Smart Antenna Implementation using MUSIC and ESPRIT Algorithms

Suraya Mubeen, Dr. A.M. Prasad, Dr. A. Jhansi Rani
Dept. of ECE, KL University, AP, India
Dept. of ECE, JNTU Kakinada, AP, India
Dept. of ECE, VRSEC Vijayawada, AP, India

Abstract
Smart Antenna system is the One of the most rapidly developing areas of communications is a multi-element antenna where the signals received at each antenna element are intelligently combined to improve the performance of the wireless system. 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 being used more often in wireless communications, because it shows improvement in channel capacity and co-channel interference. However, performance of smart antenna system greatly depends on efficiency of digital signal processing algorithms. The algorithm uses the Direction of Arrival (DOA) algorithms to estimate the number of incidents plane waves on the antenna array and their angle of incidence. MUSIC, ESPRIT and ROOT MUSIC on the uniform linear array in the presence of white noise. The simulation results show that MUSIC algorithm is the best. Thus, DOA estimations can be done.

Keywords
ESPRIT, MUSIC, DOA, ARRAY DESIGN

I. Introduction
The high demand on the usage of the wireless communication system calls for higher system capacities. 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. One of the approaches is to use existing spectrum more efficiently, which is a challenging task. 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 techniques, the frequency efficiency can be improved by Multiple Access Technique (MAT), which gives mobile users access to scarce resource (base station) and hence improves the system’s capacity [1]. 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) [3]. The performance of SAS greatly depends on the performance on DOA estimation.

II. MUSIC Algorithm
MUSIC estimates the frequency content of a signal or autocorrelation matrix using an eigen space method. This method assumes that a signal, x(n), consists of complex exponentials in the presence of Gaussian white noise. Given an MxM autocorrelation matrix, Rxx, if the eigenvalues are sorted in decreasing order, the eigenvectors corresponding to the p largest eigenvalues span the signal subspace. The frequency estimation function for MUSIC is

\[ \hat{P}_{MU}(e^{j\omega}) = \frac{1}{\sum_{i=p+1}^{M} |e^{H}v_i|^2}, \]

MUSIC and ESPRIT provide high resolution, they are more accurate and not limited to physical size of array aperture. Subspace method based on the eigenvector decomposition of the covariance matrix

\[ R_{xx} = E(x(i)x^H(i)) \]

Performing SVD on the covariance matrix

\[ R_{xx} = U\Lambda U^H \]

The eigen values can be classified as coming from the source, interference and noise

\[ \lambda_1 = \lambda_2 = \ldots = \lambda_p = \sigma^2 \]

Projecting the array factor to the noise subspace produces the vector

\[ z = P_A a(\theta) \]

\[ P_A^\perp = I - AA^H = U_\Lambda U^H = U_\Lambda U^H \]

Searching the magnitude squared of the projection vector where it is zero determines the DOA of the signals

\[ f(\theta) = z^H z = a_H^H(\theta) P_A a(\theta) = a_H^H(\theta) U_\Lambda U^H a(\theta) \]

Simulated MUSIC Spectrum

Fig. 1:

Advantage: Provides high resolution DOA estimate
Disadvantage: MUSIC breaks down for correlated signals
III. ESPRIT Algorithm
Estimation of Signal Parameters via Rotational Invariance Techniques Subspace method that exploits the rotational invariance of the signal subspaces of subsets of the array receiver. ESPRIT is the formation of two ‘identical arrays i.e. matched arrays

\[ x_1(k) = v_1 s(k) + n_1(k) \]
\[ x_2(k) = v_1 B s(k) + n_2(k) \]

where the diagonal matrix B has elements given by

\[ Z_i = \exp \left( \frac{2 \pi i}{\lambda} \left\{ d_x \sin \theta_i \sin \phi_i + d_y \cos \theta_i \cos \phi_i \right\} \right) \]

The matrix describes the translation invariance of the first array. The output of the array is given as

\[ z(k) = \begin{bmatrix} x_1(k) \\ x_2(k) \end{bmatrix} = \begin{bmatrix} v_1 \\ Bv_2 \end{bmatrix} s(k) + \begin{bmatrix} n_1(k) \\ n_2(k) \end{bmatrix} \]

Adantage: array calibration requirements are not stringent
Disadvantage: limited array geometry

Simulated ESPRIT spectrum

IV. Assumptions
• Narrow band sources (D<M) so that one knows the translational phase relationship between the multiple arrays to be used
• These sources are assumed to be of 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.
• It assumes multiple identical arrays called doublets (These arrays are displaced translationally but not rotationally).

V. Simulation Results
The MUSIC and ESPRIT techniques for DOA estimations are simulated using MATLAB. Performance of the algorithm has been analyzed by considering Mean Squared Error (MSE) for 50 trials as a function of array elements, of SNR and as a function of snapshots. The simulation has been run for four signals coming from different angles 14°, 24°, 35°, 55° for 500 snapshots, SNR of 10dB, and 16 array elements.

A. MUSIC Spectrum for Varying Number of Array Elements
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: DOA of ESPRIT can be calculated by

\[ \theta_i = \sin^{-1} \left( \frac{\text{arg}(a_i)}{kd} \right) \]

where,

\[ a_i = e^{i k d \sin(\theta_i)} i = 1, 2, \ldots, D \]

B. MUSIC Spectrum for Varying Number of SNR
Fig. 4, indicates that as SNR value decreases, peaks in spectrum start to disappear and hence resolution capability of MUSIC for closely spaced signals like 28° and 35° decreases.

Fig. 3: MUSIC Spectrum for Varying Number of SNR

Multiple Signal Classification (MUSIC) and Estimation of Signal Parameter via Rotational Invariance (ESPRIT). The results obtained from simulations shows that MUSIC algorithm exhibits...
high resolution, but it can be computationally intensive, whereas ESPRIT algorithm also provides the high resolution of MUSIC, but it doesn’t require a costly search. ESPRIT allows the DOA’s to be computed directly. MUSIC fail to resolve correlated sources, resolution will be more for large number of array elements and time samples and more sensitive to both sensor gain and phase errors. ESPRIT resolution is more for large number of overlapping elements, more sensitive to only phase errors and has been used with different array geometries.

VI. Conclulsion
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 and compares MUSIC and ESPRIT, DOA estimation algorithms which are widely used in the design of smart antenna system. MUSIC and ESPRIT algorithms provide high angular resolution and hence they are explored much in detail by varying various parameters of smart antenna system. However simulation in this paper shows that 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.

References