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Smart antenna for doa using music and esprit

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ABSTRACT: *Smart adaptive antenna technology is considered to be the last technology frontier that has the potential of leading to large increases in systems performance. Time domain techniques have been extensively exploited. Space domain techniques, on the other hand, have not been exploited to the same extent. When applied to wireless, the benefits of smart adaptive array a antennas are as follows: (i) increased covered, which is important in the early stages of life cycle, (ii) increased capacity, which is important in the later stages of life cycle, (iii) improved link quality, (iv) reduced costs and increased return on investment, (v) lower handset power consumption, and (vi) assistance in user location by means of direction finding. This paper discusses an experimental neural network based smart antenna capable of performing direction finding and the necessary beam forming.*

The algorithm operates in two stages. The field of view of the antenna array is divided into spatial sectors ,then each network is trained in the first stage to detect signals emanating from sources in that sector. According to the outputs of the first stage, one or more networks of the second stage can be activated so as to estimate the exact location of the sources. No a priori knowledge is required about the number of sources, and the networks can be designed to arbitrary angular resolution. Some experimental results are shown and compared with other algorithms, such as, the Fourier Transform and the MUSIC algorithm AND ESPRIT variations is done in the proposed research work

KEYWORDS*:DOA ,MUSIC,ESPRIT*

I. INTRODUCTION

A smart antenna consists of an antenna array combined with signal processing in both space and time. The concept of using antenna arrays and innovative signal processing has been used before in the radar and aerospace technology [1]. Until recently, however, cost effectiveness has prevented their use in commercial systems. The emergence of very fast and low cost digital signal processors have made smart antennas a practical possibility for mobile communications systems .Recently, the application of smart antenna arrays has been recommended for mobile communications systems to overcome the problem of limited channel bandwidth, satisfying a growing demand for a large number of mobiles on communications channels. Smart antennas, help in improving the system performance by increasing spectrum efficiency and channel capacity, extending range coverage, and steering multiple beams to track several mobiles. They are also effective in reducing delay spread, multipath fading, co-channel interferences, and bit error rate (BER). Delay spread and multipath fading can be reduced with an antenna array that is capable of forming beams in certain directions and nulls in others, thereby canceling some of the delayed arrivals. Typically, in the transmit mode, the array focuses energy in the desired direction, which yields in the reduction of multipath reflections and delay spread. On the other hand, in the receive mode, the array provides compensation in multipath fading by adding the signals emanating from other clusters after compensating for delays, as well as by canceling delayed signals emanating from directions other than that of the desired mobile. The increase in the spectrum efficiency, is a result of the capability of the antenna array to provide virtual channels in an angle domain (Spatial Division Multiple Access), which means that one can multiplex channels in the spatial dimension just as in the frequency and time dimensions [2]. Perhaps, the main merit of a smart antenna system is its capability to cancel co-channel interferences. Co-channel interference in the transmit mode is handled by focusing the main antenna beam in the direction of a desired signal and nulls in the directions of other receivers, as shown in Figure 1 The ability to smoothly track users with main lobes and interferers with null insures that the link budget is constantly maximized. This effect is similar to a person's hearing. When one person listens to another, the brain of the listener collects the sound in both ears, combines it to hear better and determines the direction from which the speaker is talking. If the speaker is moving, the listener, even if his eyes are closed , can continue to update the angular position based solely on what he hears. The listener also has the ability to tune out unwanted noise, interference and focus on the conversation at hand. In the receive mode, co-channel interference is reduced by knowing the location of the signal's source (mobile) and utilizing interference cancellation.

There are many algorithms used to update the array weights, each with its speed of convergence and required processing time [3, 4]. Algorithms also exist that exploit properties of signals to eliminate the need of training signals in some circumstances. In this paper, neural networks are used along with adaptive array antennas to yield truly smart antennas that can be used for both , determining the direction of arrival of a signal (DOA) and for achieving beam-forming in real time. The new approach is based on dividing the field of view of the antenna array into angular spatial sectors, then train each network in the first stage of the architecture to detect signals emanating from sources in that sector. Once this first step is performed, one or more networks of the second stage (DOA estimation stage) can be activated so as to estimate the exact location of the sources. The main advantage of this new approach is a dramatic reduction in the size of the training set required to train each smaller neural network. Several theoretical and experimental results are shown to support the validity of this approach.

II. DIRECTION OF ARRIVAL:

We have seen that there is a one-to-one relationship between the direction of a signal and the associated received steering vector. It should therefore be possible to invert the relationship and estimate the direction of a signal from the received signals. An antenna array therefore should be able to provide for direction of arrival estimation. We have also seen that there is a Fourier relationship between the beam pattern and the excitation at the array. This allows the direction of arrival (DOA) estimation problem to be treated as equivalent to spectral estimation.

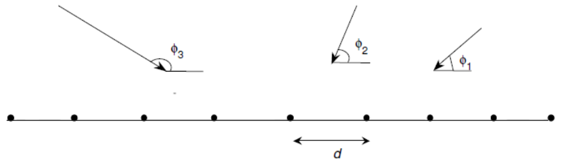

Fig 1: DOA estimation problem

The problem set up is shown in Fig. 1. Several (M) signals impinge on a linear, equispaced, array with N elements, each with direction $\emptyset_i = 1{,}2{,}3$. The goal of DOA estimation is to use the data received at the array to estimate _i, i = 1, . . .M. It is generally assumed that M < N, though there exist approaches (such as maximum likelihood estimation) that do not place this constraint.

In practice, the estimation is made difficult by the fact that there are usually an unknown number of signals impinging on the array simultaneously, each from unknown directions and with unknown amplitudes. Also, the received signals are always corrupted by noise. Nevertheless, there are several methods to estimate the number of signals and their directions.

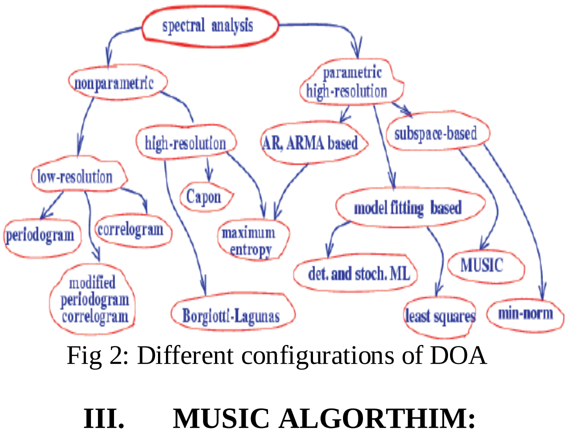

Fig 2: Different configurations of DOA

III. MUSIC ALGORTHIM:

MUSIC is probably the most popular technique. MUSIC, as are many adaptive techniques, is dependent on the correlation matrix of the data $X = S\alpha + n$ (1)

$$S = s(\emptyset_1)s(\emptyset_2)\ldots\ldots s(\emptyset_M) \qquad (2)$$

$$\boldsymbol{\alpha} = \boldsymbol{\alpha}_1 , \boldsymbol{\alpha}_2 \text{---------} \boldsymbol{\alpha}_M \qquad (3)$$

The matrix S is a N ×M matrix of the M steering vectors. Assuming that the different signals to be uncorrelated, the correlation matrix of x can be written as

$$\begin{aligned}\mathbf{R} &= \mathrm{E}\left[\mathbf{x}\mathbf{x}^H\right],\\ &= \mathrm{E}\left[\mathbf{S}\alpha\alpha^H\mathbf{S}^H\right]+\mathrm{E}\left[\mathbf{n}\mathbf{n}^H\right],\\ &= \mathbf{S}\mathbf{A}\mathbf{S}^H+\sigma^2\mathbf{I},\\ &= \mathbf{R}_s+\sigma^2\mathbf{I},\end{aligned}$$

(4)

$$\mathbf{R}_s = \mathbf{S}\mathbf{A}\mathbf{S}^H$$

Where

$$\mathbf{A} = \begin{bmatrix}\mathrm{E}\left[|\alpha_1|^2\right] & 0 & \cdots & 0\\ 0 & \mathrm{E}\left[|\alpha_2|^2\right] & \cdots & 0\\ 0 & 0 & \cdots & \mathrm{E}\left[|\alpha_M|^2\right]\end{bmatrix}$$

(5)

For any eigen vector q_m £ Q

$$\mathbf{R}_s\mathbf{q}_m = \lambda\mathbf{q}_m$$

$$\begin{aligned}\mathbf{R}\mathbf{q}_m &= \mathbf{R}_s\mathbf{q}_m+\sigma^2\mathbf{I}\mathbf{q}_m,\\ &= (\lambda_m+\sigma^2)\mathbf{q}_m,\end{aligned}$$

(6)

any eigenvector of Rs is also an eigenvector of R with corresponding eigenvalue $\lambda+\sigma^2$.

$$\mathrm{R} = \mathrm{Q}\left[\Lambda+\sigma^2\mathrm{I}\right]\mathrm{Q}^H$$

$$= \mathrm{Q}\begin{bmatrix}\lambda_1+\sigma^2 & 0 & \cdots & 0 & 0 & \cdots & 0\\ 0 & \lambda_2+\sigma^2 & \cdots & 0 & 0 & \cdots & 0\\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \vdots\\ 0 & 0 & \cdots & \lambda_M^2+\sigma^2 & 0 & \cdots & 0\\ 0 & 0 & \cdots & 0 & \sigma^2 & \cdots & 0\\ \vdots & \vdots & \vdots & \vdots & \vdots & \ddots & \vdots\\ 0 & 0 & \cdots & 0 & 0 & \cdots & \sigma^2\end{bmatrix}\mathrm{Q}^H$$

Let $\mathbf{R}_s = \mathbf{Q}\Lambda\mathbf{Q}^H$. (7)

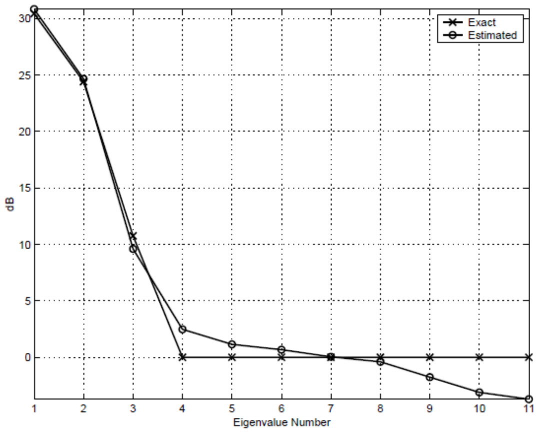

Fig 3: The eigen values of the ideal and estimated correlation matrix

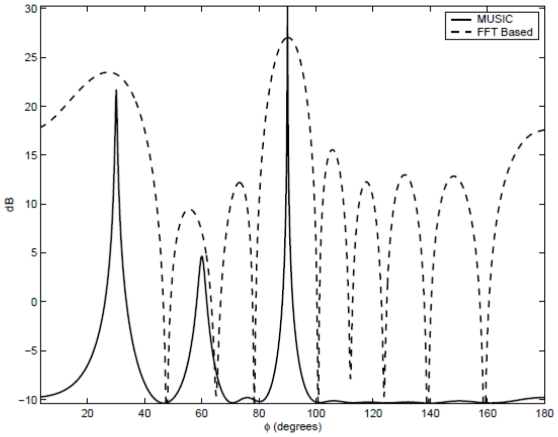

Fig 4: Comparison of the performance of the correlation (FFT) approach and the MUSIC algorithm.

Fig 4 plots the performance of the two algorithms (correlation and MUSIC) for the same example as in Fig. 3. The correlation plot is marked “FFT-based” since, for a linear array of equispaced isotropic sensors, the correlation approach is equivalent to taking a DTFT. Note the huge improvement of MUSIC over the non-adaptive correlation technique. The three peaks in MUSIC are clear and almost exactly on target. The signal arriving from angle 60° was the weakest, resulting in the broadest peak

IV.ESPRIT ;

ESPRIT is another parameter estimation technique, based on the fact that in the steering vector, the signal at one element is a constant phase shift from the earlier element .Let $z_m = e^{jkd\cos\phi_m}$ the correlation matrix is dependent on S, the N ×M matrix of steering vectors given by

$$\mathbf{S} = \begin{bmatrix} 1 & 1 & \cdots & 1 \\ z_1 & z_2 & \cdots & z_M \\ \vdots & \vdots & \ddots & \vdots \\ z_1^{N-2} & z_2^{N-2} & \cdots & z_M^{N-2} \\ z_1^{N-1} & z_2^{N-1} & \cdots & z_M^{N-1} \end{bmatrix} \quad \textbf{(8)}$$

Based on this matrix, define two (N − 1) ×M matrices, S0 and S1,

$$\mathbf{S}_0 = \begin{bmatrix} 1 & 1 & \cdots & 1 \\ z_1 & z_2 & \cdots & z_M \\ \vdots & \vdots & \ddots & \vdots \\ z_1^{N-2} & z_2^{N-2} & \cdots & z_M^{N-2} \end{bmatrix} \quad \mathbf{S}_1 = \begin{bmatrix} z_1 & z_2 & \cdots & z_M \\ \vdots & \vdots & \ddots & \vdots \\ z_1^{N-2} & z_2^{N-2} & \cdots & z_M^{N-2} \\ z_1^{N-1} & z_2^{N-1} & \cdots & z_M^{N-1} \end{bmatrix} \quad \textbf{(9)}$$

Increasing the number of temporal averaging improves DOA performance. Figure 5 shows the estimated angle error as a function of number of snapshots N using a 19 element honeycomb array. Increasing the number of temporal averaging improves the matrix element estimation; consequently the estimated angle error is reduced. The 19 element array provides sufficient number of spatial smoothing in matrix element estimation. The estimated angle error after spatial smoothing is considerably smaller than the estimated angle error without spatial smoothing. After spatial smoothing, temporal averaging over 200 snapshots provides a very good estimation. Further increasing the number of snapshots does not significantly reduce the estimation error.

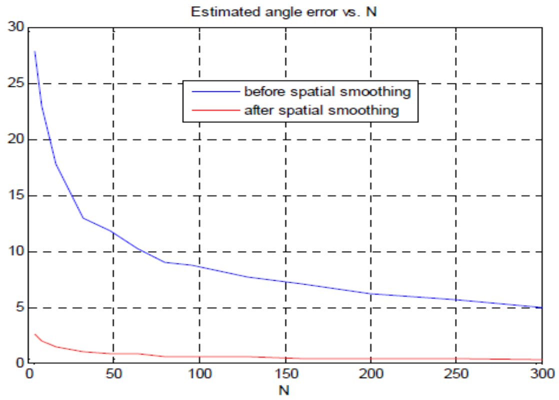

Fig 5: Estimated Angle Error as a Function of the Number of Temporal Averaging N

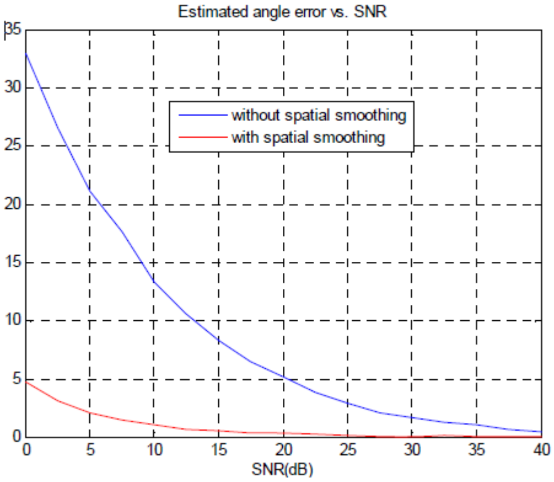

Fig 6: Estimated Angle Error as Function of SNR

IV. CONCULSION

The conclusions based on the results of this simulation study are summarized as follows, The ESPRIT method estimates signal DOA by finding the roots of two independent equations closest to the unit circle. This method does not require using a scan vector to scan over all possible directions like the MUSIC (Multiple Signal Classification) algorithm. Estimation error is relatively independent of signal azimuth angle if the signal impinging the array from low elevation angle.

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