ISSN 2229-5518

Performance Analysis of Direction of Arrival Estimation Algorithms for Smart Antenna for Mobile Communication Systems

Gaurav Chaitanya[#1] ,Ankit Jain[#2], Nitin Jain[*3]

[#]*M.E. Pursuant, Department of ECE, IES IPSA Indore*
Madhya Pradesh, India

[*]*Assistant Professor, Department of ECE, IES IPSA. Indore*
Madhya Pradesh, India

Abstract- Mobile communication networks face ever-increasing demands on their spectrum and infrastructure resources. Increased minutes of use, capacity-intensive data applications and the steady growth of worldwide mobile subscribers means that carriers will have to find effective ways to accommodate increased wireless traffic in their networks. Thus, the smart antennas system becomes capable to locate and track signals by the both: users and interferers and dynamically adapts the antenna pattern to enhance the reception in Signal-Of-Interest direction and minimizing interference in Signal-Of-Not-Interest direction. Hence, Space Division Multiple Access system, which uses smart antennas, is widely used in mobile communication systems, because it shows improvement in channel capacity and co-channel interference. But on the other hand the performance stability of smart antenna system greatly depends on efficiency of Direction of Arrival (DOA), which is used to estimate the angle of arrival of the number of incidents plane waves on the antenna array. This paper shows an effort on the study of performance analysis of DOA estimation Algorithms- MUSIC and ESPRIT for Adaptive Array Smart Antenna for Mobile Communication on different performance parameters such as number of elements, number of snap shots, noise mean, noise variance and spacing between elements.

Index Term- Smart Antenna, DOA, ESPRIT, MUSIC.

I. INTRODUCTION

In recent years a substantial increase in the development of broadband wireless access technologies for evolving wireless Internet services and improved cellular systems has been observed. Because of them, it is widely foreseen that in the future an enormous rise in traffic will be experienced for mobile and personal communications systems. The rise in traffic will put a demand on both manufacturers and operators to provide sufficient capacity in the networks. The system capacity can be improved either enlarging its frequency bandwidth or allocating new portion of frequency spectrum to wireless services. But since the electromagnetic spectrum is a limited resource, it is not easy to get new spectrum allocation without the international coordination on the global level. Efficient source and channel coding as well as reduction in transmission power or transmission bandwidth or both are possible solutions to the challenging issue. With the advances in digital communication techniques, the efficient use of frequency can be improved by multiple access technique (MAT). Since this approach allows more users to be supported within a limited spectrum allocation, compared with conventional antennas, it can lead to improved capacity of the communication system. The Smart Antenna System (SAS) employs the antenna elements and the digital signal processing which enables it to form a beam to a desired direction taking into account the multipath signal components. In this way, Signal-to-Interference-and-Noise Ratio (SINR) improves by producing nulls towards the interferers Signal-Of–No-Interest (SONI).The performance of SAS greatly depends on the performance on DOA estimation. In this paper we are analyzing the performance of simulated MUSIC and ESPRIT DOA algorithms with MATLAB as a simulation tool on different parameters such as number of elements, number of snap shots, noise mean, noise variance and spacing between elements.

II .DOA ESTIMATION ALGORITHMS

The DOA estimation has also been known as spectral estimation, or bearing estimation. Some of the earliest references refer to spectral estimation as the ability to select various frequency components out of a collection of signals. The DOA algorithms are classified as quadratic type and subspace type. The Barltett and Capon (Minimum Variance Distortion less Response) are quadratic type algorithms. These both methods are highly dependent on physical size of array aperture, which results in poor resolution and accuracy. Subspace based DOA estimation method is based on the eigen value decomposition. The subspace based DOA estimation algorithms MUSIC and ESPRIT provide high resolution; they are more accurate and not limited to physical size of array aperture.

DATA MODEL CONSIDERED

Entire description about DOA estimation algorithms is based on certain assumptions which are applied on the data observed.

- Far-field assumption: Signal sources are enough far that the wave front generated is planar. This happens when distance is larger than $2D^2/\lambda$, where d being the dimension of antenna array.
- AWGN channel: Additive white Gaussian noise is considered which is uncorrelated with the signals.
- Isotropic medium: Medium has its physical properties same throughout the region.
- Linear transmission medium: Signals at a particular point are superimposed linearly.
- Narrowband assumption: Carrier frequency of each signal from every source is same.

A. *MUSIC*

MUSIC (**Mu**ltiple **Si**gnal **C**lassification) is one of the earliest proposed and a very popular method for super-resolution direction finding. Within the class of the so-called signal-subspace algorithms, MUSIC has been the most widely examined. The popularity of the MUSIC algorithm is in large part due to its generality. For example, it is applicable to arrays of arbitrary but known configuration and response, and can be used to estimate multiple parameters per source (e.g., azimuth, elevation, range, polarization, etc.). In estimating DOA, MUSIC deals with the decomposition of covariance matrix into two orthogonal matrices, i.e., signal-subspace and noise-subspace. Estimation of DOA is performed from one of these subspaces, assuming that noise in each channel is highly uncorrelated. This makes the covariance matrix diagonal. The covariance matrix is given by:

$$S_x = F(\theta)\, S_{ss}\, F(\theta)^H + \sigma^2_w I \qquad (1)$$

Where $F(\theta) = [f(\theta_1):f(\theta_2):\ldots..:f(\theta_D)]$ is a M X D array steering matrix. σ^2_w is noise variance and I is an identity matrix of size M X M.

Writing the spatial covariance matrix in terms of eigenvalues and eigenvectors gives:

$$S_x = \sum_{i=1}^{M} P_i \phi_i \phi_i^H \qquad (2)$$

The noise subspace eigenvalues and eigenvectors are:

$$p_i = \quad i=D+1,D+2,\ldots\ldots,M \qquad (3)$$

$$\phi_i = \quad i=D+1,D+2,\ldots\ldots,M \qquad (4)$$

The noise subspaces can be written in the form of M X (M-D) matrix:

$$U_N = [\phi_{D+1}, \phi_{D+2}, \ \ldots\ldots, \phi_M] \qquad (5)$$

Equation (5) indicates that we can find out the desired value DOA of $\theta_1, \theta_2, \ldots\ldots, \theta_D$ by finding a set of vectors that span U_N and projecting array manifold matrix $f(\theta)$ onto U_N for all values of θ and evaluating the D values of θ , where the projection is zero .

$$||F_i^H U_N||^2 = 0, \quad i=0,1,\ldots\ldots,D \qquad (6)$$

The MUSIC Pseudo spectrum is given as,

$$P_{mu}(\theta) = \frac{1}{\text{abs}\,[F(\theta)^H U_N U_N^H F(\theta)]} \qquad (7)$$

B. *ESPRIT*

ESPRIT stands for **E**stimation of **S**ignal **P**arameters via **R**otational **I**nvariance **T**echniques which is another subspace based DOA estimation algorithm [7][8]. It does not involve an exhaustive search through all possible steering vectors to estimate DOA and dramatically reduces the computational and storage requirements compared to MUSIC. 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. It is based on the array elements placed in identical displacement forming matched pairs, with M array elements, resulting in m=M/2 array pairs called "doublets".

Computation of signal subspace for the two sub arrays, P_1 and P_2, results in two vectors $V_1$and V_2, such that Range [S] = Range [B]. Also, there should exist a non-singular matrix T of D X D such that $V_s = B\,T$, where V_s can be decomposed into V_1 and V_2 :

$$V_1 = BT\ ,\ V_2 = B\varphi T \qquad (8)$$

$$\varphi = \text{diag}[\ e^{jkd\sin(\theta_1)}, e^{jkd\sin(\theta_2)}, \ldots\ldots, e^{jkd\sin(\theta_D)}\ ] \qquad (9)$$

If D X D is diagonal, unitary matrix with phase shifts between doublets for each DOA, there exists a unique rank D matrix such that,

$$[V_1 \ \ V_2]F = V_1W_1+V_2W_2 = BTW_1 + B\,\varphi\, TW_1 = 0 \qquad (10)$$

Rearranging equation (10), we get:

$$BT\Psi = B\,\varphi T \qquad \text{where, } \Psi = -F_1 F_2^{-1}$$

With B as full rank and sources are having distinct DOA, then

$$\Psi = T^{-1} \varphi T \qquad (11)$$

Equation (11) indicates that if we are able to find out eigenvalues of Ψ , which are diagonal elements of φ , we can estimate DOA as $\varphi=(a_1,a_2,.....,a_D)$ where,

$$a_i = e^{jkd\sin(\theta_i)} \qquad i=1,2,\ldots\ldots,D \qquad (12)$$

DOA can be calculated by:

$$\theta_i = \sin^{-1}\left(\frac{\arg(a_i)}{kd}\right) \qquad (13)$$

III. SIMULATION RESULTS

MATLAB tool has been used for the simulation of MUSIC and ESPRIT, DOA estimation techniques. Simulation has been run for four signals coming from different angles 140,240,350,550, for 500 snapshots, SNR of10dB, and 16 array elements.

1. MUSIC spectrum for varying number of array element

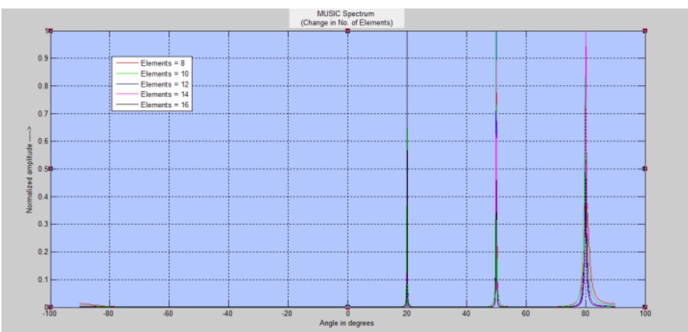

Fig1: Angle versus normalized amplitude graph varying number of array elements

2. MUSIC spectrum for change in noise variance:

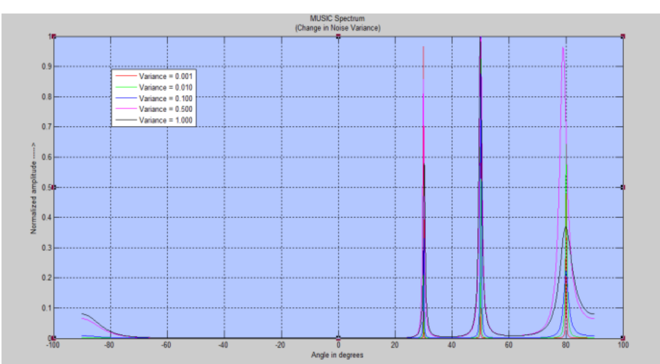

Fig2: Angle versus normalized amplitude graph by varying number of SNR

3. MUSIC spectrum for varying number of snapshots:

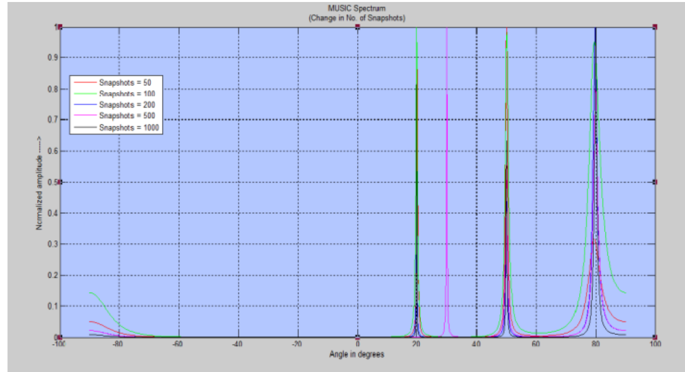

Fig 3: Angle versus normalized amplitude graph by varying no. of snapshots

4. MUSIC spectrum for varying spacing between elements:

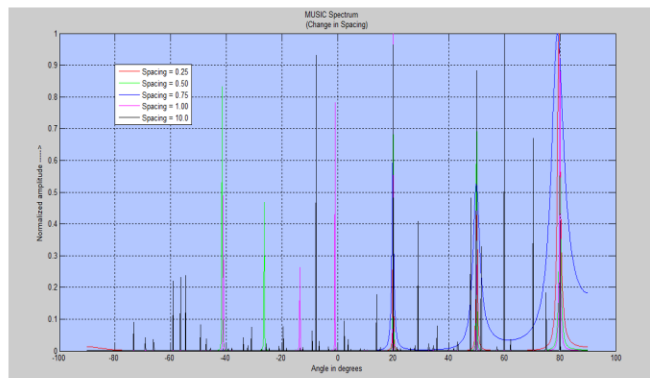

Fig 4: Angle versus normalized amplitude graph by varying spacing between elements

Comparison for both algorithms has been performed for DOA estimation for varying number of snapshots (n=200, 500, 700 and 1000) for four angles (14º, 28º, 35º and 55º) with SNR=10dB, array size=16 shown in Tables 1 to 8

DOA estimation by MUSIC

Table 1: Varying no. of snapshots (MUSIC)

DOA	n = 50	n = 100	n = 200	n = 500	n = 1000
20	19.2052	19.9036	20.2041	20.1169	20.0068
50	48.9045	49.8903	50.2351	50.0213	50.0010
80	79.1098	80.5637	80.0094	80.0021	80.0002

Table 2: Varying Noise Variance (MUSIC)

DOA	σ2=0.001	σ2=0.010	σ2 =0.10	σ2=0.5	σ2 =1.0
20	20.1258	20.9654	21.8745	24.7659	25.347

50	50.5748	50.9874	49.658	50.026	50.002
80	80.3654	81.8765	80.009	83.865	85.987

Table 3: Varying no. of elements (MUSIC)

DOA	E=8	E=10	E=12	E=14	E=16
20	19.106	19.4062	20.3485	20.2587	20.004
50	50.695	50.4125	49.674	50.041	50.078
80	79.028	79.7056	80.258	80.157	80.124

Table 4: Varying inter element Spacing (MUSIC)

DOA	S=0.25λ	S=0.50λ	S=0.70λ	S=1.00λ	S=10.00λ
20	19.994	19.130	20.856	21.953	25.5520
50	50.002	50.452	51.668	52.025	53.0022
80	79.852	79.1540	80.6810	82.2584	86.1000

DOA estimation by ESPRIT

Table 5: Varying no. of snapshots (ESPRIT)

DOA	n =50	n =100	n =200	n =500	n=1000
20	19.969	19.998	19.908	20.035	19.961
50	49.950	49.894	50.003	49.974	49.959
80	79.957	80.352	79.890	79.991	80.210

Table 6: Varying Noise Variance (ESPRIT)

DOA	σ^2=0.001	σ^2=0.01	σ^2=0.1	σ^2=0.5	σ^2=1.0
20	19.999	20.022	19.932	20.054	19.948
50	50.001	49.997	49.956	49.940	49.598
80	80.035	79.924	80.026	79.644	80.701

Table 7: Varying inter element Spacing (ESPRIT)

DOA	S=0.25λ	S=0.50λ	S=0.70λ	S=1.00λ	S=10.0λ
20	20.127	20.066	19.970	20.018	2.406
50	50.130	49.909	-41.471	-13.032	49.598
80	79.298	80.612	-26.334	-0.824	-0.871

Table8: Varying no. of elements (ESPRIT)

DOA	E=8	E=10	E=12	E=14	E=16
20	20.029	20.026	19.997	19.990	20.009
50	50.120	50.013	49.963	49.991	50.016
80	80.317	79.642	80.162	80.002	80.069

IV.CONCLUSION AND RESULTS

Fig.1 indicates that as array size increases from 8 to 16, peaks in the spectrum become sharper and hence resolution capability of MUSIC increases. Fig.2 indicates that as Noise Variance value changes, peaks in spectrum start to disappear and hence resolution capability of MUSIC for closely spaced signals like 30 and 50 decreases. Fig.3 indicates the ability of MUSIC to resolve closely spaced signals 30 and 50 as a function of number of snapshots. As snapshots increase from 50 to 1000, resolution capability of MUSIC increases, and the two signals can be clearly identified. Peaks in the spectrum become further sharper for snapshots 500 and 1000. Fig.5 indicates that if the spacing between array elements increases from 0.25 to 10.0 the accuracy of algorithm diminishes and the spectrum becomes wide. The simulation results from table 1 to 8 indicates that performance of MUSIC and ESPRIT improves with more no. of elements, higher no. of snapshots, decrease in element spacing and decrease in noise variance. These improvements are analyzed in the form of sharper peaks in MUSIC spectrum and smaller errors in angle detection.

V. REFERENCES

[1].Balanis, C.A., *Antenna Theory: Analysis and design*, 3rd ed.,New York: John Wiley & sons,2005.

[2].Frank Gross–*Smart Antenna for Wireless Communication*, Mcgraw-hill, September 14,2005 Zhizhang Chen, Gopal Gokeda & Yiqiang Yu "Introduction to Direction-of-Arrival Estimation" Artech House, 2010.

[3]. Zhizhang Chen, Gopal Gokeda & Yiqiang Yu "*Introduction to Direction-of- Arrival Estimation*" Artech House, 2010.

[4].Weber, R.J. Yikun Huang," *Analysis for Capon and MUSIC DOA estimation algorithms*", Antennas and Propagation Society International Symposium, 2009. APSURSI '09. pp 1 – 4, June 2009

[5].Haardt, M., et al., *"2D Unitary ESPRIT for Efficient 2D Parameter Estimation*," Proc. IEEE Int. Conf. Acoust., Speech, Signal Processing, Vol. 3, May 9–12, 1995, pp. 2096–2099.

[6].Roy, R., and T. Kailath, *"ESPRIT-Estimation of Signal Parameters Via Rotational Invariance Techniques*," IEEE Trans. on Acoust., Speech, Signal Processing, Vol. 37, No. 7, July 1989, pp. 984–995.

[7]. Lal C. Godara, –*Application of antenna arrays to mobile communications, partΠ: beam- forming and direction-of-arrival consideration*, Proceeding of the IEEE, Vol. 85, No. 8, pp.1195-1234, August 1997.

[8]. Khan, Z.I. Awang, R.A. Sulaiman, A.A. Jusoh, M.H. Baba, N.H. Kamal, M.M.D. Khan, N.I.," *Performance analysis for Estimation of signal Parameters via Rotational Invariance Technique (ESPRIT) in estimating Direction of Arrival for linear*

ISSN 2229-5518

array antenna",IEEE International Conference on RF and Microwave Conference, 2008,pp530– 533 , Dec. 2008.

[9].T.B. Lavate, V.K. Kokate & A.M. Sapkal "*Performance analysis of MUSIC and ESPRIT DOA estimation algorithms for adaptive array smart antenna in mobile communication*" International Journal of Computer Networks (IJCN), Vol. (2): Issue (3).2011

[10]. Nur Alina Zureen Bt Rosli & Politeknik Seberang Perai "*Simulation of a smart antenna system*" PSP's Research Digest