Study of Various Algorithms for Direction of Arrival Estimation In Smart Antenna

Tithi Gunjan , M.Tech. Persuant , Electronic and Communication Department
Acropolis Institute of Technology and Research
Indore, India
tithi.gunjan@gmail.com

Gaurav Chaitanya , Asst. Proffesor , Electronic and Communication Department
Acropolis Institute of Technology and Research
Indore, India
gauravchaitanya@acropolis.in

Abstract—Smart Antenna system has received much attention in the last few years because they can increase system capacity by dynamically tuning out interference while focusing on the intended user along with impressive advances in the field of digital signal processing. They offer wide bandwidth, less interference, flexibility, high speed, phase and low propagation loss. On the other hand the performance stability of smart antenna depends upon the Direction of arrival estimation of the signals which are incident on the antenna array. In Smart antenna, to locate the desired signal, various direction of arrival (DOA) estimation algorithms are used. In this paper besides a short review on the advances on smart antenna, certain assumptions for the DOA estimation has been shown. A uniform linear array is used to explain the algorithms. In the rest of study, we focus on different types of algorithms for DOA estimation with their performance comparison

Keywords: Smart Antenna, DOA

I. INTRODUCTION

Smart antenna generally refers to any antenna array with aided signal processor, which can adjust or adapt its own beam pattern in order to focus on the signals of interest and to minimize interfering signals [1]. 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) [2]. The term Smart implies the use of signal processing in order to shape the beam pattern according to some conditions. Smart antennas generally are of two types that is switched beam and adaptive array systems. Switched beam systems have several pre-determined fixed beam patterns. At an instant of time decision is made as to which beam to be access, adaptive systems allow the antenna to steer the beam to any direction of Interest while simultaneously making nulls in the direction of interfering signals .[1]

The smart antenna technology is based on antenna arrays where the Radiation pattern is changed by adjusting the amplitude and relative phase on the different Elements of the array. Beam forming is a technique in which an array of antennas are used to achieve maximum reception in a specified direction by estimating the signal arrival from the desired direction If there are several transmitters operating simultaneously, [11] each source creates many multipath components at the receiver and hence receiver array must be able to estimate the angles of arrival in order to decide 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 performance or suppress interferers to improve the capacity of cellular mobile communication.

DATA MODEL

Most of the modern approaches to signal processing are model-based; they depend on some assumptions on the data which is observed in real world. The following scenario is assumed as follows [10]:-

1) **Isotropic and Linear Transmission Medium**: The transmission medium between the source and the array is isotropic and linear that means the medium's physical properties are same in all direction and signals at any point can be superposed linearly.

2) **Far Field Assumption**: The signal sources are located far from the array in such a way that the wavefront generated by each source arrives at all the elements at an equal direction of propagation and the wavefront is planar. Hence the propagating fields of the signals which arrive at the array are considered to be parallel to each other.

3) **The Noise is Assumed to be White Noise**: The additive noise is taken from a zero mean, spatially uncorrelated random process, which is uncorrelated with the signals.

II. APPLICATION OF DOA IN WIRELESS COMMUNICATION

In signal processing literature, direction of arrival denotes the direction from which usually a propagating wave arrives at a point, where usually a set of sensors are located. This set of sensors forms what is called a sensor array. Various engineering applications are as follows:

Smart Antenna systems are used in MIMO systems due to their tremendous spectral efficiency. MIMO is the use of multiple antennas at both the transmitter and receiver to improve communication performance, in an urban environment; signals bounce off trees, buildings, etc. and continue on their way to their destination (the receiver) but in different directions. With MIMO, the receiving end uses DOA algorithms and signal processing algorithms to sort out the multiple signals to produce one signal that has the originally transmitted data.

1-Find the direction relative to the array where the underwater sound source is located.

2-Radio telescopes use these techniques to look at a certain location in the sky.

III. Classification of DOA Estimation

DOA estimation algorithms can be classified into two types that is Conventional algorithms and Subspace based algorithms Conventional algorithms include Bartlett, Capon, Min-norm algorithms, Linear Prediction, Maximum Entropy. Subspace based algorithms include MUSIC and ESPRIT, Matrix Pencil etc. both the methods depends upon array size of the physical aperture[1,3,4] Subspace based algorithms provide high resolution and accuracy[2] and hence our study is based on subspace algorithms.

Subspace Algorithm

These methods search for the directions such that steering vectors associated with these directions are orthogonal to noise subspace and are contained in the signal subspace. These methods are also used to for finding the DOA's when the background noise is not white but has a known covariance, or when the sources have near field.

These methods depend on the following properties of the matrix space defined by Rxx:

1. The space, spanned by its eigenvectors, can be partitioned into two orthogonal subspaces, namely, the signal subspace and noise subspace.

2. The steering vectors correspond to the signal subspace.

3. The noise subspace is spanned by the Eigen vectors associated with the smaller Eigen values of the correlation matrix.

4. The signal subspace is spanned by the eigenvectors associated with the larger Eigen values. [2]

The algorithms which come under this technique are as follows:-

1.MUSIC DOA estimation
2.ROOT MUSIC DOA estimation
3.SMOOTH MUSIC DOA estimation

1) Music DOA Estimation:

MUSIC (multiple signal classification) is very popular method for direction finding, it is the most widely used method. It is applicable to arrays of arbitrary but known configuration and response and can be used to estimate multiple parameters per source (azimuth, elevation, range, polarization) [2]. It deals with the decomposition of covariance matrix into two 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 uncorrelated. [1]

Steps involved are as follows:-

- Estimation the correlation matrix R .Find its eigendecomposition.
- Partition Q to obtain Q_n, corresponding to the (N-M) smallest eigenvalues of Q, which spans the noise subspace.
- Plot, as a function of Ø, the MUSIC function $P_{MUSIC(\phi)}$.
- The M signal direction are the M largest peaks of $P_{MUSIC(\phi)}$.

Hence the MUSIC plots the spectrum as follows:-

$$P_{MUSIC}(\phi) = \frac{1}{\sum_{m=M+1}^{N}\left(q_m^H \; s(\emptyset)\right)^2} = \frac{1}{s^H(\emptyset) Q_n Q_n^H \; s(\emptyset)} \qquad \dots (8)$$

2) Root Music DOA Estimation:

The accuracy of MUSIC algorithm is limited by the discretization at which the MUSIC function PMUSIC ϕ) is calculated. It requires either human interaction to decide on the largest 'M' peaks or a comprehensive search algorithm to determine these peaks. This is an extremely computationally intensive process. Therefore, MUSIC by itself is not very practical hence we require a method that results directly in numeric values for the estimated directions. This method is known as Root-MUSIC.

MUSIC is a technique that estimates the spectrum of the incoming data stream, i.e. it is a spectral estimation technique. The end product is a function of DOA, ϕ; Root-MUSIC is an example of a model-based parameter estimation (MBPE) technique. We use a model of the received signal as a function of the DOA; the model is the steering vector. The DOA is a parameter in this model. Based on this model and the received data, we will estimate this parameter.

The DOA is calculated as follows:-

- Estimate the correlation matrix R .Find its eigendecomposition.
- Partition Q to obtain Q_n, corresponding to the (N-M) smallest eigenvalues of Q, which spans the noise subspace.
- Obtain C l by assuming the l-th diagonal of C.
- Find the Zeros of the resulting polynomial in term of (N-1) pairs.
- Of the (N-1) root within the unit circle, choose the M closest to the unit circle. And with the following equation find DOA

$$\emptyset_m = \cos^{-1}\left[\frac{\ln(Z_m)}{kd}\right], \text{ m= 1, 2…, M}$$

International Journal of Scientific & Engineering Research, Volume 5, Issue 3, March-2014
ISSN 2229-5518

3) **Smooth Music DOA Estimation**:

Smooth-MUSIC overcomes the MUSIC assumption that all incoming signals are uncorrelated. In a communication situation, assuming flat fading, there may be multipath components from many directions. These components would be correlated with each other. Correlated components reduce the rank of the signal correlation matrix Rs, resulting in more than (N −M) noise Eigen values.[3] In smooth-MUSIC, the N elements are subdivided into L overlapping sub arrays, each with 'P' elements. For example, sub array 0 would include elements 0 through 'P – 1', sub array 1 elements 1 through P, etc. Therefore, L = N − P + 1. Using the data from each sub array, 'L' correlation matrices are estimated, each of dimension P × P. The MUSIC algorithm then continues using a smooth correlation matrix.

$$R_L = \frac{1}{L}\sum_{l=0}^{L-1} R_l$$

This formulation can detect the DOA of up to L-1 correlated signals. This is because the signal correlation matrix component of R_L becomes full rank. [2]

IV SIMULATION RESULTS

MATLAB tool has been used for simulation, simulation model used two source node , 8 sensors and the number of snapshot is taken 256 .The resolution is calculated by a progressive reduction of the angular difference of the two DOA. Spacing between elements is assumed to be 0.5λ.

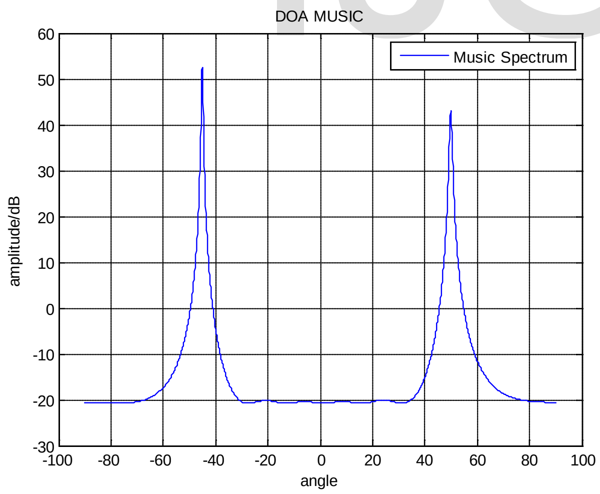

Fig:1 DOA estimation by MUSIC

MUSIC promises to provide unbiased estimates of the number of signals, The number of signal snapshots used to generate realistic signal model is a key factor in the realization of practical antennas. Increased snapshots leads to sharper MUSIC spectrum peaks indicating more accurate detection and better resolution.

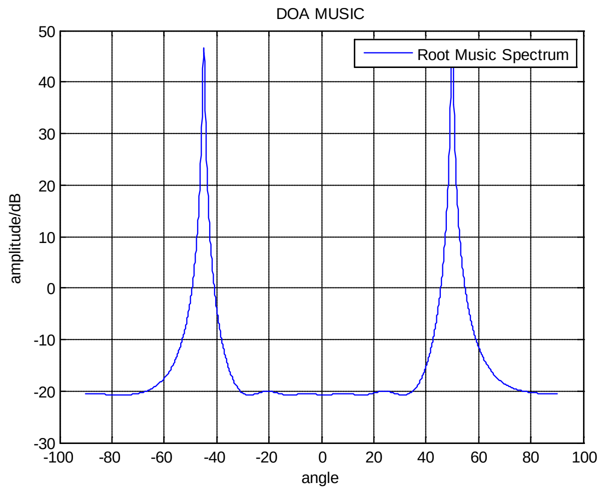

Fig:2 DOA estimation by ROOT-MUSIC

The MUSIC algorithm in general can apply to any arbitrary arrayregardless of the position of the array elements. Root-MUSIC impliesthat the MUSIC algorithm is reduced to finding roots of a polynomial as opposed to merely plotting the pseudospectrum or searching for peaks in the pseudospectrum.

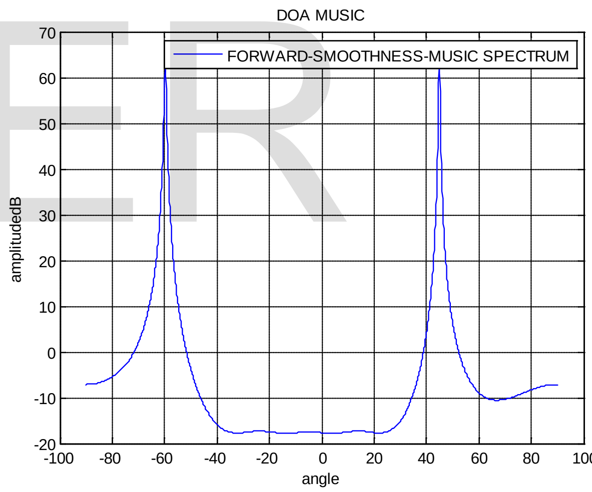

Fig:3 DOA estimation by SMOOTH-MUSIC

CONCLUSION

This paper shows basic description of direction of arrival estimation algorithms, Conventional type methods highly depend 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 hence provide high resolution, they are more accurate and not limited to physical size of array aperture. The MUSIC algorithm is simple and high-resolution hence widely used it has greater resolution and accuracy than the other algorithms (i.e. Bartlett, CAPON) and hence its variants that is ROOT-MUSIC and SMOOTH-MUSIC are being investigated much in detail. The results show the performance of simple MUSIC, root MUSIC and smooth music. The performance can be improved with more elements in the array, with higher number of snapshots of signals and greater angular separation between the signals. These are responsible for the form of sharper peaks in MUSIC spectrum and smaller errors in angle detection., ROOT-MUSIC, SMOOTH MUSIC etc require less snapshots of signals hence provides more accuracy.

Notations

- Rxx = covariance matrix
- W = array weight vector
- θ = direction of source
- d = number of sources
- M = signals incident on an array
- $S^H S(\emptyset_m)$ = cauchy-schwarz relation
- Q_n = Noise subspace
- R = signal covariance matrix
- T = transformation matrix
- RL = smooth correlation matrix
- Zm = poles of the system
- $P_B(\theta)$ = power estimated by Bartlette
- method as a function of θ

References

- Performance Analysis of DOA estimation algorithm for smart antenna for mobile communication" ; Gaurav Chaitanya, Ankit Jain, Nitin Jain, International journal of scientific & engineering research vol 3, Issue 7, july 2012
- " Algorithm for the direction of arrival estimation in a smart antenna" ; by K.Karuna Kumari, B.Sudheer,K.V. suryakiran, IJCEA, vol 2, issue 4 july 2011
- A Survey on Smart Antenna System" By Savitri Katariya, IJECT vol 2; Issue 3 ; sept 2011
- "Application to MUSIC, ESPRIT & ROOT-MUSIC in DOA estimation" ; by Tanuja S Dhope; University of Zagreb, crotia
- "Antenna theory, Analysis and design" , 3rd edition , john wiley & Hoboken, New jersey, 2005
- "Performance analysis of Root-Music" ; Rao, B.D. Hari, K.V.S. IEEE transactions on acoustics, speech &signal processing vol 37 pp:1939-1949 dec 1989
- "Performance analysis of MUSIC & ESPRIT DOA estimation for adaptive array smart antenna in mobile communication" T.B. Lavate, V.K. Kokate, Dr. A.M. Sapkal; Pune university
- "Smart Antennas For wireless communication"; Frank Gross; MC Graw Hill; New York 2005
- "Introduction to Smart Antenna"; Constantine A. Balanis, Panayiotis Ioannides, Department of Electrical Engineering, Arizona State University
- "Introduction to Direction of arrival estimation" ZhinZhang chen, Gopal Gokeda, Yiqiang Yu.
- "Application of Antenna Arrays to Mobile Communications, Part II: Beam-Forming and Direction-of-Arrival Considerations" ; LAL C. Godara, Proc. IEEE, Vol. 8, Issue: 8, pp. 1195 – 1245. Product Type: Conference Publications, April 1997.
- L. C. Godara, "Applications of antenna arrays to mobile communications. Part I: Performance improvement, feasibility, and system considerations," in Proc. IEEE, vol. 85, pp. 1031–1060, July 1997.