce electromagnetic radiation. Let us consider a case in which the wire length is small compared to the wave-length of the radiations emitted. If this is the case, then the current I flowing between the conductors has the same phase along the whole length of the wire. It follows that

$$I(t)=dq/dt = I_0\cos(\omega t).$$

Where $I_0 =\omega q_0$ .This type of antenna is called a *Hertzian dipole*, after the German physicist Heinrich Hertz. Now we will find the fields due to a hertzian dipole, Consider an infinitesimal dipole element of length dl, placed with origin as centre as shown in figure 3.4

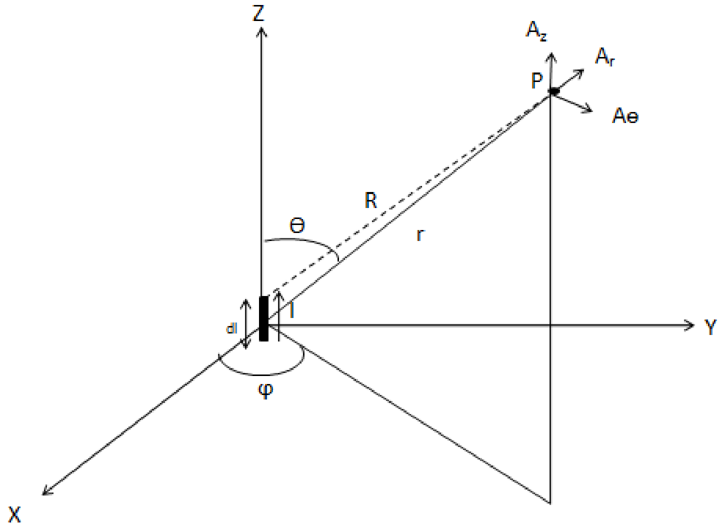

Figure 3.4. Hertzian dipole antenna.

Let **I** be the alternating current passes through this element dl, which implies a current density **J**. Let **A** be the vector magnetic potential at point P.

Therefore,

$$\mathbf{A} = \frac{\mu}{4\pi}\int_V \frac{Je^{-jkR}}{R}\,dv$$

$$= \frac{\mu}{4\pi}\iiint \frac{Je^{-jkR}}{R}\,dv`$$

We are having only z-component of the current, therefore $\mathbf{A}=\mathbf{A_z}$ only.

$$\mathbf{A_z} = \frac{\mu}{4\pi}\iiint \frac{Je^{-jkR}}{R}\,dx`dy`dz`.$$

As $\mathbf{J}=J_0\mathbf{z}$, because $I=I_z$ only.

$$= J_0\frac{\mu \mathbf{z}}{4\pi}\int_0^{dl}\frac{e^{-jkR}}{R}dz`.$$

As dl is small so, r=R.

$$= J_0\frac{\mu \mathbf{z}}{4\pi}\int_0^{dl}\frac{e^{-jkr}}{r}dz`.$$

$$\mathbf{A} = J_0\frac{\mu}{4\pi r}e^{-jkr}\,dl\,\mathbf{z}.$$

$$\mathbf{A} = A_z\,\mathbf{z}$$

We know that,

$$\mu\mathbf{H} = \mathbf{\Delta} \times \mathbf{A}.$$

$$=\mathbf{\Delta} \text{ X } A_z\mathbf{z}.$$

Using spherical coordinates,

$$\mathbf{\Delta} \text{ X } \mathbf{A} = \frac{\mathbf{1}}{\boldsymbol{r^2 sin\Theta}} \cdot \begin{vmatrix} \boldsymbol{r} & r\Theta & rsin\Theta\,\boldsymbol{\varphi} \\ \frac{\partial}{\partial r} & \frac{\partial}{\partial \Theta} & \frac{\partial}{\partial \varphi} \\ Ar & rA_\Theta & rsin\Theta A\varphi \end{vmatrix} \qquad \mathbf{3.1}$$

$\mathbf{A_r} = \mathbf{A.r} = A_z\mathbf{z.r} = A_z cos\Theta.$

$\mathbf{A_\Theta} = -A_z sin\Theta.$

$\mathbf{A_\varphi} = 0.$

Therefore equation 3.1 becomes

$$\mu\mathbf{H} = \frac{\mathbf{1}}{\boldsymbol{r^2 sin\Theta}} \cdot \begin{vmatrix} \boldsymbol{r} & r\boldsymbol{\Theta} & rsin\Theta\,\boldsymbol{\varphi} \\ \frac{\partial}{\partial r} & \frac{\partial}{\partial \Theta} & \frac{\partial}{\partial \varphi} \\ \boldsymbol{Ar} & r\mathbf{A}_\Theta & rsin\Theta\boldsymbol{A\varphi} \end{vmatrix}$$

and the radiated field **H** can be given as

$$\mathbf{H} = \frac{\mathbf{1}}{\boldsymbol{\mu r^2 sin\Theta}} \cdot \begin{vmatrix} \boldsymbol{r} & r\boldsymbol{\Theta} & rsin\Theta\,\boldsymbol{\varphi} \\ \frac{\partial}{\partial r} & \frac{\partial}{\partial \Theta} & \frac{\partial}{\partial \varphi} \\ \boldsymbol{Ar} & r\mathbf{A\Theta} & rsin\Theta\boldsymbol{A\varphi} \end{vmatrix}$$

on solving, we get

$$\mathbf{H} = J_0 \frac{e^{-jkr} sin\Theta\, dl}{4\pi} \left[\frac{jk}{r} + \frac{1}{r2} \right] \boldsymbol{\varphi} \qquad \mathbf{3.2}$$

Using Maxwell's equations,

$$\Delta \text{ X } \mathbf{H} = jw\mathcal{E}\,\mathbf{E}.$$

$$\textbf{As, } H_r=0,\ H_\circ=0 \ \&\ H_\varphi = J_0 \frac{e^{-jkr} sin\Theta\, dl}{4\pi} \left[\frac{jk}{r} + \frac{1}{r2} \right].$$

$$\Delta \text{ X } \mathbf{H} = \frac{\mathbf{1}}{\boldsymbol{r^2 \sin\Theta}} \begin{vmatrix} \boldsymbol{r} & r\boldsymbol{\Theta} & rsin\Theta\varphi \\ \frac{\partial}{\partial r} & \frac{\partial}{\partial \Theta} & \frac{\partial}{\partial \varphi} \\ 0 & 0 & H_\varphi \end{vmatrix}$$

$$\mathbf{E} = \Delta \text{ X } \mathbf{H}\frac{\mathbf{1}}{jw\mathcal{E}}$$

$$\mathbf{E} = J_0 \frac{e^{-jkr} \eta cos\Theta\, dl}{2\pi r} \left[\frac{1}{r} - \frac{j}{kr^2}\right]\mathbf{r} + J_0 \frac{e^{-jkr} sin\Theta\, jw\mu\, dl}{4\pi r} \left[1 + \frac{1}{jkr} - \frac{1}{kr^2}\right]\boldsymbol{\Theta} \qquad \mathbf{3.3}$$

Where $\eta = \sqrt{\frac{\mu}{\mathcal{E}}} = \frac{w\mu}{k}$

For Far fields r >> λ, then all terms with r in denominator tends to zero.

Therefore equation 3.3 becomes.

$$\mathbf{E_{Far}} = J_0 \frac{e^{-jkr} sin\Theta \; jw\mu \, dl}{4\pi r} \boldsymbol{\Theta}$$

& using equation 3.2

$$\mathbf{H_{Far}} = J_0 \frac{dl \; e^{-jkr} jk}{4\pi r} sin\Theta \, \boldsymbol{\varphi} \, .$$

3.4 Array Antennas

Many applications of us are in need of a radiation pattern which is not achieved by a single element. However, it is possible that a collection of many radiating elements in an geometrical and electrical arrangement, in the form of an array, will definitely result in a radiation characteristics which is desired.

The array is arranged in such a way that the radiation from the antenna elements adds up to generate a radiation maximum in a desired direction or directions, while very less in non desired directions.

To achieve higher gain or directivity in a particular direction we need to either increase the size of antenna element or enlargement of the dimensions of the antenna without necessarily increasing the size of individual elements, that is to form an assembly of radiating elements, & this assembly is termed as **array** that could be ***linear, planar*** and ***circular***.

To achieve directivity we have to ensure that the fields being generated by the elements of the antenna array constructively interfere in a particular direction and destructively interfere in all other remaining directions.

Overall, there are five basic controls which can be used to give shape to the overall pattern of the antenna. Following are the controls:

1. The geometrical configuration of an overall array (rectangular , linear, circular etc.).
2. The relative displacement between the elements.
3. The excitation amplitude of the individual elements.
4. The excitation phase of the individual elements.
5. The relative pattern of the individual elements.

3.4.1 Array factor

An array factor(**AF**) is a mathematical factor in the directivity equation of an array antenna. This factor needs to be multiplied by the directivity function in order to get the directivity of the entire array.The radiation pattern of a single antenna element which is in isolation is given by a function D(θ, φ) where 'θ' is the azimuthal angle and 'φ' is the elevation angle ,this gives the signal strength radiated at any given angle. The radiation pattern of the entire array is given by another directivity function D_{array} (θ, φ).

$$D_{array}(\theta, \boldsymbol{\varphi})=AF^* D(\theta, \boldsymbol{\varphi}).$$

3.4.2 Some antenna array arrangements

Now we are going to discuss the linear and circular array arrangements.

3.4.2.1 Linear Array

The uniform linear array (ULA) arranges identical sensor elements along a line in space with uniform/non uniform spacing. A typical linear array antenna arrangement is shown in the figure 4.5.

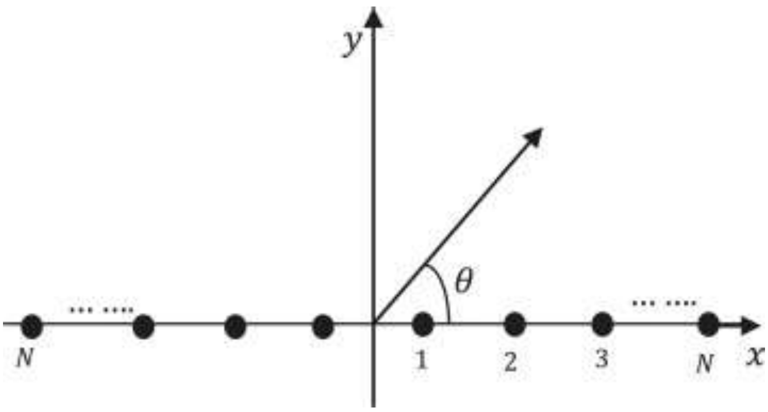

Figure 3.5. Uniform Linear Array [12].

This figure shows the arrangement of 2N antenna element along a straight horizontal line x, with equal spacing between the elements, such type of array arrangement with uniform spacing is known as ***Uniform Linear Array(ULA).*** Now, the matlab plots of ULA for number of antenna elements N=3,10 for Different values of azimuth angle $\varphi = 0^0, 60^0, 90^0$ are shown in figure 3.6

ULA

1.)For N=3, φ =0,60,90 respectively

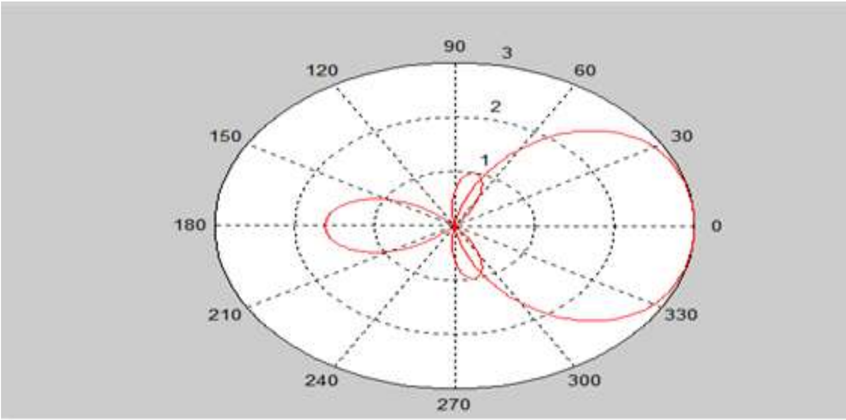

Fig 1.: φ =0

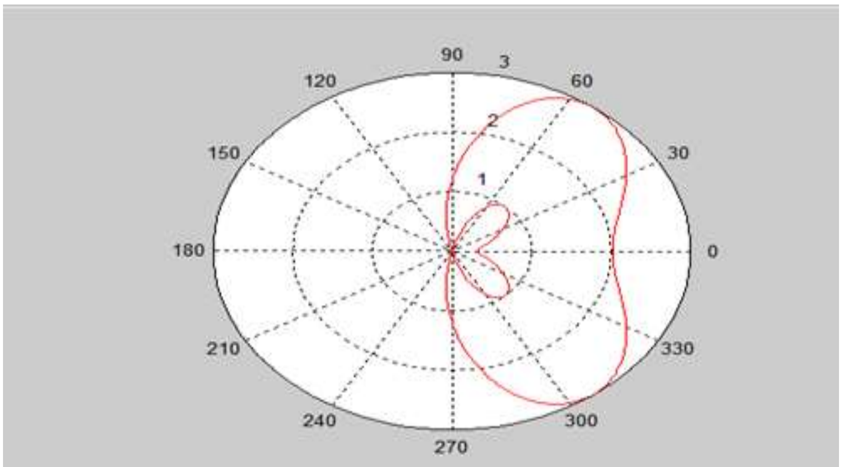

Fig 2.: φ =60

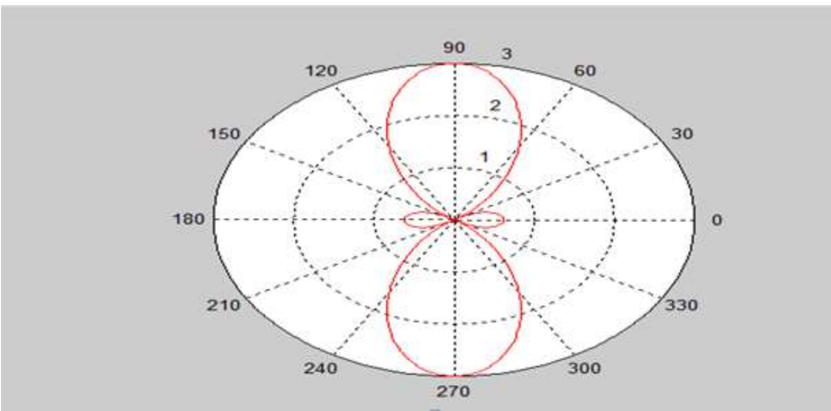

Fig 3.: φ =90

Figure 3.6. Uniform Linear Array N=3.

2.)For N=10, $\boldsymbol{\varphi}$ =0,60,90 respectively

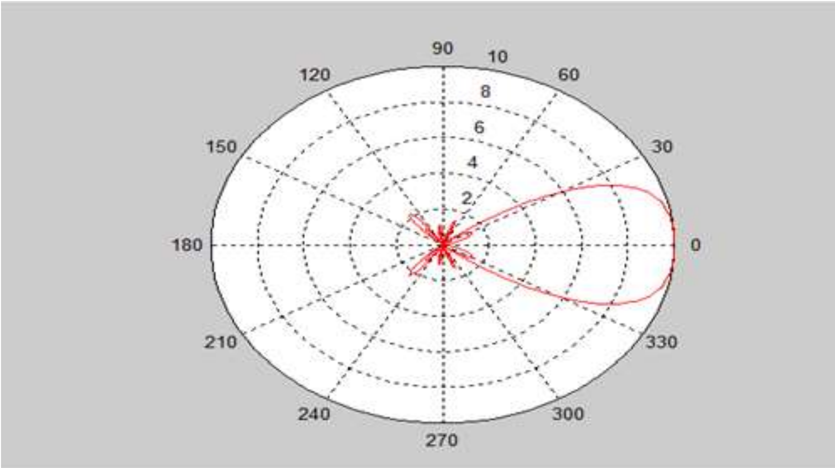

Fig.1: $\boldsymbol{\varphi}$ =0

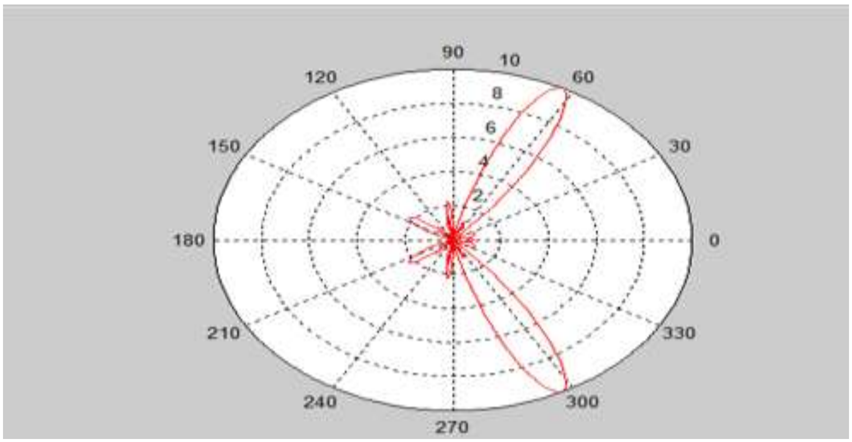

Fig.2: $\boldsymbol{\varphi} = 60$

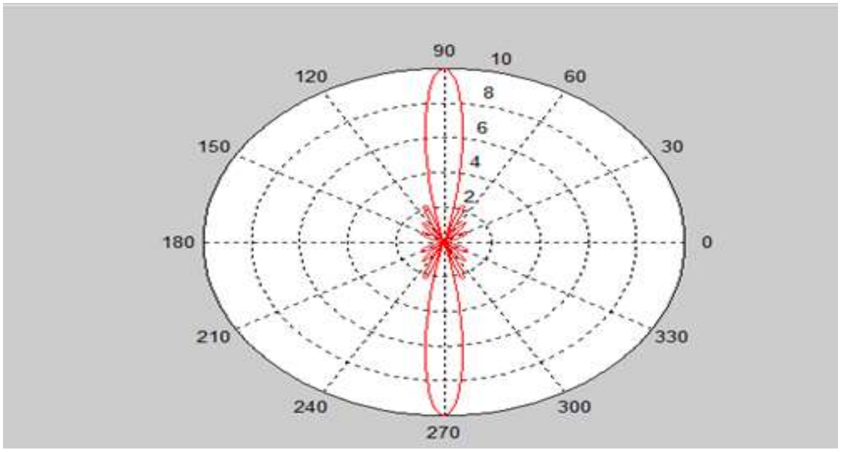

Fig. 3: $\boldsymbol{\varphi}$ =90

Figure 3.7. Uniform Linear Array N=10.

From the above plots, it is concluded that for a Uniform Linear Array antenna there are two main beams and the width of these two main beams depend on the azimuth angle ***φ*** as well as on the number of antenna elements N**,** for N=10 the beams are much finer than for N=3**.** The length of main beam is equal to the number of antenna elements N.

3.4.2.2 Circular Array

It is an array arrangement pattern in which antenna elements are arranged around a **circular** ring. A typical circular array antenna arrangement is shown in the figure 4.8.

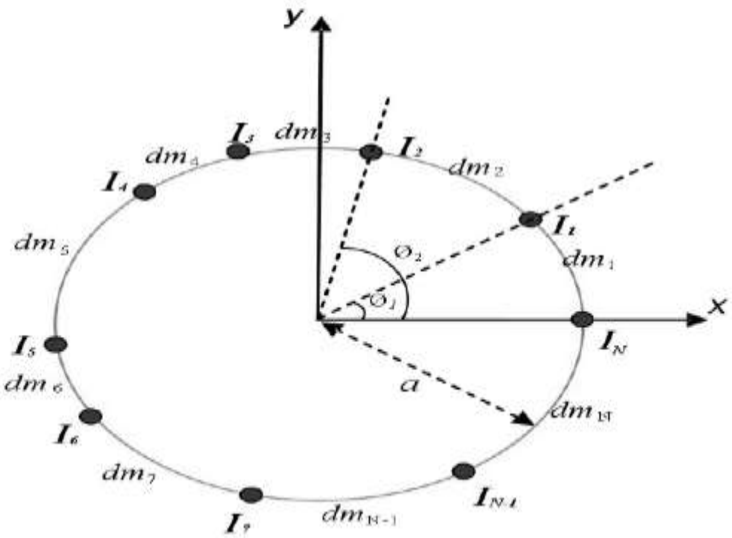

Figure 3.8. Uniform Circular Array [13]

with equal spacing between the elements, such type of array arrangement with uniform spacing is known as ***Uniform Circular Array(UCA).*** The matlab plots for UCA with number of elements N=3,10 &using different values of azimuth is shown below.

<u>UCA</u>

1.)For N=3, ***φ*** =0,60,90 respectively

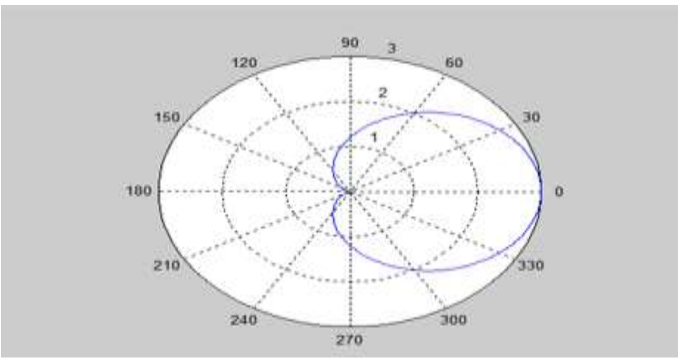

Fig. 1: ***φ*** =0

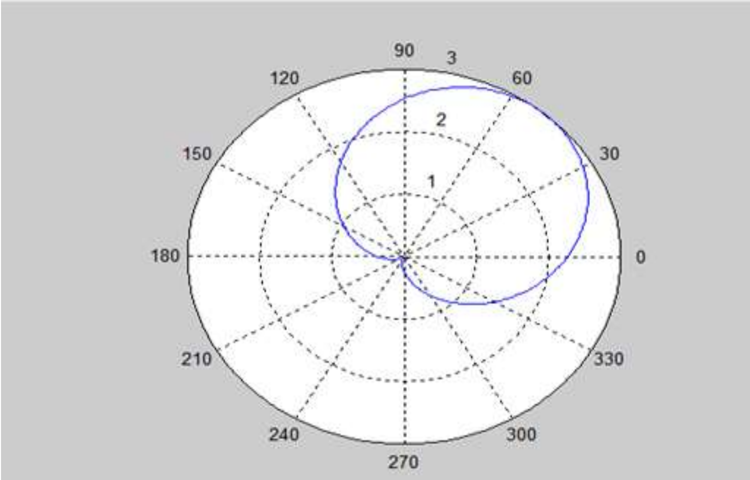

Fig. 2: φ =60

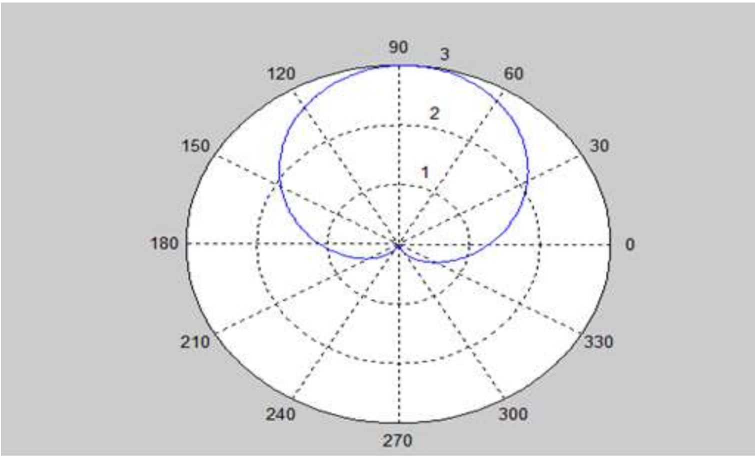

Fig. 3: φ =90

Figure 3.9. Uniform Circular Array for N=3.

2.)For N=10, φ =0,60,90 respectively

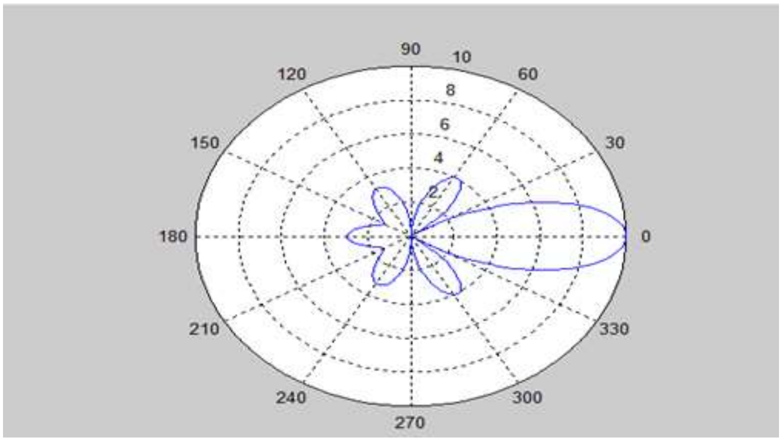

Fig. 1: φ =0

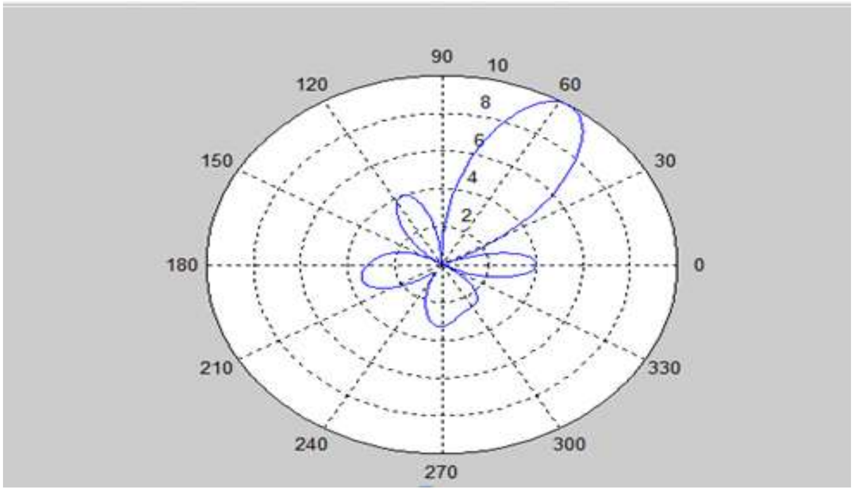

Fig. 2: $\boldsymbol{\varphi}$ =60

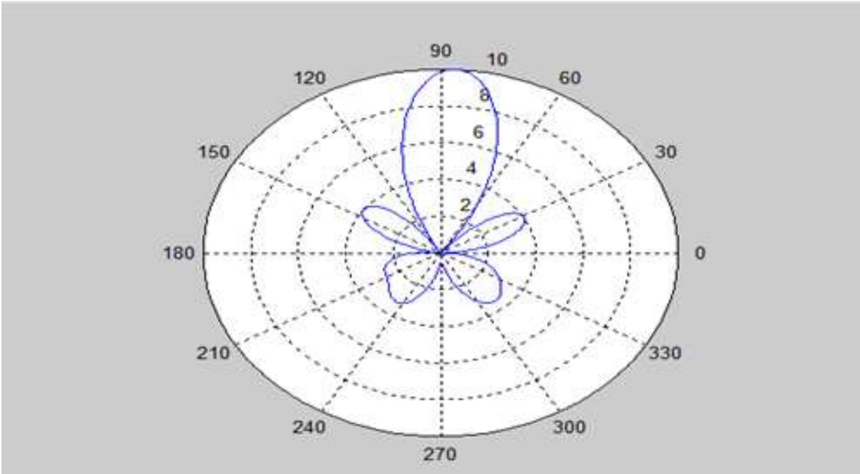

Fig. 3: $\boldsymbol{\varphi}$ =90

Figure 3.10. Uniform Circular Array for N=10.

From the above plots, it is concluded that for a Uniform Circular Array antenna there is only one main beams and the width of the main beam depends only on the number of antenna elements N **,**for N=10 the beams are finer than for N=3**.** The length of main beam is equal to the number of antenna elements N.

RESULTS

Table.3.1 Results of UCA and ULA

No of Antenna element(N)	UCA		ULA	
	Gain(G)	HPBW(azimuth=0)	Gain(G)	HPBW(azimuth=0)
3	3.09	110	4.77	105
10	8.48	40	6.5	54

3.4.3 2D Array

In 2D antenna array plane, lot of antenna elements are deployed in comparison to the traditional multiple antenna systems used in wireless cellular communications, is placed on the FD-MIMO base station. The antenna elements allow adaptive and dynamic precoding to be performed jointly across all antennas. Due to such a precoding, the base station is able to achieve more directional transmissions in the azimuth and elevation domain simultaneously to a larger number of UEs (User Equipment). A 2D Antenna array is basically characterized by the number of antenna elements in the vertical (V) and horizontal (H) dimension of the array, the polarization type (co-located, alternating, linear, dual-linear etc.), and the element spacing in V and H dimensions. A typical antenna element arrangement in the 2D array is shown in the figure 4.11.

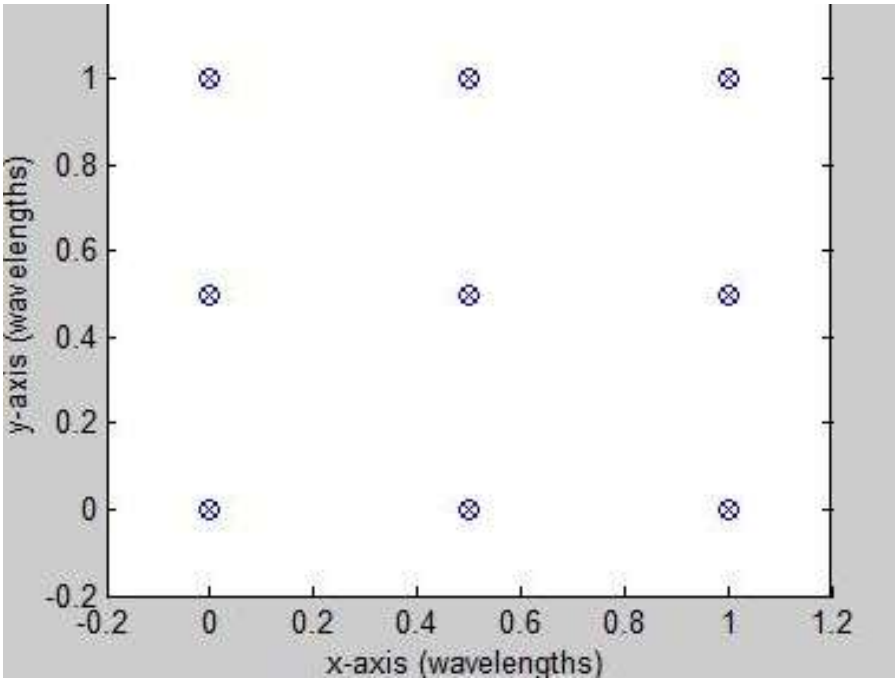

Figure 3.11. A 2D antenna array [14]

CHAPTER 4
INVESTIGATION OF THE EFFECT OF DIRECTIONAL ANTENNA ON CRAHNs

4.1 Introduction

This chapter deals with designing a wireless cognitive radio network in MATLAB. We have tried to model a static network which is practical in nature. In the network there are two types of users. Primary Users (PUs), who have paid money for the spectrum usage and hence are given priority in terms of their connection establishment when they want to communicate in the network. Second type of users are Secondary Users (SUs), they are the users who wants to communicate over the network opportunistically, as they will not pay anything for the spectrum usage. They will use the spectrum of the Primary Users when the primary users are not active. In the section 5.2 of the chapter we have given a detailed description of our network model. In network model we have also framed the valid assumptions listed in subsection 5.2.1.Most of the assumptions are in compliance with the practical network that we have in reality. Once the network is designed we will at first, deploy omnidirectional antenna and then directional antenna at every user in the network and then will calculate the probability of connectivity between the secondary users. Channel availability is also one of the important parameter as far as wireless cognitive radio network is concerned. So, in section __ we have made a comparison between probability of channel availability in omni directional antenna network and directional antenna network.In section __ we have tried to change the parameters like transmission range, number of PUs and SUs, status of PUs etc and have compared the results for omni directional and directional network. At last we have concluded the chapter while commenting on as to which configuration is better and how based on our results.

4.2 Network model

Our model is a very basic wireless cognitive radio network, wherein we have two types of users: Primary Users(PUs) and Secondary Users (SUs), who are disrtributed randomly in 1 Km sq area. It is a semi ad hoc network as PUs will make use of the Base Station which is implanted at the center of the network whereas SUs will communicate over the network in an ad hoc fashion. Our semi ad hoc network assumption is in compliance to the realistic nature of wireless network wherein , the users who are trying to access the spectrum for communication without paying for it cannot access the BTS and will have to connect with other users in an adhoc manner. The number of SUs we have assumed to be greater than PUs as the number of paid users is most of the time less than number of unpaid users.

4.2.1 Physical representation of network

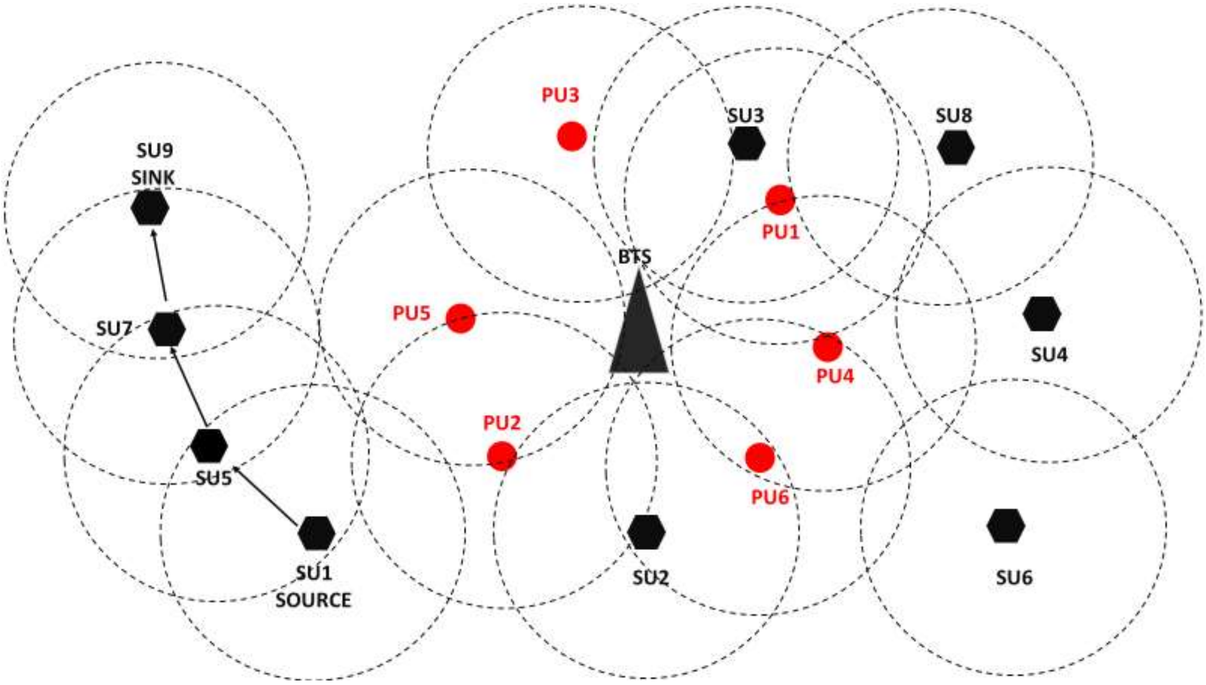

Figure 4.1. Random distribution of PU and SU with omni directional antenna

In fig 4.1, a physical representation of SUs and PUs having omni directional antenna, along with BTS is shown. From the figure it is clear that SU1 which is a source node is connected to SU9 , the sink node, as no other PU is in the transmission range. So all the SUs in the path from SU1 to SU9 can use the unutilized channel. But in fig. 4.2 we have PU3, which is active, and is in the transmission range of SU2, SU5, SU7, SU8 but still SU2 is connected to SU8 as PU3 is communicating with the BTS on a different channel w.r.t the channel on which SU1 to SU8 are communicating. We can also see from the fig.4.2 that SU1 cannot connect to SU9 as there is no SU in the transmission range of SU1, who can help in establishing the link between SU1 to SU9. Channel availability is also an important parameter, if two secondary user want to communicate with each other than all the primary users in the network who are active should not be in the transmission range of any secondary user who will help the source and sink node to establish the connection ,otherwise there will be no channel available for the transmission of data between the source node and sink node and hence connection again will not be established.

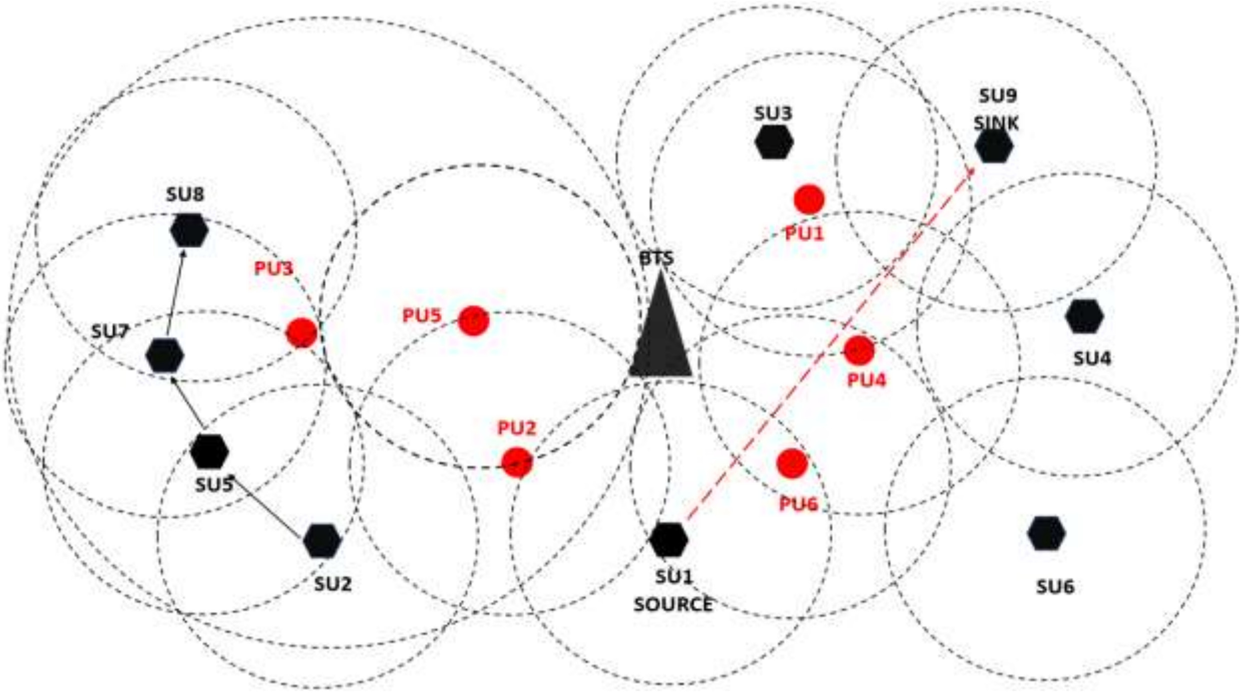

Figure 4.2. SU2 is connected to SU8, SU1 cannot connect to SU9

4.2.2 Physical representation with directional antenna

Omnidirectional antenna have a lot of limitations like less gain, insufficient directivity which makes their use in wireless networks limited, to remove all these limitations directional antenna was put into use.Fig.4.3 shows the radiation pattern of directional antenna(UCA), here we can see the directivity is enhanced and gain is also enhanced.

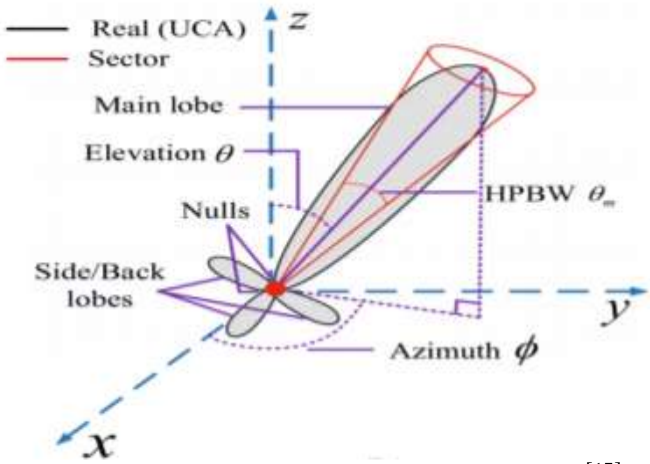

Figure 4.3. 3D beam of directional antenna [15]

Fig.4.3 shows the random distribution of secondary users and primary user where all are mounted with directional antenna. All the primary users have their antenna steered towards the BTS, which will allocate the channel to all the active primary users. The secondary user SU1 is connected to the secondary user SU12.We can see from the figure that secondary user SU8 is very near to primary user PU6, if PU6 is active then also the node SU8 will help SU1 to connect to SU12 as with directional antenna there is no interference to PU6 from SU8.

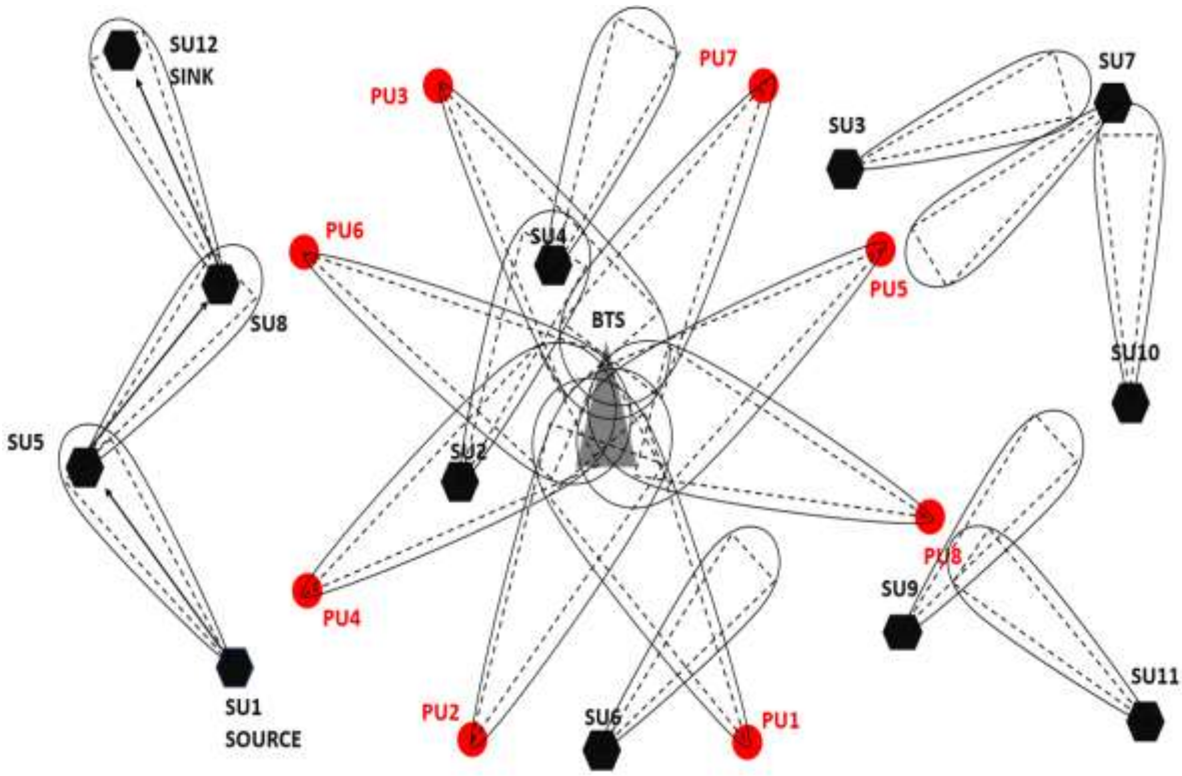

Figure 4.4. Random distribution of PU and SU with directional antenna

4.2.3 Assumptions taken

1.SUs and PUs are static i.e. they are immobile.

2. The geographical network represents a cellular network with one BTS placed at the center of the cell.

3. Frequencies available for communication are equal to number of active primary users in the network.

4. Channels are allocated randomly to PUs by the BTS.

5. If a channel is allocated to PU then all the SUs in its transmission range cannot use that channel.

6. Sink node is one of secondary node and is fixed.

7. Packet arrival rate of PU is uniform.

8. Beam width is uniform for a directional antenna.

9. The routing protocol used is Least Distance Remaining(LDR).

10. In directional antenna network, active PUs are communicating with the BTS.

11. PUs cannot help SUs in multihop connectivity, as paid users will not prefer wasting energy for the communication between SUs.

4.2.4 Algorithm used in multihop connectivity of SUs

The algorithm used in our network for multihop connectivity is called 'Least distance remaining (LDR). Following are the steps:

1. The distance of secondary source node from all its neighbor SUs and PUs is calculated.

2. The SUs and PUs which are in the transmission range of source node are found.

3. Channel used by all the active PUs in transmission range are sensed by the source node and occupy the unused channel.

3. The distance of all the in range secondary nodes from sink node is calculated.

4. A node with the least distance from sink node is found. This node will help in the hop for its source node.

5. Repeat steps 2,3,4 till sink node is not found.

4.3 Results

All the results are compiled on MATLAB software version 2017a.Fig 4.5 is our basic network. It is clear from the figure that our BTS is in the middle of the network, which will facilitate the communication of primary users whereas all the secondary nodes will try to utilize the free channels opportunistically.

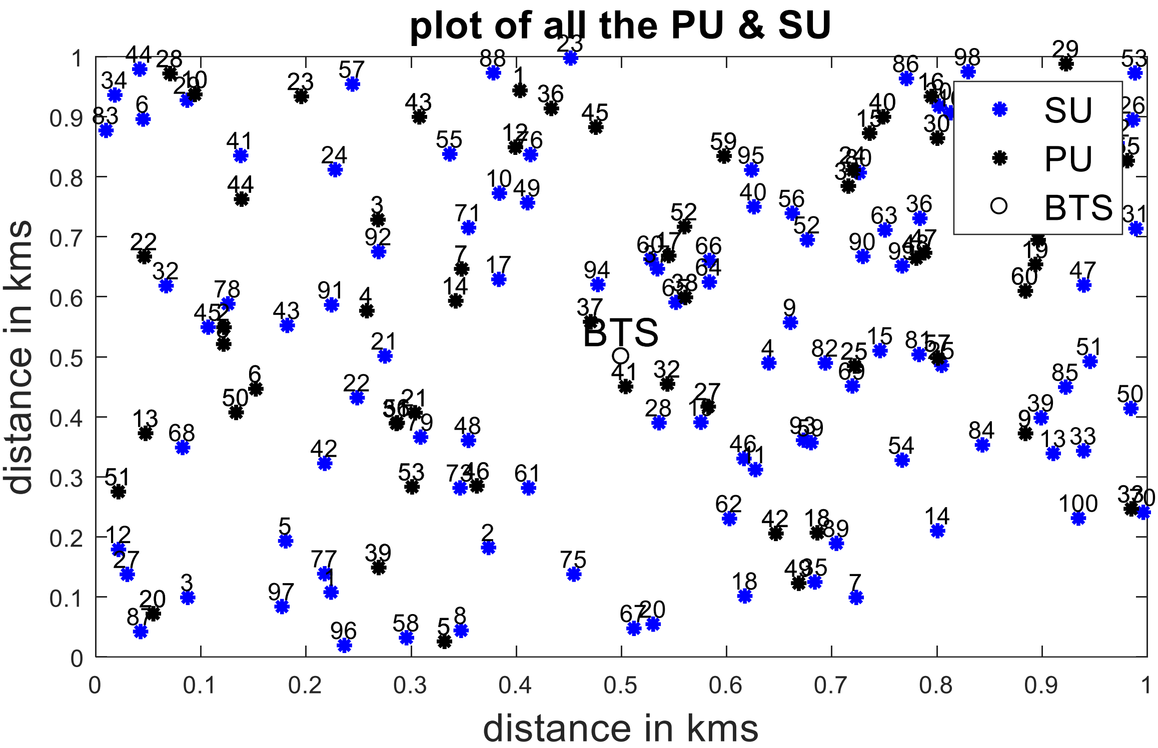

Figure 4.5. Network plotted in 1km square area

In fig 4.5 secondary users are greater in number than the primary users, and both the users are distributed randomly in 1 km square area. Due to large number secondary users and less number of primary users ,the channel available for transmission of data would also be less and finding a channel for the successful transmission of data would be more challenging for secondary users.

In the next section we have plotted the results and interpreted the graphs.

4.3.1 Effect of directional antenna(UCA,ULA) on the probability of channel availability in comparison to omni directional antenna

Parameters Fixed: No of secondary users=30,No of primary users=20,Tx range secondary=200 mtrs,Tx range primary=200 mtrs

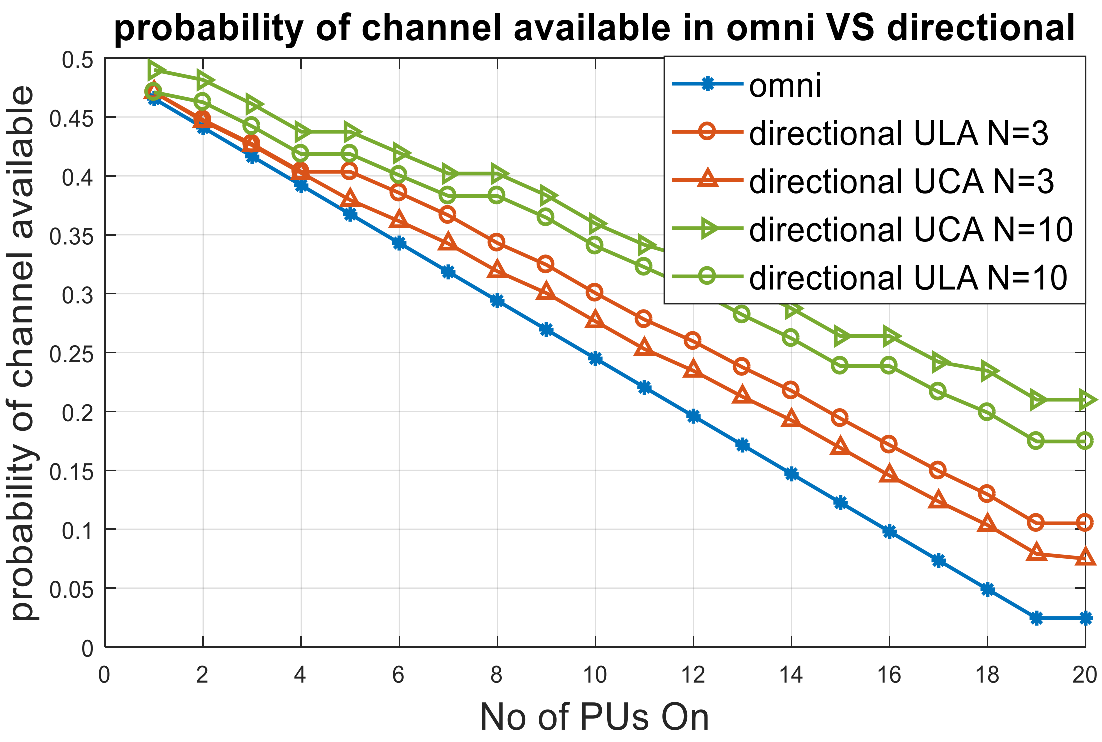

Figure 4.6. Probability of channel available for omni vs directional antenna

INTERPRETATION OF GRAPHS: It is evident by seeing fig 4.6 that when number of array elements in both ULA and UCA is 3 then gain of ULA is higher as compared to gain of UCA, because of which HPBW for ULA is lower than HPBW of UCA. This results in higher interference to SUs by PUs in the case of UCA and less channel availability to SUs for communication. Whereas the opposite is true, when number of antenna elements increased to 10. Then gain of UCA is higher and HPBW is lower than ULA, which results in better channel availability to SUs with UCA.

4.3.2 Effect of directional antenna(UCA,ULA) on the probability of connectivity in comparison to omnidirectional antenna

Parameters Fixed: No of secondary users=40, No of primary users=25, Tx range secondary=500 mtrs

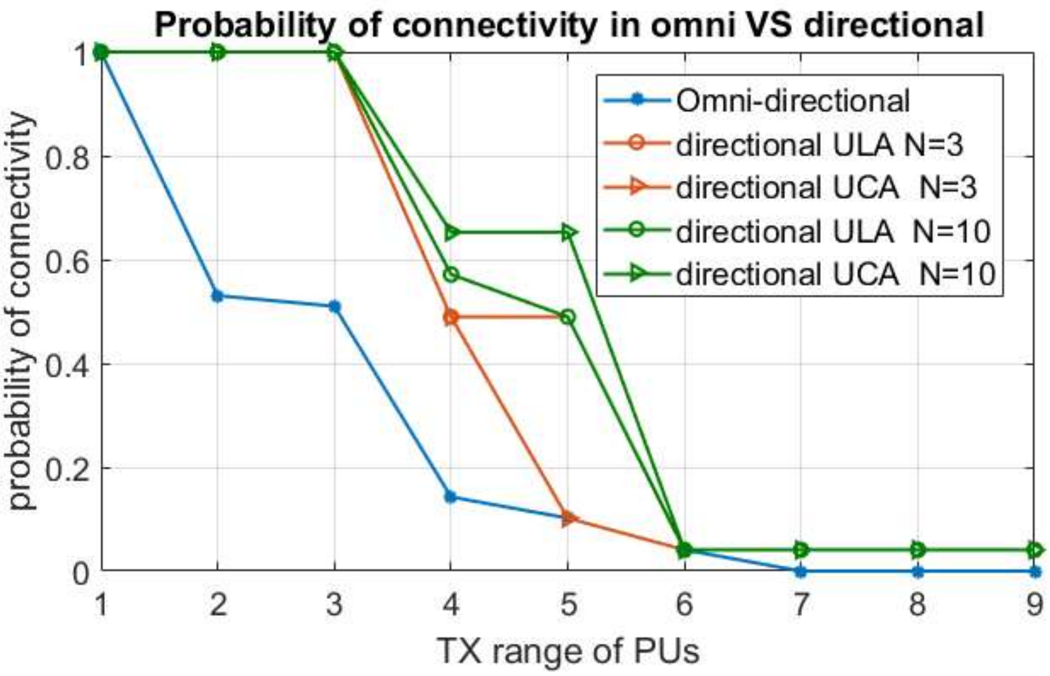

Figure 4.7. Probability of connectivity for omni vs directional antenna

INTERPRETATION OF GRAPHS: While finding the probability of connectivity when transmission range of PUs is varied, we can see from fig 4.7, that probability of connectivity is good for ULA and UCA directional antenna as compared to the probability of connectivity of omni directional antenna.

CHAPTER 5
CONCLUSION AND FUTURE SCOPE

5.1 Conclusion

By seeing the results in chapter 5 and interpreting the graphs we can conclude that directional antenna, whether UCA or ULA ,are far better than omni directional antenna in terms of probability of channel availability and probability of connectivity.It is only when we have to vary number of antenna elements that we have to make a choice between UCA and ULA. From our results it is shown that if cost is an issue and we have to deploy less antenna elements while fabricating an array antenna then we must choose ULA due to its high gain and less HPBW. But if we can compromise with the cost and want to deploy more antenna elements in antenna array in order to have high gain and correspondingly high data rate than we must go for UCA.

5.2 Future scope

While designing our network and calculating our results we have made a lot of assumptions. One of the assumptions was that we neglected the side lobes of UCA and ULA and just took the ideal case that when our beam will steer to communicate with other users then its size will not change, which in reality is not true. So, our next target is to modify our network and analyze whether we can make use of the side lobes in communication or we have to minimize the side lobes as much as we can to improve the gain of the main beam. We will also analyze the performance of our network when beam width of the main beam will change while steering.
As far as routing protocol is concerned we would like to modify our routing protocol and also take into consideration the data rate,energy that is being used by the nodes and will try to optimize these parameters with our modified routing protocol.

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