بسم الله الرحمن الرحيم

Bachelor of Science
in
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A Thesis on

Comparison among Different Beam Forming Algorithms used in Smart Antenna System for 3G+ Mobile Communications

By

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Dedicated to-

OUR PARENTS…

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A B S T R A C T

Smart antenna manipulates the impinging signals on various antenna elements through array processing so that the main lobe is formed towards the desired direction and nulls are placed towards the interference or unwanted directions. Direction of Arrival (DOA) estimation is an important part of direction of arrival based beam forming. The direction of arrival algorithm computes the angle of arrival of all impinging signals. A systemic study of smart antenna system and comparison of the performance of the Bartlett and MUltiple SIgnal Classification(MUSIC) DOA algorithms along with different non blind beam forming algorithms through simulation have been extensively analyzed in this thesis work. Our comparative analysis shows that MUSIC algorithm is highly accurate and stable and provides high angular resolutions compared to Bartlett algorithm. So MUSIC algorithm can be widely used in mobile communication to estimate the DOA of arriving signals. Among LMS, SMI, RLS beam forming algorithms RLS algorithm is the fastest to converge the weights through least computational complexity.

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Chapter 1

Introduction

The increasing demand for mobile communication services without a corresponding in-crease in RF spectrum allocation motivates the need for new techniques to improve spectrum utilization. One approach for increasing spectrum efficiency in digital cellular is the use of spread spectrum code division multiple access (CDMA) technology. Another approach that shows real promise for substantial capacity enhancement is the use of spatial processing with a cell site adaptive antenna array. The adaptive antenna array is capable of automatically forming beams in the directions of the desired signals and steering nulls in the directions of the interfering signals. By using the adaptive antenna in a CDMA system, we can reduce the amount of co-channel interference from other users within its own cell and neighboring cells, and therefore increase the system capacity.
There exist many adaptive algorithms that can be used in the adaptive antenna array. However, for the adaptive array used in a CDMA system, where multiple users occupy the same frequency band, the adaptive algorithm should have the ability to separate and extract each user's signal simultaneously.

In propagation channel, even for one source there are many possible propagation paths and angle of arrival. If several transmitters are operating simultaneously, each source potentially creates many multipath components at the receiver. Therefore it is important for a receive array to be able to estimate the angle of arrival in order to decide which emitter are present and what are their possible angular locations. This information can be used to eliminate or combine signals for greater fidelity, suppress interferers or both. This involves localization of sources radiating energy by observing their signal received at spatially separated sensors. A critical assumption of the most DOA estimate algorithms is that the number of incident signals should be strictly less than the number of antenna elements. This requirement can be relaxed if the properties of incident signals are exploited .Simulations for various estimation methods are carried out by assuming number of array elements, users, and samples and signal to noise ratio per sample and comparative study of performance has been done.

Adaptive beam forming is a technique in which an array of antennas is exploited to achieve maximum reception in a specified direction by estimating the signal arrival from a desired direction while interferer signals from other direction are rejected .this phenomenon basically uses the idea that though the signals emanating from different transmitters occupy the same frequency channel ,they still arrive from different directions .This spatial separation is exploited to separate the desired signal from interfering signals . smart antenna pattern are controls by algorithms based upon certain criteria, this criteria could be maximizing the signal to interference ratio (SIR), minimum variance (MV), minimizing the mean square error (MSE), steering more power towards desired signals (Beam Steering) and minimum power towards the interferer signal (Nulling).A performance comparison of LMS, SMI, RLS algorithms has been presented for 3G mobile communication.

CHAPTER 2

Antenna Basics

2.1 Basic Antenna Nomenclature

Here some important parameters are defined that are basic and related to every type of antenna [1]-[2].

2.1.1 Input Impedance

For an efficient transfer of energy, the impedance of the radio, of the antenna and of the transmission cable connecting them must be the same. Transceivers and their transmission lines are typically designed for 50Ω impedance. If the antenna has impedance different from 50Ω, then there is a mismatch and an impedance matching circuit is required [1].

2.1.2 Return loss

The return loss is another way of expressing mismatch. It is a logarithmic ratio measured in dB that compares the power reflected by the antenna to the power that is fed into the antenna from the transmission line. The relationship between SWR and return loss is the following [2]:

$$Return\ Loss\ (in\ dB) = 20\log_{10}\frac{SWR}{SWR-1} \tag{2.1}$$

2.1.3 Bandwidth

The bandwidth of an antenna refers to the range of frequencies over which the antenna can operate correctly. The antenna's bandwidth is the number of Hz for which the antenna will exhibit an SWR less than 2:1. The bandwidth can also be described in terms of percentage of the center frequency of the band.

$$BW = 100 \times \frac{F_H - F_L}{F_c} \tag{2.2}$$

Where $F_H$the highest frequency in the band, F_L is the lowest frequency in the band, and F_C is the center frequency in the band. In this way, bandwidth is constant relative to frequency. If bandwidth was expressed in absolute units of frequency, it would be different depending upon the center frequency. Different types of antennas have different bandwidth limitations [2].

2.1.4 Directivity and Gain

Directivity is the ability of an antenna to focus energy in a particular direction when transmitting, or to receive energy better from a particular direction when receiving. In a static situation, it is possible to use the antenna directivity to concentrate the radiation beam in the wanted direction. Gain is not a quantity which can be defined in terms of a physical quantity such as the Watt or the Ohm, but it is a dimensionless ratio. Gain is given in reference to a standard antenna. The two most common reference antennas are the isotropic antenna and the resonant half-wave dipole antenna. The isotropic antenna radiates equally well in all directions. Real isotropic antennas do not exist, but they provide useful and simple theoretical antenna patterns with which to compare real antennas. Any real antenna will radiate more energy in some directions than in others. Since it cannot create energy, the total power radiated is the same as an isotropic antenna, so in other directions it must radiate less energy.
The gain of an antenna in a given direction is the amount of energy radiated in that direction compared to the energy an isotropic antenna would radiate in the same direction when driven with the same input power. Usually we are only interested in the maximum gain, which is the gain in the direction in which the antenna is radiating most of the power mathematically the directivity is given by the formula,

$$D_0 = \frac{4\pi Umax}{\int_0^{2\pi}\int_0^{\pi} U(\theta,\varphi)\sin\theta d\theta d\varphi} \qquad (2.3)$$

Where,

D_0 = Directivity

$Umax$ = Maximum radiation intensity

$U(\theta, \varphi)$ = Radiation intensity at the desired direction (θ, φ)

2.1.5 Radiation Pattern

The radiation or antenna pattern describes the relative strength of the radiated field in various directions from the antenna, at a constant distance. The radiation pattern is a reception pattern as well, since it also describes the receiving properties of the antenna. The radiation pattern is three-dimensional, but usually the measured radiation patterns are a two dimensional slice of the three-dimensional pattern, in the horizontal or vertical planes. These pattern measurements are presented in either a rectangular or a polar format. The following figure shows a rectangular plot presentation of a typical 10 element Yagi. The detail is good but it is difficult to visualize the antenna behavior at different directions [2].

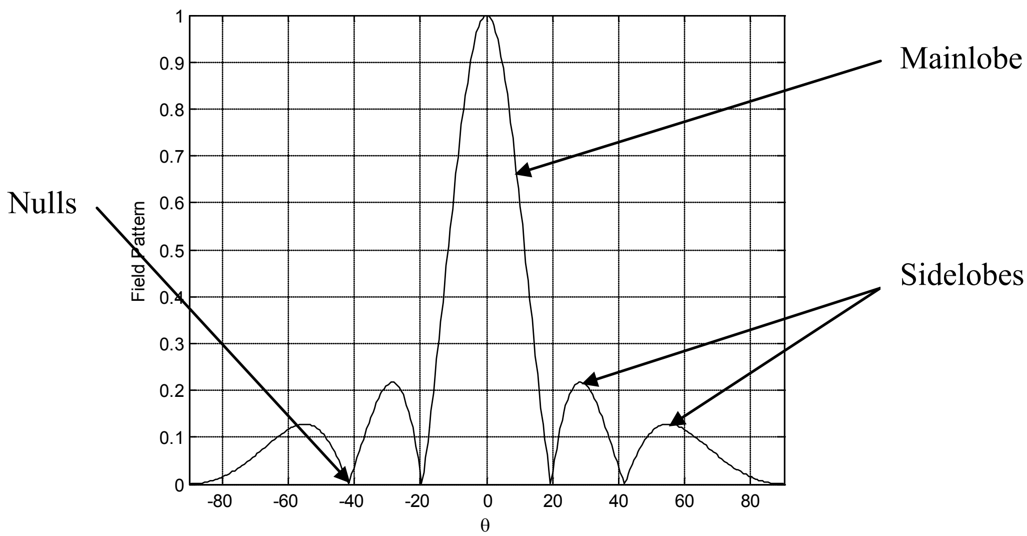

Fig 2.1: Rectangular plot of the radiation pattern of 10 elements Yagi [2]

Polar coordinate systems are used almost universally. In the polar coordinate graph, points are located by projection along a rotating axis (radius) to an intersection with one of several concentric circles. Following is a polar plot of the same 10 element Yagi antenna.

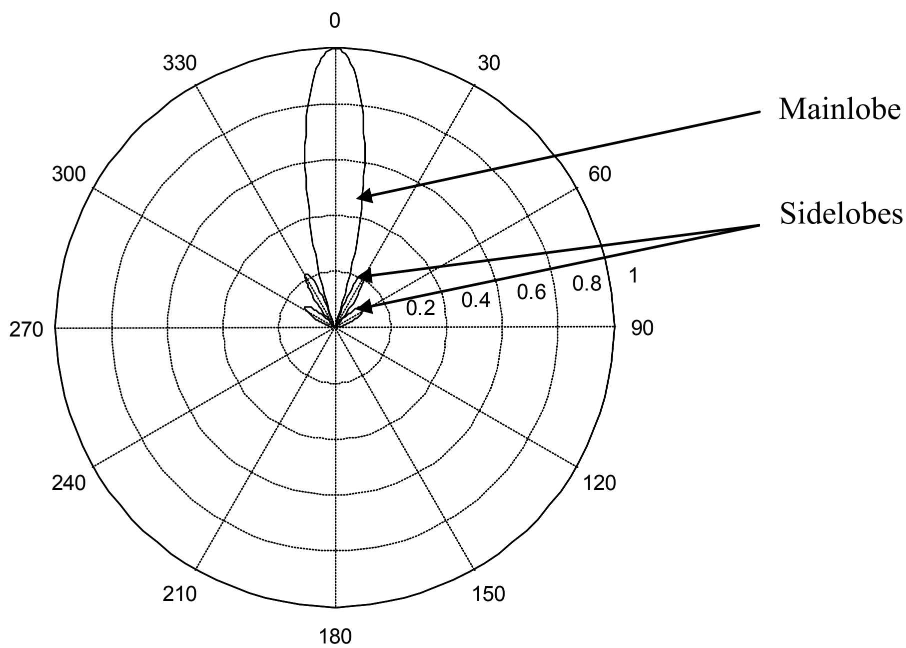

Fig 2.2: Polar plot of the radiation pattern of 10 elements Yagi [2]

Polar coordinate systems may be divided generally in two classes: linear and logarithmic. In the linear coordinate system, the concentric circles are equally spaced, and are graduated. Such a grid may be used to prepare a linear plot of the power contained in the signal. For ease of comparison, the equally spaced concentric circles may be replaced with appropriately placed circles representing the decibel response, referenced to 0 dB at the outer edge of the plot. In this kind of plot the minor lobes are suppressed. Lobes with peaks more than 15 dB or so below the main lobe disappear because of their small size. This grid enhances plots in which the antenna has a high directivity and small minor lobes. The voltage of the signal, rather than the power, can also be plotted on a linear coordinate system. In this case, too, the directivity is enhanced and the minor lobes suppressed, but not in the same degree as in the linear power grid.

There are two kinds of radiation pattern: absolute and relative. Absolute radiation patterns are presented in absolute units of field strength or power. Relative radiation patterns are referenced in relative units of field strength or power.

The radiation pattern in the region close to the antenna is not the same as the pattern at large distances. The term near-field refers to the field pattern that exists close to the antenna, while the term far field refers to the field pattern at large distances. The far-field is also called the radiation field, and is what is most commonly of interest. Ordinarily, it is the radiated power that is of interest, and so antenna patterns are usually measured in the far-field region. For pattern measurement it is important to choose a distance sufficiently large to be in the far-field, well out of the near-field. The minimum permissible distance depends on the dimensions of the antenna in relation to the wavelength. The accepted formula for this distance is:

$$r_{min} = \frac{2d^2}{\lambda} \tag{2.4}$$

Where r_{min} the minimum distance from the antenna, d is is the largest dimension of the antenna, and λ is the wavelength [1].

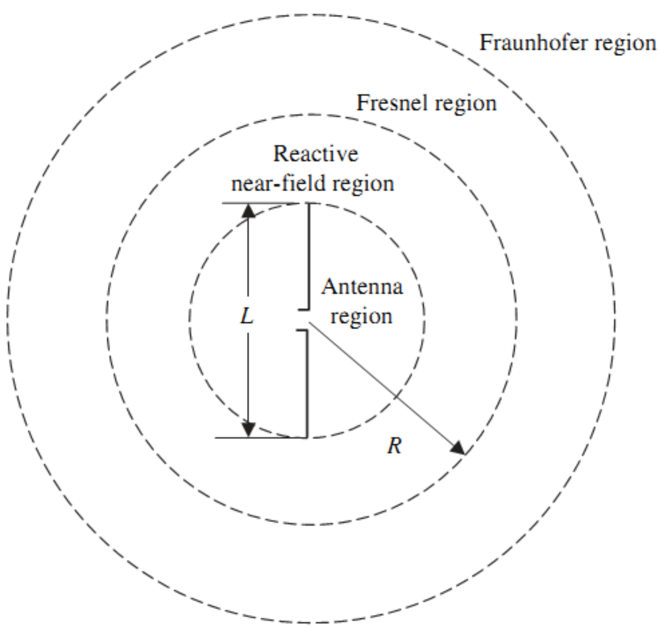

Fig 2.3: Antenna field regions [1]

2.1.6 Beamwidth

An antenna's beamwidth is usually understood to mean the half power beamwidth. The peak radiation intensity is found and then the points on either side of the peak which represent half the power of the peak intensity are located. The angular distance between the half power points is defined as the beamwidth. Half the power expressed in decibels is 3dB, so the half power beamwidth is sometimes referred to as the 3dB beamwidth. Both horizontal and vertical beamwidths are usually considered. Assuming that most of the radiated power is not divided into sidelobes, then the directive gain is inversely proportional to the beamwidth: as the beamwidth decreases, the directive gains increases.

2.1.7 Sidelobes

No antenna is able to radiate all the energy in one preferred direction. Some is inevitably radiated in other directions. The peaks are referred to as sidelobes, commonly specified in dB down from the main lobe.

2.1.8 Nulls

In an antenna radiation pattern, a null is a zone in which the effective radiated power is at a minimum. A null often has a narrow directivity angle compared to that of the main beam. Thus, the null is useful for several purposes, such as suppression of interfering signals in a given direction.

2.1.9 Polarization

Polarization is defined as the orientation of the electric field of an electromagnetic wave. Polarization is in general described by an ellipse. Two special cases of elliptical polarization are linear polarization and circular polarization. The initial polarization of a radio wave is determined by the antenna. With linear polarization the electric field vector stays in the same plane all the time. Vertically polarized radiation is somewhat less affected by reflections over the transmission path. Omni directional antennas always have vertical polarization. With horizontal polarization, such reflections cause variations in received signal strength. Horizontal antennas are less likely to pick up man-made interference, which ordinarily is vertically polarized. In circular polarization the electric field vector appears to be rotating with circular motion about the direction of propagation, making one full turn for each RF cycle. This rotation may be right-hand or left-hand. Choice of polarization is one of the design choices available to the RF system designer.

2.1.10 Polarization Mismatch

In order to transfer maximum power between a transmit and a receive antenna, both antennas must have the same spatial orientation, the same polarization sense and the same axial ratio. When the antennas are not aligned or do not have the same polarization, there will be a reduction in power transfer between the two antennas. This reduction in power transfer will reduce the overall system efficiency and performance. When the transmit and receive antennas are both linearly polarized, physical antenna misalignment will result in a polarization mismatch loss which can be determined using the following formula:

$$Polarization\ Mismatch\ Loss\ (dB)\ =\ 20\log(cos\ \ \theta) \qquad (2.5)$$

Where θ is the misalignment angle between the two antennas. For θ=15° we have a loss of 0.3 dB, for θ=30° we have 1.25 dB, for θ=45° we have 3 dB and for θ=90° we have an infinite loss. The actual mismatch loss between a circularly polarized antenna and a linearly polarized antenna will vary depending upon the axial ratio of the circularly polarized antenna. If polarizations are coincident no attenuation occurs due to coupling mismatch between field and antenna, while if they are not, then the communication can't even take place.

2.1.11 Front-to-back ratio

It is useful to know the front-to-back ratio that is the ratio of the maximum directivity of an antenna to its directivity in the rearward direction. For example, when the principal plane pattern is plotted on a relative dB scale, the front-to-back ratio is the difference in dB between the level of the maximum radiation, and the level of radiation in a direction 180 degree.

2.2 Types of Antennas

A classification of antennas can be based on:

2.2.1 Frequency and Size

Antennas used for HF are different from the ones used for VHF, which in turn are different from antennas for microwave. The wavelength is different at different frequencies, so the antennas must be different in size to radiate signals at the correct wavelength. We are particularly interested in antennas working in the microwave range, especially in the 2.4 GHz and 5 GHz frequencies. At 2.4 GHz the wavelength is 12.5 cm, while at 5 GHz it is 6 cm.

2.2.2 Directivity

In general, antennas of individual elements may be classified as isotropic, omnidirectional and directional according to their radiation characteristics.

i) Isotropic Radiators

An isotropic radiator is one which radiates its energy equally in all directions. Even though such elements are not physically realizable, they are often used as references to compare to them the radiation characteristics of actual antennas.

ii) Omnidirectional Antennas

Omnidirectional antennas are radiators having essentially an isotropic pattern in a given plane (the azimuth plane in Fig. 2.3) and directional in an orthogonal plane (the elevation plane in Fig. 2.3). Omnidirectional antennas are adequate for simple RF environments where no specific knowledge of the users directions is either available or needed. However, this unfocused approach scatters signals, reaching desired users with only a small percentage of the overall energy sent out into the environment [3]. Thus, there is a waste of resources using omnidirectional antennas since the vast majority of transmitted signal power radiates in directions other than the desired user. Given this limitation, omnidirectional strategies attempt to overcome environmental challenges by simply increasing the broadcasting power. Also, 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. Moreover, the single-element approach cannot selectively reject signals interfering with those of served users. Therefore, it has no spatial multipath mitigation or equalization capabilities. Omnidirectional strategies directly and adversely impact spectral efficiency, limiting frequency reuse.

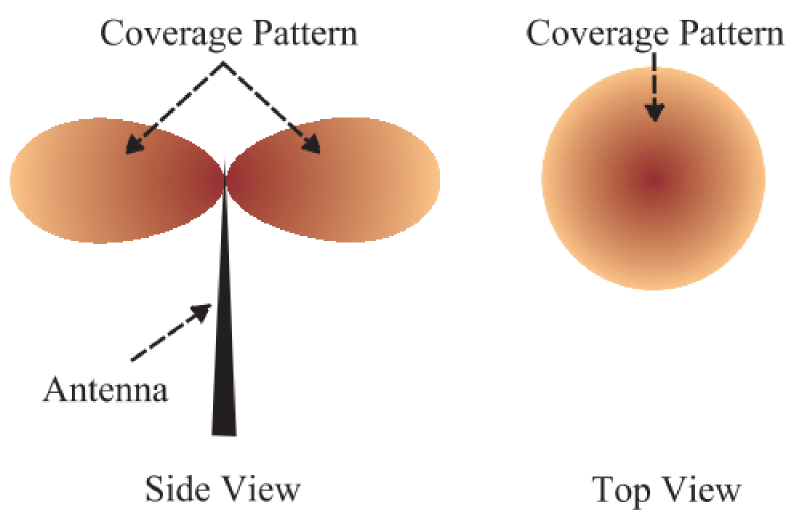

Fig 2.4: Omnidirectional antennas and coverage pattern [3]

These limitations of broadcast antenna technology regarding the quality, capacity, and geographic coverage of wireless systems initiated an evolution in the fundamental design and role of the antenna in a wireless system.

iii) Directional Antennas

Unlike an omnidirectional antenna, where the power is radiated equally in all directions in the horizontal (azimuth) plane as shown in Fig. 2.3, a directional antenna concentrates the power primarily in certain directions or angular regions. The radiating properties of these antennas are described by a radiation pattern, which is a plot of the radiated energy from the antenna measured at various angles at a constant radial distance from the antenna. In the near field the relative radiation pattern (shape) varies according to the distance from the antenna, whereas in the far field the relative radiation pattern (shape) is basically independent of distance from the antenna. The direction in which the intensity/gain of these antennas is maximum is referred to as the boresight direction. The gain of directional antennas in the boresight direction is usually much greater than that of isotropic and/or omnidirectional antennas. The radiation pattern of a directional antenna is shown in Fig. 2.4 where the boresight is in the direction $\theta = 0^{\circ}$. The plot consists of a main lobe (also referred to as major lobe), which contains the boresight and several minor lobes including side and rear lobes. Between these lobes are directions in which little or no radiation occurs. These are termed minima or nulls. Ideally, the intensity of the field toward nulls should be zero (minus infinite dBs). However, practically nulls may represent a 30 or more dB reduction from the power at boresight. The angular segment subtended by two points where the power is one-half the main lobe's peak value is known as the half-power beamwidth.

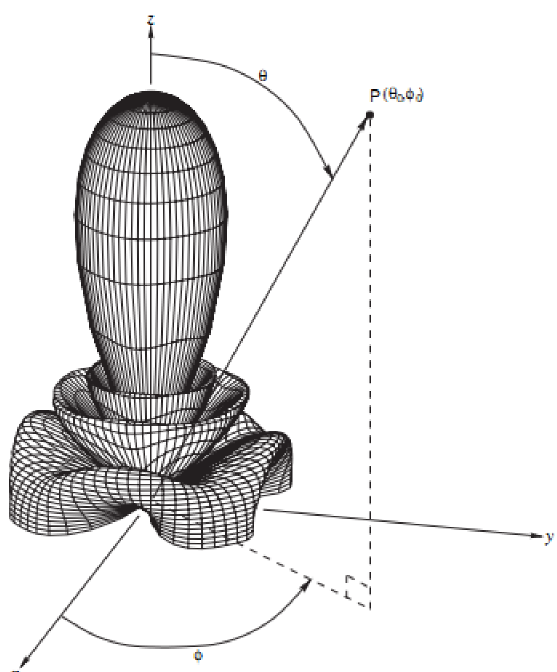

Fig 2.5: 3-D Radiation pattern of a directional antenna [1]

Chapter 3

Review of Antenna Array Theory

3.1 Introduction

There's a huge family of antennas and monopole, dipole, patch, slot, wave guide, loop, and helix etc. are all cousins. All of them have their specific radiation patterns. Instead of using these antennas individually, they can also be used collectively, such symmetry is called antenna array. An array consists of two or more antenna elements that are spatially arranged and electrically interconnected to produce a directional radiation pattern. The interconnection between elements, called the feed network, can provide fixed phase to each element or can form a phased array. As Smart antenna is a special application of antenna array, therefore in chapter we have explained the basic parameters related to an antenna array, which must be familiarized before going to Smart antennas.

3.2 Radiation Pattern

Radiation pattern is the variation of the field intensity of an antenna as an angular function [1]. It is graphical representation of the distribution of radiation from an antenna as a function of angle. It's always the same for receiving as for transmitting. This property is known as reciprocity [2]. An electromagnetic wave measured at a point far from the antenna is the sum of the radiation from all parts of the antenna. Each small part of the antenna is radiating waves of a different amplitude and phase, and each of these waves travels a different distance to the point where a receiver is located. In some directions, these waves add constructively to give a gain. In some directions they add destructively to give a loss. For e.g. the practical center-fed dipole usually consists of a pair of tubular conductors of diameter d aligned in tandem so that there is a small feeding gap at the center. A voltage is applied across the gap, often by means of a two-wire transmission line. The resulting current distribution on the pair of tubular conductors gives rise to a radiating field. The fig 3.1 shows its radiation pattern.

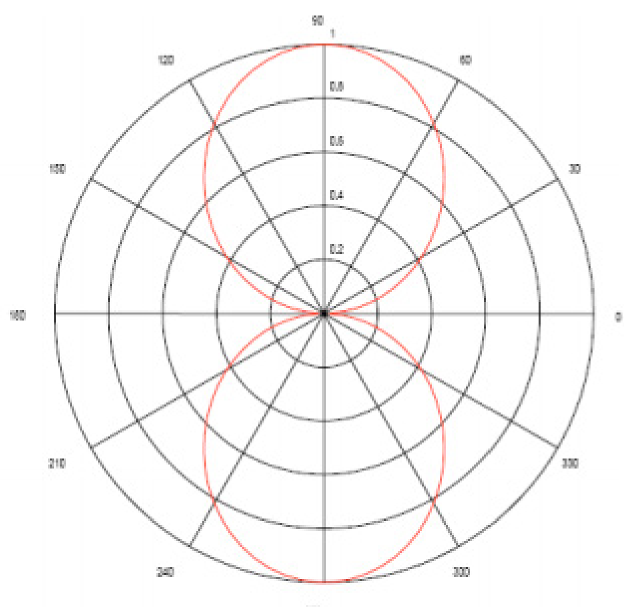

Fig 3.1: Half wave dipole antenna, length ½ λ [4]

3.3 Different Types of Array

On the basis of symmetry there are three types of arrays i.e. Linear Arrays, Planar Arrays and 3-D Arrays. The antenna elements can be arranged in various geometries, with linear, circular and planar arrays being very common. In the case of a linear array, the centers of the elements of the array are aligned along a straight line. If the spacing between the array elements is equal, it is called a uniformly spaced linear array.
A circular array is one in which the centers of the array elements lie on a circle. In the case of a planar array, the centers of the array elements lie on a single plane. Both the linear array and circular array are special cases of the planar array. But here we will focus only on linear arrays.

A simple directional antenna consists of a linear array of small radiating antenna elements, each fed with identical signals (the same amplitude and phase) from one transmitter. As the total width of the array increases, the central beam becomes narrower. As the number of elements increases, the side lobes become smaller. The following figure is the radiation pattern for a linear array of 4 elements spaced 1/2 wavelength apart.

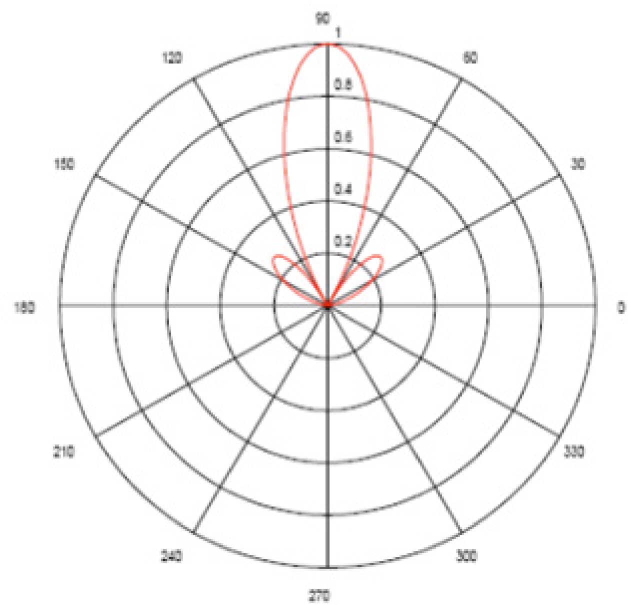

Fig 3.2: 3-4 Element 1.5 λ linear array 4 identical omnidirectional antennas [4]

If the spacing is increased to more than 1/2 wavelength, large side lobes begin to appear in the radiation pattern. However, the central beam gets narrower because the overall length of the antenna has increased. The following radiation pattern, for 4 elements spaced 1 wavelength apart, illustrates this.

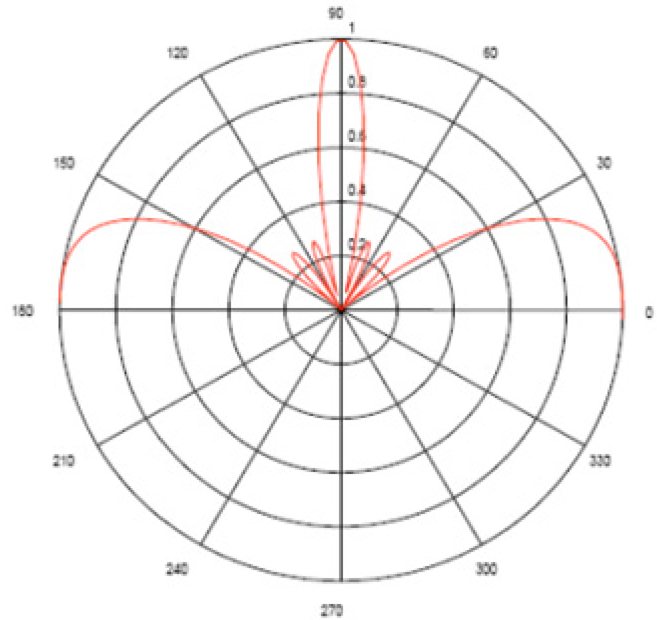

Fig 3.3: 4 Element linear array, spacing λ [4]

By keeping the overall length the same, and adding elements to reduce the spacing back to 1/2 wavelength, the side lobes are reduced. Following is the radiation pattern if 3 more elements are added to the linear array above to reduce the element spacing.

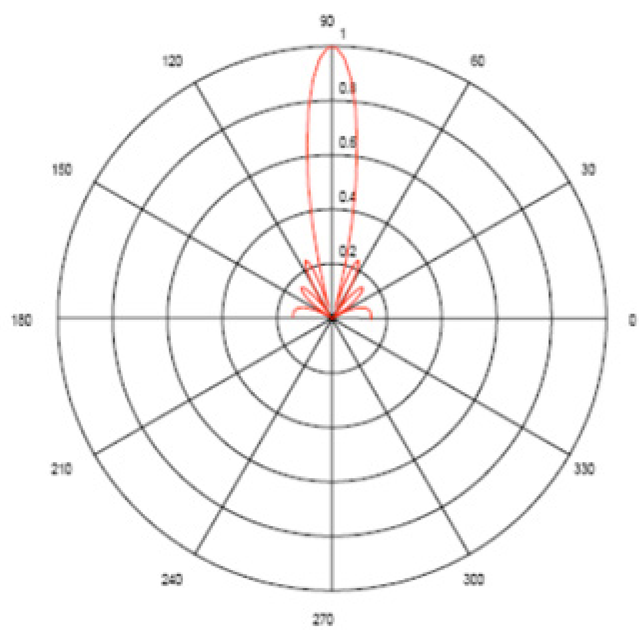

Fig 3.4: 7 Element 3 λ linear array [4]

Hence we can conclude that the radiation pattern of an antenna array is affected by following parameters [1]:

1. Difference in amplitude of currents fed to different array elements
2. Difference in phase of current fed to different array elements
3. Distances between individual antenna elements i.e. inter element spacing.
4. No. of elements
5. Radiation pattern of individual elements.

3.4 Array Factor (AF)

The array factor is a function of the geometry of the array and the excitation phase. By varying the separation d and/or the phase β between the elements, the characteristics of the array factor and of the total field of the array can be controlled. It has been illustrated [5]that the far-zone field of a uniform two-element array of identical elements is equal to the product of the field of a single element, at a selected reference point (usually the origin), and the array factor of that array. That is, [5]

$$E\text{ (total)} = [E\text{ (single element at reference point)}] \times [\text{array factor}] \tag{3.1}$$

This is referred to as pattern multiplication for arrays of identical elements. Although it has been illustrated only for an array of two elements, each of identical magnitude, it is also valid for arrays with any number of identical elements which do not necessarily have identical magnitudes, phases, and/or spacing between them. This will be demonstrated in this chapter by a number of different arrays. Each array has its own array factor. The array factor, in general, is a function of the number of elements, their geometrical arrangement, their relative magnitudes, their relative phases, and their spacing. The array factor will be of simpler form if the elements have identical amplitudes, phases, and spacing. Since the array factor does not depend on the directional characteristics of the radiating elements themselves, it can be formulated by replacing the actual elements with isotropic (point) sources. Once the array factor has been derived using the point-source array, the total field of the actual array is obtained by the use of equation (3.1).

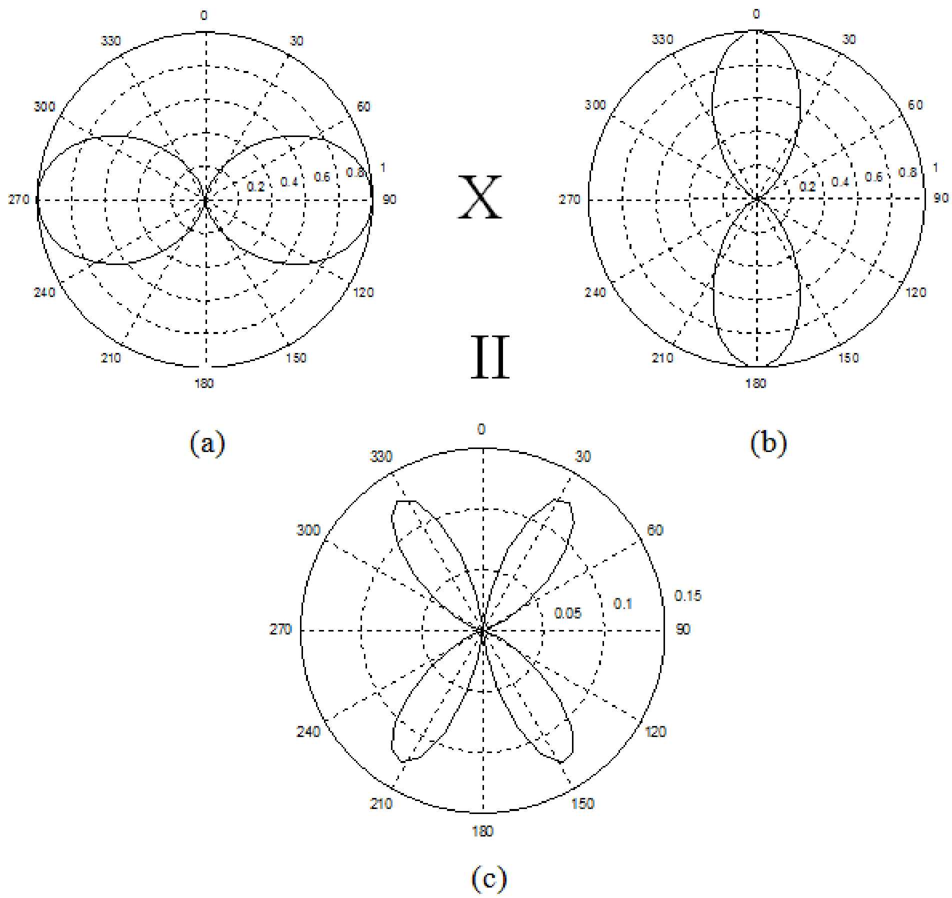

Fig 3.5:(a) Dipole Pattern, (b)Array factor pattern, (c) Total pattern[5]

3.5 Uniform linear array

As we have used uniform linear array in particular for smart antenna analysis, we are going to formulate and have a brief discussion on it.

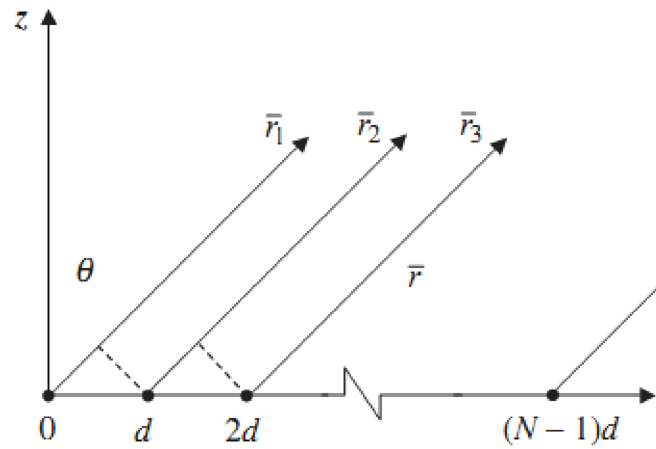

Fig 3.6: N element uniform linear (1-D) array of isotropic [1]

Here, we consider an N element linear array consists of isotropic radiating antenna elements. Antenna elements are separated from each other by a distance d. The field point is located at a distance r from the origin such that r >> d. We can therefore assume that the distance vectors $\bar{r}_1, \bar{r}_2, \ldots, \bar{r}_N$ are all approximately parallel to each other. It is assumed that the nth element leads the (n − 1) element by an electrical phase shift of δ radians. This phase shift can easily be implemented by shifting the phase of the antenna current for each element.

We can derive the array factor as follows:

$$AF = 1 + e^{j(kdsin\,\theta+\delta)} + e^{j2(kdsin\,\theta+\delta)} + \cdots + e^{j(N-1)(kdsin\,\theta+\delta)} \quad [3.2]$$

$$\mathrm{AF} = \sum_{n=1}^{N} e^{j\,(n-1)(kdsin\,\theta+\delta)} = \sum_{n=1}^{N} e^{j(n-1)\psi} \quad [3.3]$$

Where $\psi = kd\ \sin\theta + \delta$

It should be noted that if the array is aligned along the *z*-axis then $\psi = kd\ \cos\theta + \delta$. Since each isotropic element has unity amplitude, the entire behavior of this array is dictated by the phase relationship between the elements. The phase is directly proportional to the element spacing in wavelengths. The array processing and array beamforming textbooks have taken an alternative approach to expressing Eq. (3.3). Let us begin by defining the array vector.

$$\bar{a}\,(\theta) = \begin{bmatrix} 1 \\ e^{j\,(kd\sin\theta+\,\delta)} \\ \vdots \\ e^{j\,(N-1)(kd\sin\theta+\,\delta)} \end{bmatrix} = [1 \quad e^{j\,(kd\sin\theta+\,\delta)} \quad \ldots \quad e^{j\,(N-1)(kd\sin\theta+\,\delta)}]^T \quad [3.4]$$

Where [ ] ^{T} signifies the transpose of the vector within the brackets.

Therefore, the array factor, in Eq. (3.3), can alternatively be expressed as the sum of the elements of the array vector.

$$AF \;= sum(\,\bar{a}\,(\theta)) \qquad [3.5]$$

We may simplify the expression in Eq. (3.2) by multiplying both sides by $e^{j\,\psi}$ such that

$$e^{j\,\psi}\,AF = \;e^{j\,\psi} + \;e^{j2\psi} + \cdots + e^{jN\psi} \qquad [3.6]$$

Subtracting Eq. (3.2) from Eq. (3.6) yields

$$\left(e^{j\,\psi} - 1\right)AF = (e^{jN\psi} - 1) \qquad [3.7]$$

The array factor can now be rewritten.

$$AF = \frac{(\,e^{jN\psi} - 1\,)}{(\,e^{j\psi} - 1\,)} = \frac{e^{j\frac{N}{2}\psi}\,(\,e^{j\frac{N}{2}\psi} \;- e^{-j\frac{N}{2}\psi})}{e^{j\frac{\psi}{2}}(\,e^{j\frac{\psi}{2}} - e^{-j\frac{\psi}{2}})}$$

$$= \;e^{j\frac{(N-1)}{2}\psi}\,\frac{\sin(\frac{N}{2}\psi)}{\sin(\frac{\psi}{2})} \qquad [3.8]$$

The $e^{j\frac{(N-1)}{2}\psi}$ term accounts for the fact that the physical center of the array is located at $(N-1)d/2$. This array center produces a phase shift of $(N-1)\,\frac{\psi}{2}$ in the array factor. If the array is centered about the origin, the physical center is at 0 and Eq. (3.8) can be simplified to become

$$|AF| = \frac{sin(\frac{N}{2}\psi)}{sin(\frac{\psi}{2})} \qquad [3.9]$$

The maximum value of AF is when the argument $\psi = 0$ in that case AF = N. This is intuitively obvious since an array of N elements should have a gain of N over a single element. We may normalize the AF to be re expressed as

$$AF_n = \frac{1}{N}\;\frac{sin(\frac{N}{2}\psi)}{sin(\frac{\psi}{2})} \qquad [3.10]$$

Chapter 4

Comparative Study of Direction of Arrival (DOA) Algorithms

4.1 What is Direction of Arrival (DOA) or Angle of Arrival (AOA)?

For one source there are many possible propagation paths and angles of arrival. If several transmitters are operating simultaneously, each source potentially creates many multi path components at the receiver. Therefore, it is important for a receive array to be able to estimate the angles of arrival in order to decipher which emitters are present and what are their possible angular locations. This information can be used to eliminate or combine signals for greater fidelity, suppress interferers, or both.
The goal of DOA estimation techniques is to define a function that gives an indication of the angles of arrival based upon maxima vs. angle. This function is traditionally called the pseudospectrum P (θ) and the units can be in energy or in watts (or at times energy or watts squared). There are several potential approaches to defining the pseudospectrum via beamforming, the array correlation matrix, eigenanalysis, linear prediction, minimum variance, maximum likelihood, Min-norm, MUSIC, Root-MUSIC, and many more approaches. Popular Direction of Arrivals estimation methods are [5] - [9]

1. Bartlett DOA estimate
2. Capon DOA estimate
3. Linear Prediction DOA estimate
4. Maximum Entropy DOA estimate
5. Pisarenko Harmonic Decomposition
6. Min-norm DOA estimate
7. MUSIC DOA estimate
8. Root-MUSIC DOA estimate
9. ESPRIT DOA estimate

4.2 Discussion on Bartlett DOA Estimate

If the array is uniformly weighted, we can define the Bartlett DOA estimate as

$$P_B(\theta) = \bar{a}^H(\theta)\bar{R}_{xx}\,\bar{a}(\theta) \tag{4.1}$$

The Bartlett DOA estimate is the spatial version of an averaged periodogram and is a beamforming DOA estimate. Under the conditions where $\bar{s}$ represents uncorrelated monochromatic signals and there is no system noise.

The periodogram is thus equivalent to the spatial finite Fourier transform of all arriving signals. This is also equivalent to adding all beamsteered array factors for each angle of arrival and finding the absolute value squared[5]-[9].

4.3 Discussion on MUSIC DOA estimate

MUSIC is an acronym which stands for Multiple Signal Classification. This approach is a popular high resolution eigenstructure method [5]-[9]. MUSIC promises to provide unbiased estimates of the number of signals, the angles of arrival, and the strengths of the waveforms. MUSIC makes the assumption that the noise in each channel is uncorrelated making the noise correlation matrix diagonal. The incident signals may be somewhat correlated creating a nondiagonal signal correlation matrix. However, under high signal correlation the traditional MUSIC algorithm breaks down and other methods must be implemented to correct this weakness. These methods will be discussed later in this chapter. One must know in advance the number of incoming signals or one must search the eigenvalues to determine the number of incoming signals. If the number of signals is D, the number of signal eigenvalues and eigenvectors is D, and the number of noise eigenvalues and eigenvectors is M− D (M is the number of array elements). Because MUSIC exploits the noise eigenvector subspace, it is sometimes referred to as a subspace method. As before we calculate the array correlation matrix assuming uncorrelated noise with equal variances.

$$\bar{R}_{xx} = \bar{A}\,\bar{R}_{ss}\,\bar{A}^H + \sigma_n^2\bar{I} \tag{4.2}$$

We next find the eigenvalues and eigenvectors for $\bar{R}_{xx}$. We then produce D eigenvectors associated with the signals and M−D eigenvectors associated with the noise. We choose the eigenvectors associated with the smallest eigenvalues. For uncorrelated signals, the smallest eigenvalues are equal to the variance of the noise. We can then construct the M× (M− D) dimensional subspace spanned by the noise eigenvectors such that

$$\bar{E}_N = [\,\bar{e}_1\ \bar{e}_2\ \ldots\ \bar{e}_{M-D}\,] \tag{4.3}$$

The noise subspace eigenvectors are orthogonal to the array steering vectors at the angles of arrival $\theta_1, \theta_2, \ldots, \theta_D$. Because of this orthogonality condition, one can show that the Euclidean distance

$$d^2 = \bar{a}^H(\theta)\bar{E}_N\,\bar{E}_N^H\,\bar{a}(\theta) = 0 \tag{4.4}$$

For each and every arrival angle $\theta_1, \theta_2, \ldots, \theta_D$. Placing this distance expression in the denominator creates sharp peaks at the angles of arrival. The MUSIC pseudospectrum is now given as

$$P_{MU}(\theta) = \frac{1}{|\bar{a}(\theta)^H\,\bar{E}_N\,\bar{E}_N^H\,\bar{a}(\theta)|} \tag{4.5}$$

4.4 Comparison between Bartlett and MUSIC DOA estimate

4.4.1 Impact of No. of Array Element of the Antenna

(a)Testing Environment

No of array elements = 6
Noise variance = 0.1
Element spacing = 0.5 λ

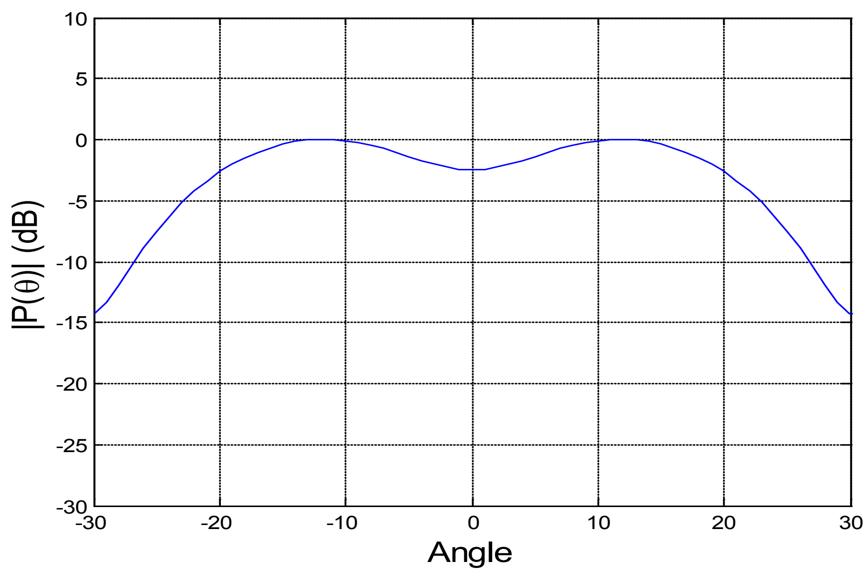

Fig 4.1: Studies of Bartlett DOA Algorithm with array element 6

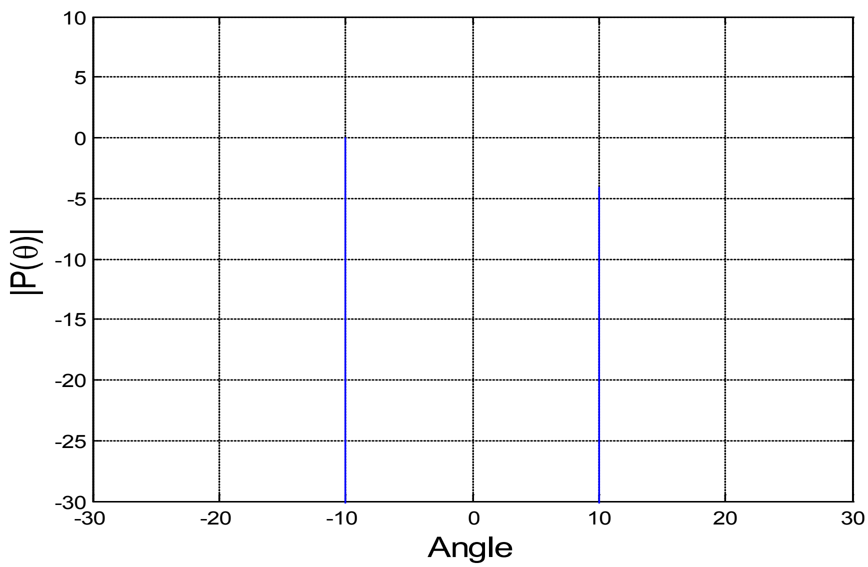

Fig 4.2: Studies of MUSIC DOA Algorithm with array element 6

(b)Testing Environment

No of array elements = 20
Noise variance = 0.1
Element spacing = 0.5 λ

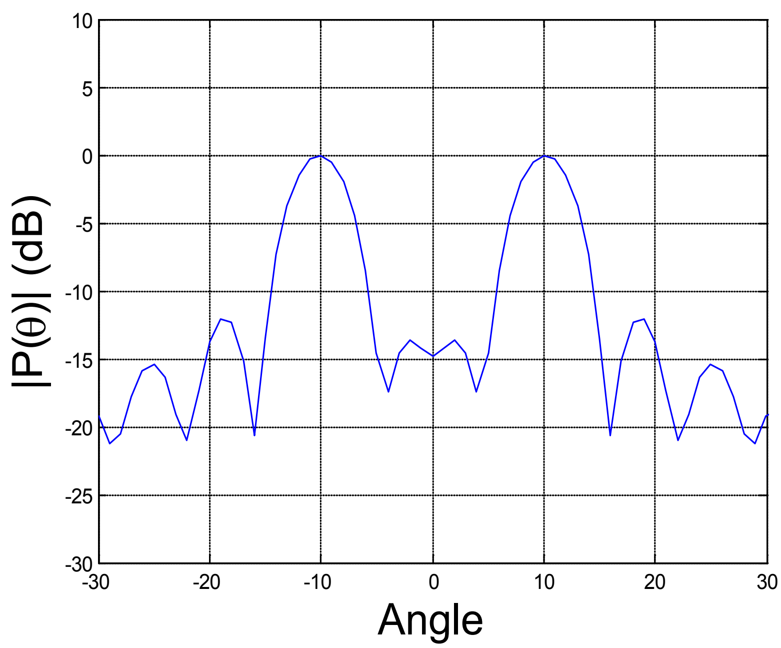

Fig 4.3: Studies of Bartlett DOA Algorithm with array element 20

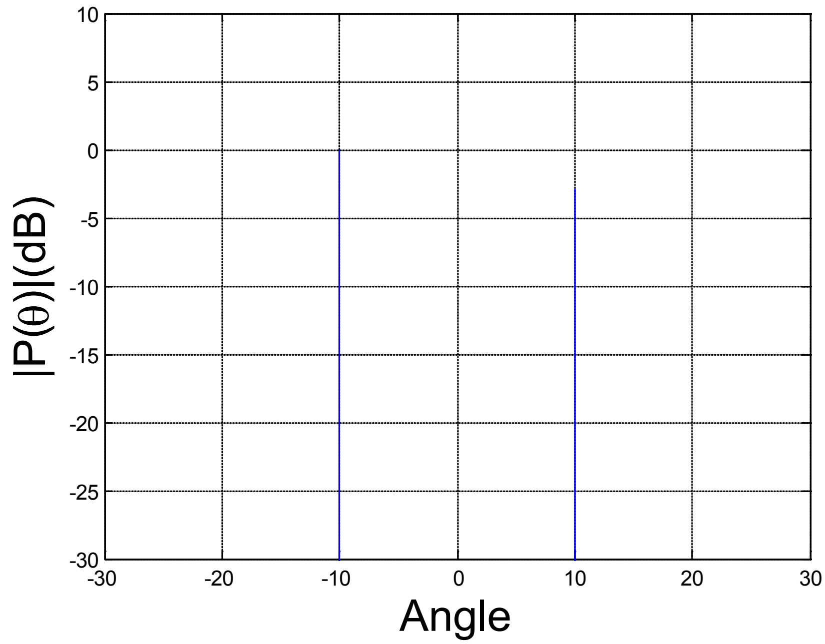

Fig 4.4: Studies of MUSIC DOA Algorithm with array element 20

Discussion

In case of both Bartlett DOA estimate and MUSIC DOA estimate we have taken array element, M=6 and our test signals were coming at an angle -10^0 and$+10^0$. But applying Bartlett DOA estimate we haven't got very sharp peak at our point of interest and at -10^0 and $+10^0$ signals were almost indistinguishable. But in case of MUSIC, the sharp peaks were found at our point of interest. And they were quite distinguishable.

Again, when we have taken array element, M=20 for both the Bartlett and MUSIC DOA estimate. Now due to changing the number of array element the peaks become sharp in case of Bartlett DOA estimate and the peaks were significantly distinguishable. And in MUSIC DOA estimate peaks become sharper.

Therefore, we can could as if we increase the no of array element; it has an impact on the peaks produced by the different DOA estimate algorithm. But we can't increase the number of array element abruptly because we have to excite the array element individually, so it becomes more complex to provide individual excitation current to each array element.

4.4.2 Multiple Signal Performance

(a)Testing Environment

Noise variance =0.1,
Element spacing = 0.5 λ
Equal Amplitude, Signals are Uncorrelated and Considering Linear Arrays

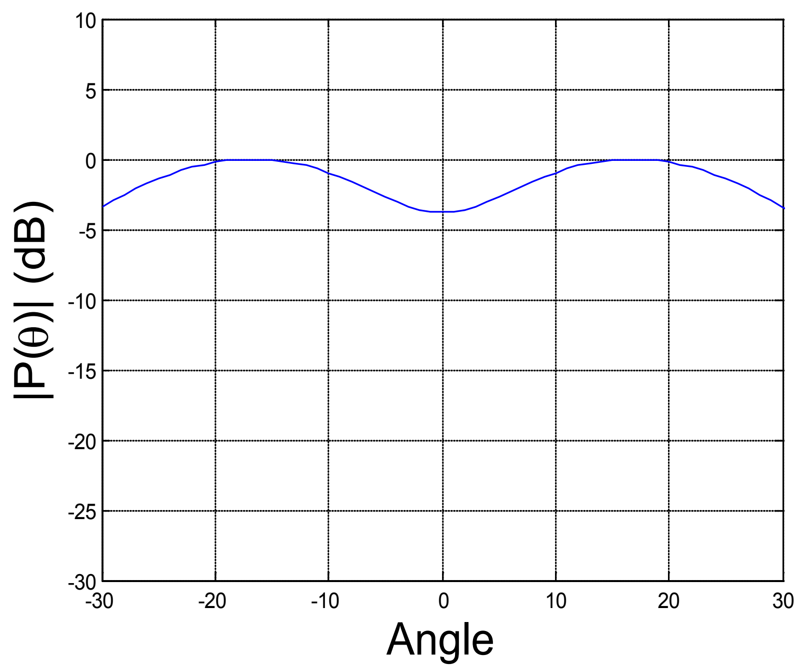

Fig 4.5: Bartlett DOA Algorithm performance with 4 signals

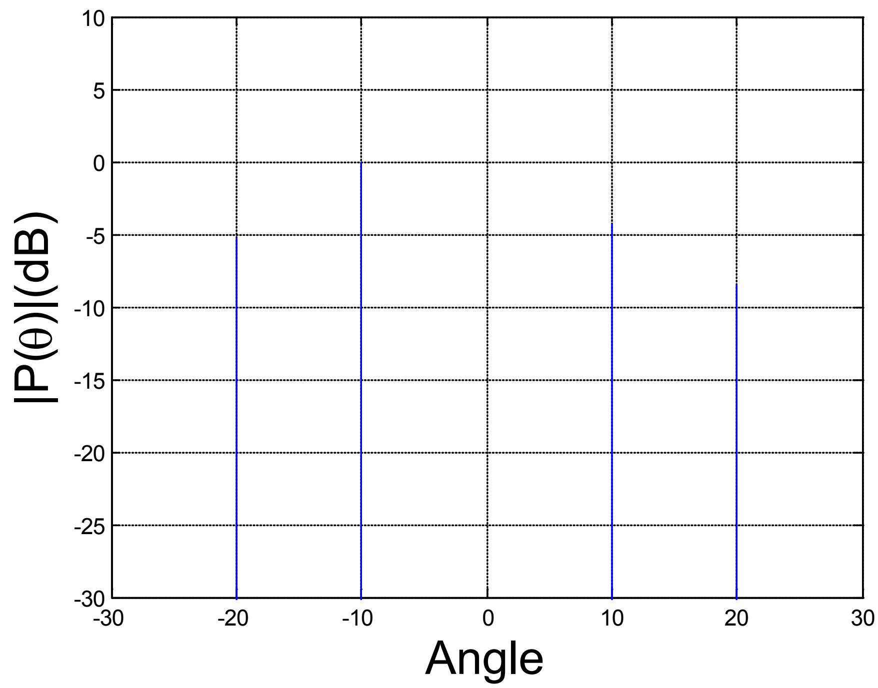

Fig 4.6: MUSIC DOA Algorithm performance with 4 signals

Discussion

In this case the number of array elements were 6 and signals were coming from -10^0, $+10^0, -20^0$and $+20^0$. But using Bartlett DOA estimate it was unable to differentiate the signals of interest individually. But when the MUSIC DOA algorithm was adopted sharp peaks were found in the angles of interests.
Therefore, we can conclude with the bottom line that MUSIC DOA algorithm is more advantageous over Bartlett DOA algorithm in case of multiple signal arrivals.

4.4.3 Resolution

(a)Testing Environment

Noise variance = 0.1,
Element spacing = 0.5 λ
Equal Amplitude, Signals are Uncorrelated and Considering Linear Arrays
Angle of arrival at - $5^0$and + 5^0

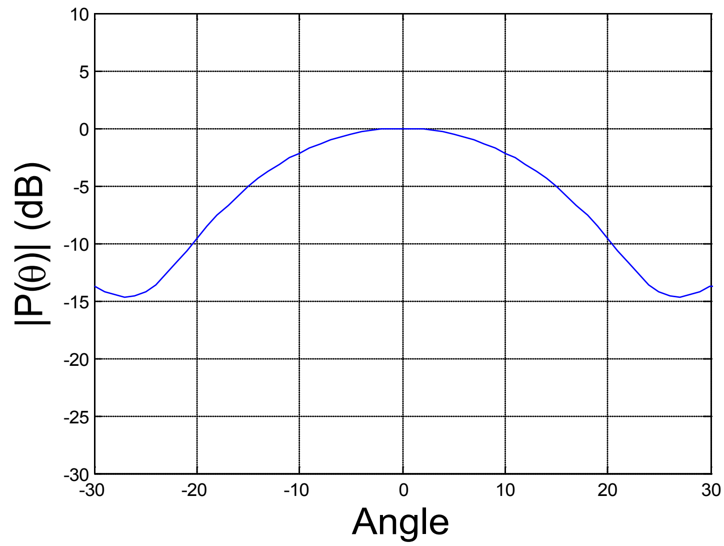

Fig 4.7: Bartlett pseudospectrum for $\theta_1 = -5^0\ and\ \theta_2 = +5^0$

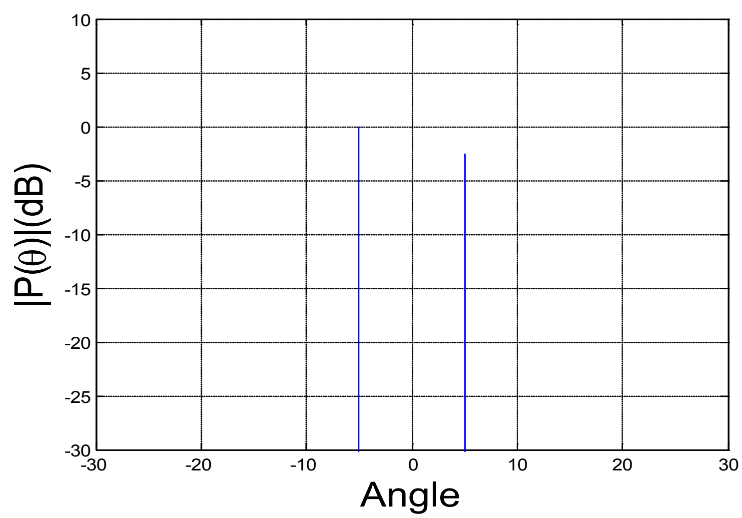

Fig 4.8: MUSIC pseudospectrum for $\theta_1 = -5^0\ and\ \theta_2 = +5^0$

Discussion

In case of both the Algorithm testing signals were coming from the angle - 5^0 and $+5^0$. But for Bartlett DOA the resolution is very poor, these two signals are almost indistinguishable at those angles, where as for MUSIC DOA algorithm sharp peaks are found at those points of interest angles. We can estimate the beam width of this M = 6 element array to be ≈ 8.5^0. Thus, the two sources, which are 20^0 apart, are resolvable with the Bartlett approach. The two sources, which are 10◦ apart, are not resolvable. Herein lies one of the limitations of the Bartlett approach to DOA estimation: the ability to resolve angles is limited by the array half-power beamwidth. An increase in resolution requires a larger array. For large array lengths with $d = \lambda/2$ spacing, the DOA resolution is approximately $1/M$. Thus, $1/M$ is the DOA resolution limit of a periodogram and in the case above is an indicator of the resolution of the Bartlett method.

Therefore, we can conclude that MUSIC DOA is more advantageous over Bartlett DOA when the angles of interest are very close to each other e.g. their resolution is very high.

Chapter 5

Beamforming

5.1 Introduction

There are two types of beam forming approaches; one is fixed beam forming approach which was used if the angles of arrivals don't change with time i.e. the user emitting the desired signals is fixed and not moving. This type of fixed technique actually does not steer or scan the beam in the direction of the desired signal. Switched beam employs an antenna array which radiates several overlapping fixed beams covering a designated angular area. The fixed beam forming techniques used are the maximum signal to interference ratio (MSIR), the Maximum likelihood method (ML) and the Minimum Variance method (MV). If the arrival angles are such that they do not change with time, the optimum array weights will not need to be adjusted.

However, if the desired arrival angles change with time, it is necessary to devise an optimization scheme that operates dynamically according to the changing environment so as to keep recalculating the optimum array weights. The receiver signal processing algorithm then must allow for the continuous adaptation to an ever-changing electromagnetic environment. Thus, if the user emitting the desired signal is continuously moving due to which the angle of arrival is changing, this user can be tracked and a continuous beam can be formed towards it by using one of the adaptive beam forming techniques. This is achieved by varying the weights of each of the sensors (antennas) used in the array. It basically uses the idea that, though the signals emanating from different transmitters occupy the same frequency channel, they still arrive from different directions. This spatial separation is exploited to separate the desired signal from the interfering signals. In adaptive beam forming the optimum weights are iteratively computed using complex algorithms based upon different criteria. The adaptive beam forming algorithms are classified into two types:

5.1.1 Non-blind adaptive algorithms

These types of algorithms make use of a reference signal to modify the array weights iteratively, so that at the end of each and every iteration, the output of the weights is compared to the reference signal and the generated error signal is used in the algorithms to modify the weights [5] . The examples of this type of algorithm are Least Mean Square Algorithm (LMS), Recursive Least Square algorithm (RLS), Sample Matrix Inversion (SMI) and Conjugate Gradient (CG).

5.1.2 Blind adaptive algorithms

Unlike the non-blind adaptive algorithms, the blind adaptive algorithms do not make use of the reference signal and hence no array weight calibration is required. The examples of this type of algorithms are Constant Modulus Algorithm (CMA) and Least Square Constant Modulus (LS-CMA) [5, 6].

5.2 Comparison among the non-blind Adaptive Beamforming Algorithms

Simulation was modeled keeping the following parameters fixed for all algorithms

- Number of Array Element M = 5
- Array Spacing d = 0.5 λ
- Array geometry : Linear array
- Received Signal Arriving at the Angle = 30^0
- Interferer Signal Arriving at the Angle = - 60^0

5.2.1 Least Mean Square (LMS)

The LMS algorithm is probably the most widely used adaptive filtering algorithm, being employed in several communication systems [5, 8, 9, and 11]. It has gained popularity due to its low computational complexity and proven robustness. It incorporates new observations and iteratively minimizes linearly the mean-square error. The LMS algorithm changes the weight vector w along the direction of the estimated gradient based on the negative steepest descent method. The LMS algorithm updates the weight vector according to

for each k

{

$e(k) = d(k) - W^H(k)\, x(k)$

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

}

Where,

K	No of samples
W	Weight
E	Error Signal
D	Desired Signal
G	Gain Vector
R_{xx}	Correlation Matrix

Here we have taken step size μ = 0.0217

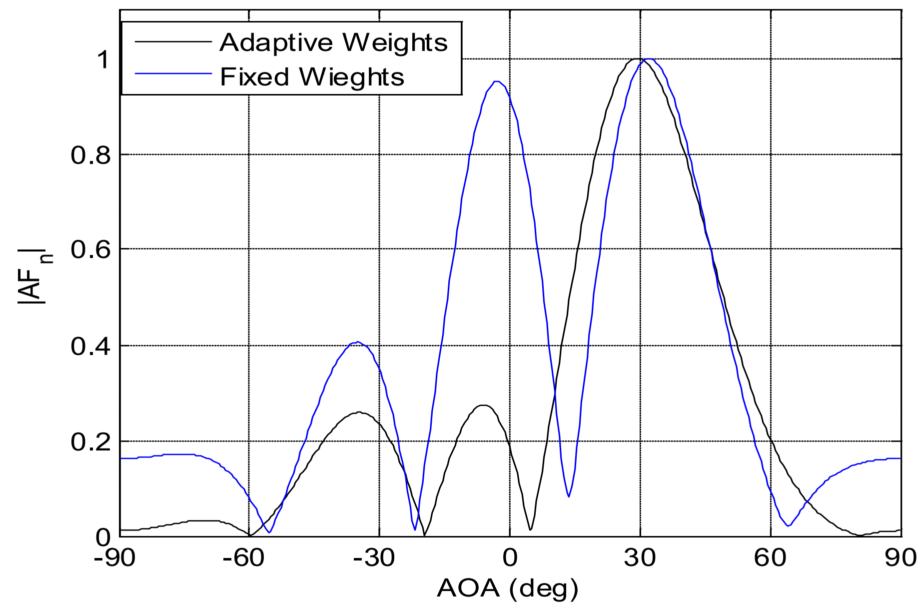

Fig 5.1: LMS Array Pattern

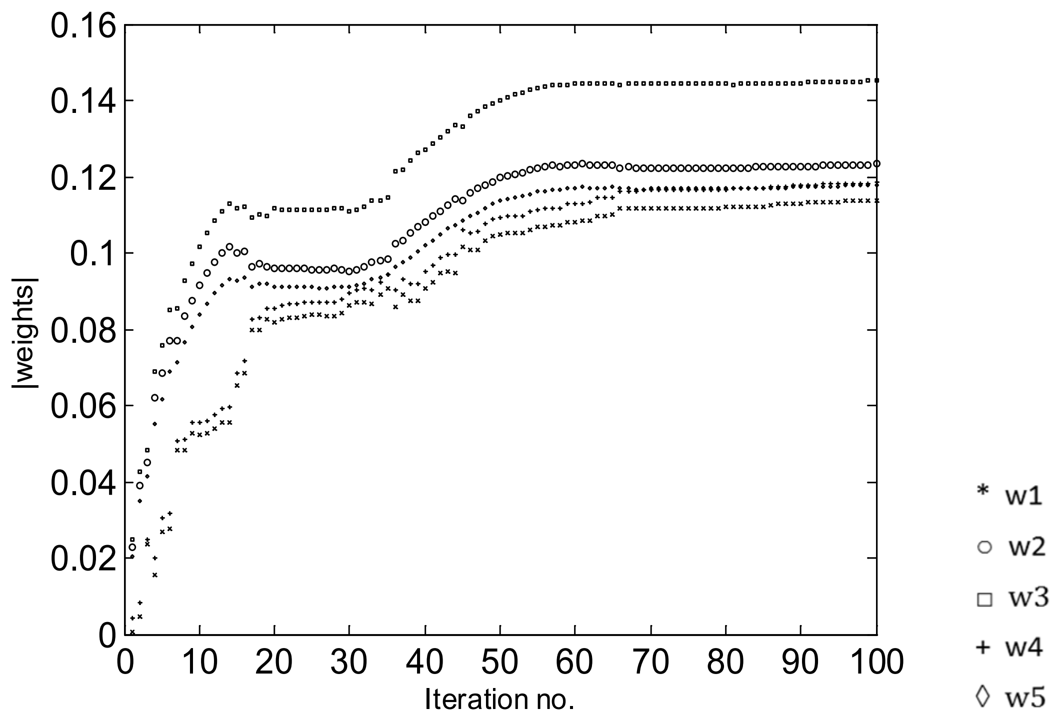

Fig 5.2: LMS Algorithm |Weights| vs. Iteration Curve

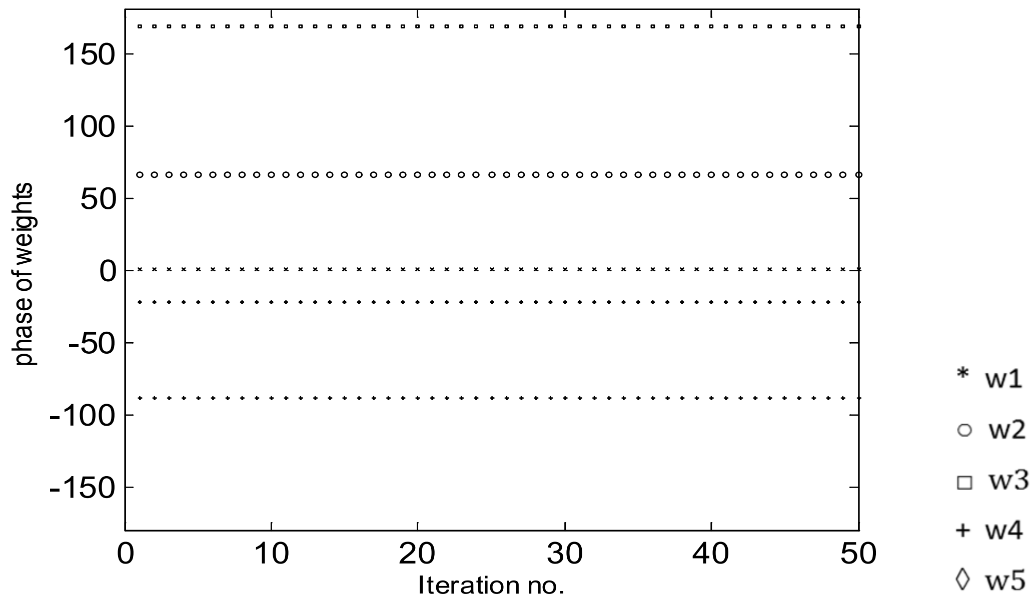

Fig 5.3: LMS Algorithm Phase vs. Iteration Curve

Table: 5.1 Amplitude and Phase Excitation Coefficients of a five-Element Array Using the LMS Algorithm

Weights,w_{opt}	Amplitude	Phase(in degree)
W_1	1	0
W_2	1.079	65.56
W_3	1.425	168.656
W_4	1.076	-88.382
W_5	1	-22.877

Discussion

In LMS Algorithm adaptation from figure (a) it is evident that while fixed weights are used then at our desired angle of interest the produced gain was not satisfactory. But in case of adaptation of LMS Algorithm the adaptive weights are used which causes the sharp peak gains at our angle of interest e.g. at +30 degree and -30 degree. Besides that the LMS algorithm reduces the side lobe effect on which causes unnecessary power dissipation.

5.2.2 SMI Algorithm

SMI method is also alternatively known as direct matrix inversion (DMI). The sample matrix is a time average estimate of the array correlation, matrix using K -time samples. If the random processes ergodic in the correlation, the time average estimate will equal the actual correlation matrix [5, 11].

For each k

{

$$\hat{R}_{xx}(k) = \frac{1}{K}\,\bar{X}_K(k)\,\bar{X}_K^H\,(k)$$

$$\hat{r}(k) = \frac{1}{K}\,\bar{d}^*(k)\,\bar{X}_K(k)$$

$$\bar{w}_{SMI}(k) = \bar{R}_{xx}^{-1}\,(k)\,\bar{r}\,(k)$$

$$= [\bar{X}_K(k)\,\bar{X}_K^H\,(k)\,]^{-1}\,\bar{d}^*(k)\,\bar{X}_K(k)$$

}

Since we use a K -length block of data, this method is called a block-adaptive approach. We are thus adapting the weights block-by-block. Here we have taken a block length of K=100 samples.

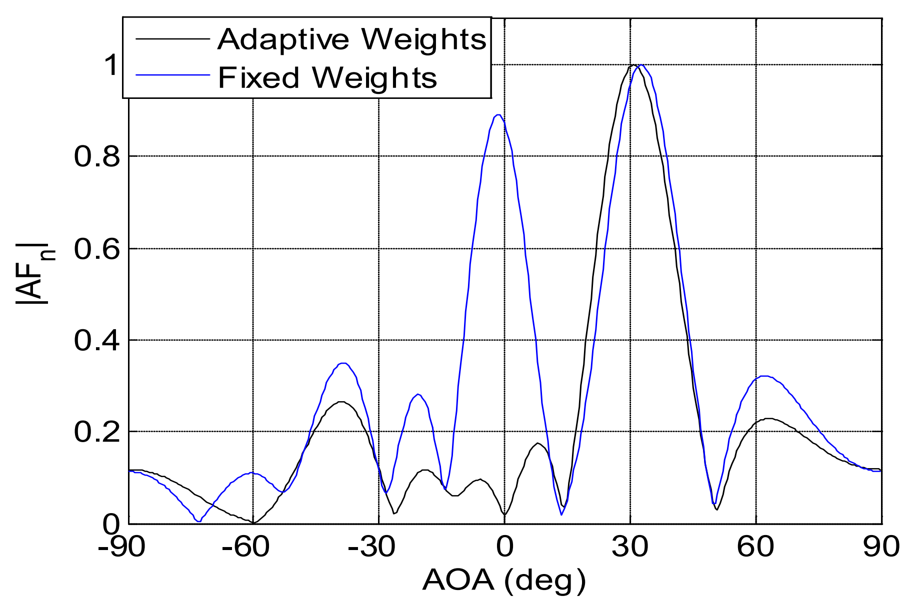

Fig 5.4: SMI Array Pattern

Table 5.2: Amplitude and Phase Excitation Coefficients of a five-Element Array Using the SMI Algorithm

Weights, w_{opt}	Amplitude	Phase(in degree)
W_1	1	0
W_2	.824	-66.597
W_3	1.51	-169.895
W_4	.808	94.42
W_5	.992	17.046

Discussion

Although SMI algorithm converges very quickly compared to LMS algorithm, has several drawbacks. Even with the powerful DSP's available today it is a very challenging task to perform inversion of correlation matrix in real time because the base operation of this algorithm is matrix inversion. The SMI algorithm has other disadvantages. The sample matrix cannot be inverted until N samples could be collected, because it rank is not complete. Even if the rank is complete (k>N) the singularity condition causes calculation errors. In addition, for large arrays, there is the challenge of inverting large matrices.

5.2.3 RLS Algorithm

The basic approach taken by RLS is to recursively perform the matrix inversion as required by the direct calculation approach so that at no time no time direct matrix inversion computation is required .we can find $\widehat{R}_{xx}$ recursively to update the weight vectors[5,6,8,12].

for each k

{

$$\widehat{R}_{xx}(k) = \alpha \sum_{i=1}^{k-1} \alpha^{k-1-i}\ \bar{x}(i)\, \bar{x}^H(i) + \bar{x}(k)\, \bar{x}^H(k)$$

$$= \alpha\widehat{R}_{xx}(k-1) + \bar{x}(k)\, \bar{x}^H(k)$$

$$\bar{g}(k) = \widehat{R}_{xx}^{-1}(k)\, \bar{x}(k)$$

$$\bar{w}(k) = \bar{w}(k-1) - \bar{g}(k)\ \bar{x}^H(k)\, \bar{w}(k-1) + \bar{g}(k) d^*(k)$$

$$= \bar{w}(k-1) - \bar{g}(k)[d^*(k) - \bar{x}^H(k)\, \bar{w}(k-1)]$$

}

Here we have taken forgetting factor $\alpha = 0.9$

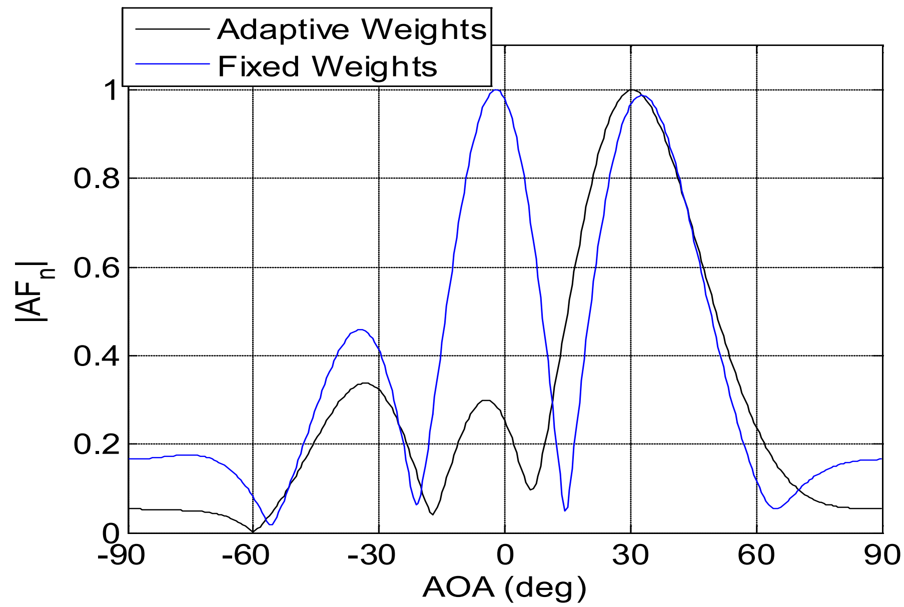

Fig 5.5: RLS Array Pattern

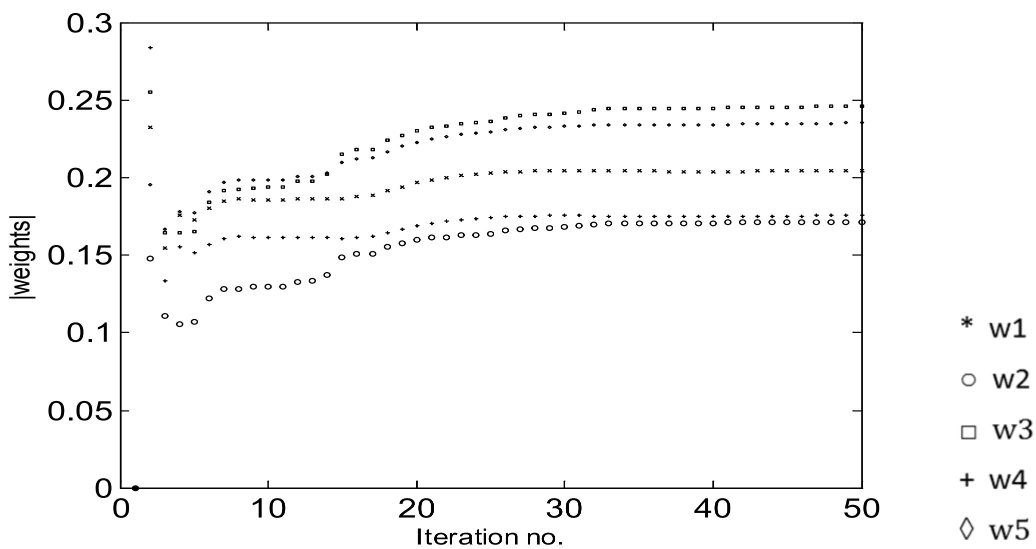

Fig 5.6: RLS algorithm |Weights| vs. Iteration Curve

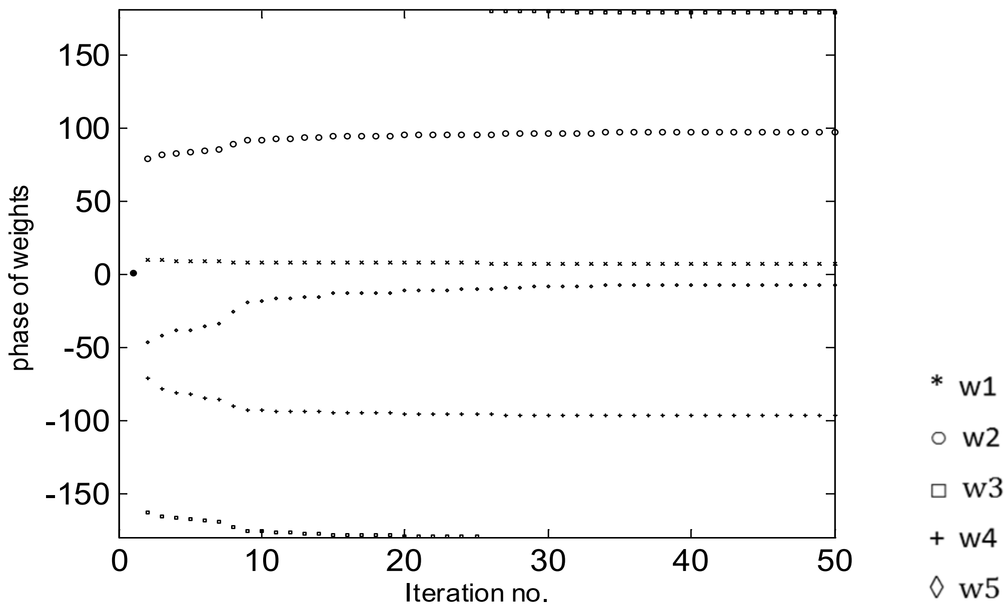

Fig 5.7: RLS Algorithm Phase vs. Iteration Curve

Table 5.3: Amplitude and Phase Excitation Coefficients of a five-Element Array Using the RLS Algorithm

Weights, w_{opt}	Amplitude	Phase(in degree)
W_1	0.195	5.61
W_2	0.2066	71.95
W_3	0.267	179.914
W_4	0.1797	-73.15
W_5	0.169	-2.306

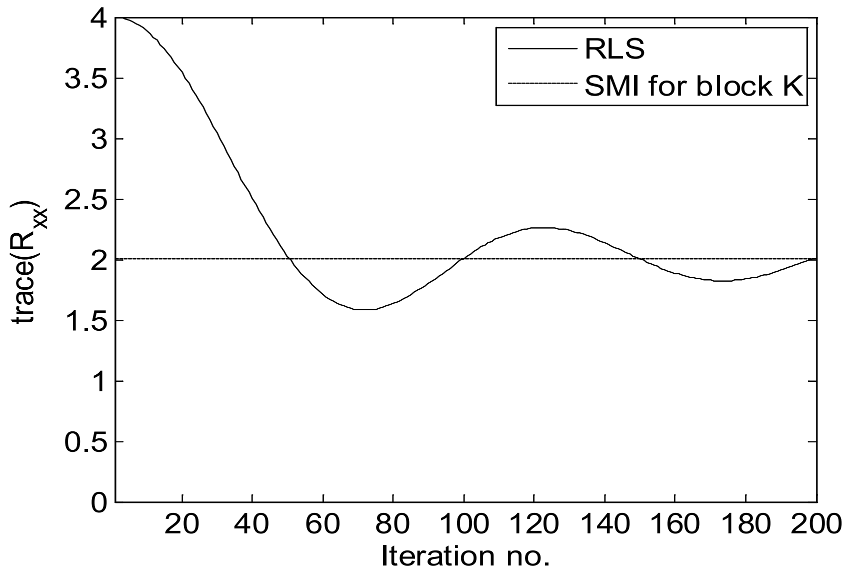

Fig 5.8: Trace vs. Iteration no of RLS and SMI

Discussion

The advantage of the recursion approach is that one need not calculate the correlation for an entire block of length K. Rather, each update only requires one block of data samples and the previous correlation matrix. It can be seen that the recursion formula oscillates for different block lengths and that it matches the SMI solution when k = K. The recursion formula always gives a correlation matrix estimate for any block length k but only matches SMI when the forgetting factor is 1.However, in LMS the nulls are positioned on directions slightly shifted from interfering users. On the other hand, null steering in SMI and RLS approaches work well, but in SMI deeper nulls are obtained.

Chapter 6

Smart Antenna System

6.1 MOTIVATION FOR USING SMART ANTENNA

Wireless communication systems, as opposed to their wire line counterparts, pose some unique challenges [6, 10]:

I. the limited allocated spectrum results in a limit on capacity
II. the radio propagation environment and the mobility of users give rise to signal fading
III. and spreading in time, space and frequency
IV. the limited battery life at the mobile device poses power constraints
V. In addition, cellular wireless communication systems have to cope with interference due to frequency reuse

The commercial adoption of smart antenna techniques is a great promise to the solution of the aforementioned wireless communications' impairments.

6.2 BENEFITS OF SMART ANTENNA

Smart antennas have numerous important benefits in wireless applications as well as in sensors such as radar. In the realm of mobile wireless applications, smart antennas can provide higher system capacities by directing narrow beams toward the users of interest, while nulling other users not of interest. This allows for higher signal-to-interference ratios, lower power levels, and permits greater frequency reuse within the same cell. This concept is called space division multiple access (SDMA).

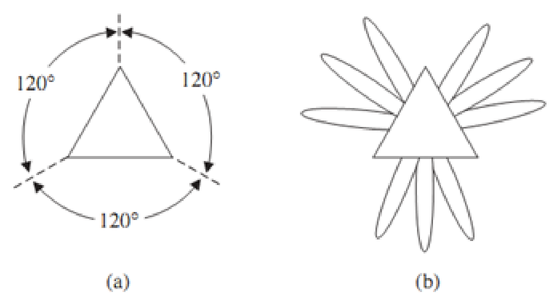

Fig 6.1: (a) Sectorized (b) Smart Antennas[6]

In the United States, most base stations sectorized each cell into three 120◦ swaths as seen in Fig. 6.1a. This allows the system capacity to potentially triple within a single cell because users in each of the three sectors can share the same spectral resources. Most base stations can be modified to include smart antennas within each sector. Thus the 120◦ sectors can be further subdivided as shown in Fig. 6.1b. This further subdivision enables the use of lower power levels, and provides for even higher system capacities and greater bandwidths.

Another benefit of smart antennas is that the deleterious effects of multipath can be mitigated. This will dramatically reduce fading in the received signal. Higher data rates can be realized because smart antennas can simultaneously reduce both co-channel interference and multipath fading. Multipath reduction not only benefits mobile communications but also applies to many applications of radar systems.

Smart antennas can be used to enhance direction-finding (DF) techniques by more accurately finding angles-of-arrival (DOA). A vast array of spectral estimation techniques can be incorporated, which are able to isolate the DOA with an angular precision that exceeds the resolution of the array [10]. The accurate estimation of DOA is especially beneficial in radar systems for imaging objects or accurately tracking moving objects. Smart antenna DF capabilities also enhance geo location services enabling a wireless system to better determine the location of a particular mobile user.
Additionally, smart antennas can direct the array main beam toward signals of interest even when no reference signal or training sequence is available. This capability is called blind adaptive beamforming.

Smart antennas also play a role in MIMO communications systems and in waveform diverse MIMO radar systems. Since diverse waveforms are transmitted from each element in the transmit array and are combined at the receive array, smart antennas will play a role in modifying radiation patterns in order to best capitalize on the presence of multipath. With MIMO radar, the smart antenna can exploit the independence between the various signals at each array element in order to use target scintillation for improved performance, to increase array resolution, and to mitigate clutter.

In summary, let us list some of the numerous potential benefits of smart antennas [5].

- Improved system capacities
- Higher permissible signal bandwidths
- Space division multiple access (SDMA)
- Higher signal-to-interference ratios
- Increased frequency reuse
- Sidelobe canceling or null steering
- Multipath mitigation
- Constant modulus restoration to phase modulated signals
- Blind adaptation
- Improved angle-of-arrival estimation and direction finding
- Instantaneous tracking of moving sources
- Reduced speckle in radar imaging
- Clutter suppression
- Increased degrees of freedom
- Improved array resolution
- MIMO compatibility in both communications and radar

6.3 SMART ANTENNA SYSTEM

In this chapter the basic principle behind smart antennas is explained. In the first two sections the block diagrams of smart antenna receiving and transmitting systems are presented.

6.3.1 Basic Principle

The processing of events occurring in 3G smart antenna communication systems could be presented as the following sequence:

- “Snapshot”, or sampling, is taken of the training signals coming from all of the antenna elements.
- DOA estimation. The number of incoming wave fronts and their DOA’s is estimated.
- DOA classification. First, the spatially resolved wave fronts, each incident from an estimated DOA extracted from the input data. Then, user identification decides whether a DOA belongs to a user or to an interfere.
- The optimum weight calculation. The processor calculates the optimum weights to maximize the SIR for each user. A beamforming algorithm forms an antenna pattern with a main beam steered into the direction of the user, while minimizing the influence of the interfering wave fronts.
- Tracking. The user DOA’s are tracked to increase the reliability of the DOA estimates.

6.3.2 Smart Antenna Receiver

The antenna array contains M elements. The M signals are being combined into one signal, which is the input to the rest of the receiver (channel decoding, etc.)[10] .
As the figure shows, the smart antenna reception part consists of four units. In addition to the antenna itself it contains a radio unit, a beam forming unit and a signal processing unit .The array will often have a relatively low number of elements in order to avoid unnecessarily high complexity in the signal processing.

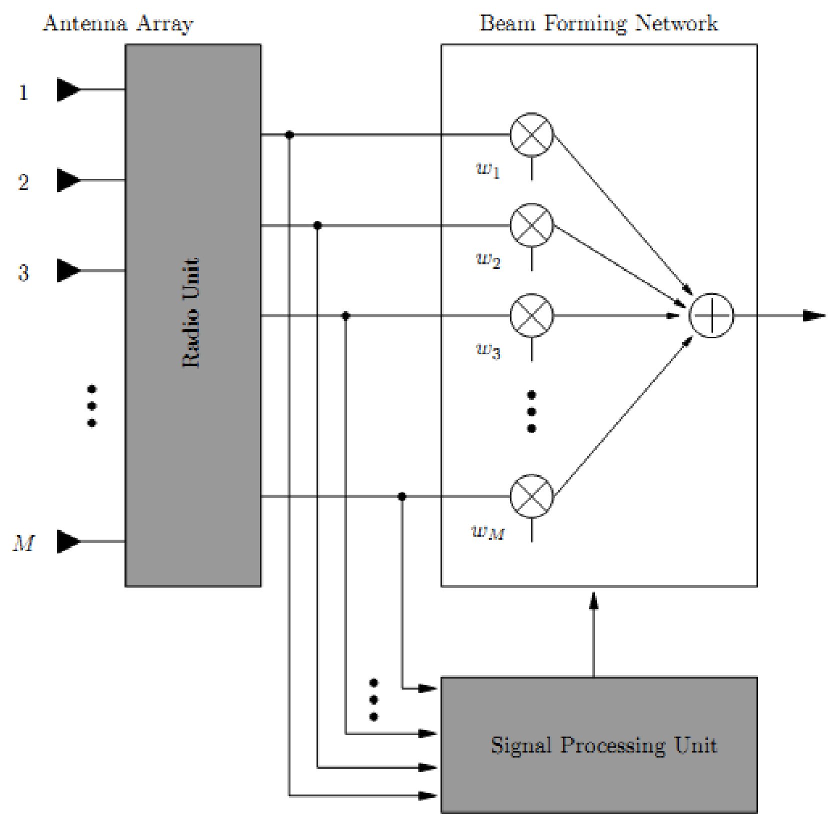

Fig. 6.2: shows schematically the elements of the reception part of a smart antenna [10]

The radio unit consists of down–conversion chains and (complex) analog-to-digital converters (A/D). There must be M down-conversion chains, one for each of the array elements [10].

The signal processing unit will, based on the received signal, calculate the complex weights w_1,..., w_M with which the received signal from each of the array elements is multiplied. These weights will decide the antenna pattern in the uplink direction (which will be shown in more detail later). The weight scan be optimized from two main types of criteria: maximization of received signal from the desired user (e.g. switched beam or phased array) or maximization of the SIR by suppressing the signal from interference sources (adaptive array). In theory, with M antenna elements one can "null out" M – 1 interference sources, but due to multipath propagation this number will normally be lower. The method for calculating the weights will differ depending on the type of optimization criterion. When switched beam (SB) is used, the receiver will test all the pre-defined weight vectors (corresponding to the beam set) and choose the one giving the strongest received signal level. If the phased array approach (PA) is used, which consists of directing a maximum gain beam towards the strongest signal component, the direction-of-arrival (DOA) is first estimated and then the weights are calculated. If maximization of SIR is to be done (AA), the optimum weight vector (of dimension M) W_{opt} can be computed using a number of algorithms such as optimum combining and others. When the beam forming is done digitally (after A/D), the beam forming and signal processing units can normally be integrated in the same unit (Digital Signal Processor, DSP). The separation in Fig. 6.2 is done to clarify the functionality. It is also possible to perform the beam forming in hardware at radio frequency (RF) or intermediate frequency (IF).

6.3.3 Smart Antenna Transmitter

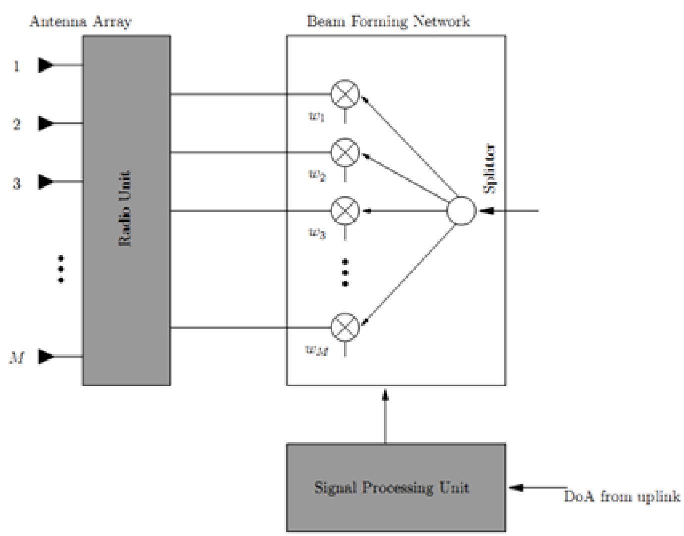

Fig 6.3: Transmission part of a Smart Antenna [10]

The transmission part of the smart antenna is schematically very similar to the reception part. An illustration is shown in Fig. 6.3. The signal is split into M branches, which are weighted by the complex weights w_1, ... ,w_M in the beam forming unit. The weights, which decide the radiation pattern in the downlink direction, are calculated as before by the signal processing unit. The radio unit consists of D/A converters and the up converter chains. In practice, some components, such as the antennas themselves and the DSP will of course be the same as on reception [10].

The principal difference between uplink and downlink is that no knowledge of the spatial channel response is available on downlink. In a time division duplex (TDD) system the mobile station and base station use the same carrier frequency only separated in time. In this case the weights calculated on uplink will be optimal on downlink if the channel does not change during the period from uplink to downlink transmission. However, this cannot be assumed to be the case in general, at least not in systems where the users are expected to move at high speed. If frequency division duplex (FDD) is used, the uplink and downlink are separated in frequency. In this case the optimal weights will generally not be the same because of the channel response dependency on frequency.

Thus optimum beamforming (i.e., AA) on downlink is difficult and the technique most frequently suggested is the geometrical approach of estimating the direction-of-arrival (DOA). The assumption is directional reciprocity, i.e., the direction from which the signal arrived on the uplink is the direction in which the signal should be transmitted to reach the user on downlink. The strategy used by the base station is to estimate the DOA of the direction (or directions) from which the main part of the user signal is received. This direction is used on downlink by choosing the weights $w_1, ..., w_M$ so that the radiation pattern is a lobe or lobes directed towards the desired user. This is similar to Phased Array Systems. In addition, it is possible to position zeros in the direction towards other users so that the interference suffered by these users is minimized. Due to fading on the different signal paths, it has been suggested to choose the downlink direction based on averaging the uplink channel over a period of time. This will however be sub-optimum compared to the uplink situation where knowledge about the instantaneous radio channel is available.

It should be stressed that in the discussion above it is assumed that the interferers observed by the base stations are mobile stations and that the interferers observed by the mobile stations are base stations. This means that when the base station on transmission positions zeros in the direction towards other mobile stations than the desired one, it will reduce the interference suffered by these mobiles. If, however, the interferers observed by mobiles are other mobiles, as maybe the case, there will be a much more fundamental limitation in the possibility for interference reduction at the mobile.

Chapter 7

Conclusion

In this thesis work we have provided an overview of smart antenna technologies. Smart antennas installed at the base stations will play a major role in providing the optimum capacity and coverage for third generation mobile communication. Conventional resource allocation based wireless technology can be improved by space division multiple access technology introduced by smart antenna. We have discussed about Bartlett and MUSIC DOA Algorithms here and compared between them on the basis of number of array elements, multiple signal performance, resolution. From our comparative analysis we found that in case of fewer array elements Bartlett algorithm gives worse performance. But MUSIC works well in case of fewer array elements. Also we found that Bartlett algorithm shows poor performance to detect Angle of Arrivals for multiple impinging signals. MUSIC algorithm detected multiple signals very well. To get the same result as MUSIC Algorithm we had to increase the number of array elements while using Bartlett algorithm. Bartlett is a Beamforming DOA approach. If two sources impinge in the half power beamwidth they are not separable. But MUSIC exploits eigen structure approach so it can provide high resolution. So MUSIC performs better over Bartlett DOA Algorithm in all aspects.

We discussed and compared the performances of three popular non-blind adaptive beamforming techniques LMS, RLS and SMI. LMS algorithm has shown less computational complexity compared to others. However, the algorithm needs about 70 iterations to have the weights converge to steady state value. That means this algorithm is computationally slow compared to others. On other hand, SMI algorithm utilizes direct matrix inversion approach. This results in computational complexity. But the convergence of SMI algorithm is much faster than LMS.RLS algorithm also converges faster than LMS algorithm but it does not need to calculate matrix inverse. This algorithm is based on recursive approach. So RLS is the best choice among the above non blind beamforming algorithms for quick tracking of the signals.

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