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Analysis of Direction of Arrival Estimations Algorithms for Smart Antenna

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ABSTRACT—*Smart antenna consists of several antenna elements, whose signal is processed adaptively in order to exploit the spatial domain of the mobile radio channel. The smart antenna technology can significantly improve wireless system performance and economics for a range of potential users. Generally co-located with a base station, a smart antenna system combines an antenna array with a digital signal-processing capability to transmit and receive in an adaptive, spatially sensitive manner. In other words, such a system can automatically change the directionality of its radiation patterns in response to its signal environment. This can dramatically increase the performance characteristics (such as capacity) of a wireless system. This is a new and promising technology in the field of wireless and mobile communications in which capacity and performance are usually limited by two major impairments multipath and co-channel interference. Smart antennas (also known as adaptive array antennas and multiple antennas) are antenna arrays with smart signal processing algorithms to identify spatial signal signature such as the Direction of arrival (DOA) of the signal and use it to calculate beam forming vectors, to track and locate the antenna beam on the mobile targets. Smart antennas involve processing of signals induced on an array of sensors such as antennas, microphones, and hydrophones. They have applications in the areas of Radar, Sonar, Medical Imaging and Mobile Communication. Smart antennas have the property of spatial filtering, which makes it possible to receive energy from a particular direction while simultaneously block energy from others direction Co-channel interference is interference between two signals that operate at the same frequency. A smart antenna enables a higher capacity in wireless networks by effectively reducing multipath and co-channel interference. This is achieved by focusing the radiation only in the desired direction and adjusting itself to changing traffic conditions or signal environments. Smart antennas employ a set of radiating elements arranged in the form of an array.*

KEYWORDS—*Smart antenna, spatial distribution, angle of arrival, resolution, directivity, direction of arrival, matlab*

I. INTRODUCTION

In the last few years, lot of research has been taken place in array antennas which are smart enough to distinguish between desired and interference signal. Currently, the use of smart antennas in mobile communication to increase the capacity of communication channels has reignited research and development in this very exciting field. One such innovation is Smart Antenna (SA) and the type of multiple accesses it works on is Space Division Multiple Access (SDMA).

II. SPACE DIVISON MULTILPE ACCESS

Space Division Multiple Access (SDMA) concept is different from Frequency Division Multiple Access (FDMA) and Time Division Multiple Access (TDMA). SDMA system utilizes techniques by which signals are distinguished at the Base Station (BS) based on their origin in space. SDMA is usually used in conjunction with FDMA, TDMA or Code Division Multiple Access (CDMA) in order to provide the latter with the additional ability to explore the spatial properties of the signals.Signal arriving from a distant source reaches different antennas in an array at different times due to their spatial distribution. This delay is utilized to differentiate one or more users in one area from those in another area. The scheme allows an effective transmission to take place in one cell without disturbing a simultaneous transmission in another cell. Figure 1 shows the simple SDMA scheme. For example, conventional Global System for Mobile Communication (GSM)/ General Packet Radio Service (GPRS) allows only one user at a time to transmit or receive in a frequency band to the base station. If GSM/GPRS is used along with SDMA, multiple simultaneous transmissions can take place at same frequency band thereby increasing the capacity of the system.

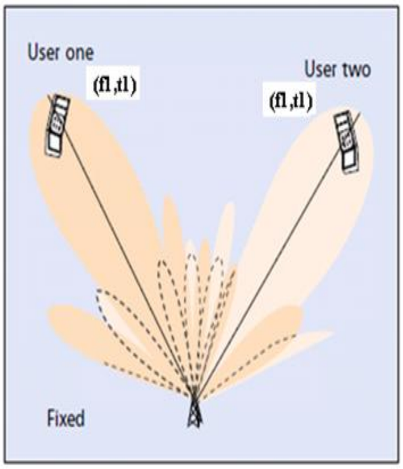


Figure1 Scheme for SDMA

From the Figure1, there are 2 beams of same frequency f_1 at the same time t_1 but in different directions. Hence the capacity of system is increased by a factor of 2. With SDMA; several mobiles can share the same frequency. Multiple signals arriving at the base station can be separated by the base station receiver as long as their angular separation is larger than the transmit/receive beam widths.

1.2 SMART ANTENNA

Smart antennas involve processing of signals induced on an array of sensors such as antennas, microphones, and hydrophones. They have applications in the areas of Radar, Sonar, Medical Imaging and Mobile Communication. Smart antennas have the property of spatial filtering, which makes it possible to receive energy from a particular direction while simultaneously block energy from other direction. This property makes smart antennas a very effective tool in detecting, locating sources and finally forming the main beam in the look direction and nulls in the interfering signal directions.

A typical smart antenna system is as shown in figure 2. It consists of antenna elements, Analog to Digital Converter (ADC) / Digital to Analog Converter (DAC) converters with DSP processor to perform required task using smart algorithms. In current scenario we have one set of antenna elements along with trans/receiver multiplexer to perform both reception and transmission. Antenna elements are broadband enough to accommodate transmitting and receiving frequencies.

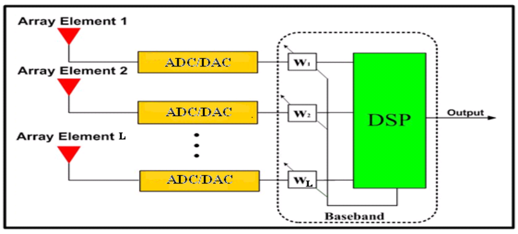


Figure 2Typical smart antenna system

III. TYPES OF AOA ALGORITHMS

The AOA algorithms are classified into two types, Classical Methods and Subspace methods. Classical AOA methods are essentially based on beam forming. The two classical techniques for DOA are the Maximum Entropy Method and the Maximum Likelihood method. The basic idea behind the classical methods is to scan a beam through space and measure the power received from each direction. Directions from which the largest amount of power is received are taken to be the AOAs.

Subspace AOA estimators have high-resolution estimation capabilities, where the autocorrelation (or auto covariance) of a signal plus noise model is estimated and then it is used to form a matrix whose Eigen structure gives rise to the signal and noise subspaces.

2.1Classical Methods of Angle of Arrival

Bartlett method

In this method a rectangular window of uniform weighting is applied to the time series data to be analysed. For bearing estimation problems using an array, this is equivalent to applying equal weighting on each element. Bartlett method is also called Ordinary Beam forming Method (OBM). This method estimates the mean power $P_B(\theta)$ by steering the array in θ direction.
The power spectrum in bartlett method is given by

$$P_B(\theta) = \frac{S_\theta^H R S_\theta}{L^2}$$

Where, 'S_θ' denotes the steering vector associated with the direction θ,
'R' is the array correlation matrix.
'L' denotes the number of elements in the array

In DOA estimation, a set of steering vectors $\{S_\theta\}$ associated with various direction θ is often referred to as the **array manifold**. In practice, it may be measured at the time of array calibration. From the array manifold and an estimate of the array correlation matrix, $P_B(\theta)$ is computed. Peaks in $P_B(\theta)$ are then taken as the directions of the radiating sources.

2.2Subspace Method of Angle of Arrival Algorithms

A.Multiple Signal Classification (MUSIC)

MUSIC is an acronym which stands for Multiple Signal Classification. 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 correlated creating a non-diagonal signal correlation matrix. However, under high Signal correlation the traditional MUSIC algorithm breaks down and other methods must be implemented to correct this weakness.

One must know in advance the number of incoming signals or one must search the Eigen values to determine the number of incoming signals. If the number of signals is M, the number of signal Eigen values and eigenvectors is M and the number of noise Eigen values and eigenvectors are L-M (L is the number of array elements). Because MUSIC exploits the noise eigenvector subspace, it is sometimes referred to as a **subspace method**.

The Eigen values and eigenvectors for correlation matrix R is found. M eigenvectors associated with the signals and L−M eigenvectors associated with the noise are separated. The eigenvectors associated with the smallest Eigen values are chosen to calculate power spectrum. For uncorrelated signals, the smallest Eigen values are equal to the variance of the noise. The L× (L− M) dimensional subspace spanned by the noise eigenvectors is given by

$$E_N = [e_1 \, e_2 \, e_3 \, ... \, ... \; e_{L-M}]$$

Where, e_i is the ith Eigen Value.

The noise subspace Eigen vectors are orthogonal to the array steering vectors at the angles of arrival $\theta_1, \theta_2, ...\theta_M$. Because of this orthogonally condition, one can show that the Euclidean distance $d^2 = a(\theta)^H E_N E_N^H a(\theta) = 0$ for each and every angle of arrival $\theta_1, \theta_2, ...\theta_M$ .Placing this distance expression in the denominator creates sharp peaks at the angles of arrival. The MUSIC pseudo spectrum is given by

$$P_{MUSIC} = \frac{1}{a(\theta)^H E_N E_N^H a(\theta)}$$

Where, $a(\theta)$ is steering vector for an angle θ and E_N is L x L-M matrix comprising of noise Eigen vectors.

B.Estimation of Signal Parameters via Rotational Invariance Techniques (ESPRIT)

The goal of the ESPRIT technique is to exploit the rotational invariance in the signal subspace which is created by two arrays with a translational invariance structure. ESPRIT inherently assumes narrowband signals so that one knows the translational phase relationship between the multiple arrays to be used. ESPRIT assumes that there are M<L narrow-band sources centered at the center frequency *f*. M is number of sources and L is the number of antenna elements. These signal sources are assumed to be of a sufficient range so that the incident propagating field is approximately planar. The sources can be either random or deterministic and the noise is assumed to be random with zero-mean. ESPRIT assumes multiple identical arrays called **Doublets**. Doublets can be separate arrays or can be composed of sub arrays of one larger array. It is important that these arrays are displaced translationally but not rotationally.

L element linear array is composed of two identical (L-1) element sub-arrays or two doublets. These two sub arrays are translationally displaced by the distance d.

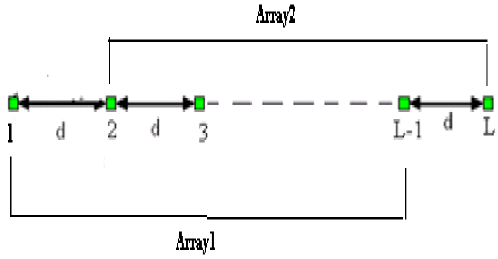


Figure 3 ESPRIT array elements division

The signals induced on each first set of array is given by

$$x_1(k) = [a_1(\theta_1)\ \ a_1(\theta_2)\ \ \ldots\ldots\ldots a_1(\theta_M)]\begin{bmatrix} b_1(k) \\ b_2(k) \\ . \\ . \\ b_M(k) \end{bmatrix} + n_1(k)$$

Where, $x_1(k)$ the induced signal on first doublet of uniform linear array, $a_1(\theta_1)\ a_1(\theta_2)$ .... $a_1(\theta_M)$ are L-1x1 steering vectors, M is number of sources, L is number of array elements, $b_1(k)$,……….., $b_M(k)$ are the amplitudes of M sources and $n_1(k)$ is Lx1 matrix of zero mean Gaussian noise comprising of random variables.

In short hand notation equation (2.34) can be written as

$$x_1(k) = A_1\, b(k) + n_1(k)$$

Where, A_1 is L-1xM the array manifold vector and $b(k)$ is Mx1 matrix comprising of source amplitudes.

The induced signal corresponding to second doublet is given by

$$x_2(k) = A_2\, b(k) + n_2(k) = A_1\, \phi b(k) + n_2(k)$$

Where, A_2 is L-1xM array manifold vector corresponding to last L-1 array elements, $n_2(k)$ is L-1x1 matrix of Gaussian noise and ϕ is the a $M\times M$ diagonal unitary matrix, which defines phase shifts between the doublets for each AOA given by

$$\phi = \begin{bmatrix} e^{jk\,d\,\sin\theta_1} & 0 & \ldots\ldots\ldots\ldots\ldots\ldots & 0 \\ 0 & e^{jk\,d\,\sin\theta_2} & \ldots\ldots\ldots\ldots\ldots\ldots & 0 \\ . & . & & . \\ 0 & 0\ldots\ldots\ldots\ldots\ldots\ldots & & e^{jk\,d\,\sin\theta_M} \end{bmatrix}$$

The complete received signal considering the contributions of both sub arrays is given by

$$x(k) = \begin{bmatrix} x_1(k) \\ x_2(k) \end{bmatrix} = \begin{bmatrix} A_1 \\ A_1\,\phi \end{bmatrix} b(k) + \begin{bmatrix} n_1(k) \\ n_2(k) \end{bmatrix}$$

The correlation matrix for either the complete array or for the two sub-arrays can be computed. The correlation matrix for the complete array is given by

$$R_{xx} = E[x\,x^H] = A\,R_{ss}\,A^H + \sigma^2\,I$$

Where, A is LxM array manifold vector, $R_{ss} = E[b(k)*b(k)^H]$, σ^2 is the variance of noise and I is the identity matrix.

The correlation matrices for the two sub-arrays are given by equations

$$R_{11} = E[x_1\,x_1^H] = A_1\,R_{ss}\,A_1^H + \sigma^2\,I$$

$$R_{22} = E[x_2\,x_2^H] = A_2\,R_{ss}\,A_2^H + \sigma^2\,I$$

Where, R_{11} is correlation matrix corresponding to first sub-array and R_{22} is correlation matrix corresponding to second sub-array.

Each of the full rank correlation matrices, given in equations (4.9) and (4.10) have a set of Eigen vectors corresponding to the M signals present. Creating the signal subspace for the two sub-arrays results in the two matrices namely E_1 and E_2.Creating the signal subspace for the entire array results in one signal subspace given by E_x. Because of the invariance structure of the array, E_x can be decomposed into the sub-spaces E_1 and E_2.

Both E_1 and E_2 are LxMmatrices whose columns are composed of the M Eigen vectors corresponding to the largest Eigen values of R_{11} and R_{22}. Since the arrays are transnationally related, the subspaces of Eigen vectors are related by a unique non-singular transformation matrix ψ which is given by

$$E_1\,\psi = E_2$$

There must also exist a unique non-singular transformation matrix T given by equations

$$E_1 = AT$$

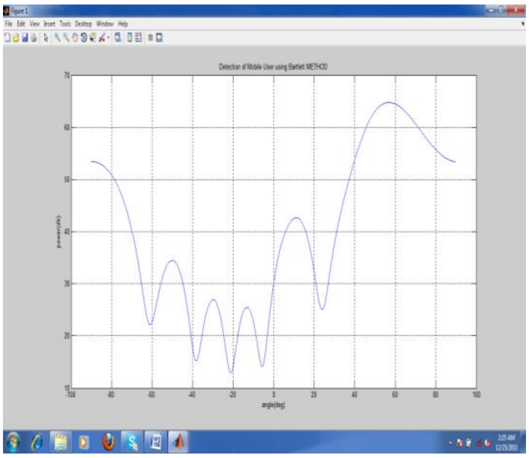
$$E_2 = A\phi T$$

By assuming that A is of full-rank, one can arrive at the relationship given by

$$T\,\psi\,T^{-1} = \phi$$

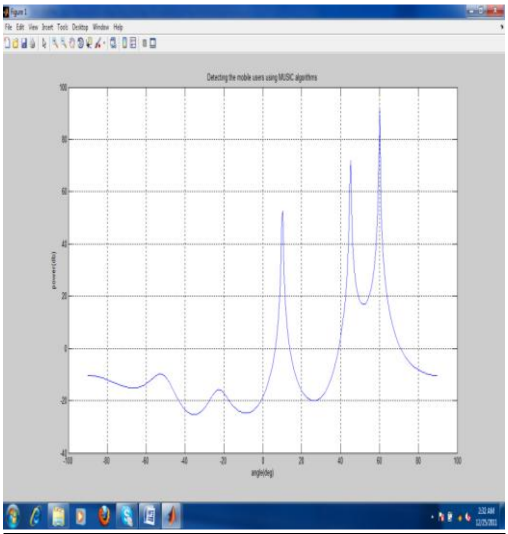
Thus, the eigen values of ψ must be equal to the diagonal elements of ϕ i.e. $\lambda_1 = e^{jkd\sin\theta_1}, \lambda_2 = e^{jkd\sin\theta_2}, \ldots\ldots\ldots \ldots\ldots\ldots \ldots, \lambda_M = e^{jkd\sin\theta_M}$ andthe columns of T must be the Eigen vectors of ψ . ψ is rotation operator that maps the signal subspace E_1 into the signal subspace E_2 .

IV. PERFORMANCE CHARACTERSTICS OF AOA ALGORITHMS



The different criteria used to compare the performance of different AOA algorithms are bias, resolution and variability.

Bias: An estimate is said to be unbiased if the expected value of the estimate equals the true value of the parameter. Otherwise, the estimate is said to be biased. The bias is usually considered to be additive. The bias depends on the number of observations an estimate variance equals the mean squared estimation error only if the estimate is unbiased



Resolution: The ability of the estimate to reveal the presence of equal energy sources which have nearly equal angles. When two sources are resolved, two distinct peaks are present in the spectrum. If not resolved, only one peak is found, better resolved bearing would seemingly correspond to a narrower spectral peak. Spectral estimate yielding the sharpest peak usually implies that the angle has been best resolved. Enables a higher capacity in wireless networks by effectively reducing multipathand co-channel interference. This is achieved by focusing the radiation only in the desired direction and adjusting itself to changing traffic conditions or signal environments.Co-channel interference is interference between two signals that operate at the same frequency more operational definition of resolution is how well a spectral estimate allows the presence of two sources to determine.

Variability: The range of angles over which the location of a spectral peak is expected to vary analytical evaluation of the variability for a given spectral estimate is usually difficult.The smart antenna induced the variation of the across the channel and the capability to reduce and variation of certain angle and cause the interference to null from the variation in the difficult from the other angle.

V. SIMULATION AND RESULTS

Algorithm	Number of Antenna Elements	Direction	Number of Mobile Users
Bartlett	8	[10 45 60]	3
MUSIC	8	[10 45 60]	3
ESPRIT	8	[10 45 60]	3

Figure 4 Bartlett Method

From the Figure4 Bartlett Method is not capable of detecting the mobile users at the angles 10, 45 and 60. But it detects only one source which is at 60 degree.

Figure 4.1MUSIC Method

From the Figure4.1 MUSIC Method is capable of detecting the mobile user’s at the angles 10, 45 and 60.

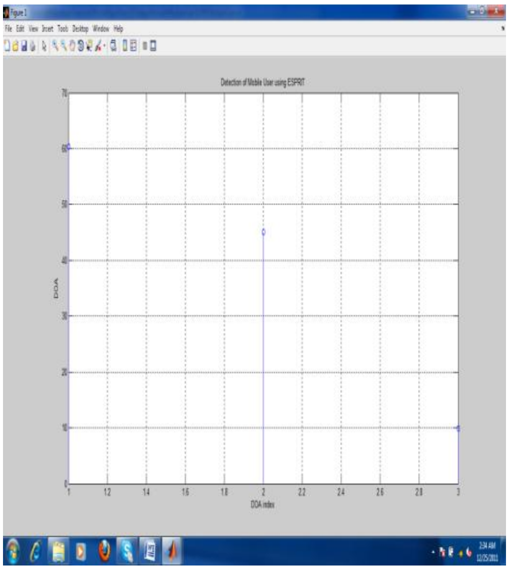


Figure 4.2 ESPRIT Method

From the Figure4.2 ESPRIT method is capable of detecting the mobile users at the angles 10, 45 and 60.

VI. CONCLUSION

[1] When it comes for Multiple Mobile user Direction for the Case of Less Antenna Elements and Widely Spaced Sources MUSIC performs better.
[2] When it comes for Multiple Mobile user Direction for the Case of More Antenna Elements and Widely Spaced Sources MUSIC performs better
[3] When it comes for Multiple Mobile user Direction for the Case of Less Antenna Elements and Closely Spaced Sources MUSIC performs better
[4] When it comes for Multiple Mobile user Direction for the Case of More Antenna Elements and Closely Spaced Sources MUSIC performs better

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