Direction of Arrival in Smart Antenna using Different types of Uniform Array Configuration

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ABSTRACT

Antennas, so far a neglected component in wireless mobile communications, have gained a renewed interest among researchers. In the form of “smart antennas” or “adaptive array antennas”, they meet the challenging demand and bring many benefits to the wireless communications services.

Until now, the investigation of smart antennas suitable for wireless communication systems has involved primarily uniform linear arrays (ULA). Different algorithms have been proposed for the estimation of the direction of arrivals (DOAs) of signals arriving to the array and several adaptive techniques have been examined for the shaping of the radiation pattern under different constraints imposed by the wireless environment.

Smart antennas so far, little attention has been paid to other array topologies. In this, the performance of different types of uniform array configuration like circular, planar and planar circular have been analyzed and compared for the estimation of direction of arrival of the signal.

Keywords

smart Antenna, direction of arrival (DOA), uniform linear array (ULA), uniform circular array (UCA)

1. INTRODUCTION

Smart antennas, or adaptive arrays, have gained great interest among researchers during recent years. Wireless operators are currently searching for new technologies that would be implemented into the existing wireless communications infrastructures to provide broader bandwidth per user channel, better quality, and new value-added services. Such research efforts will enable wireless carriers to maximize the spectral efficiency of their networks so as to meet the explosive growth of the wireless communications industry, and so as to take advantage of the huge market opportunity.

Deployed at the base station of the existing wireless infrastructure, smart antennas are capable of bringing outstanding capacity improvement (very important in urban and densely populated areas) to the frequency-resource-limited radio-communications system by an efficient frequency reuse scheme. This unique feature has been made feasible through the impressive advances in the field of digital signal processing, which enable smart antennas to dynamically tune out interference while focusing on the intended user.

2. CONCEPT OF SMART ANTENNA

The basic idea on which smart antenna systems were developed is most often introduced with a simple intuitive example that correlates their operation with that of the human auditory system. A person is able to determine the Direction of Arrival (DOA) of a sound by utilizing a three-stage process.One’s ears act as acoustic sensors and receive the signal. Because of the separation between the ears, each ear receives the signal with a different time delay.The human brain, a specialized signal processor, does a large number of calculations to correlate information and compute the location of the received sound.

Electrical smart antenna systems work the same way using two antennas instead of two ears, and a digital signal processor instead of the brain. Thus, based on the time delays due to the impinging signals onto the antenna elements, the digital signal processor computes the direction-of-arrival (DOA) of the signal-of-interest (SOI), and then it adjusts the excitations (gains and phases of the signals) to produce a radiation pattern that focuses on the SOI while tuning out any interferers or signals-not-of-interest (SNOI).

2.1 Smart Antenna Configurations

Basically, there are two major configurations of smart antennas:

(i) Switched-Beam: A finite number of fixed, predefined patterns or combining strategies (sectors).

(ii) Adaptive Array: A theoretically infinite number of patterns (scenario-based) that are adjusted in real time according to the spatial changes of SOIs and SNOIs.

2.1.1 Switched-Beam Systems

A switched-beam system is a system that can choose from one of many predefined patterns in order to enhance the received signal and it is obviously an extension of cell sectoring as each sector is subdivided into smaller sectors. As the mobile unit moves throughout the cell, the switched-beam system detects the signal strength, chooses the appropriate predefined beam pattern, and continually switches the beams as necessary. The overall goal of the switched-beam system is to increase the gain according to the location of the user.

2.1.2 Adaptive Array Systems

The adaptive concept is far superior to the performance of a switched-beam system. Because of the ability to control the overall radiation pattern in a greater coverage area for each cell site. Adaptive array systems can provide great increase in capacity.

Adaptive array systems can locate and track signals (users and interferers) and dynamically adjust the antenna pattern to enhance reception while minimizing interference using signal processing algorithms. A functional block diagram of the digital signal processing part of an adaptive array antenna system is shown in Fig. 1.

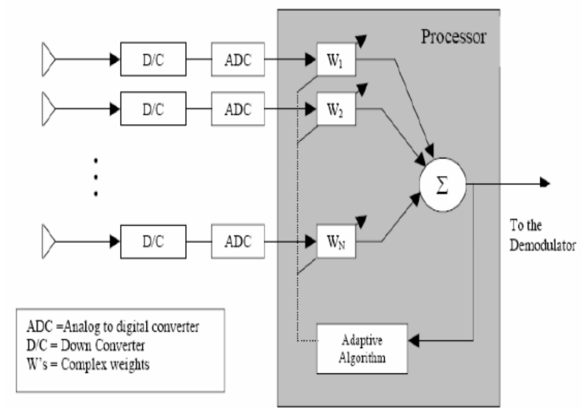


Figure 1: Functional block diagram of an adaptive array system. [1]

3. UNIFORM ARRAY

3.1 Uniform Planar Arrays (UPA)

Usually the radiation pattern of a single element is relatively wide, and each element provides low values of directivity (gain). In many applications it is necessary to design antennas with very directive characteristics (very high gains) to meet the demands of long distance communication. This can only be accomplished by increasing the electrical size of the antenna.

Enlarging the dimensions of single elements often leads to more directive characteristics. Another way to enlarge the dimensions of the antenna, without necessarily increasing the size of the individual elements, is to form an assembly of radiating elements in an electrical and geometrical configuration. This new antenna, formed by multielements, is referred to as an array. In most cases, the elements of an array are identical. This is not necessary, but it is often convenient, simpler, and more practical.

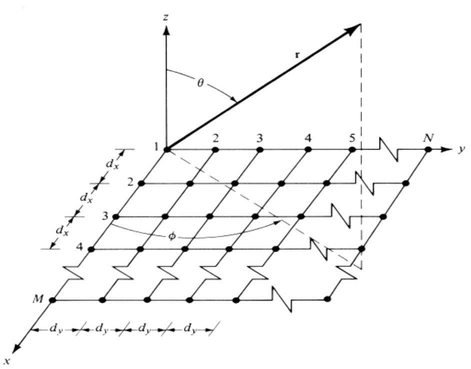


Figure 2 Planar array geometry.[4]

The array factor for the entire planar array can be written as

$$S = I \sum_{m=1}^{M} e^{j(m-1)(k\,dx\,\sin\theta\cos\phi+\beta x)} \sum_{n=1}^{N} e^{j(n-1)(k\,dy\,\sin\theta\sin\phi+\beta y)}$$

If m elements are initially placed along the x-axis, and n elements in y-axis and they are equally spaced of distances dx and dy respectively. Where $k= 2\pi/\lambda$ I = Overall amplitude excitation and θ,ϕ = elevation and azimuth angle.

3.2 Circular Array

Uniform circular array with radius a and consisting of N uniformly distributed antenna elements, assumed to be identical and omnidirectional, is located on the x-y plane and is illuminated by an "impinging planar wavefront. A spherical coordinate system is used to represent the arrival directions from incoming plane waves. The origin of the coordinate system is located at the centre of the array. Source elevation angles, θ E [0, π/2], are measured from the z axis, and azimuth angles, ϕ E [0,2π],

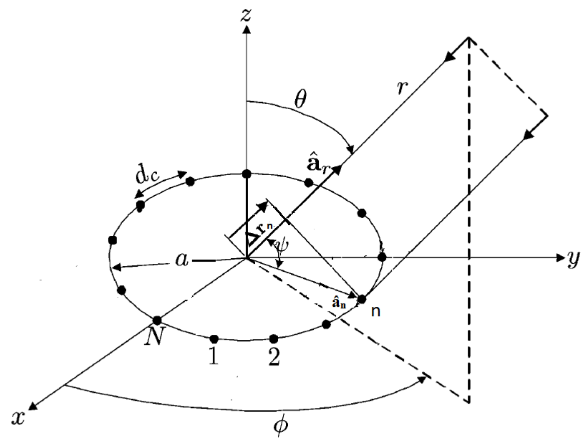


Figure 3: Geometry of an N-element circular array.[6]

The angular position of the nth element of the array is given by

$$\phi_n = 2\pi\left(\frac{n}{N}\right) \qquad n=1, 2,\ldots..N$$

The narrowband planar wave with wavelength λ. (and corresponding wavenumber $k = 2\pi/\lambda$) arrives at the antenna from elevation angle θ and azimuth angle Ø.

Further, assuming that the wavefront passes through the origin at time t=0, it impinges on the nth element of the array at the relative time [6]

$$T_{mn} = -\frac{a}{c}\sin\theta\cos(\phi-\phi_n) \qquad n=1,2,\ldots..N$$

Where c is the speed of light in free space. Positive time delay indicates that the wavefront impinges on the nth element after it passes through the origin, whereas negative time delay indicates that the wavefront impinges on the nth element before it arrives at the origin.

Array factor for N isotropic elements are equally spaced on the *x-y* plane along a circular ring of the radius *a* is given as

$$AF(\theta,\emptyset) = \sum_{n=1}^{N} In\, e^{j[ka\sin\theta\cos(\emptyset-\emptyset n)]}$$

Where $k= 2\pi/\lambda$

I_n = amplitude excitation of the nth element
a = radius of the circle
θ,ϕ= elevation and azimuth angle
ϕ_n = angular position of nth element

4. DIRECTION OF ARRIVAL (DOA) ESTIMATION ALGORITHMS

The purpose of DOA estimation is to use the data received by the array to estimate the direction of arrival of the signal. DOA estimation is then used by the array to design the adaptive beam former in such way as to maximize the power radiated towards the users and to suppress the interference. In the design of adaptive array smart antenna for mobile communication the performance of DOA estimation algorithm depends on many parameters such as number of mobile users and their space distribution , the number of array elements and their spacing, the number of signal samples and signal to noise ratio (SNR).

4.1 Subspace Method to DOA Estimation

The other main group of DOA estimation algorithms is called the subspace methods. Geometrically, the received signal vectors form the received signal vector space whose vector dimension is equal to the number of array elements N. The received signal space can be separated into two parts: the signal subspace and the noise subspace. The subspace algorithms exploit the orthogonality to estimate the signals' DOAs.

4.1.1 The MUSIC Algorithm

MUSIC stands for **MU**iltiple **SI**gnal **C**lassification, one of the high resolution subspace DOA algorithms. The popularity of the MUSIC algorithm is in large part due to its generality.
It is applicable to arrays of arbitrary but known configuration and response. MUSIC algorithm can only be used to estimate incoherent signal sources. For coherent signals, the performance of MUSIC will be degraded and it is not an efficient tool.

It is high resolution technique based on exploiting the eigenstructure of input covariance matrix. MUSIC makes assumption that the noise in each channel is uncorrelated making correlation matrix diagonal. The incident signals are somewhat correlated creating non diagonal signal correlation matrix.

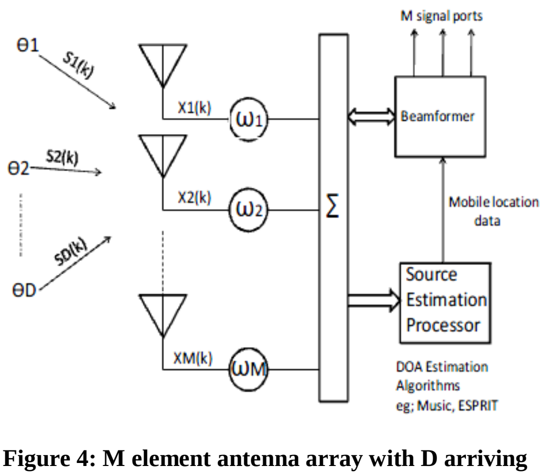


Figure 4: M element antenna array with D arriving signals.[10]

If the number of signals impinging on M element array is D, 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 [10]

$$Rxx = A*Rss*A^H + \sigma_n^2 * I$$

Where A= [a(θ1) a(θ2) a(θ3) --- a(θD)] is M x D array steering matrix

σ^2_n = noise variance

I = Identity matrix

Rss = $[s1(k)\ s2(k)\ s3(k)\ \text{----}\ sD(k)]^T$ is D x D source correlation matrix

Rxx has D eigenvectors associated with signals and M-D eigenvectors associated with the noise. We can then construct the M x (M-D) subspace spanned by the noise eigenvectors such that

$$V_N = [v1\ v2\ v3\ \text{-------}\ v_{M-D}]$$

The noise subspace eigenvectors are orthogonal to array steering vectors at the angles of arrivals θ1, θ2, θ3, θD and the MUSIC Pseudospectrum is given as

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

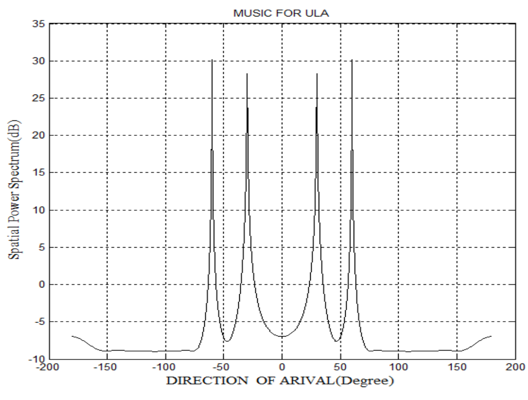
5. PERFORMANCE ANALYSIS OF DIFFERENT UNIFORM ARRAY CONFIGURATION

In this, the performance of different uniform array configuration (circular, planar, circular planar) has been analysis on the basis of MUSIC algorithm which is simulated in MATLAB. All the identical array elements with equal and unit amplitude excitation are placed in xy plane and assuming that the plane wave incident in the xy-plane.

5.1 Uniform Linear Array (ULA)

Uniform Linear array: - To analysis of the performance of other array geometry .We first analysis the performance of uniform linear array so that we can compare the other array geometry with respect to it.

SIMULATION1:-ULA with no. of antenna element N=10, SNR=10 dB, distance between elements d = λ/ 2 and no. of snapshots=1000 and DOA 30° and 60° have been simulated using MUSIC algorithm in MATLAB.

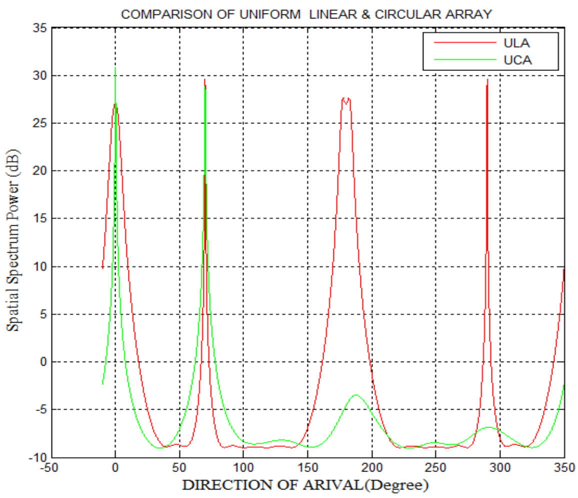


MUSIC spatial spectrum for ULA and DOA 30° ,60°

5.2 Uniform Circular array (UCA)

For a circular array of N＝8 antenna elements evenly spaced on a circle of radius R= Nd/2 π are placed in xy plane. Assume that the plane wave incident in the xy-plane.

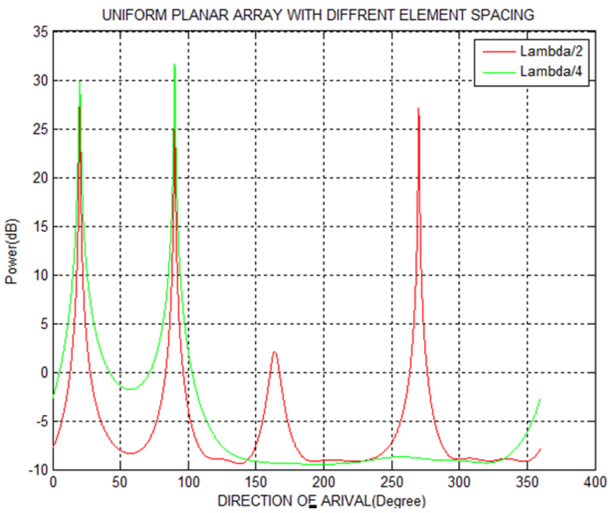
SIMULATION 2:-UCA with no. of antenna element N=8, SNR=10 dB, distance between elements d = λ/ 2 and no. of snapshots=1000 and DOA 0° and 70° have been simulated using MUSIC algorithm in MATLAB.



MUSIC spatial spectrum for ULA and UCA and DOA 0°, 70°

5.3 Uniform Planar Array (UPA)

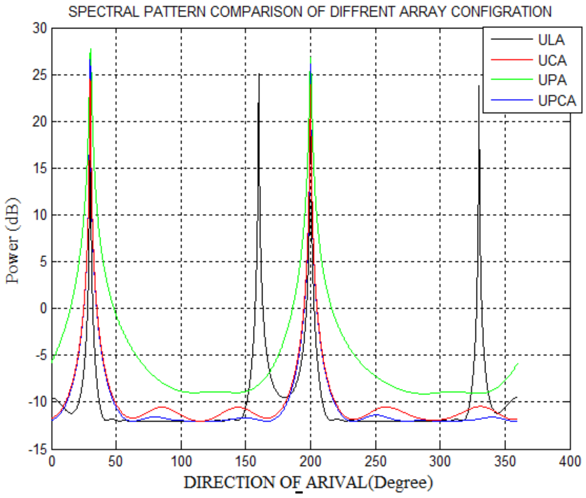
SIMULATION 3:- UPA of no. of element in x direction =4, in y direction =4, so total elements N=16, SNR 10 dB, no. of snapshots= 1000, and different adjacent elements spacing (dx = dy =λ/ 4 and dx = dy = λ/ 2) have been simulated using MUSIC algorithm in MATLAB.



MUSIC spatial spectrum for UPA with different no. of elements and DOA 20°, 90°

Remark: - UPA (adjacent element spacing λ/ 2) gives lower but shaper spectrum than UPA (adjacent element spacing λ/ 4). In UPA (adjacent element spacing λ/ 2) there are two trivial ambiguities at 160°,270°. At 270° it gives a very high (27 dB) and sharp spike. UPA (adjacent element spacing λ/ 4) gives no trivial ambiguity in 360° range but with lower sharp spectrum.

SIMULATION 4:- In this simulation we compare the ULA, UCA, UPA and UPCA of no. of elements N=16, element spacing d = λ/2(for ULA, UCA, PUCA), d = λ/4 (for UPA) and SNR=10dB, no. of snapshots =1000 have been simulated using MUSIC algorithm in MATLAB.



MUSIC spatial spectrum for ULA, UCA, PUCA and UPA and DOA 30°, 200°

Remark: - UPA gives higher spectrum peak than others but lower sharpness. Performance of UCA and UPCA provide similar sharp pattern but UPCA gives higher peak than UCA.ULA gives sharpest peak with lower spike and it gives lowest minimum value between two DOA of the signals. But ULA gives two trivial ambiguities for both DOA of the signal at 160°, 330°.

5.5 Comparisons of Different Array Geometry on the basis of Area

In this uniform planar array (UPA), uniform circular array (UCA) and planar uniform circular array (PUCA) have compared on the basis of area of the geometry.

Table1: Comparison between different uniform array geometries

Array Geometry	No. of Elements and Spacing		Area
Uniform planar array(UPA)	M= 4 dx =0.5 λ N=4 dy =0.5 λ		2.25 λ^2
Uniform circular Array(UCA)	a_1 = 8 λ /2π (d=0.5 λ)		5.093 λ^2
Uniform circular Array(UCA)	a_1 = 8 λ /2π (d=0.5 λ)		5.093 λ^2
Planar Uniform circular array (PUCA)	First UCA	N1 =6 a_1 = 3 λ /2π (d1=0.5 λ)	1.989 λ^2
	Second UCA	N2 =10 a_2 = 5 λ /2π (d2=0.5λ)	

In UPCA, 16 elements in two uniform circular arrays, 6 elements in first uniform circular ring (d1=0.5 λ) and 10 elements in second uniform circular ring (d1=0.5 λ) having radius 3 λ /2π and 5λ /2π respectively have lowest geometry area as compare to other geometry. The area of PUCA is less than half of area of UCA. UCA having 16 elements have largest area than PUCA and UPA.

6. CONCLUSION

In this dissertation work, I have analysis the performance of uniform linear, circular and planar and planar circular array for estimation of direction of the signal using MUSIC algorithm.ULA is not suitable for 360^o range of operation because of trivial ambiguity. Uniform planar array with

λ/ 2 adjacent element spacing also gives trivial ambiguity for the direction of arrival at 90^o, 180^o and near this angle of direction so uniform planar array with λ/4 adjacent element spacing would preferred for 360^o angular range although its angular resolution is lesser than uniform planar array with λ/ 2 adjacent element spacing. Increasing number of elements in the array configuration the spectrum becomes sharper means angular accuracy becomes more.

Performance of Uniform circular array and planar circular array is almost similar to each other but uniform planar circular array of 16 elements (λ/ 2 element spacing) requires less than half area of the geometry of uniform circular array of 16 elements(λ/ 2 element spacing). On the basis of area of the geometry, uniform planar circular array geometry would be preferred because it requires less area.

7. FUTURE WORK

Two main functions of smart antenna are estimation of direction of arrival of the signal and then beamforming in that particular direction. The performance of smart antenna in beamforming is dependent on performance of estimation of direction of arrival of the signal. In this dissertation work uniform circular, planar and planar circular array structures have been analysis for estimation of direction of arrival of the signal so in future other array configuration like non uniform and also any arbitrary array structures may be analysis to improve direction of arrival estimation and having less geometry area because MUSIC algorithm is applicable for any arbitrary geometry of arrays but known configuration.

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