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A Novel Snapshot Based Approach for Direction of Arrivial Estimation with Least Bias

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Abstract*— Adaptive array smart antenna involves the array processing to manipulate the signals induced on various antenna elements in such way that the main beam directing towards the desired signal and forming the nulls towards the interferers. Such smart antennas are widely used in wireless mobile communications as they can increase the channel capacity and coverage range. In adaptive array smart antenna, to locate the desired signal, various direction of arrival (DOA) estimation algorithms are used. This paper investigates Novel Snapshot Based approach using Estimation of Signal Parameters via Rotational Invariance Technique. ESPRIT algorithms provide high angular resolution and hence they are explored much in detail by varying various parameters of smart antenna system.

***Index Terms*—Smart antenna, ESPIRT, DOA, AOA**

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)**.**One of the most promising techniques for increasing the capacity in 3G cellular is the adaptive array smart antenna. The smart antenna technology is based on antenna arrays where the radiation pattern is altered by adjusting the amplitude and relative phase on the different elements. If several transmitters are operating simultaneously, each source creates many multipath components at the receiver and hence receive array must be able to estimate the angles of arrival in order to decipher which emitters are present and what are their angular locations. This information in turn can be used by the smart antenna to eliminate or combine signals for greater fidelity or suppress interferers to improve the capacity of cellular mobile communication. Adaptive array smart antenna involves the array processing to manipulate the signals induced on various antenna elements in such way that the main beam directing towards the desired signal and forming the nulls towards the interferers. Such smart antennas are widely used in wireless mobile communications as they can increase the channel capacity and coverage range. In adaptive array smart antenna, to locate the desired signal, various direction of arrival (DOA) estimation algorithms are used. This paper simulates ESPIRT and MUSIC with 1024 snapshots.

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II. DIRECTION OF ARRIVAL

A. 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.

B. Sub space Method

In the propagation channel of wireless systems, it is apparent that even for one source there are many possible propagation paths and angles 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 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 and suppress interferers. In order to understand AOA algorithms the knowledge of steering vector, auto correlation, cross correlation, norm vector, signal subspace, noise subspace, variance, Eigen values, Eigen vectors, hermitian transpose. The AOA algorithms will take number of array sensors, number of signal sources, source amplitude and sources direction as input and produce peaks for the corresponding angles as an output. 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.

III. ESPRIT USING MULTIPLE SNAPSHOT

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.

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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.

IV. SIMULATION METHODOLOGY OF ESPIRT

1. Compute the two array manifold vectors A_1 corresponding to first L-1 array elements and A_2 corresponding to last L-1 array elements.
2. Compute the two array correlation matrices namely R_{11} and R_{22} .
3. Compute the M (signal) Eigen vectors of array correlation matrices R_{11} and R_{22} namely E_1 and E_2 .
4. The 2Mx2M matrix C is found by using
$$C = \begin{bmatrix} E_1^H \\ E_2^H \end{bmatrix} [E_1 \;\; E_2]$$
5. Perform the Eigen value decomposition of C such that the Eigen values satisfies the condition $\lambda_1 \geq \lambda_2 \geq .... \geq \lambda_{2M}$ to obtain 2Mx2M matrix E_C .
6. The matrix E_C is partitioned into four MxM matrices given by
$$E_C = \begin{bmatrix} E_{11} & E_{12} \\ E_{21} & E_{22} \end{bmatrix}$$
7. The rotation operator ψ is a MxM matrix given by
$$\psi = -E_{12}\, E_{22}^{-1}$$
8. The M eigen values $\{\lambda_1, \lambda_2, ..., \lambda_M\}$ of rotational operator ψ are obtained.
9. The Angle of Arrival for M sources is given by
$$\theta_i = \sin^{-1}\left(\frac{\tan^{-1}(\lambda_i)}{kd}\right) \quad i = 1,2,3,....M$$

Where, d is the distance between antenna elements and k is the propagation constant.

The value R in Multiple Snapshot approach of ESPRIT is given by

$$R_{snapshot} = \frac{X\,X^H}{K}$$

Where,

$$X = A\sqrt{P}\,S_{Bpsk} + N_{noise}$$

A.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.

B. Simulation methodology of MUSIC

1. The steering vector 'A' for an antenna array comprising of L elements is calculated by using equation
$$A = \begin{bmatrix} 1 & 1 & ...... & 1 \\ e^{i2\pi d\sin\theta_1} & e^{i2\pi d\sin\theta_2} & ...... & e^{i2\pi d\sin\theta_{M-1}} \\ \vdots & \vdots & \vdots & \vdots \\ e^{i2\pi d(L-1)\sin\theta_1} & e^{i2\pi d(L-1)\sin\theta_2} & ...... & e^{i2\pi d(L-1)\sin\theta_{(M-1)}} \end{bmatrix}$$

2. The signal amplitude vector 's' is a column vector of order Mx1 given by
$$s = \begin{bmatrix} a_1 \\ a_2 \\ \vdots \\ \vdots \\ a_M \end{bmatrix}$$

3. The Hermitian transpose 's^H' of signal vector S is given by
$$s^H = \begin{bmatrix} a_1^* & a_2^* & \ldots & \ldots & a_M^* \end{bmatrix}$$

4. The signal correlation matrix 'P' is given by
$$P = E[ss^H]$$

5. The signal vector 'S' is MxM diagonal matrix comprising of only diagonal elements of matrix 'P' given by
$$S = \begin{bmatrix} a_1a_1^* & 0 & \ldots & \ldots & 0 \\ 0 & a_2a_2^* & \ldots & \ldots & 0 \\ \vdots & \vdots & \vdots & & \vdots \\ \vdots & \vdots & \vdots & & \vdots \\ 0 & 0 & \ldots & \ldots & a_M a_M^* \end{bmatrix}$$

6. The Signal subspace is a LxL matrix given by
$$R_s = ASA^H$$

7. The Noise subspace is LxL matrix given by
$$R_n = \sigma^2 I = \sigma^2 \begin{bmatrix} 1 & 0 & \ldots & 0 \\ 0 & 1 & \ldots & 0 \\ \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & \ldots & 1 \end{bmatrix} = \begin{bmatrix} \sigma^2 & 0 & \ldots & 0 \\ 0 & \sigma^2 & \ldots & 0 \\ \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & \ldots & \sigma^2 \end{bmatrix}$$

8. The array correlation matrix is given by
$R = R_S + R_n$ Where, R_S is signal subspace and R_n is noise subspace.

10. Find the eigen values of array correlation matrix by performing Eigen Value Decomposition .

V. SIMULATION RESULT

The MUSIC & ESPRIT methods of DOA estimation are simulated using MATLAB. A uniform linear array with M elements has been considered here.

Table 1:Input to algorithms for 8 antenna elements

Name	Number of antenna elements	Amplitude	Direction	Number of sanpshot
ESPIRT	8	3v	60	1024
MUSIC	8	3v	60	1024

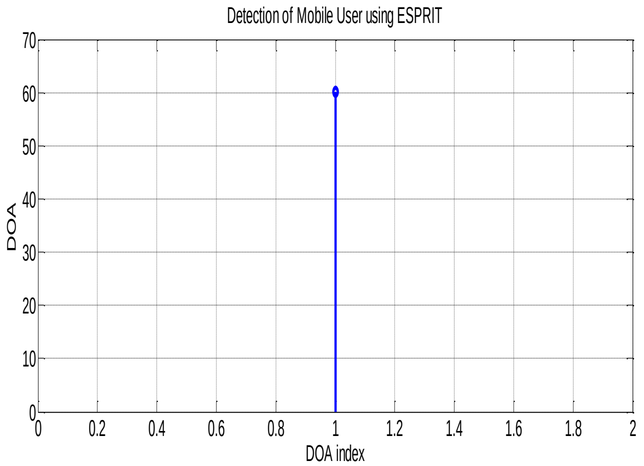

Figure 1:Detection of user in look direction by ESPIRT for 8 antenna elements

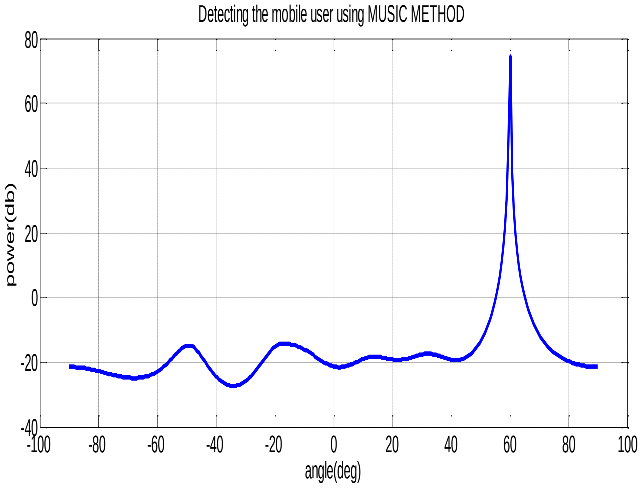

Figure 2:Detection of user in look direction by MUSIC for 8 antenna elements

Table 2: Input to algorithms for 100 antenna elements

Name	Number of antenna elements	Amplitude	Direction	Number of snapshots
ESPIRT	100	2V	45	1024
MUSIC	100	2v	45	1024

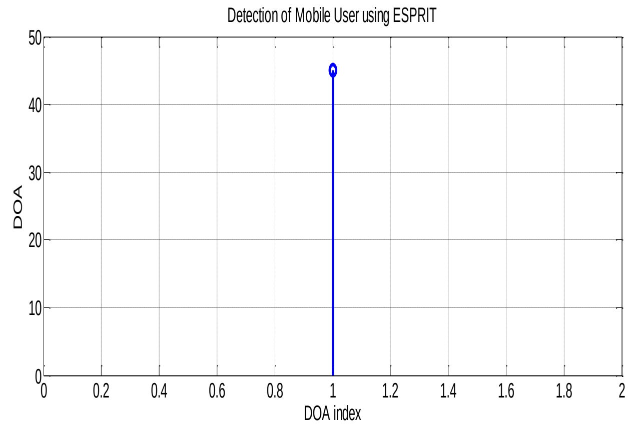

Figure 3:Detection of User in look direction by ESPIRT for 100 antenna elements

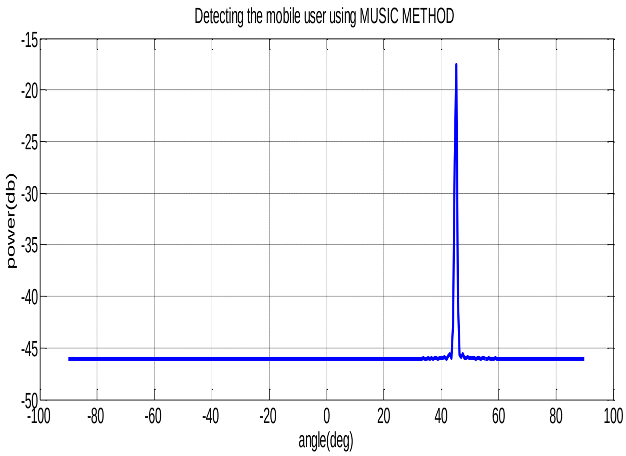

Figure 4: Detection of user in look direction ny MUSIC for 100 antenna elements.

Table 3:Output for DOA algorithms for Bias comparison

Name	True direction	Estimated direction	Bias
ESPIRT	60	59.9964	0.0036
MUSIC	60	60.1149	0.1149

A. *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

B. *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. The more operational definition of resolution is how well a spectral estimate allows the presence of two sources to determine.

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VI. DISCUSSION

MUSIC involves finding the Eigen vectors corresponding to noise. The Eigen values of the noise will be equal to variance of noise. In the case where the source correlation matrix is not diagonal or the noise variances vary, the resolution will diminish. In the more practical application we must collect several time samples of the received signal plus noise, assume ergodicity and estimate the correlation matrices via time averaging.

ESPRIT is similar to MUSIC. ESPRIT correctly exploits the underlying data model. Beyond retaining most of the essential features of the arbitrary array of sensors, ESPRIT achieves a significant reduction in the computation and storage costs. This is done by imposing a constraint on the structure of the sensor array to possess displacement invariance, i.e, sensors occurs in matched pairs with identical displacement vectors. Such conditions are or can be satisfied in many practical problems. In addition to obtaining signal parameters efficiently, ESPRIT is also less sensitive to array imperfections than other techniques including MUSIC.

VII. CONCLUSION

This paper presents the results of direction of arrival estimation using ESPRIT & MUSIC. These two methods have greater resolution and accuracy and hence these are investigated much in detail. The simulation results of both MUSIC and ESPRIT show that their performance improves with more elements in the array, with large snapshots of signals and greater angular separation between the signals. These improvements are seen in form of the sharper peaks in the MUSIC and ESPRIT. The number of signal snapshots used to generate realistic signal model is a key factor in the realization of practical antennas. While the bias of the algorithms is measured for the antenna array having less antenna elements the bias of ESPRIT is the best when compared to MUSIC. Therefore one can conclude that Novel Snapshot Based approach perform well for MUSIC and ESPRIT.

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