DEVELOPMENT OF INTERFERENCE MITIGATION SCHEMES IN 4G TECHNOLOGY USING SMART ANTENNAS

A Thesis submitted in partial fulfilment of the Requirements for the degree of

Bachelor of Technology in Electrical Engineering and Master of Technology in Electronics system and communication

(Dual Degree)

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Dedicated to

My Grandmother……

CERTIFICATE

This is to certify that the work in this thesis entitled ***Development of interference mitigation schemes in 4G technology using Smart Antennas*** *by* ***Lipsa Subhadarshini*** *is a record of original research work carried out by her during 2014-2015 under my supervision and guidance in partial fulfilment of the requirements for the award of the* ***dual degree of Bachelor of technology in Electrical Engineering and Master of Technology in Electronics System and Communication****, National Institute of Technology, Rourkela.*

26th May 2015 — ***Prof. Susmita Das***

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DECLARATION

I hereby certify that,

- The work done in this thesis is solely by myself under the general supervision of my supervisor.
- The work has not been submitted to any other institute for any degree or diploma.
- I have followed the guidelines provided by the institute in writing the thesis.
- Whenever I have used materials (data, theoretical analysis, and texts) from other sources, I have given due credit to them by sighting in the text of the thesis and giving their details in the references.
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Lipsa Subhadarshini

12th May 2015

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Lipsa Subhadarshini

ABSTRACT

With the increase in demand of mobile users and high speed data requirements, the world is now migrating towards 4G. this has led to increase in Co-Channel interference and multipath in urban/dense urban environment by which the network capacity has been reduced. Hence there is a necessity of developing new schemes and methods which can optimally exploit the limited resources and minimize the interference for higher user capacity and qualitative wireless communication. Smart Antenna has now come to the rescue of the changing trends in wireless communication. It efficiently reduces the effect of CCI and Multipath by adapting the antenna pattern to track and locate the desired user while eliminating the undesired ones. So this project aims in modelling, analysis and simulation of an efficient smart antenna system by studying and comparing various weight updating algorithms of Direction of Arrival (DOA) like MUSIC algorithm and ESPRIT algorithm and adaptive beam forming algorithms like Least Mean Square algorithm, Sample Matrix Inversion algorithm and Conjugate Gradient Method Algorithm choosing the most efficient ones for the system design.

Table of Contents

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

R_{xx} : array correlation matrix

A: array steering matrix

R_{ss}: source correlation matrix

A^H: Hermittian array steering matrix

I: identity matrix

V_N: eigen vector of noise

Θ: angle of arrival

x(k): input signal

K: block number

y(k)= output signal

d(k): desired/reference signal

e(k): error signal

E[.]: expected value

C(n): performance function

$e(n)^2$: mean square error

w(k): weight

R: auto correlation matrix

P= cross correlation matrix

$\nabla \hat{h}^H$ = filter coefficient

∇ = gradient

μ= step size

k= block number

K=block length

$\overline{D}$= direction vector

d= space between array elements

δ= phase shift between array elements

Φ= total phase difference

Φ=current phase difference

E= total electric field

AF= array factor

N= total no. of input signal

ϕ_{max}= direction of maximum radiation

ϕ_{null}= direction of null

ϕ_{SL}= direction of side lobe

λ= wavelength

D= directivity

D_{BS}= directivity of broadside array

D_{EF}= directivity of end-fire array

1. CHAPTER-1

INTRODUCTION

The growing demand of mobile users and high speed data requirements has led the world towards 4G technology. But with this increase in the number of mobile users and network congestion, CCI and Multipath is very prominent in urban and dense areas. Hence there is a necessity of developing new schemes and methods which can optimally exploit the limited resource and minimise the interference for higher user capacity and qualitative wireless communication.

Smart Antenna is the recent technique used to mitigate these CCI and Multipath effects and increasing the network capacity. Hence this project aims in modelling, analysis and simulation of an efficient smart antenna system by comparing various weight updating algorithms of DOA and adaptive beam forming and choosing the most efficient ones for the system design.

1.1 MOTIVATION

The demand of wireless data services is growing day by day. So, the world is now migrating towards 4G replacing the 3G. The migration towards 4G networks has now allowed the service providers to provide the useful applications that has compelled users to upgrade their phones. 4G system now offers a downlink data rate of 100Mbps which is around 10 times faster than 3G. It's low latency makes consumer experience worthy. There is flexibility in the network connections and efficient use of spectrum. With the eye-catching application that it provides, consumers get what they want.

But the Co-channel interference and multipath in urban/ dense areas has limited capacity of the network. There is a necessity to develop some schemes which can mitigate these effects and improve the performance of the system and its capacity. The conventional antenna system fails to achieve all these.

So, to avoid such issues, the concept of smart antennas has been developed through these years which provide a lot of advantages. Also developing interference mitigation schemes is also a major issue in the recent year to minimize the effect of CCI and multipath caused due to the ever growing traffic and to improve the wireless system performance. This has motivated the researchers to come up with recent techniques and more advanced version of smart antenna system that provides a lot many advantages.

1.2 OBJECTIVE OF THE WORK

The aim of this project is to analyze the problems arising due to the multipath effects and the CCI in 4G technology and come up with some interference mitigation schemes to tackle these problems and increase the wireless system efficiency and performance .

In order to achieve these objectives, the following study and analysis is carried out.

- Detailed study and analysis of the already available interference mitigation schemes in smart antenna technology.
- Comparison of the performance of the various schemes to the changing antenna parameters and choosing the optimum ones for the system design
- Simulation based testing of those optimum algorithms in order to prove its efficacy.

1.3 LITERATURE SURVEY

- The paper published by Ramachandran, S. in the year 2012 on "***Smart Antennas in 4G***" deals with the advantages of smart antenna system and how does it work. It focuses on how the smart antenna has helped to improve the wireless communication system by improving the capacity of the network, efficient use of bandwidth, SDMA and increase security. [7]

- In the paper published by Alexiou, Angeliki, and Martin Haardt. on "***Smart antenna technologies for future wireless systems: trends and challenges***" in Communications Magazine, IEEE 42, no. 9 (2004): 90-97, the pros and cons of smart antenna system has been discussed first. Various network conditions and challenges faced during system design are described. Finally, the finance and the cost factor for the implementation has been discussed. [8]

- In the paper presented by Das. Susmita. on "***Smart antenna design for wireless communication using adaptive beam-forming approach***" in TENCON 2008-2008 IEEE Region 10 Conference, pp. 1-5. IEEE, 2008, provides description, comparative analysis and utility of various reference signal based algorithms as well as blind adaptive algorithms. [10]

- In the paper published by Prof.B.G. Hogade , Ms. Sheetal Wadhe , Dr.Shrikant K.Bodhe in the year 2012 on “***Mitigating the Effect of CCI and multipath in mobile communication using smart antenna”*** in IJERA ISSN: 2248-9622 the comparative analysis of LMS and SMI Algorithm has bben discussed. MATLAB simulations have been carried out to prove the proposed methods. [29]

- The paper published by Lavate, Tukaram Baburao, V. K. Kokate, and A. M. Sapkal on "***Performance analysis of MUSIC and ESPRIT DOA estimation algorithms for adaptive array smart antenna in mobile communication***" in Computer and Network Technology (ICCNT), 2010 Second International Conference on, pp. 308-311. IEEE, 2010 makes a detailed and comparative study between MUSIC and ESPRIT Algorithm. [13]

- In the paper presented by Shrivastava, Neha, Sudeepn Baudha, Rahul Singh Rathore, and Bharti Tiwari on "***Study and Simulation of Smart Antenna using SMI and CGM algorithm***" in IJEIT 1, no. 6 (2012): 11-15 detailed study of SMI and CGM adaptive beamforming techniques are done and proved that CGM is a better method for adaptive beamforming than SMI. [5]

1.4 THESIS CONTRIBUTION

Various Direction of Arrival techniques and adaptive beam forming techniques exist that try to mitigate interference due to multipath fading and Co-channel interference thereby increasing the performance and efficiency of the smart antenna system. The goal of this thesis is to come up with the optimum and the best technique that can be the most effective one in the current scenario of 4G technology. The contribution of this thesis is given below:

- The optimum DOA estimation algorithm and adaptive beam forming algorithm for smart antenna system has been proposed out of the already existing ones which is best suitable to mitigate interference in 4G technology.

- Detailed mathematical analysis of those techniques has been done and the afficacy of these schemes has been done using MATLAB software.

1.5 THESIS ORGANISATION

The thesis is categorized into six chapters. The ongoing chapter introduces the thesis first. The motivation and objective of the thesis has been discussed in this chapter followed by the literature review. The uttermost sub section provides the contribution of the thesis towards this field of research and the flow of the thesis is finally discussed.

Chapter 2 gives a brief idea about the recent 4G technology and how the world migrated towards it. Some of the benefits of this technology and challenges faced by it are discussed here. The effect of multipath fading and Co-channel interference on the wireless channel has been discussed in details in this chapter.

Chapter 3 focuses on various antennas and antenna systems existing in the current scenario. The chapter starts with an introduction where the concept of frequency reuse is discussed followed by the various multiple access schemes and their advantages and disadvantages. The concept of smart antenna and the details of its types and working principle have been discussed in this chapter. The benefits and drawbacks of such system has also been cited.

Chapter 4 starts with an introduction to the concept of DOA. A detailed study of ULA has been carried out as throughout the thesis this adaptive array structure has been used. Then study and comparison of various DOA estimation schemes are carried out. The results of the comparison are simulated using the MATLAB software and cited in this chapter.

Chapter 5 introduces to the concept of adaptive beam forming. Different types of beamforming techniques have been discussed and compared in this chapter followed by the complete description of how does and adaptive beamformer work. Then various adaptive beamforming techniques have been discussed in detail and MATLAB simulations have been carried out

Chapter 6 concludes the entire thesis and gives a brief description on the future scope in this area of research

2. CHAPTER-2

4G TECHNOLOGIES

2.1 INTRODUCTION:

In the telecommunication the number of smart phone users is increasing and most of the traffics is changing from speech based communication to multimedia communications. The world is now migrating towards 4G. 4G technology is providing high speed mobile broad band Internet Access. It provides a comprehensive IP where voice, data and multimedia access can be given at high speeds to users anytime and anywhere. Furthermore, nowadays most of the users equipped with a mobile device such as "iPhone" or "Blackberry" want to enjoy Internet and all its multimedia applications. However those type of applications, such as high-definition television, require a higher data rate than the one needed by standard data or voice traffic. But with this the multipath and CCI effect has decreased the coverage of the network thereby decreasing the system efficiency . In order to optimize the transmission to achieve a higher data rate and increase in capacity of the network, several techniques can be applied either at the transmitter or receiver side. Nowadays the most challenging techniques are estimation of Direction of Arrival (DOA) and Adaptive Beamforming.

2.2 FROM 1G TO 4G:

Going from the 1G to the fourth has made it possible for more and more services to be available on the mobile phones. This evolution has been obtained due to the digitalization of the information and the updating of the already available technologies.

The first Generation evolved around 1970s followed by the invention of the microprocessors. It used analog signal for transmission and reception and provided a data rate of 2.4kbps. AMPS was launched in United States as 1G of mobile system. It was based on FDMA technology which allowed users to make voice calls within one country. It had a few limitations like poor voice quality, battery life, poor handoff, large phone size, no security and limited capacity. No data traffic was available yet, the voice itself was the main traffic.

At the end of 1980s the 2G was developed. It was launched in Finland in 1991. Digitalization of the control link between mobile and base station and digitalization of the voice signal were the most advanced characteristics. The new system provided better quality and higher capacity. GSM and GPRS were the services available and TDMA the technology used. It provided a data rate of 64kbps and allowed services like SMS and MMS. No videos or other complex data could be exchanged.

2.5G was introduced between 2G and 3G which was 2G combined with GPRS. It provided an internet speed of 64-144kbps. Camera phones were introduced and it provided additional services like sending and receiving e-mails. It also allowed web browsing.

The 3G network was deployed in Japan in 2001 which provides a data transmission rate of 144Kbps to 2Mbps. The systems in this standard are an update from 2G, going from circuit switched nodes to packet oriented nodes. The advantages of 3G systems are mainly the increase of available bandwidth per single user to 5-20MHz with an increased frequency of 1.6-2GHz and the possibility to have multimedia entertainment services like exchanging both audio and video on the mobile phones with a download and upload rate of 5.8Mbps. A lot of technology are being standardized for the 3G system all around the World, but the most important change comparing with the 2G is the use of CDMA as access technology. Regarding the 3G, some of the services have been standardized are enhanced data rates for global evolution EDGE and UMTS. But then it also had some limitations like expensive and large phones were required to avail this technology.

The service provided by 4G is referred as the MAGIC (M- Mobile Multimedia, A- Anytime Anywhere, G- Global Mobility Support, I- Integrated Wireless Solution, C- Customized Personal Service) technology. The 4G services are expected to be ultra-broad band with an increased bandwidth of 100MHz offering a frequency of 2-8GHz, with large capacity, with high-speed transmission of 100Mbps to 1Gbps and download and upload rate of 14Mbps. Going from 3G to 4G the infrastructure will have only packet switched traffic also named as all-IP. Voice, data and multimedia application can all be availed on the same Communication System. The 4G systems are OFDM based system, which is a technology that increases the system capacity and the spectrum utilization in order to have a wide band communication. The technologies which are considered to be pre-4G are WiMax and 3GPP LTE (Long Term Evolution).

2.3 ADVANTAGES OF 4G TECHNOLOGIES:

4G [9] [30] technology opened doors for LTE, WiMax and HSPA+ have been designated as 4G as they provide multiple data rates per second both downstream and upstream which is way higher than provided by 3G network system.

Upgrading to 4G networks allowed the two CDMA networks, Sprint and Verizon to offer a higher data transmission rate than 3G.

Streaming video works better in 4G, with less stuttering and higher resolution. Video conferencing and multiplayer online games work better with the faster data rate offered by 4G. 4G internet connections are about four times faster than the predecessors. It provides global access, service portability, scalable mobile services, better scheduling and call admission control techniques.

A broader network is provided by 4G which is opposed in Wi-Fi and other network connections. An entire city or block can be turned to a hotspot using 4G. Coverage can go as far as 30 miles or more.

4G guarantees high security. Its protocol makes use of a security plan that is the most advanced in wireless technology. It is very strong and reliable network prevents information from being taken or hacking to take place.

2.4 CHALLENGES IN INTEGRATING 4G WIRELESS SYSTEM

A number of challenges are faced while migrating from 3G to 4G. these challenges are classified into three categories as Mobile system, system and service.

- **Mobile station:** we have to use a completely different mobile and network here which is an important issue. “Multi-mode devices” can be used to mitigate this issue. The most applicable technology based on time, places and services can’t be accessed due to privatization of protocols of various service providers. The concept of “System- initiated discoveries” is used to avoid this issue where depending on the network to which the user is connected, the most applicable apps are automatically downloaded. Also the end user can be connected to different networks through an overlay network to avoid such a problem. There are also issues related to the proper selection of wireless networks and the incompatible roaming frequencies.

- **System challenges:** Location management and hand-offs are major issues in 4G technology. In 4G wireless environment there is a problem in integrating the IP based and the non-IP based systems. There is a high risk of security attacks because of the nature of 4G technology. So increased authentication is required to protect the data transmitted across the network.
- **Services**: 4G networks are still years away in reality. It has only been implemented in some major cities like London, Germany, etc. billing and providing services to the customers has become quite complicated. Personal mobility is also another concern here.

2.5 MULTIPATH AND CO-CHANNEL INTERFERENCE

2.5.1 Multipath

Multipath [12] is a condition where multiple signal paths are generated between base station and the user due to reflection from various physical obstacles.

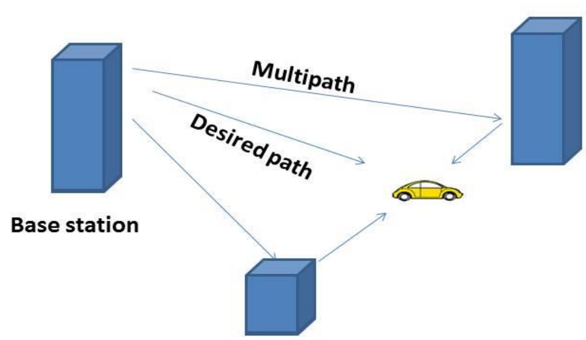

Figure 2.1: The Effect of Multipath on a Mobile User

2.5.2 Problems Associated with Multipath

The problem is due to the phase of arriving waves at the receiver which don't match always due to the combination of undesired reflected signal. Figure 2.2 illustrates unsynchronized signals as received by the receiver.

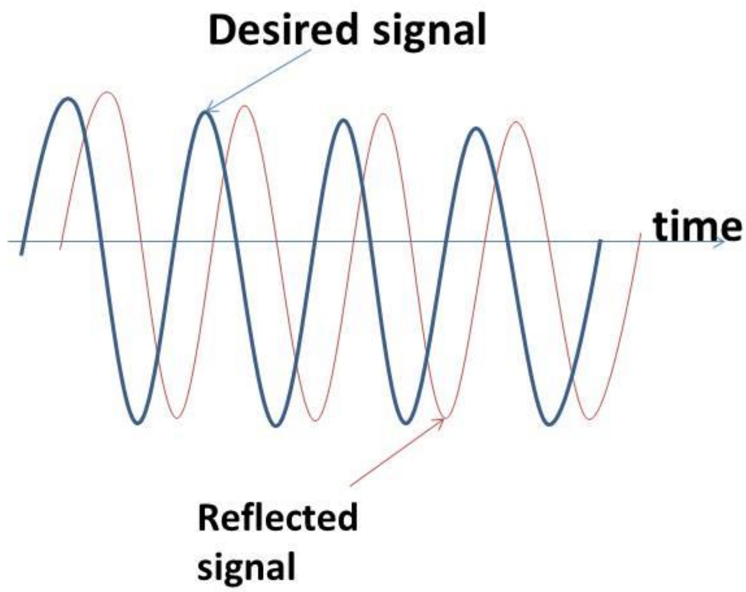

Figure 2.2: Two unsynchronized Multipath Signals

2.5.3 Conditions caused by multipath

- **Fading –**signal strength reduces when the the signals propagating are out of phase. This is a fade. This constantly changing 3-D phenomenon is known as "Rayleigh fading" or "fast fading." There are tiny fade zones, which cause periodic attenuation of signal whenever a user passes through it that leads to degradation in quality of the signal.

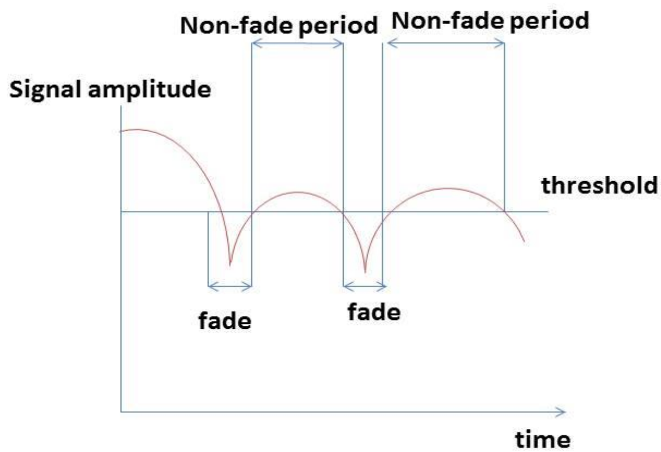

Figure 2.3: A Representation of the Rayleigh Fade Effect on a User Signal

- **Phase cancellation--** The signals will cancel each other by rotating the waves of two multipath signals by 180°. When there is no signal with a poor quality a call can survive for a small amount of time.

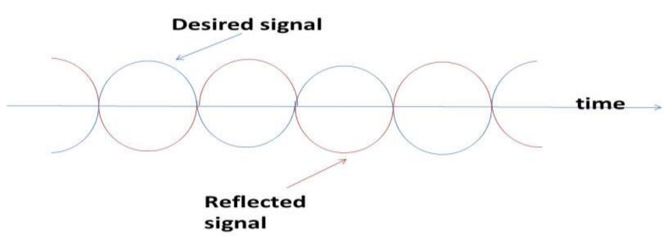

Figure 2.4: Illustration of Phase Cancellation

- **Delay Spread—**Due to the multipath effect, the signal quality TDMA can be slightly different. Here, the main concern is that multiple reflections of the same signal which can result in ISI which can be a problem for the receiver. The bit error rate rises due to this and hence there is a major degradation in signal strength.

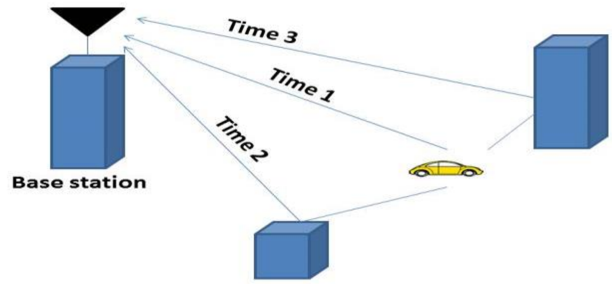

Figure 2.5: Multipath: The Cause of Delay Spread

2.5.4 Co-channel interference

CCI [12] occurs when the signals of same carrier frequency reaches the same receiver from two separate transmitters.

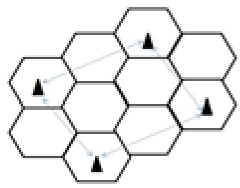

Figure 2.6: Illustration of Co channel Interference in a Typical Cellular Grid

Both conventional and directional antenna systems scatter signals over a wide range. The signals that miss a desired user can become interference for other users on the same frequency in the same or adjoining cells.

So there is a very much necessity of managing the effect of CCI. Smart antennas are now used to mitigate these effects.

3. CHAPTER-3

ANTENNAS AND ANTENNA SYSTEMS

3.1 INTRODUTION:

In most wireless communication system, base stations and mobiles are two major components. The base station is found at the middle of a coverage area called a ‘cell’ and the mobiles can be anywhere inside the cell. Communication between the base station and the mobile takes place through the wireless channel. For signal transfer, a certain amount of spectrum is assigned to a cell. Wider spectrum can provide service to a huge number of users. To serve a large area, one can rely on a high power base station to cover the entire area which then limits the number of users. So instead of having a single large cell, multiple cells with smaller size are used to cover a large area. To avoid severe interference between cells, base stations that are adjacent to one other are allocated different spectrum or channel groups. Also the output power of the base station is set in such a way that it is enough to cover the whole area up to the cell boundary. With this way, cells that are separated by an adequate amount of distance can use the same spectrum and this method is termed as Frequency Reuse. This is true as long as the interference caused by surrounding co-channel cells is within tolerable limits. Figure 3.1 shows a frequency reuse topology with a cluster size of seven. In this frequency reuse pattern, each cell in the cluster has one-seventh of the total spectrum, and the same spectrum is used in cells with the same label.

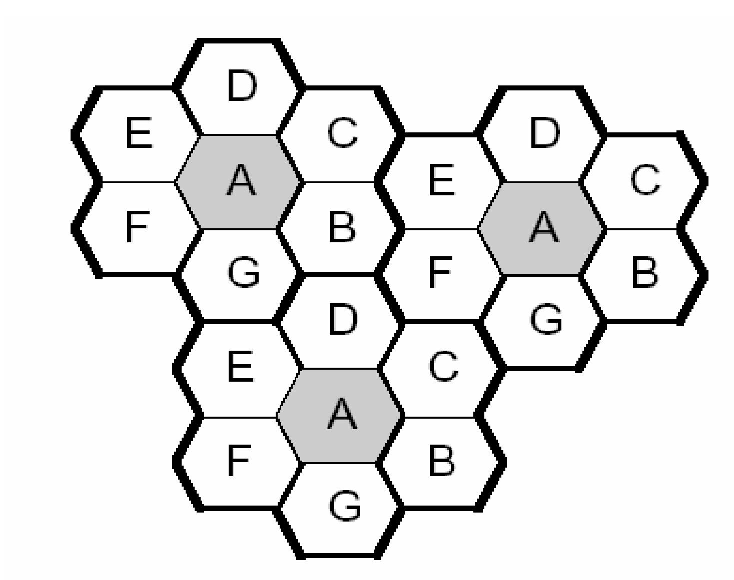

Figure 3.1: Frequency reuse topology

For making simultaneous communication with multiple users within the same cell possible, the system has to incorporate methods to separate the signals from each user and this can be done by separating users through allocating different frequencies by proper filtering.

To improve the system performance, the easiest way is to use more spectrum in each cell so that more users can be handled by the same base station without changing the users' bandwidth or more bandwidth can be assigned to each user to achieve faster data rate in wireless channel. But this is an impractical and expensive approach because limited spectrum is allocated for wireless applications which costs a lot of money for the service providers to rent it. More spectrum is available at higher frequencies, but the cost of building RF components that work at these frequency ranges becomes an issue. Another approach to increase the capacity and the performance of the system is to minimize the size of a cell so that each serves a smaller area with the same amount of users, increasing overall density. This method is used by most service providers to increase the system capacity. However, there is still a limitation in how close co-channel cells can be put together to avoid CCI. Besides, more base stations are required to cover the same area, driving up the cost.

The next and optimal approach is little different from the previous two. In this technique, instead of finding more spectrums to serve the same number of users, different transmission techniques are used so that the system can serve more users with the same amount of available spectrum. Unlike the prior two approaches that do not require changes in the system design, this method needs hardware customized to the transmission method. Although the base station is more expensive, the additional cost is likely less than that of buying more spectrums. This system makes better use of the available spectrum and has a higher spectral efficiency.

The simplest access scheme is FDMA that is mainly used in analog systems. It is used in applications like TV broadcast, radio broadcast, cellular system, etc. Here signals from different users are transmitted in different frequencies to avoid interference. By passing the received signals through a band pass filter each signal is isolated from others. But with the invention of digital technology, TDMA and CDMA have become more popular these days. Unlike FDMA, which can only support one user per channel, both of these support multiple users per channel and increase the capacity of the system.

However, it is always a challenge to provide higher system capacity in the network to fulfill the growing demand. After a lot of research one recent development in this area is the use of smart antenna with algorithm, also known as SDMA technology.

SDMA is a totally different concept compared to TDMA and CDMA. It uses a different technique to separate users. Instead of using time or code, it separates user by their spatial locations. In the past, SDMA was used in military to counter electronic jamming in electronic warfare. It uses the fact that the jammer is usually located at a different point to the desired communication partner. By adjusting the radiation pattern of the antenna structure, the effect of the jammer can be reduced by placing a null in the direction of the jammer. This was sometimes done in by manually changing the orientation of a highly directional antenna. The same concept is now used to reduce interference from co-channel users. Also, no more hand-tuning is needed in the antenna since the radiation pattern can be changed by software.

The antenna design of SDMA system is different from the other systems. In a regular base station, the antenna is either Omni-directional or sectored. To make a connection between the base station and the mobile, the transmitted signal is broadcast from the base station antenna. Its goal is to cover the entire cell or sector so that the mobile can pick up the broadcast signal as long as it is within the coverage area. However, this kind of signal transmission wastes a lot of energy due to the fact that the mobile being addressed can only occupy one spot at a time. With broadcasting, most of the power is radiated in other directions instead of traveling toward the desired user. Besides, the broadcasting signal also causes undesired interference to other users located within the cell. If there is a way to point out a user within the cell so that the transmitting antenna aims toward the desired user, power wastage will be lessened. Also a lot of unnecessary interference can be removed from the desired signal. SDMA aims in combating these limitations.

Though the concept has been there since many years, it has not been implemented properly till date as the computation requirement is too complex and costly. As mentioned earlier, in order for the system to have a flexible radiation pattern, some types of adaptation process has to be implemented in the system. Also, there wasn’t a reason for the provider to use so much of money on something that was not necessary at that time. Only recently has the demand for system capacity gone up tremendously so that sophisticated multiple access schemes are now economically viable.

For the design of next generation wireless communication system, adoption of smart antenna technique is required which provides many advantages like mitiagating the effects of multipath and CCI, efficient use of spectrum,

3.2 ANTENNAS

An antenna (or aerial) is an electrical device where the electric power is converted into radio waves, and vice versa. The different types of antennas are discussed below.

3.2.1 Omni Directional Antennas

From the past years of wireless communications, the omni-directional antenna has been used, which radiates and receives in all directions. Here to overcome environmental challenges simply the power level of the broad casted signal is boosted. In a setting of numerous users (and interferers), this makes a bad situation worse in that the signals that miss the intended user become interference for those in the same or adjoining cells having the same frequency.

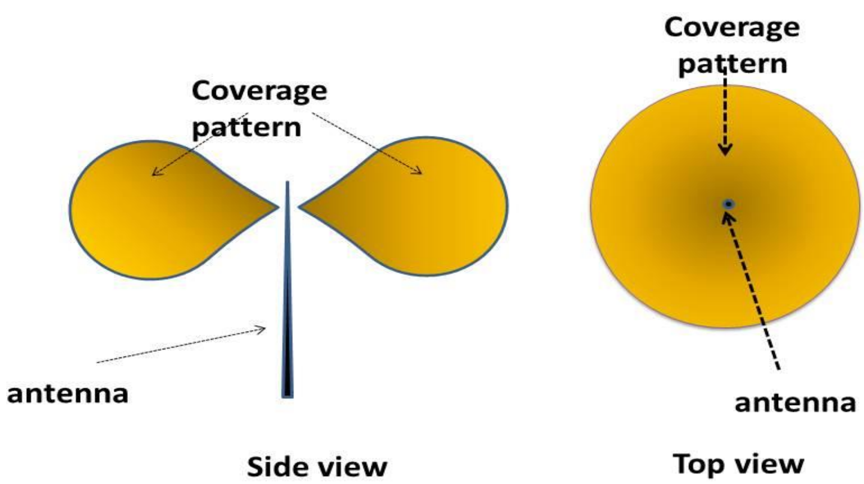

Figure 3.2: Omni directional Antenna and Coverage Patterns

3.2.2 Directional Antennas

Directional antennas have certain fixed preferential transmission and reception directions. The antennas have been sectorized like a 360 degree sector can be subdivided into 120 deg sectors which provide increased gain but the co-channel interference cannot be overcome through this sectorized antennas.

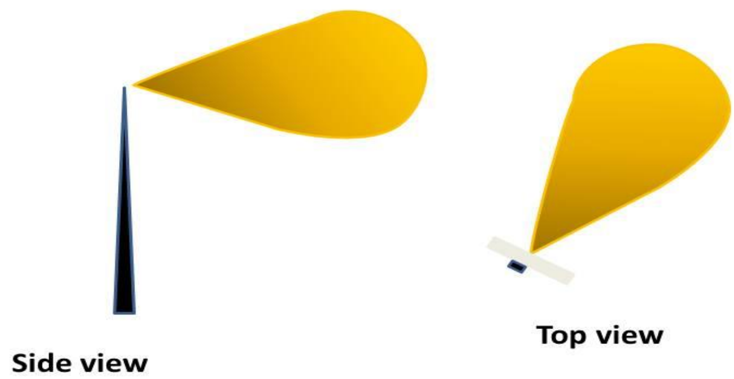

Figure 3.3: Directional Antenna and Coverage Pattern

3.3 ANTENNA SYSTEMS

Phased array antenna systems have been designed now to make the antennas more intelligent where the weights are continuously adapted to shift the signal before transmission and reception.

The following summarizes antenna developments in order of increasing benefits and intelligence.

3.3.1 Sectorized Systems

Here the cell is divided into a number of sectors and each sector is treated as a different cell. The frequency reuse factor can be increased through this by reducing the potential interference access across the original cell.

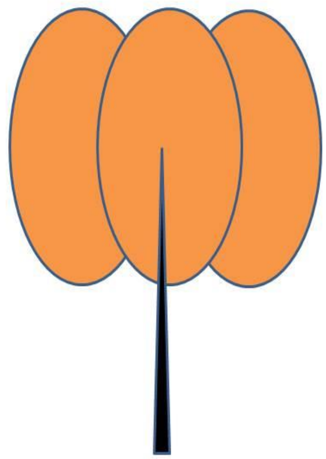

Figure 3.4: Sectorized Antenna and Coverage Patterns

3.3.2 Diversity Systems

SDMA is used to mitigate the effects of multipath. The following are the diversity technique used to increase the signal strength.

• **Switched diversity**: here the beam is switched according to the element with the largest output considering that there is atleast one antenna in the favourable location. Though they reduce the effect of signal fading but they can only increase the gain of one antenna element at a time.

• **Diversity combining:** here the phase error between the two signals is reduced and the signals are combined to improve the gain. Other diversity systems, such as maximal ratio combining systems, combine the outputs of all the antennas to maximize the ratio of combined received SNR. But this technique fails in high interference system. And the interfering signal might be received rather than the desired ones.

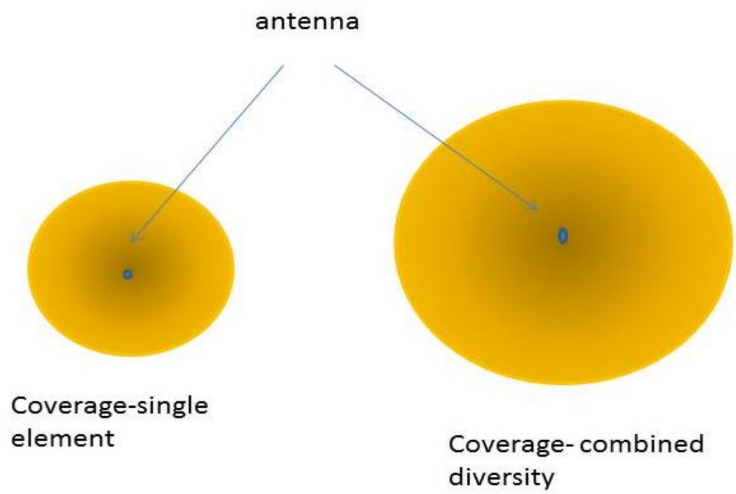

Figure 3.5: Combined Diversity Effective Coverage Pattern with Single Element and Combined Diversity

3.4 SMART ANTENNAS

The availability powerful DSPs and ASICs as well as innovative software-based algorithms for signal processing have made intelligent antennas practical for wireless communications systems. A smart antenna system can be implemented which can detect the desired user while nullifying the undesired ones. Let us now study the different types of smart antenna systems, how they work and the pros and cons of smart antenna systems.

3.4.1 Types of Smart Antenna Systems

Smart antenna systems are categorized into switched beam or adaptive array systems. The following gives the difference in both the systems.

• **Switched beam**: A finite number of fixed and predefined patterns or combining strategies (sectors)

• **Adaptive array**: An infinite number of patterns (scenario-based) that are adjusted in real time.

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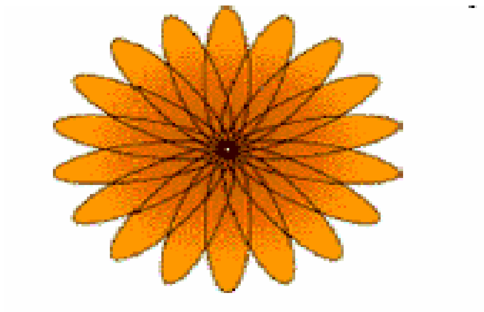

Figure 3.6: Switched Beam System Coverage Patterns (Sectors)

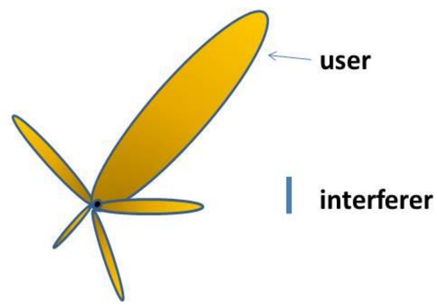

Figure 3.7: Adaptive Array Coverage

Both types of smart antenna systems provide significant gains over conventional sectored systems. In adaptive array system the gain towards the undesired user is lowered and gain towards the desired user is increased. So the interference due to the undesired ones is decreased.

Figure 3.8: Beam forming Lobes and Nulls that Switched Beam (Red) and Adaptive Array (Blue) Systems might choose for Identical User Signals (black Line) and Co channel Interferers (grey lines)

Antenna elements can be arranged in the configuration show in the figure below. They can be either implemented at the base station or in the laptops or mobile phones.

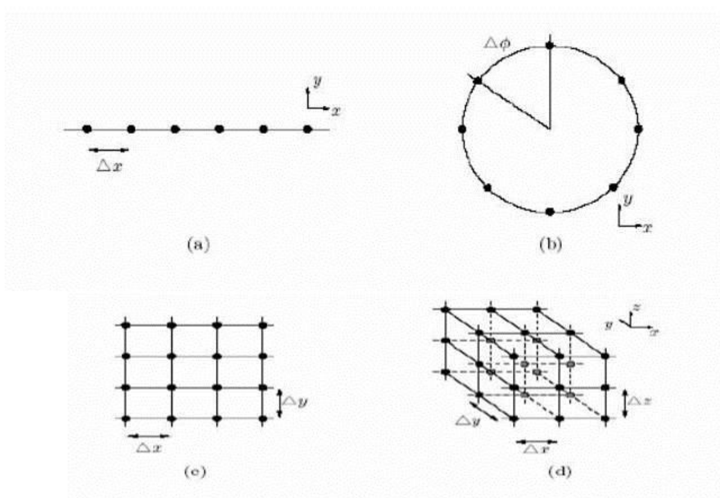

Figure 3.9: Different array geometries for smart antenna: a) Uniform linear array, b) Circular array, c) Two dimensional grid array and d) Three dimensional grid array

3.4.2 How do smart antenna systems work?

Smart antenna systems use the adaptive array systems which consist of two main functions:

- The first function is Direction of Arrival (DOA) in which the angle of arrival of the desired user can be detected so that the main beam can be directed towards it.
- The second function is the beamforming, where the adaptive antenna arrays are updated to direct the main beam towards the desired user and place nulls in the direction of undesired users.

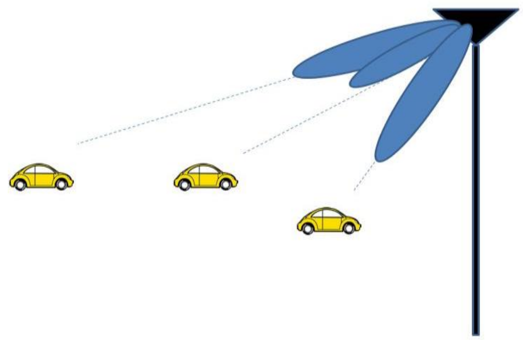

Figure 3.10: Smart antenna system

3.4.3 Advantages of implementing Smart Antennas [8]

• **Reduction in Co-channel interference:** Smart antenna can focus radiated energy in the form of narrow beams only in the direction of the desired user through spatial filtering.

• **Range improvement:** The adaptive array elements used in Smart Antennas radiate narrow beams with increased gain as compared to conventional antennas with same power. This increase the range and coverage of the system and less number of base stations are used to cover a given area.

• **Increase in capacity:** Reduction of co-channel interference using smart antennas increases the frequency reuse factor which increases the system capacity.

• **Reduction in transmitted power:** Smart Antennas radiate energy only in the desired direction which reduces the wastage of power and also reduces interference towards other users.

• **Reduction in hand-off:** Congested cells are further broken into micro cells to improve the capacity of a crowded cellular network by increasing the frequency re-use factor. This result in frequent hand-offs due to smaller cell size. With the use of Smart Antennas this cellular division can be avoided as capacity is increased by using spot beams. So, hand-offs occur rarely, only when two beams using the same frequency cross each other.

- **Mitigation of Multipath effects:** Smart Antennas can either reject multipath components as interference, thus mitigating its effect in terms of fading or it can use the multipath components and add them constructively to enhance system performance.
- **Compatibility:** Smart Antenna systems can be implemented in various multiple equipment and add them constructively to improve system performance.

3.4.4 A few drawbacks of Smart Antenna

Computational complexity is more. The establishing cost is high but it is very beneficial in long term and is cheaper. It requires very powerful DSP systems. Separate transceiver chains are required for each antenna element with accurate real time caliberation.

4. CHAPTER-4

DIRECTION OF ARRIVAL

4.1 INTRODUCTION:

Direction of Arrival (DOA) estimation has been an active area of research since past few years. These techniques have found wide applications in the field of radar, sonar, electronic surveillance and seismic exploration. The goal of DOA estimation is to estimate the direction of arriving signal by collecting the data received from the array. The DOA estimation results are further used to design the adaptive beam former by the array to optimize the power radiated towards the users and to damp out the interference due to other users (Figure 4.1). In a nutshell, the successful design of adaptive array smart antenna depends highly on the performance of DOA estimation algorithm. The efficiency of DOA estimation depends on various parameters such as the density of mobile users, the number of array elements used and the spacing between them, the number of signal samples and signal to noise ratio (SNR). DOA estimation algorithms can be broadly categorized into four methods which are; convolutional techniques, maximum likelihood techniques, subspace based techniques, and integrated techniques. The conventional methods lack angular resolution capability. Hence high angular resolution subspace methods such as MUSIC and ESPRIT algorithms are used in common.

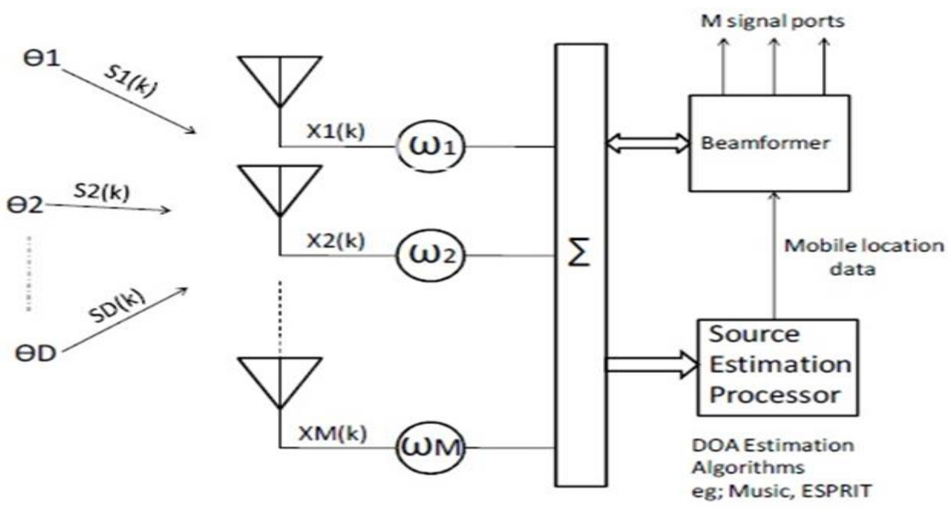

Figure 4.1: M element antenna array with D arriving signals

4.2 ANTENNA ARRAYS:

Antenna arrays have a number of identical antenna elements which have identical orientation distributed

4.2.1 Uniform Linear Array:

Uniform linear arrays are equispaced and are excited with uniform current with constant progressive phase shift.

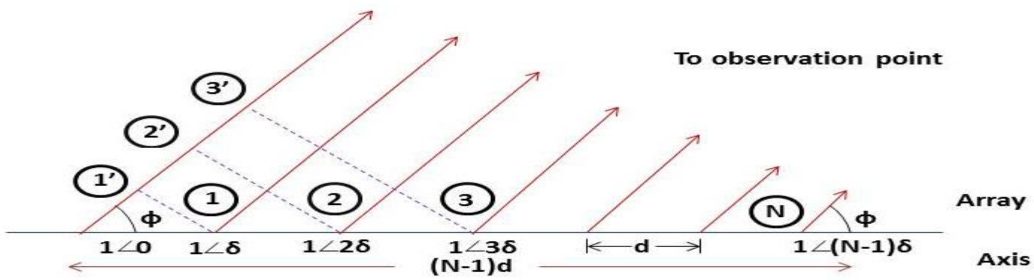

Figure 4.2: Uniform linear array

4.2.1.1 Element spacing 'd':

This is the spacing between any two adjacent antenna elements of the array.

4.2.1.2 Phase shift between the array elements 'δ':

This is the phase shift between the currents of any two adjacent antenna elements of the array.

The phase of the field has two components:

(1) The phase due to the phase of the excitation current.

(2) The phase due to propagation. If the observation point P is in a direction which makes an angle ϕ with the array axis, the propagation phase difference between radiations from two adjacent elements is $\beta d\cos\phi$.

The total phase difference, ϕ, between the fields due to adjacent elements is algebraic sum of the current and the propagation phase difference

$$\Phi = \beta d\cos\phi + \delta$$

Without losing generality, let’s assume that the electric field due to individual antenna element has unit amplitude at the observation point P. Let the first element be the reference element. So by definition the phase of the field due to antenna 1 is zero. And now the total electrical field at the observation point is,

$$E = e^{j0} + e^{j\phi} + ... + e^{j(N-1)\phi}$$

$$E = \{1 + e^{j\phi} + ... + e^{j(N-1)\phi}\}$$

After some manipulations, we obtain the electric field at the observation point as,

$$|E| = \left| \frac{\sin(\frac{N\phi}{2})}{\sin(\frac{\phi}{2})} \right|$$

The maximum electric field is obtained when all the terms in the series add in phase (i.e. for $\phi=0$). The maximum field therefore is N. The expression gives the variation of field as a function of the direction, ϕ , and hence gives the radiation pattern of the antenna array. The radiation pattern is generally normalized with respect to the maximum value N to get the ‘ **Array Factor** ' as,

$$AF \equiv \frac{1}{N} \frac{\sin(\frac{N\phi}{2})}{\sin(\frac{\phi}{2})}$$

This is the general expression for the radiation pattern of a uniform array.

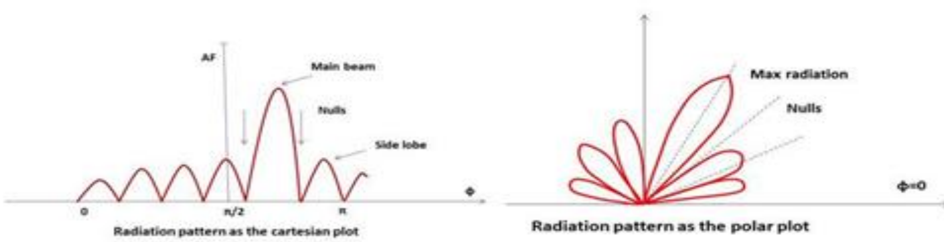

Figure 4.3: A typical radiation pattern

4.2.1.3 Direction of maximum radiation:

The direction of maximum radiation (direction of the main beam) is one of the important features of the array. The maximum radiation is obtained when ϕ=0 . If the direction of maximum radiation is denoted by ϕ_{max} we have,

$$\phi = \beta d \cos\phi_{max} + \delta = 0$$
$$\Rightarrow \cos\phi_{max} = -\frac{\delta}{\beta d}$$
$$\Rightarrow \phi_{max} = \cos^{-1}\left(-\frac{\delta}{\beta d}\right) = \cos^{-1}\left(\frac{\delta\lambda}{2\Pi d}\right)$$

The array phase in terms of the direction of main beam can be written as,

$$\phi = \beta d(\cos\phi - \cos\phi_{max})$$

Two things are inferred from the equation.

(1) The direction of the maximum radiation is independent of the number of elements in the array.

(2) The direction of the main beam can be changed from 0 to by changing the progressive phase shift δ from –βd to +βd.

4.2.1.4 Broadside array and End-fire array:

.An array is said to be End-fire array if the main beam is along the axis of the array. An array is said to be Broadside array if the main beam is perpendicular to the axis of the array.

There are two end-fire directions for an array but the broadside is a plane perpendicular to the array axis.

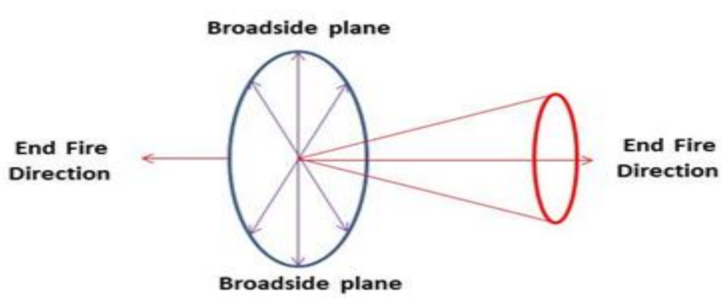

Figure 4.4: Radiation pattern of broadside and end-fire array

4.2.1.5 Directions of Nulls

The nulls of the radiation patterns can be obtained by equating the array factor to zero. The direction of the null, ϕ_{null} can then be represented as,

$$\cos\phi_{null} = \cos\phi_{\max} \pm \frac{m\lambda}{dN}$$

For finding the directions of the nulls all possible values of have to be tested.

4.2.1.6 Directions of Side-lobes

The Local maximum in the radiation pattern is known as the side lobe. One side lobe is present between two adjacent nulls except the main beam. There is a side-lobe in the radiation pattern whenever the numerator of the AF is maximum. The directions of the side-lobes are generally taken approximately half way between two adjacent nulls. The direction of a side lobe is represented as

$$\cos\phi_{SL} = \cos\phi_{\max} \pm (m+\frac{1}{2})\frac{\lambda}{2d}$$

where m=1,2,…..

The amplitude of the side lobe can be obtained by substituting the value of ϕ in the AF. The amplitude of the m^{th} side lobe is,

$$\frac{1}{N}\left|\frac{1}{\sin(\pm(m+\frac{1}{2})\frac{\pi}{N})}\right|$$

For a large array $N >> 1$ and the side lobe amplitude is approximately equal to $\frac{2}{(2m+1)\pi}$

The first, second, third side lobe amplitudes are $2/3\pi$, $2/5\pi$, $2/7\pi$ respectively. The important thing to note is that the side lobe amplitudes are independent of the array size and the direction of the main beam.

4.2.1.7 Grating lobe

Grating lobe is identical to the main beam but is directed in the undesired direction. The power radiated by the array is divided between the main beam and the grating lobe for which power efficiency in the direction of the main beam is consequently reduced. And therefore a grating lobe should be avoided in the radiation pattern. A grating lobe appears when $\phi=2m\pi$, where ‘m’ is an integer.

For broadside array the grating lobe appears when $d \geq \lambda$, and for the end-fire array it appears when $d \geq \lambda / 2$. So we can conclude that to avoid grating lobe in the radiation pattern for any array the inter-element spacing ‘d’ should be less than λ/2.

4.2.1.8 Effect of antenna radiation on the array:

The radiation pattern of the antenna elements used in the array is called the ‘primary pattern'. If the array consists of non-isotropic similar elements, the effect of the primary pattern can be detected very easily. Since the radiation due to every element is weighted by the primary pattern, the total radiation pattern of an array is the product of the primary pattern and the AF.

Radiation pattern = Primary pattern * Array Factor

So while analyzing the array of non-isotropic and identical elements first find the AF assuming the elements to be isotropic and then multiply the AF with the primary pattern to obtain the total radiation pattern.

4.3 ARRAY DIRECTIVITY:

The directivity of an array [29] depends on the array element spacing ‘d’ and the phase shift between them.

4.3.1 Directivity

The directivity of the uniform array is given by,

$$D = \frac{4\pi}{\iint |AF|^2 \, d\Omega}$$

For larger arrays, the directivities for the broadside and end-fire arrays are given as,

$$D_{BS} = \frac{4\pi}{2\pi\phi_{BS}} = \frac{2dN}{\lambda}$$

$$D_{EF} = \frac{4\pi}{\pi(\frac{\phi_{EF}}{2})^2} = \frac{8dN}{\lambda}$$

4.3.2 Effect of varying element spacing ‘d’ on Broad-side array

Consider a 4-element broadside array and observe the change in the radiation pattern as the element spacing ‘d’ is varied.

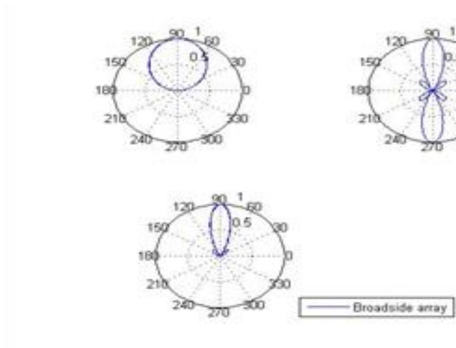

Figure 4.5: broadside array for no. of elements=4 and d=0.5

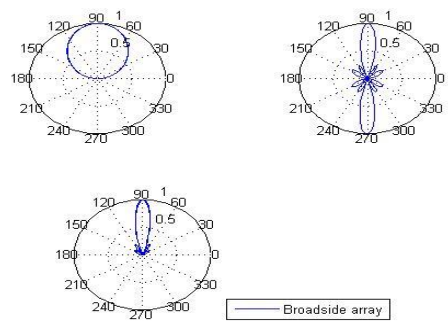

Figure 4.6: broadside array for no. of elements=4 and d=0.75

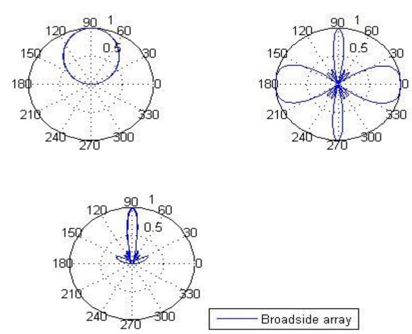

Figure 4.7: broadside array for no. of elements=4 and d=1

Broadside array generates two main lobes, one is in desired direction and other is undesired direction. The undesired lobe may result intoto interference. That problem will reduce by introducing some phase shift like in the end fire array.

4.3.3 Effect of varying element spacing ‘d’ on End-fire Array:

Consider a 4-element End-fire array and observe the change in the radiation pattern as the element spacing ‘d’ changes from 0.5 to 1.

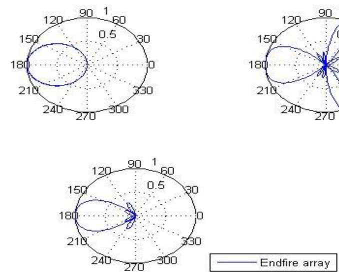

Figure 4.8: End-fire array for no. of elements=4 and d=0.5

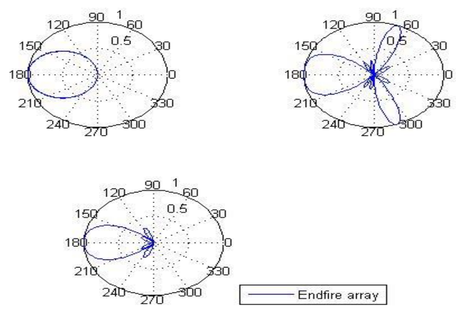

Figure 4.9: End-fire array for no. of elements=4 and d=0.75

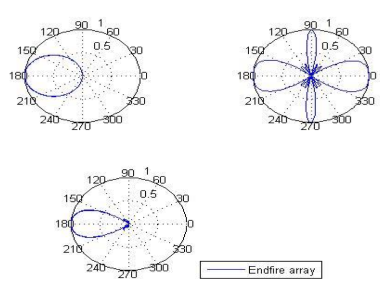

Figure 4.10: End-fire array for no. of elements=4 and d=1

4.4 DOA ESTIMATION ALGORITHMS

4.4.1 MUSIC Algorithm:

MUSIC (Multiple Signal Classification) [13] [15] goes through the input covariance matrix for weight updation. In MUSIC an assumption is undertaken, that the noise in each channel is uncorrelated to each other leading to a diagonal correlation matrix. The correlation of incident signals are found out from the non-diagonal signal elements of the correlation matrix.

Suppose D no.of signals are impinging on an M array elements. So, the number of signal eigenvalues and eigenvectors is D and number of noise eigenvalues and eigenvectors is M-D. The array correlation matrix with uncorrelated noise and equal variances is then given by,

$$R_{xx} = A*R_{ss}*A^H + \sigma_n{}^2*I$$

Where $A = [a(\theta_1)\ a(\theta_2)\ a(\theta_3)\ \text{---}\ a(\theta_D)]$ is M x D array steering matrix

$R_{ss}=[S_1(k)\ S_2(k)\ S_3(k)\ \text{----}\ S_D(k)]^T$ is D x D source correlation matrix

Rxx has D eigenvectors associated with signals and M – D eigenvectors associated with the noise. The M x (M-D) is then constructed

$$V_N = [v_1\ v_2\ v_3\ \text{-------}\ v_{M-D}]$$

At the angles of arrivals θ_1, θ_2, θ_3, $\theta_{D,}$ the noise subspace eigenvectors are orthogonal to array steering vectors and the MUSIC Pseudo spectrum is given as:

$$\mathbf{P_{MUSIC(\theta)} = 1/abs((a(\theta)\theta^H\ V_N\ V_N{}^H a(\theta))}$$

4.4.2 ESPRIT Algorithm

ESPRIT (Estimation of Signal Parameters via Rotational Invariance Techniques) [13] [15] is another subspace based DOA estimation algorithm which reduces the computational and storage requirements because it doesn’t go through all the array steering vectors. The motive behind the ESPRIT technique is that the signal subspace created by two translational invariance arrays has no rotational invariance. The assumption made in ESPRIT are that of the existence of only $D < M$ narrowband sources centered at the centre frequency f0 and there exist a number of identical arrays known as doublets which are displaced translationally but not rotationally. Figure 5.11 shows a four element linear array comprising of two doublets.

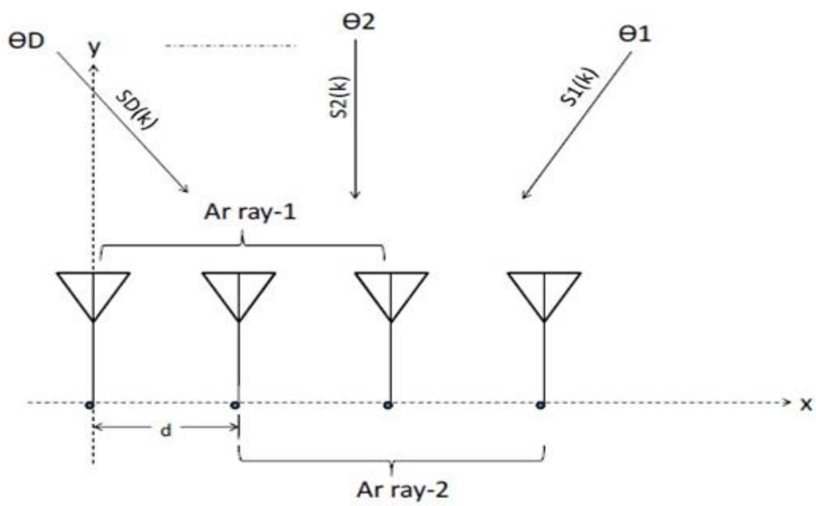

Figure 4.11: four element linear array with two doublets

The two subarrays, array-1 and array-2 are displaced by distance ‘d’. The signals induced on each of the arrays are given by

$$x_1(k) = A_1*s(k) + n_1(k)$$

and

$$x_2(k) = A_1*\Lambda *s(k) + n_2(k)$$

where $\Lambda = \text{diag}\{e^{jkdsin(\theta 1)}\ e^{jkdsin(\theta 2)} \text{-----}\ e^{jkdsin(\theta D)}\}$

This gives rise to two matrices V_1 & V_2 and since the arrays are translationally related, the subspaces of eigenvectors must be related by a unique nonsingular transformation matrix ɸ such that

$$V_1\phi = V_2$$

There must also exist a unique nonsingular transformation matrix T such that $V_1 = AT$ and $V_2 = A\Lambda T$ and finally we can derive

$$T\ \Phi T^{-1} = \Lambda$$

Thus the eigenvalues of ɸ must be equal to the diagonal elements of Λ such that

$\lambda_1 = e^{jkdsin(\theta 1)},\ \lambda_2 = e^{jkdsin(\theta 2)}$ ----- $\lambda_D = e^{jkdsin(\theta D)}$

Once the eigenvalues values calculated, we can estimate the angles of arrivals as

$$\theta_i = \sin^{-1}(\arg(\lambda_i)/kd)$$

4.5 SIMULATION AND RESULTS

4.5.1 MUSIC ALGORITHM

A GUI based MATLAB simulation was developed to study and compare the performance of MUSIC Algorithm by varying the number of elements and data snapshots while the angle of arrivals and the power of the incoming signals remain the same.

A uniform linear array with M elements was considered for the implementation.

The results are noted below.

4.5.1.1 Comparison of performance of MUSIc Algorithm by varying the number of antenna elements 'M'.

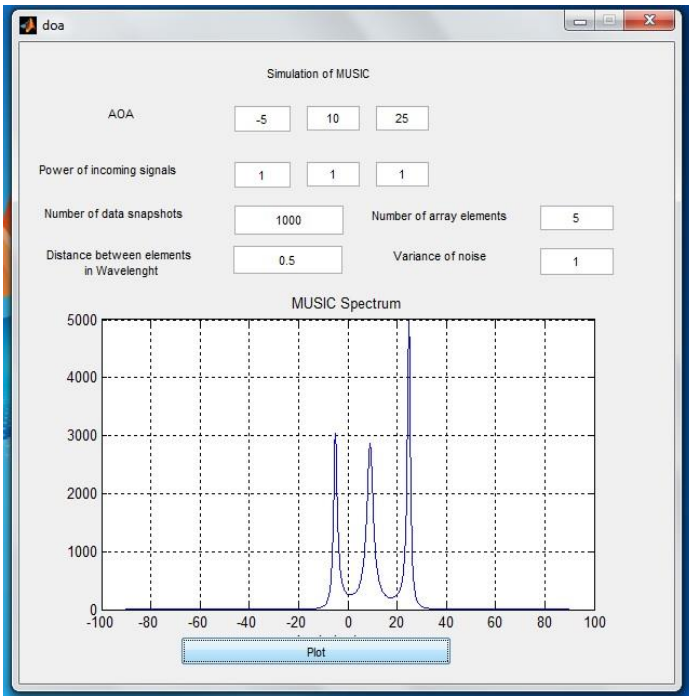

Figure 4.12: MUSIC spectrum for M=5 and AOA=-5, 10, 25

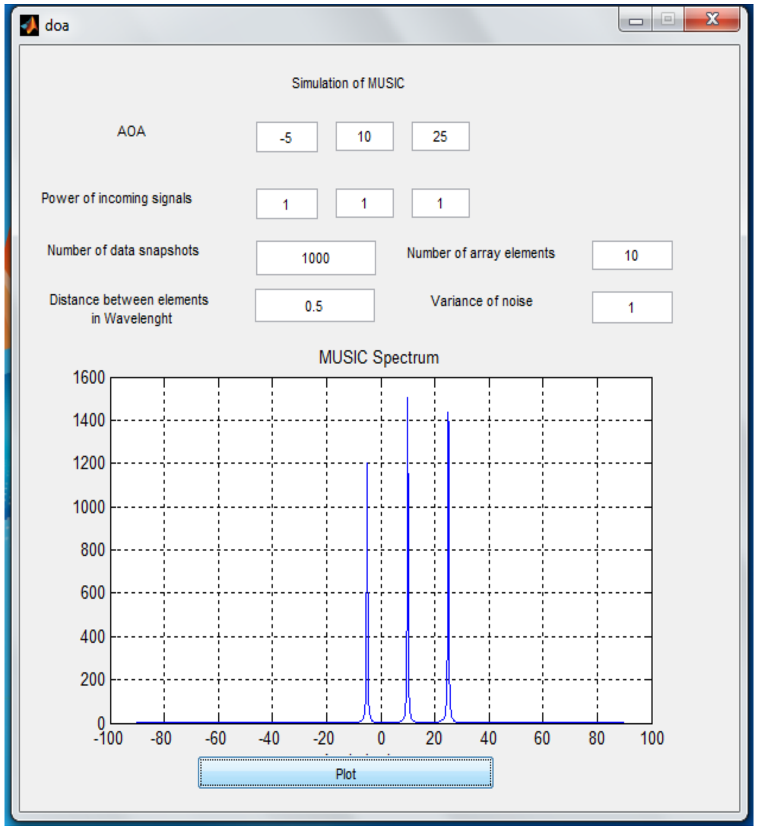

Figure 4.13: MUSIC spectrum for M=10 and AOA=-5, 10, 25

Clearly from the above two figures it is seen that as the number of antenna elements was increased from 5 to 10, then the spectrum takes the form of sharper peaks thus improving the angular resolution.

4.5.1.2 Comparison of performance of MUSIC Algorithm by varying the number of data snapshots

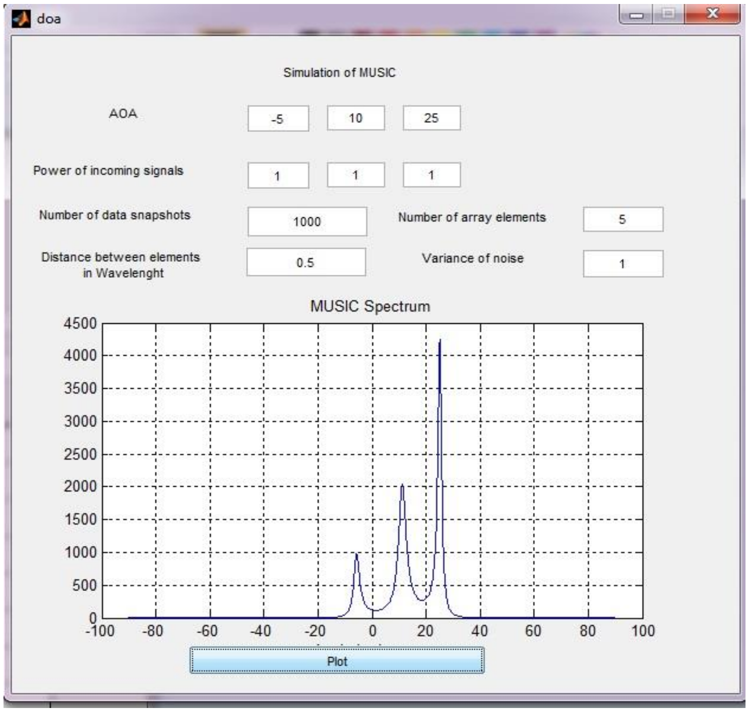

Figure 4.14: MUSIC spectrum for no. of data snapshots=1000 and AOA=-5, 10, 25

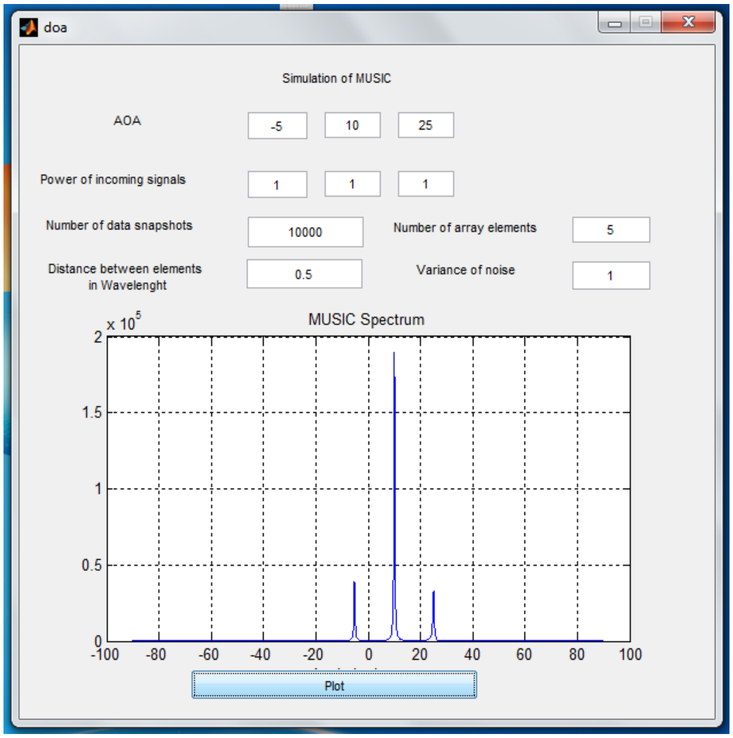

Figure 4.15: MUSIC spectrum for no. of data snapshots= 10000 and AOA=-5, 10, 25

Clearly it is seen from the above two figures that increasing the number of snapshots from 1000 to 10000, the peaks get sharper making the more accurate detection and improving the resolution.

4.5.2 ESPRIT Algorithm

A MATLAB based simulation is carried out using 4-element linear uniform array to study and compare the performance of ESPRIT Algorithm by varying differenet antenna parameters.

The observations are noted in the table and the results are discussed below.

4.5.2.1 Comparison of performance of ESPRIT Algorithm to different angular separation of incoming signals

Table 4.1: Performance of ESPRIT Algorithm by varying the angular separation of the incoming signals

Sr.no.	***θ Input (deg)***	***θ ESPRIT (deg)***
1	20	19.57
	35	34.59
2	20	20.03
	80	80.27

Clearly from the above table it can be seen that as the angular separation between the incoming signals increases, the percentage of error in DOA estimation decreases. So it is clear that the algorithm fails when the traffic is congested with more number of users and the angular separation between the signals is less.

4.5.2.2. Comparison of performance of ESPRIT Algorithm to different number of data snapshots

Table 4.2: Performance of ESPRIT Algorithm for varying number of data snapshots

K=1/15000	
θ Input (deg)	θ ESPRIT (deg)
85	84.39
25	24.92
K=1/8000	
85	85.04
25	25.00

Clearly from the above table we can infer that if the number of data snapshots is increased, the percentage of error of DOA estimation increases.

4.6 CONCLUSION

From the simulation results of MUSIC and ESPRIT it is evident that the performance of both the algorithms can be improved with the introduction of more elements in the array, using greater snapshots of signals and large spatial separation between them. The enhancements are clear from the existence of sharp peaks in MUSIC and reduced angle detection errors in ESPRIT. The use of MUSIC algorithm in DOA estimation shows less error compared to its counterpart i.e. ESPRIT algorithm which also fails to act on increasing the number of incident signals. So, from the simulation result it is clear that MUSIC algorithm is superior, stable and accurate with higher resolution as well as it introduces possibilities of user differentiation with the help of SDMA and hence can be largely implemented for the design of smart antenna system.

5. CHAPTER-5

ADAPTIVE BEAMFORMING

5.1 INTRODUCTION:

Adaptive beamforming is a method where the main beam is directed towards the desired user and nulls are placed in the direction of undesired users which is continuously updated according to the changing environment. This is achieved by varying the weights of each sensor (antennas) used in the array. In adaptive beamforming the optimum weights are iteratively computed using complex algorithms based on many criteria. An advantage of adaptive beamforming is that, there is no need to change the hardware of the system, a simple change in the program of the software is enough to update it. It can also optimize the array pattern as per the change in the electromagnetic environment.

There are various causes found to degrade the Conventional array static processing systems. Like the presence of different unwanted interfacing signal, cluster return, counter measures, reverberation returns leading to multipath interference as well as fading of signal. So, recent efforts are made to digitalize the wireless communication system by introducing the system with adaptive beamforming and digital beamforming techniques. This chapter concerns about the comparative study of the various types of adaptive beam forming algorithms and chose the optimum one for mitigating interference in 4G technologies.

5.2 TYPES OF BEAMFORMING

There are generally two major types of beamforming techniques; one is fixed beamforming technique and the other is the adaptive beamforming technique.[1] [10] [16] [29]

5.2.1 Fixed Beamforming Technique:

This beamforming approach was used if the AOA didn't change with time and the desired user was fixed, not moving. This form of method doesn't consider about steering or scanning the beam in the desired path. Also the use of switched beam technique which undertakes an antenna array over a designed angular region by radiating multiple overlapping fixed beam signals. The various fixed beamforming techniques are the MSIR technique, ML technique and MV technique. In this case the optimum array weights don't require any updating as the AOA do not change over time. But in dynamic environment where the desired user is moving and the AOA varies, this technique is a complete failure in such environment.

5.2.2 Adaptive Beamforming Technique:

If the desired AOA changes with time, it is necessary to develop a computation method to update the optimum array weight in an adaptive way in accordance to any change in environment. With this dynamic electromagnetic environment a continuous adaptation processing algorithm is generated by the receiving signal processing algorithm. So, the continuously moving desired user with different AOAs can be tracked down and a continuous beam can be directed towards it with the help of any adaptive beamforming techniques.

The working principle behind this technique is that, though the different signal coming from separate transmitters occupy same channel frequency but, the direction of origination are different for different beam. This idea of spatial separation is used to identify the desired signal among the interfering signals.

In case of adaptive beamforming the weight optimization is done by iterative computation of the complex algorithms based on different parameters. The adaptive beamforming technique is further subdivided into two categories; non-blind algorithms and blind algorithms.

5.2.2.1 Non-blind algorithms

In these algorithms, the array weights are modified using a reference signal in an iterative manner such that the weight output can be compared with the reference signal to generate an error which can be used to optimize the array weights at the end of each iteration of the algorithm. LMS, RLS, SMI and CGM are the algorithms that fall under this category.

5.2.2.2 Blind algorithms

In the case of blind algorithms one don't require any reference signals for comparison hence no weight updating is undertaken. CMA and LS-CMA algorithms are examples of blind algorithms.

Now before going in deep through some of the algorithm in detail, let's have a brief introduction on the requirement of an adaptive beamformer and how does the entire set up work.

5.3 ADAPTIVE BEAMFORMER

An adaptive beamformer [1] [10] [16] [29] is a system designed to undertake adaptive spatial signal processing with an array of transmitters/receivers. Here the signals are overlapped in such a manner to enhance the signal strength to or from a desired direction.

In order to reduce the signal to/from undesired users the signals to/from other directions are combined in a destructive manner. Such technique is employed both in radio frequency as well as acoustic arrays to provide directional sensitivity without any physical movement of array receivers or transmitters.

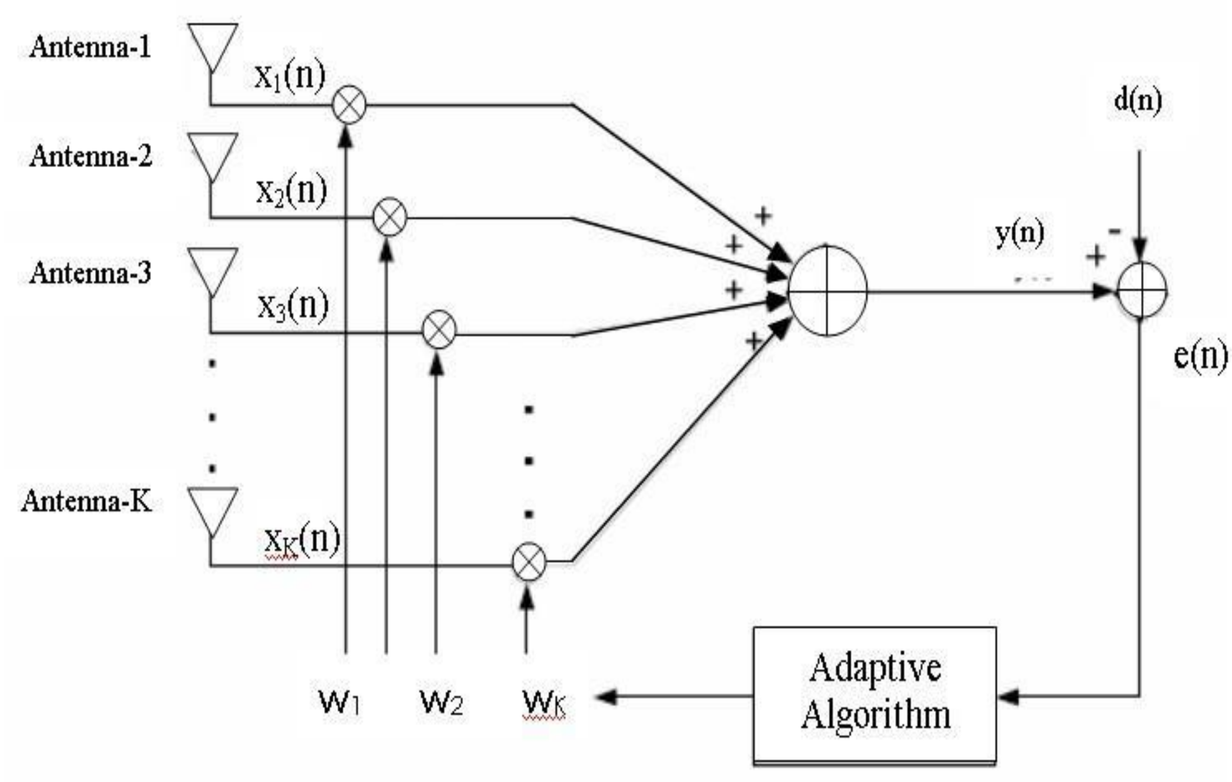

Figure 5.1: A generic adaptive beamforming system

To understand the working of adaptive beamforming technique and the various adaptive algorithms, we need to understand the concept of array weighting. In case of linearly uniform adaptive array, the largest side lobes are very less compared to the peak value. Side lobes represent any sign of undesired radiation from the array in other direction. But, the array also receives energy from random direction because of reciprocity. So, while considering a multipath environment the side lobes can receive the same signal from various spatial direction, which is the main reason for fading experience in communication. If the knowledge of direct transmission angle is present, one can reduce and deflect the beam in the desired direction so as to reduce the undesired signals. The side lobe suppression can be carried out by shading, weighting, or by windowing the array elements. The application of array element weighting have been appreciated in the field of digital signal processing (DSP), radar, radio astronomy, sonar, and other communication techniques.

5.4 HOW DOES AN ADAPTIVE BEAM FORMER WORK

Consider the following adaptive array system.

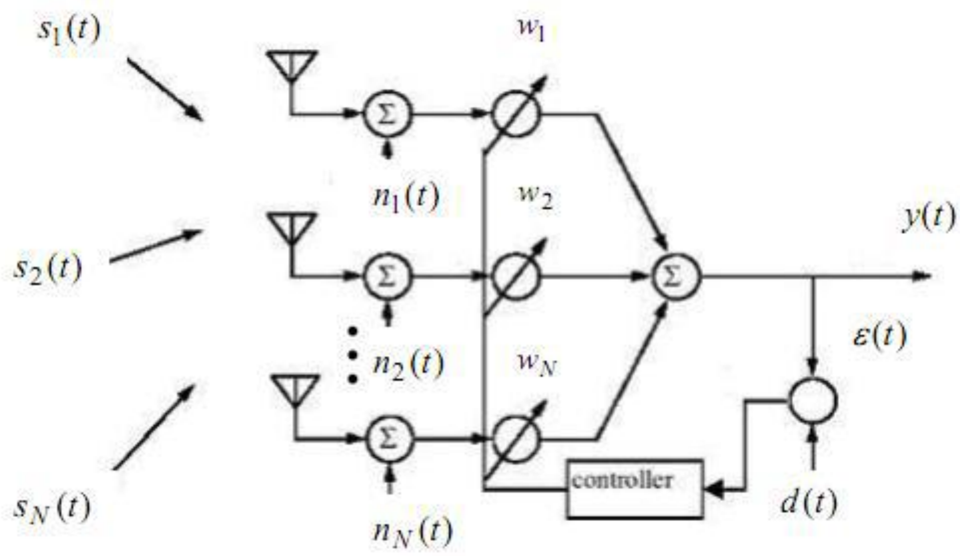

Figure 5.2: An adaptive array system

In the above figure,

$S_i(t)$= received signal, $n_i(t)$= noise at the receiver, w_m= weights of the array, d(t)= desired signal,

ε(t)= error signal, y(t)= output signal

the reference signal is taken as the desired signal by using training sequence. The array output y(t) is given by,

$$y(t) = w^H .x(t)$$

Where, w^H= complex conjugate transpose of the weight vector. In order to compute the optimum weights, the array response vector from the sampled data of the array output has to be known which is a function of the incident angle and the frequency.

The base band signal is given by,

$$x_N(t) = \sum_{i=1}^{N} a_N(\theta_i) s_i(t) e^{-j2\pi f_c \tau_N(\theta_i)}$$

The $S_i(t)$ signal comprises of the wanted and interfering signals. The $\tau_N(\theta_i)$ is the delay experienced by every signal f_c as the centre frequency.

Now, $A(\theta) = [a(\theta_1)\ \ a(\theta_2)\ \ a(\theta_3)\ ....\ \ a(\theta_d)]$

$S(t) = [s_1(t)\ \ s_2(t)\ \ s_3(t)\ .....\ s_d(t)]^T$

Therefore the incoming signals along with their array steering vector and noise are given in a matrix form as;

$$x(t) = A(\theta).S(t) + n(t)$$

in order to understand it in a better way let us separate the desired signal from the unwanted ones. Let s(t) be the desired user signal arriving at an angle θ_0 and u_i (t) be the N_u number of interference signals arriving at an angle θ_i. Thus, the output of the antenna array can be written as;

$$y(t) = s(t).a(\theta_0) + \sum_{i=1}^{N_u} u_i(t)a(\theta_i) + n(t)$$

Where, $a(\theta_i)$ and $a(\theta_0)$ are the array propagation vector of the i^{th} interfering signal and the array propagation vector of the desired signal respectively. Then the error can be calculated which is the difference between the desired signal and the output signal and then can be minimized. Another way can be by decreasing the cost function:

$$C(n) = E\left|e(n)^2\right|$$

Where, E[.] denotes the statistical expectation. Both the above stated conditions are satisfied by the performance function C(n) also known as Mean Square Error Criterion. Now it c has a single global minimum and can be tracked easily mathematically. Meanwhile the Mean Square error ($e(n)^2$) between the beam former output and the reference signal can be stated as;

$$e(t)^2 = [d(t) - w^H.x(t)]^2$$

Taking expectation on both sides of the equation above, we get;

$$E[e(t)^2] = E\{[d(t) - w^H.x(t)]^2\}$$

$$E[e(t)^2] = E\{[d(t)]^2\} - 2w^H r + w^H R w$$

Where, r = E[d(t).x(t)] that is the cross correlation matrix between the desired signal and the input received signal and, $R = E[x(t).x^H(t)]$ is the autocorrelation matrix of the received signal also known as the Covariance matrix. The minimum MSE can be developed by the following equation:

$$\nabla w\,(E[e(t)^2]) = -2p + 2Rw = 0;$$

So, the solution for optimum weight is now given as;

$$\mathbf{w_{opt} = R^{-1}p}$$

The base of some non-blind algorithms is this equation like the LMS algorithm and SMI algorithm.

Now let us study some non-blind algorithms for adaptive beam forming in details.

5.5 DETAILED STUDY OF SOME NON-BLIND ALGORITHMS

5.5.1 LMS Algorithm

The LMS algorithm [28] follows steepest descent method to adapt the system based on error at the present time. It was invented in the year 1960 by Ted. Hoff from Stanford University.

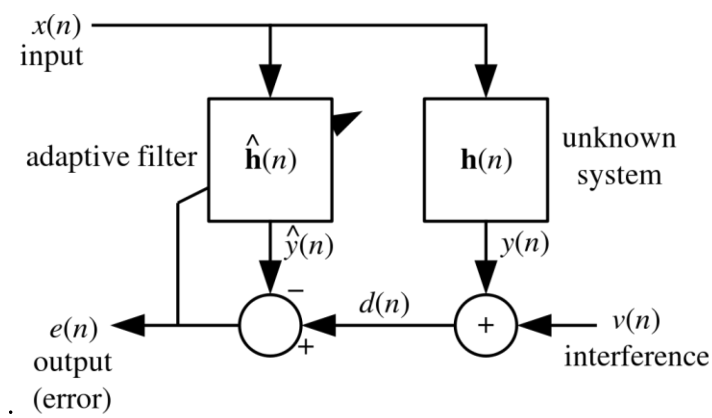

Figure 5.3: Problem setup for LMS Algorithm

The LMS Algorithm uses steepest descent for finding filter weights h(n) that minimize a cost function. The cost function can be defined as

$$C(n) = E\left\{|e(n)|^2\right\}$$

Thecost function $C(n)$ which is also the mean square error is minimized by the LMS. By applying steepest descent method we take the partial derivatives with respect to the individual entries of the filter coefficient weight vector

$$\nabla_{\hat{\mathbf{h}}^H} C(n) = \nabla_{\hat{\mathbf{h}}^H} E\left\{e(n)\,e^*(n)\right\} = 2E\left\{\nabla_{\hat{\mathbf{h}}^H}(e(n))\,e^*(n)\right\}$$

where ∇ is the gradient operator

$$\nabla_{\hat{\mathbf{h}}^H}(e(n)) = \nabla_{\hat{\mathbf{h}}^H}\left(d(n) - \hat{\mathbf{h}}^H \cdot \mathbf{x}(n)\right) = -\mathbf{x}(n)$$

$$\nabla C(n) = -2E\left\{\mathbf{x}(n)\, e^*(n)\right\}$$

Now, $\nabla C(n)$ is the point towards the steepest ascent of the cost function. To find the minimum value of the cost function, a step in the negative direction of $\nabla C(n)$ is taken. It can be expressed in mathematical terms

$$\hat{\mathbf{h}}(n+1) = \hat{\mathbf{h}}(n) - \frac{\mu}{2}\nabla C(n) = \hat{\mathbf{h}}(n) + \mu\, E\left\{\mathbf{x}(n)\, e^*(n)\right\}$$

where μ/2 is the step size. But this algorithm cannot be realized until we know $E\{X(n)e^*(n)\}$.

The convergence of this algorithm depends on the step size μ and is directly proportional to it. If the step size is in between the range that ensures convergence, the process leads to the optimal weights. So, the condition that provides stability is $0 \le \mu \le \frac{1}{2\lambda_{\max}}$ where λ_{max} is the largest eigen value of the array correlation matrix $R_{xx}(k)$.

$$R_{xx}(k) = x(k)x^H(k)$$

Where x(k) denotes the received signal vector. The array weights are updated according to the following equation,

$$w(k+1) = w(k) + \mu e^*(k)x(k)$$

Where $e(k) = d(k) - w^H(k)x(k)$

5.5.2 SMI Algorithm

SMI [5] uses Block Adaptive Approach such that samples to the system input and the desired output are collected in blocks and processed together to get a block output samples. Hence SMI Algorithm estimates the time average of the array correlation matrix by dividing the input samples into ‘k’ no. of block and each block is of ‘K’ length.

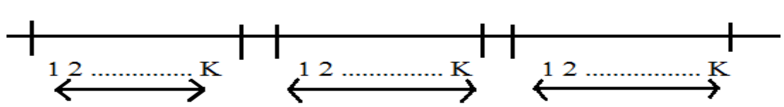

Figure 5.4: Block Adaptive approach of SMI algorithm

We know,

$$\mathbf{w_{opt} = R^{-1}p}$$

where p= cross correlation matrix between desired signal d(n) and input matrix x(n).

R= auto correlation matrix with input samples

Now a matrix $\overline{X_K}(k)$ of the kth block of $\bar{x}$ vectors is defiend that ranges over K data snapshots.

$$\overline{X_K}(k) = \begin{bmatrix} x_1(1+kK) & x_1(2+kK) & \ldots\ldots\ldots\ldots & x_1(K+kK) \\ x_2(1+kK) & x_2(2+kK) & \ldots\ldots\ldots\ldots & x_2(K+kK) \\ . & . & . & . \\ . & . & . & . \\ . & . & . & . \\ . & . & . & . \\ . & . & . & . \\ x_M(1+kK) & x_M(2+kK) & \ldots\ldots\ldots\ldots & x_M(K+kK) \end{bmatrix}$$

Where k= block number, K= block length

Thus the array correlation matrix becomes,

$$R(k) = \frac{1}{K}\overline{X_K}(k).\overline{X_K}^H(k)$$

Desired Signal vector is

$$\bar{d}(k) = \left[d(1+kK) \quad d(2+kK) \quad \ldots\ldots\ldots\ldots \quad d(K+kK)\right]$$

And the correlation vector $\bar{p}$ is given,

$$\overline{p}(k) = \frac{1}{K} d^*(k).\overline{X_K}(k)$$

Finally, the SMI weights are calculated for kth block of length K with the following equation

$$\overline{w}_{SMI}(k) = \overline{R}^{-1}(k).\overline{p}(k)$$

5.5.3 CGM Algorithm

In CGM method [5] the optimum solution is reached by choosing conjugate (perpendicular) paths after each new iteration and conjugate here is orthogonal. This method searches in orthogonal direction which makes a faster convergence towards the optimum solutionr.

It uses equation , $A.\overline{w} = \overline{d}$ to get $\overline{w}$. It also produces weight vector for each sample time, which corresponds to the complex conjugate of the smart antenna's optimum weights vector.

So, $A\overline{w}^H = \overline{d}$

Where, $A = \begin{bmatrix} x_1(1) & x_2(1) & .... & x_M(1) \\ x_1(2) & x_2(2) & .... & x_M(2) \end{bmatrix}$, a k*K matrix of array snapshots where k= no. of iterations and M= no. of input signals.

Now, $\overline{e} = \overline{d} - A.\overline{w}^H$

Where $\overline{e}$ = difference between the desired output and array output signal (error)

The initial weights vector are guessed. Then the direction vector $\overline{D}$ gives the new conjugate direction towards optimum weight.

$$\overline{D} = A^H \overline{e}$$

Now, weights can be updated as,

$$w^H(n+1) = w^H(n) - \mu(n).\overline{D}(n)$$

Where μ= step size of n^{th} iteration.

Then, $\bar{e}(n+1) = \bar{e}(n) + \mu(n).A.\overline{D}(n)$

And $\overline{D}(n+1) = A^{H}.e(n+1) - \alpha(n).\overline{D}(n)$ where $\alpha(n)$ minimizes the error function.

5.6 SIMULATION AND RESULTS

5.6.1 Comparison of amplitude responses of LMS, SMI and CGS algorithms

- **LMS Algorithm**: M=5 , d=0.5λ , Desired DOA=30˚, interfering DOA=60˚and 10º , Number of data samples:100, Number of data samples:100

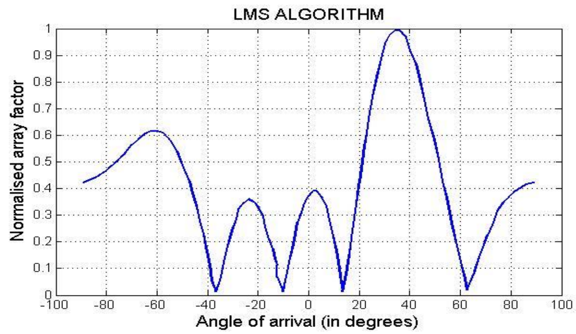

Figure 5.5: Amplitude response of LMS Algorithm

- **SMI Algorithm**: M=5 , d=0.5λ , Desired DOA=30˚, interfering DOA=60˚and 10º , Number of data samples:100, Number of data samples:100

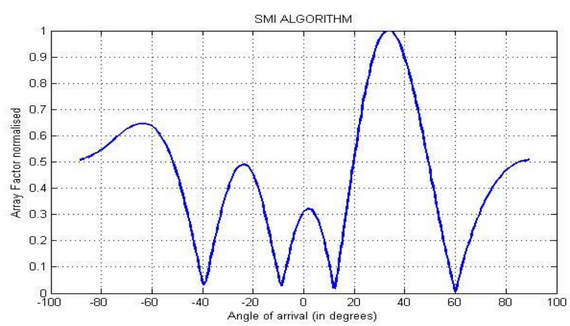

Figure 5.6: Amplitude response of SMI algorithm

- **CGM Algorithm**:M=5 , d=0.5λ , Desired DOA=30˚, interfering DOA=60˚and 10º , Number of data samples:100

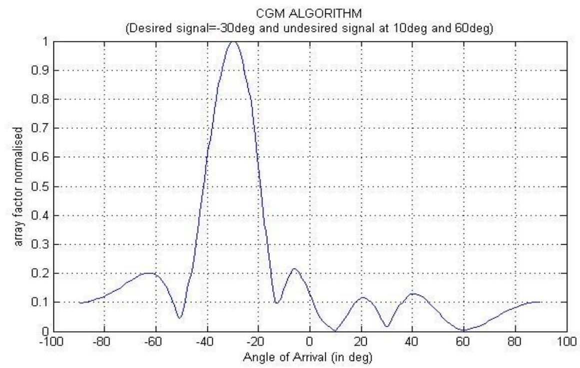

Figure 5.7: Amplitude response of CGM Algorithm

From the above figures it is clear enough that in LMS algorithm the interfering signal is not completely rejected at 60 degrees where as in SMI it is completely rejected. But in the CGM method the resolution is very high which leads to higher accuracy as the main beam focusing towards the desired user is sharper compared to the other algorithms. It has therefore a high directivity and has power level lower than what was achieved in the previous algorithms.

5.6.2 Comparison of convergence speed of LMS, SMI and CGM Algorithms

- **LMS and SMI algorithms**

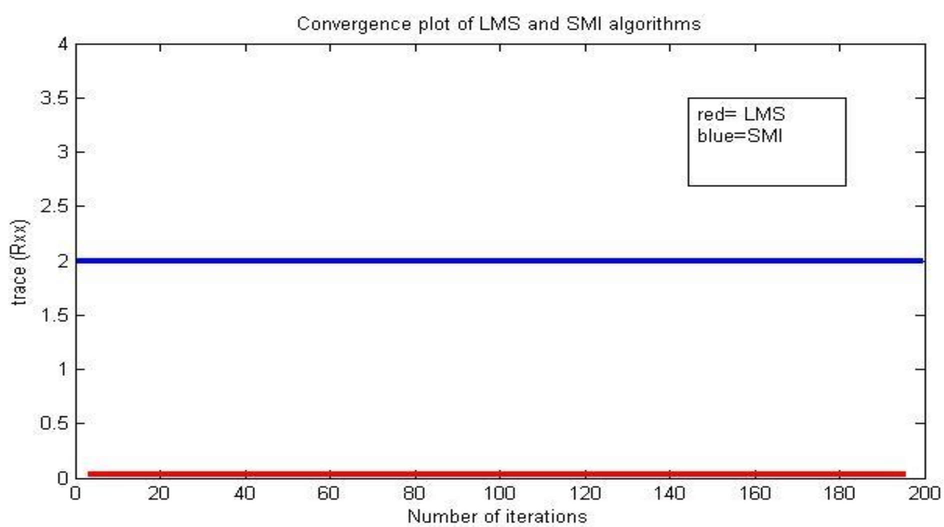

Figure 5.8: Convergence plot of LMS and SMI Algorithm

- **CG M algorithm**

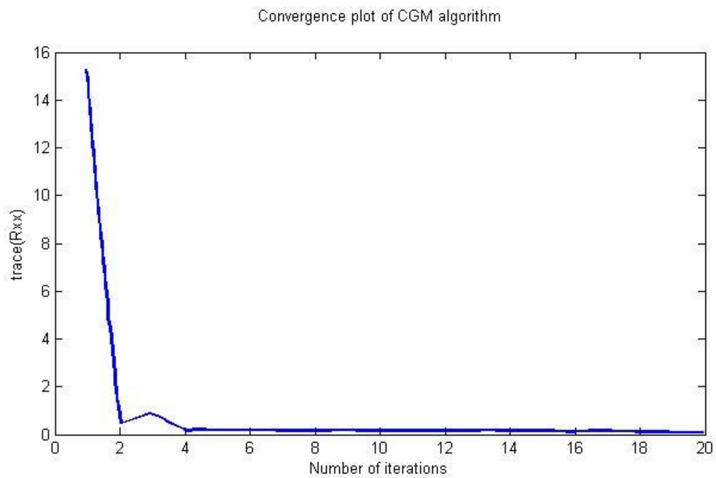

Figure 5.9: Convergence plot of CGM Algorithm

In figure 5.8, the blue line shows the trace of LMS algorithm. It shows that LMS has slower rate of convergence when the correlation matrix R possesses a large eigen spread. The SMI converges faster compared to LMS since it uses direct inversion of the covariance matrix R. The CGM converges within a few number of iterations and thus is the fastest among all algorithms.

5.6.3 Comparison of LMS, SMI and CGM Algorithm by varying the number of array element M

The following figures show the effect of variation of number of array antenna elements on the various adaptive beamforming algorithms of LMS, SMI and CGM. The beam is steered at 15 deg and null depths along the direction of interferers -15 deg and 30 deg.

- **LMS algorithm:** x axis= AOA (in degrees), y axis= AF (in dB)

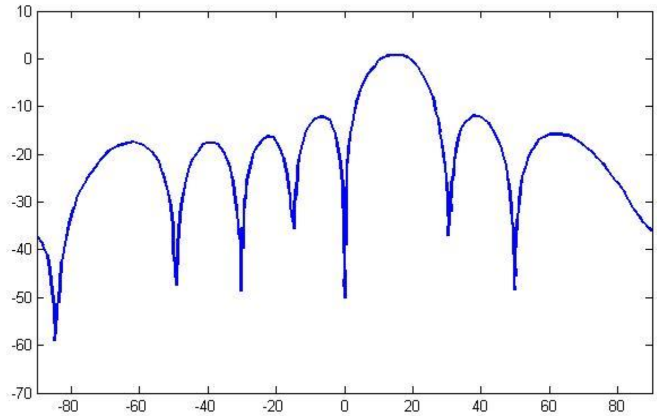

Figure 5.10: LMS algorithm for M=8

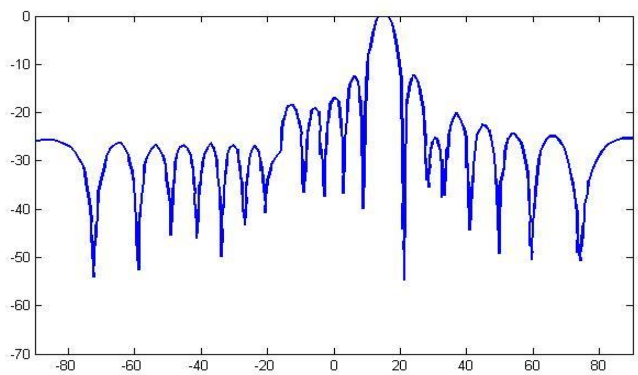

Figure 5.11: LMS algorithm for M=20

- **SMI Algorithm**: x axis= AOA (in degrees), y-axis= AF (in dB)

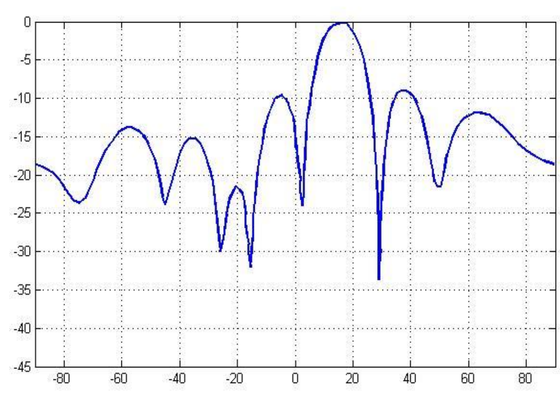

Figure 5.12: SMI algorithm for M=8

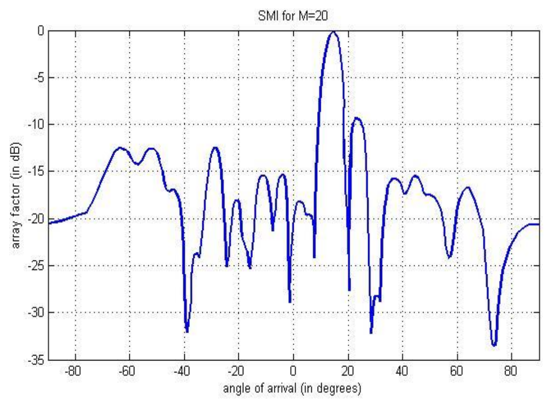

Figure 5.13: SMI algorithm for M=20

- **CGM Algorithm**: x axis= AOA (in degrees), y axis= AF (in dB)

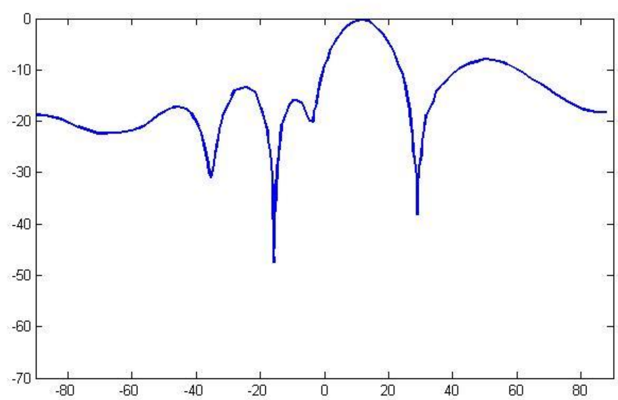

Figure 5.14: CGM algorithm for M=8

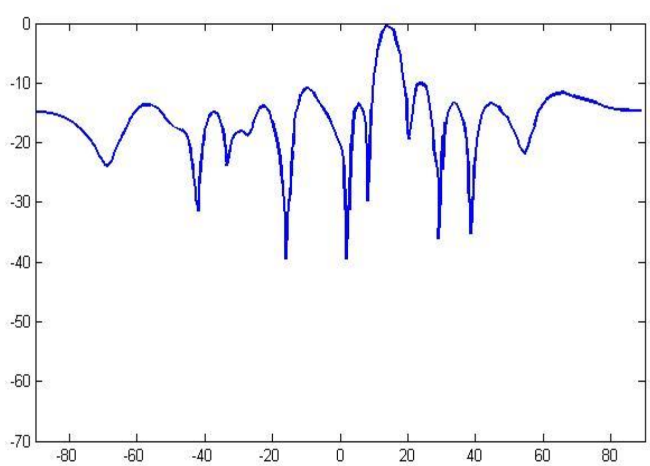

Figure 5.15: CGM algorithm for M= 20

As shown in the above figures, with the increase in no. of array elements, the directivity increases as we can notice the sharper peaks. The SLL also decreases with the increase of number of antenna elements. The SMI algorithm is found to be more accurate compared to LMS algorithm and has high directivity while the null depth becomes low as compared to LMS. But it is seen that CGM gives maximum null depth at the two interfering signals though the directivity is almost the same as LMS and SLL is slightly higher than that of LMS but less mean square error than SMI.

5.7 CONCLUSION

The steepest descent method based algorithms show many disadvantages. The rate of convergence becomes slower for large eigen value spread of correlation. This convergence rate can be improved using CGM which has now proved to be the fastest of all the algorithms as it iteratively searches for optimal solution by choosing conjugate paths. Though it creates a slightly higher side lobes but the mean square error is less compared to other algorithms.

6. CHAPTER- 6

CONCLUSION AND SCOPE FOR FUTURE WORK

6.1 CONCLUSION:

In the thesis we discussed about effects of CCI and multipath on 4G technology based systems. We studied the subspace based MUSIC and ESPRIT algorithm for DOA estimation and a MATLAB testbed was created to test the algorithms under various circumstances. It showed that MUSIC has more accuracy and resolution which is why it is preferred in Smart Antenna Systems.

Also various adaptive beam forming algorithms were studied in details with their mathematical models. Comparison of LMS, SMI and CGM algorithm was carried out by testing them under various conditions by varying the various parameters of antenna elements. CGM proved to be the fastest of all the algorithms as it iteratively searches for optimal solution by choosing conjugate paths. Though it creates a slightly higher side lobes but the mean square error is less compared to other algorithms.

6.2 SUGGESTIONS FOR FUTURE WORK

In order to prevent the failure of the discussed algorithms, due to system overloading, we need to know the maximum number of possible signals/ components and design the array with sufficient number of array elements that can ensure management of all the incoming signals without overloading. Directional elements could also be used to get a more restricted field of view.

Currently, the DOA measurement system is not capable of making real-time measurements. The DSP-96 boards are used only to sample and collect data but the processing is done through off-line PC. So, to make the system completely real-time, the DOA estimation and adaptive beam forming algorithms algorithms can be directly coded on the DSP.

Monostrip patch antennas can be used instead of the quarter wave monopoles which can provide several advantages. The DOA estimation measuring system can be utilised to do real world measurements that can be useful in manipulating the multipath channel in terms of angle spread. It can also be useful in studying the systems that employ some form of spatial diversity and to verify channel models that incorporate AOA statistics.

BIBLIOGRAPHY

[1] Beulah, R. Evangilin, and N. Aneera Vigneshwari. "*Design and Simulation of Smart Antenna Array Using Adaptive Beam forming Method*."

[2] Wadhwani, Mukesh, and Amrita Soni. "*A Review of Smart Antenna System (SAS) with Array Processing Algorithms*."

[3] Basha, TS Ghouse, P. V. Sridevi, and MN Giri Prasad. "*Beam Forming in Smart Antenna with Precise Direction of Arrival Estimation Using Improved MUSIC*." Wireless personal communications 71, no. 2 (2013): 1353-1364.

[4] Mali, Dilip, Freweyni Kidane, Tawatu Abreha, and Sinshaw Bekele. "*Interference Suppression Using Smart Antenna in CDMA Using a Novel Algorithm*." Wireless Communication 6, no. 1 (2014): 12-16.

[5] Shrivastava, Neha, Sudeepn Baudha, Rahul Singh Rathore, and Bharti Tiwari. "*Study and Simulation of Smart Antenna using SMI and CGM algorithm*." International Journal of Engineering and Innovative Technology (IJEIT) 1, no. 6 (2012): 11-15.

[6] Stevanovic, Ivica, Anja Skrivervik, and Juan R. Mosig. *Smart antenna systems for mobile communications*. No. LEMA-REPORT-2009-001. 2003.

[7] Ramachandran, S. "*Smart Antennas in 4G*." Innovative Systems Design and Engineering 3, no. 2 (2012): 7-12.

[8] Alexiou, Angeliki, and Martin Haardt. "*Smart antenna technologies for future wireless systems: trends and challenges*." Communications Magazine, IEEE 42, no. 9 (2004): 90-97.

[9] Sun, Jun-Zhao, Jaakko Sauvola, and Douglas Howie. "*Features in future: 4G visions from a technical perspective*." In Global Telecommunications Conference, 2001. GLOBECOM'01. IEEE, vol. 6, pp. 3533-3537. IEEE, 2001.

[10] Das, Susmita. "*Smart antenna design for wireless communication using adaptive beam-forming approach.*" In TENCON 2008-2008 IEEE Region 10 Conference, pp. 1-5. IEEE, 2008.

[11] Sawant, Vishal V., and M. S. Chavan. "*Performance of beamforming for smart antenna using modified LMS algorithm*." (2013).

[12] Samahi, M., and R. M. Shubair. "*Performance of smart antenna systems for signal detection and estimation in multipath fading environment*." In Innovations in Information Technology, 2006, pp. 1-4. IEEE, 2006.

[13] Lavate, Tukaram Baburao, V. K. Kokate, and A. M. Sapkal. "*Performance analysis of MUSIC and ESPRIT DOA estimation algorithms for adaptive array smart antenna in mobile communication.*" In Computer and Network Technology (ICCNT), 2010 Second International Conference on, pp. 308-311. IEEE, 2010.

[14] Sit, Yoke Leen, Christian Sturm, Johannes Baier, and Thomas Zwick. "*Direction of arrival estimation using the MUSIC algorithm for a MIMO OFDM radar*." In Radar Conference (RADAR), 2012 IEEE, pp. 0226-0229. IEEE, 2012.

[15] Dhope, Tanuja S. "*Application of MUSIC, ESPRIT and ROOT MUSIC in DOA Estimation*." Faculty of Electrical Engineering and Computing, University of Zagreb, Croatia (2010).

[16] Saxena, Prerna, and A. G. Kothari. "*Performance Analysis of Adaptive Beamforming Algorithms for Smart Antennas."* IERI Procedia 10 (2014): 131-137.

[17] Saini, Harpreet Kaur, and Isha Puri. "*Design and Analysis of Radiation Pattern of Smart Antenna for various Adaptive Algorithms*."

[18] Mietzner, Jan, Robert Schober, Lutz Lampe, Wolfgang H. Gerstacker, and Peter Adam Hoeher. "*Multiple-antenna techniques for wireless communications-a comprehensive literature survey*." Communications Surveys & Tutorials, IEEE 11, no. 2 (2009): 87-105.

[19] Rubio, Francisco, and Utz Martin. "*Space-Time-DFE for Adaptive Array Antennas in 4G Wireless Communications*." ITG FACHBERICHT (2003): 355-358.

[20] Joshi, Revati, and Ashwinikumar Dhande. "*ADAPTIVE BEAMFORMING USING LMS ALGORITHM*."

[21] Himayat, Nageen, Shilpa Talwar, Anil Rao, and Robert Soni. "*Interference management for 4g cellular standards [wimax/lte update]*." Communications Magazine, IEEE 48, no. 8 (2010): 86-92.

[22] Wang, H., and M. Glesner. "*Hardware implementation of smart antenna systems*." Advances in Radio Science 4, no. 8 (2006): 185-188.

[23] Singla, Brahm Mohinder, and Ashish Kumar. "*Efficient Smart Antenna Systems (4G) For CDMA Wireless Communication*." Journal of Engineering Computers & Applied Sciences 1, no. 1 (2012): 74-79.

[24] Porcello, John C. "*Designing and implementing Multibeam Smart Antennas for high bandwidth UAV communications using FPGAs.*" In Aerospace Conference, 2013 IEEE, pp. 1-12. IEEE, 2013.

[25] Zhang, Hongyuan, and Huaiyu Dai. *Design fundamentals and interference mitigation for cellular networks*. Nova Science Publishers, 2008.

[26] Ramineni, Bhavishya, G. Chaitanya Sagar, K. Abhishek Jain, M. Siva Ganga Prasad, T. V. Ramakrishna, and K. Sarat Kumar. "*Comparison and performance evaluation of different adaptive beam forming algorithms in wireless communications with smart antenna."* International Journal of Engineering Research and Applications (IJERA) 2, no. 3 (2012): 630-633.

[27] Sharma, Bindu, and Indranil Sarkar. "*Performance Analysis of Smart Antenna Beam forming Technique*"

[28] Singh, Jasdeep, and Abhishek Pal. "*Smart Antenna Beamforming using LMS Adaptive Filter Algorithm."* (2014).

[29] Siddiqui, Asad Ali, A. U. Khan, M. M. Manzoor, I. A. Awan, A. Ijaz, and Sangita Lal Chand. "*Interference mitigation in 4G system using smart antenna."* In Information and Communication Technologies (ICICT), 2011 International Conference on, pp. 1-6. IEEE, 2011

[30] Krenik, Bill. "*4G wireless technology: When will it happen? What does it offer?."* In Solid-State Circuits Conference, 2008. A-SSCC'08. IEEE Asian, pp. 141-144. IEEE, 2008.

[31] Kumaravel, K. "*Comparative Study of 3G and 4G in Mobile Technology."* International Journal of Computer Science Issues 8, no. 5 (2011): 256-263.

[32] Chavan, Sonali, and Vanita Mane. "*4G Wireless Networks Challenges and Benefits*."

[33] Boudreau, Gary, John Panicker, Ning Guo, Rui Chang, Neng Wang, and Sophie Vrzic. "*Interference coordination and cancellation for 4G networks*." Communications Magazine, IEEE 47, no. 4 (2009): 74-81.

[34] Shah, Amit, and Alexander M. Haimovich. "*Performance analysis of optimum combining in wireless communications with Rayleigh fading and cochannel interference*." Communications, IEEE Transactions on 46, no. 4 (1998): 473-479.

[35] Chryssomallis, Michael. "*Smart antennas*." Antennas and Propagation Magazine, IEEE 42, no. 3 (2000): 129-136.

[36] Varade, Suchita W., and K. D. Kulat. "*Robust algorithms for DOA estimation and adaptive beamforming for smart antenna application*." In Emerging Trends in Engineering and Technology (ICETET), 2009 2nd International Conference on, pp. 1195-1200. IEEE, 2009.

[37] Vorobyov, Sergiy A., Alex B. Gershman, and Zhi-Quan Luo. "*Robust adaptive beamforming using worst-case performance optimization: A solution to the signal mismatch problem*." Signal Processing, IEEE Transactions on 51, no. 2 (2003): 313-324.

[38] www.wikipedia.org

[39] www.google.com

[40] www.ieee.org