Implementation of Music Algorithm for Smart Antenna System

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Abstract

Adaptive antenna arrays use multiple antenna elements to form directional patterns in order to improve the performance of wireless communication systems. The direction-of-arrival estimation is a crucial component of the smart antenna system. Smart antenna system is based on digital signal processing algorithms. The smart antenna 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. In adaptive array smart antenna, various Direction Of Arrival (DOA) estimation algorithms are used to locate the desired signal. Direction-of-arrival (DOA) estimation is based on the MUSIC algorithm for identifying the directions of the source signals incident on the sensor array comprising the smart antenna system.

Index Terms**—** Adaptive array, DOA estimation, MUSIC, Smart antennas.

I. Introduction

Over the last few years, there has been an increasing demand for better quality on existing wireless communication networks. This demand has brought technological challenges. Antennas, so far a neglected component in wireless communication, have gained a renewed interest among researchers in the form of “smart antennas” or “adaptive array antennas” to meet the challenging demand and bring many benefits to the wireless communication services.

In truth, antennas are not smart-antenna systems are smart. Digital Signal Processing along with the antennas makes the system smart. A smart antenna system combines an antenna array with a digital signal-processing capability to transmit and receive in an adaptive manner. Such a system can automatically change the directionality of its radiation patterns in response to its signal environment. This can increase the performance characteristics (such as capacity) of a wireless system.

II. DOA estimation algorithms

DOA estimation algorithms form the heart of smart antenna systems. The estimation of source direction is very essential. DOA algorithm determines the angle of arrival of the incoming signals. Communication systems, which use smart antennas use digital signal processing algorithms. Thus, the smart antennas system becomes capable to locate and track signals by the both: users and interferers.

The DOA estimation results are 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.

The DOA algorithms are classified as,

1. Conventional type
2. Subspace type

Conventional algorithms are Bartlett and Capon (Minimum Variance Distortion less Response). The both methods are highly dependent on physical size of array aperture, which results in poor resolution and accuracy. For this reason high angular resolution subspace methods are used.

Subspace methods are MUSIC (Multiple Signal classification) and ESPRIT (Estimation of Signal Parameters via Rotational Invariance Techniques).

The subspace based DOA estimation algorithms provide high resolution; they are more accurate and not limited to physical size of array aperture. MUSIC algorithm is highly accurate and stable and provides high angular resolution compared to ESPRIT and hence MUSIC algorithm can be widely used in mobile communication to estimate the DOA of the arriving signals.

III. MUSIC algorithm

A uniform linear array is an antenna array with identical antennas, arranged in a straight line. The distance between the antennas is equal and at most $\lambda/2$, where λ is the wavelength of the center frequency of the signals. The relation between the distance d and λ is described by $d = \lambda/2$.

The angle θ is the angle of the source with respect to a vector which is orthogonal to the array. The distance between two antenna elements is d, λ is the wavelength of the signal and ϕ is the phase shift of the signal between two antennas. This phase shift is calculated by:

$$\phi = 2\pi\left({}^{d}/_{\lambda}\right)\sin\theta \quad (1)$$

Now define the array signal vector by

$$X(t) = (t),\ x_2(t),\ x_3(t) \dots \dots \dots x_n(t))^T \qquad (2)$$

The incoming signal vector by

$$S(t) = (s_1(t),\ s_2(t),\ s_3(t) \dots \dots \dots s_p(t))^T \qquad (3)$$

The noise vector by

$$n(t) = (n_1(t),\ n_2(t),\ n_3(t) \dots \dots \dots n_n(t))^T \qquad (4)$$

And the steering matrix by

$$A = \left(a_1(\phi)a_2(\phi)a_3(\phi) \dots \dots a_p(\phi)\right) \qquad (5)$$

The algorithm contains composition of a covariance matrix. A covariance matrix is calculated by multiplying a snapshot and the Hermitian adjoint of that snapshot.

A covariance matrix is calculated by:

$$R_{xx} = \frac{1}{L}\sum_{i=1}^{l} X_i X_i^H \qquad (6)$$

Where, R_{xx} is the n by n covariance matrix, X_i is the i^{th} snapshot containing n elements, and l is the number of snapshots.

After the composition of a covariance matrix, an eigen decomposition The p (number of sources) largest eigenvalues and their corresponding eigenvectors are assigned to the sources and the $n - p$ other eigenvalues and their corresponding eigenvectors are assigned to the noise (n denotes the number of antennas). The eigenvectors assigned to the noise are combined in matrix E_n (the noise subspace). Each eigenvector is a column in E_n.

The MUSIC spectrum is calculated. This is done by :

$$P_m(\theta) = \frac{1}{a^H(\theta)E_n E_n^H a(\theta)} \qquad (8)$$

Where $P_m(\theta)$ is the measure for the MUSIC spectrum, E_n is the noise subspace and $a(\theta)$ is a steering vector of the array manifold. The array manifold is a collection of predefined steering vectors. Every steering vector represents a angle in the MUSIC spectrum. $P_m(\theta)$ is calculated for every vector in the array manifold.

A source exists at the angle where the steering vector of the array manifold is (almost) orthogonal to the noise subspace.

IV. Simulation results

In the result, different parameters are changed and the effect of parameters on the MUSIC algorithm is investigated.

The array used is linear array and the distance between two antennas is $\lambda/2$. Directions of arrivals of signals are -24, 15, 30, 45 degrees.

1. The parameter N i.e. number of elements is changed. Number of sources P = 4, number of snapshots L=500, SNR=20.

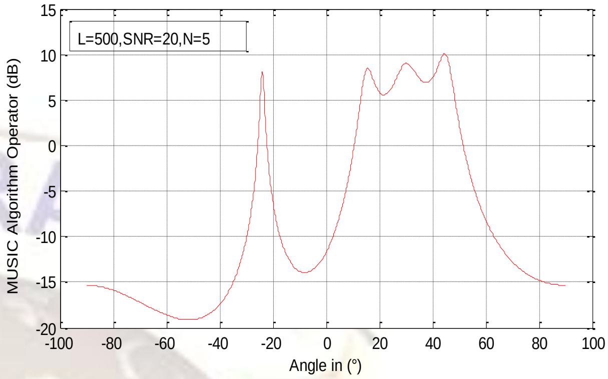

Fig.1(a) MUSIC spectrum with N=5

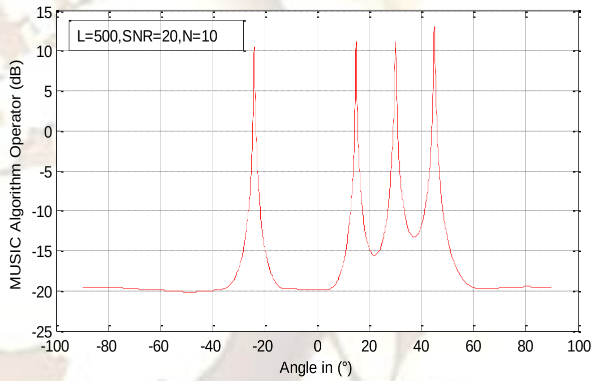

Fig.1(b) MUSIC spectrum with N=10

2. SNR i. e. signal to noise is changed. Number of sources P = 4, number of snapshots L=500. With increase in SNR peaks become more sharper i.e. angular resolution is improved.

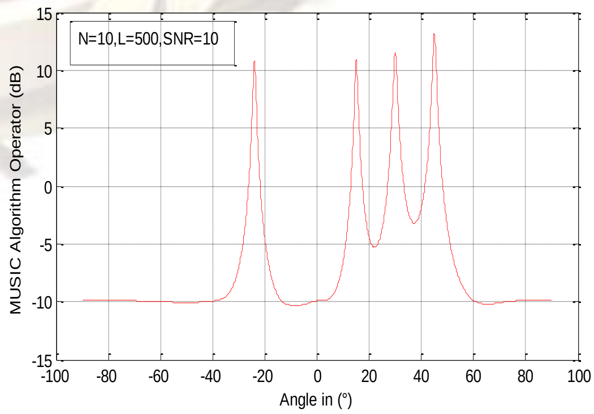

Fig.2(a). MUSIC spectrum with SNR=10

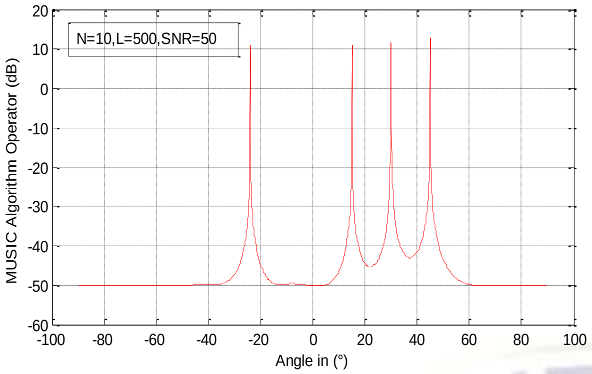

Fig.2(b). MUSIC spectrum with SNR=50

V. Conclusion

1. Number of elements: If the number of antennas is increased, peaks in MUSIC spectrum become narrower. Resolution of DOA algorithm increases.
2. Effect of SNR: If SNR is reduced, peaks become smaller. If SNR is increased, peaks become high to distinguish the sources more easily.

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