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Adaptive Beamforming Smart Antenna for Wireless Communication System

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Abstract - In this paper, how smart antennas are incorporated in wireless communication system is presented. Smart antennas are gaining popularity in the recent times by increasing user capacity by effectively reducing interference. Direction-of-Arrival estimation algorithms are presented. Also it focuses on Null steering adaptive beamforming approach based on Smart antenna and uses RLS algorithm for weight updating as well for computing the array weights. These algorithms promises very high rate of convergence highly reduced mean square error and low computational complexity. The weights obtained are used to steer the antenna array beam in the direction of desired user.

Key Words: Adaptive Beam forming, Direction-of-Arrival (DoA), MUSIC (Multiple Signal Classifier), RLS (Recursive Least Square), Smart antenna (SA).

1. INTRODUCTION

At present, many researchers have been motivated to enhance the wireless network capacity by providing high quality wireless access. The Smart antenna (SA) technology is gaining more and more interest in increasing the wireless network capacity [1] that helps to meet the demand for the subscriber growth and the high speed. Smart antenna is recognized as most promising technology in 3G wireless network for higher user capacity by effectively reducing the multipath and co-channel interference and thereby enhancing the data rate.

The conventional base station antennas were Omni-directional i.e. they used to radiate power in all direction, where there will be a waste of resources since power is radiated in all direction other than the desired user view of direction. Also the signal experiences the interference at the receiver side. To overcome this all problems, smart antennas were developed.

A smart antenna is an array of radiating antenna elements combined with digital signal processing to transmit and receive in the adaptive manner [2-6]. Adaptively in the sense, it automatically adjusts the directionality of its radiation pattern in response to the signal environment. They are also known as adaptive array antennas. Thus smart antennas can increase capacity of the channel, broadens range coverage, steer multiple beams to track many mobiles, compensates aperture distortion or reduce multipath fading and co-channel interference.

In this paper, section 2 describes smart antenna basics and technology and section 3 briefs about DoA estimation and gives descriptive knowledge of different algorithms. Section 4 explains adaptive beamforming algorithms. Finally in section 5 implemented simulated results are present.

2. SMART ANTENNA BASICS

Smart antenna offers relief by transmitting or receiving power only to or from the desired user. Basically, smart antennas are of 2 types.

1. Phased array: - It consists of either a number of fixed beams with one beam turned on towards the desired user as shown in Fig 1 or a signal beam that is steered toward the desired signal.
2. Adaptive array: - It puts a main beam in the direction of desired user and nulls in the direction of the interference as shown in Fig 2.

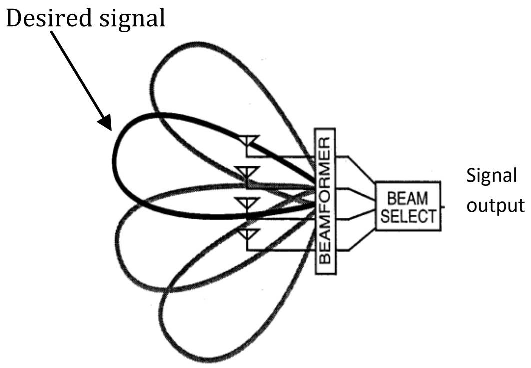

Fig 1: Phased array

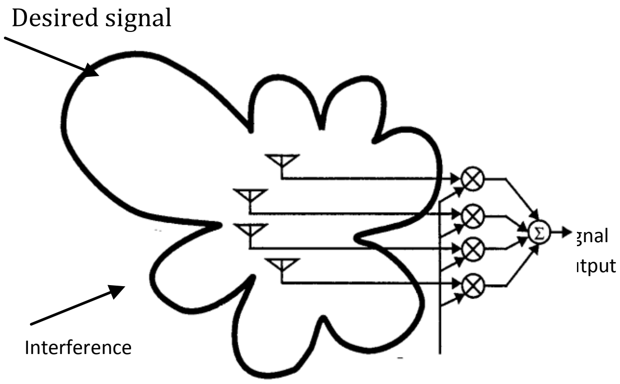

Fig 2: Adaptive array

Therefore, a smart antenna is a phased or adaptive array that adjusts to the environment. The functional block diagram of smart antenna system is as shown in Fig 3.

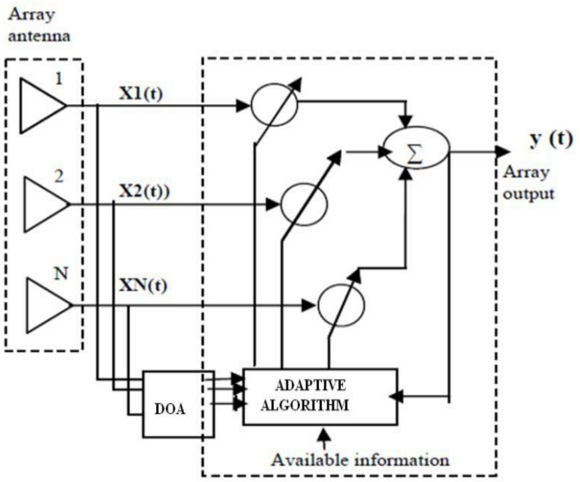

Fig 3. Functional block diagram of smart antenna system

Firstly, the digital signal processor interprets the incoming signal information using antenna array elements, determines the complex weights (amplification and phase information) and multiplies these weights to each element output to optimize the array pattern. This optimization is based on particular criteria i.e. which minimizes the interference and maximizes the main beam gain at desired direction. Thus, for computing these optimum weights and updating them we have several adaptive beamforming algorithms. But we are interested in localizing the sources, so for this, we implement DoA estimating algorithms that are mainly based on the specific properties of desired signal covariance matrix. Thus the observation space is subdivided into 2 spaces, one is signal space and other is noise space.

3. DOA ESTIMATION

Several algorithms have been developed for DoA estimation [7]-[9], [16] and [19]-[21]. The purpose of this estimation is that to acquire the information from the array element and determine the angle of direction of the desired user or signal and gives that output to the digital signal processor (adaptive beamforming algorithms). The different types of DoA estimation algorithms are

- MUSIC (Multiple Signal Classifier)
- ESPRIT (Estimation of Signal Parameters via Rotational Invariance Techniques) [22].

MUSIC is high resolution technique based on exploiting the Eigen structure of input covariance matrix. ESPRIT is based on the rotational invariance property of the signal space to make a direct estimation of DoA.

In this paper, MUSIC algorithm is implemented for DOA estimation. This algorithm uses the Eigen values and Eigen vectors of the covariance matrix of the antenna array to determine the direction of sources based on the properties of the signal and noise subspace. And it is assumed that signal and noise subspace are orthogonal to each other. Consider a Fig 4 and suppose if we have M array elements and K number of signals impinging on them.

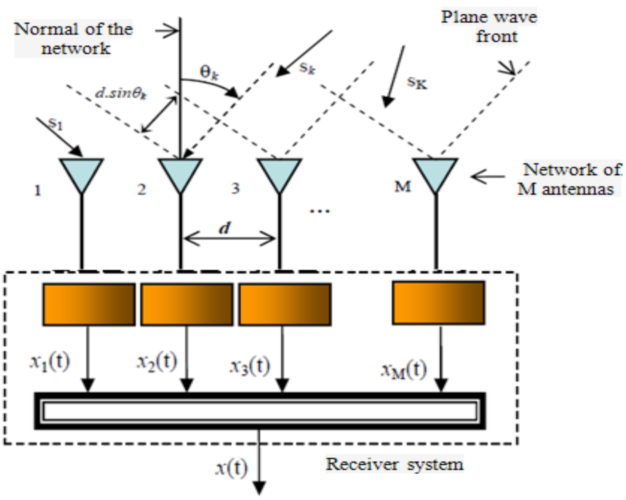

Fig 4. Geometry of Antenna array

Then there are K number of signal Eigen valves and Eigen vectors. Similarly, there is M-K noise Eigen valves and Eigen vectors. Then array covariance matrix is given by

$$R_{XX} = A * R_{SS} * A^H + \sigma_n{}^2 * I$$

where

A= [a (θ1) a (θ2) a (θ3) …………… a (θM)] is M×K array steering matrix.

R_{SS} = [s1 (k) s2 (k) s3 (k) ……….. sM (k)] is K×K source correlation matrix.

Since R_{XX} has K signal Eigen values and M-K noise Eigen vectors, we can construct M×(M-K) subspace spanned by the noise Eigen vectors such that

$$V_N = [V_1 \;\; V_2 \;\; V_3 \;\; \ldots\ldots\ldots . V_{M-K}]$$

The noise subspace eigenvectors are orthogonal to array steering vectors at the angles of arrival θ_1, θ_2, θ_3……. Θ_K and MUSIC pseudo spectrum is given by

$$P_{MUSIC} = \frac{1}{ABS(a(\theta)^H \; V_N \; V_N{}^H \;\; a(\theta))}$$

Thus above equation with time averages provides high angular resolution for coherent signals.

4. ADAPTIVE BEAMFORMING

Beamforming is process of combining signals and focusing the radiation pattern in particular direction. It makes use of DoA estimation output and determines the optimum weights of the signal at the particular angle [10]-[15] and [17]-[18]. And for updating this weight we have following algorithms.

1. Least Mean Square (LMS) algorithm.
2. Constant Modulus Algorithm (CMA) [10, 26].
3. Least-Square CMA (LS-CMA).
4. Recursive Least Square (RLS) algorithm.

In this paper, RLS algorithm is implemented for weight updating and is given by the equation

$$\hat{w}(n) = \hat{w}(n-1) + k(n)\,\xi * (n) \qquad n = 1, 2, 3\ldots\ldots\ldots$$

It does not require any matrix inversion computation as the computation of inverse correlation matrix is done directly and it requires reference signal and correlation matrix information [22]-[25].

5. SIMULATION RESULTS

For simulation, MUSIC algorithm is used for DoA estimation and RLS algorithm is used for adaptive beamforming. And the program designed is run in MATLAB R2008b to simulate the smart antenna system on a BTS Receiver (uplink). Initially an antenna array of 4 elements is considered operating at 2GHz with a separation distance of 0.075 meters. The narrowband signal is assumed and an authentication code of 10 bits is sent first. Only 2 users (signals) are served in presence of Additive White Gaussian Noise (AWGN). Null steering beamformer is used to cancel a plane wave arriving from a known direction and thus produces a null in the response pattern of the plane wave's direction of arrival. Thus a beam with unity response in the desired direction and nulls in the interference direction may be formed by estimating beamformer weights. The response patterns are as shown in Fig 5, 6, 7, for SNR=10, signal phase angle= 20, 80 (in degree).

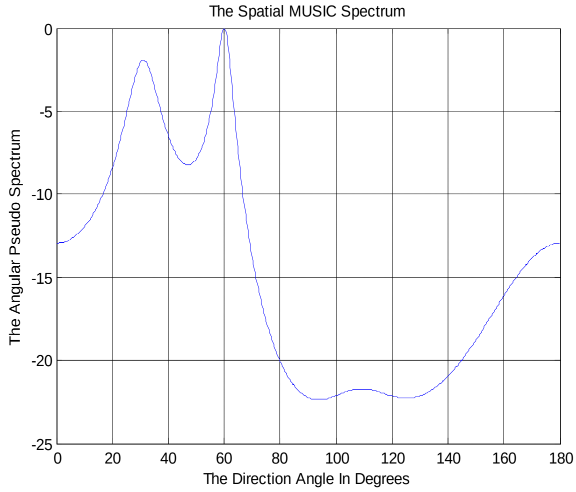

Fig 5. Pseudo spectrum for SNR= 10

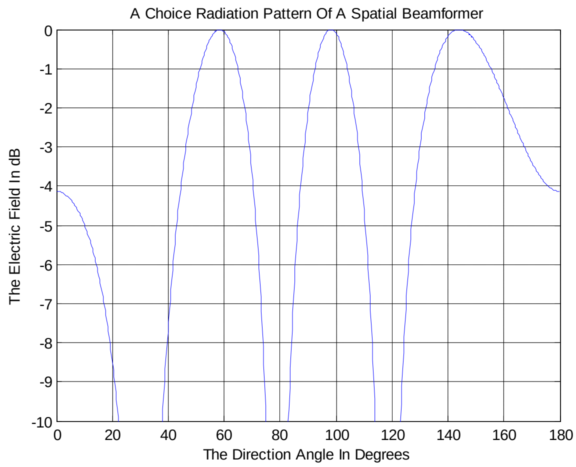

Fig 6. Null steering beamformer pattern at 30º phase angle for SNR=10.

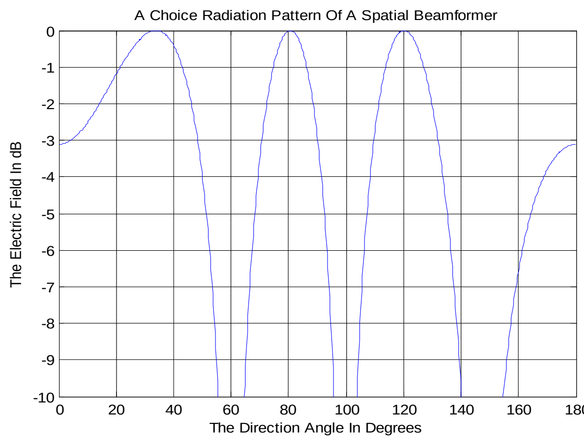

Fig 7. Null steering beamformer pattern at 60º phase angle for SNR=10.

Similarly for SNR=100 with same phase angles is shown in Fig 8, 9, 10

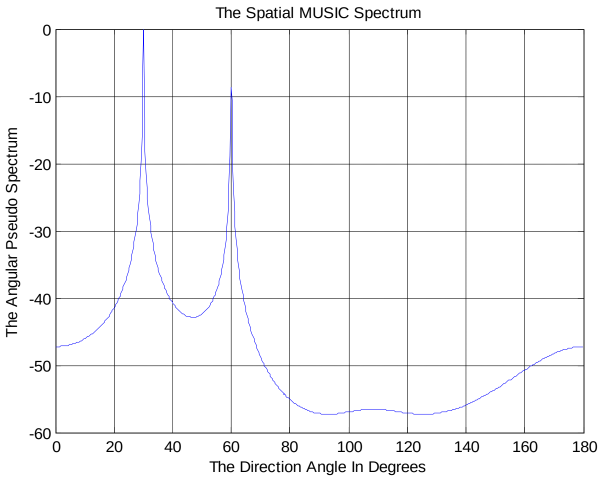

Fig 8. Pseudo spectrum for SNR=100.

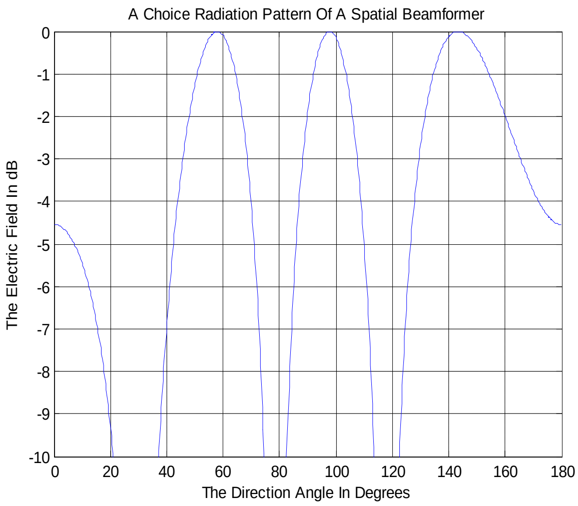

Fig 9. Null steering beamformer pattern at 30º phase angle for SNR=100.

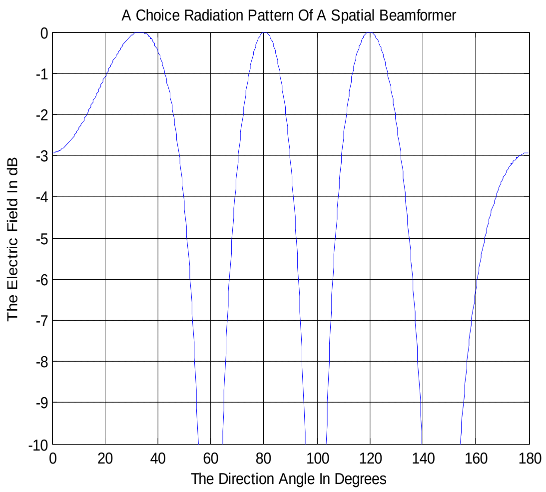

Fig 10. Null steering beamformer pattern at 60º phase angle for SNR=100.

Fig 10. Null steering beamformer pattern at 60º phase angle for SNR=100.

From the above discussion it is observed that, as the SNR increases the pseudo spectrum peak converges.

For testing, an authentication code of 10 bit is sent and those bits are regenerated back at that particular direction of arrival of desired users. And the choice output digital data and valid output digital data for SNR= 10 and SNR=100 are shown in fig 11, 12 and fig 13, 14 respectively.

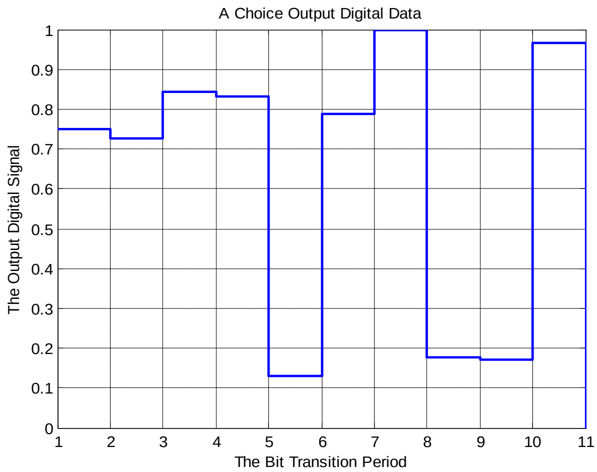

Fig 11. The choice output data at 30º phase angle for SNR=10.

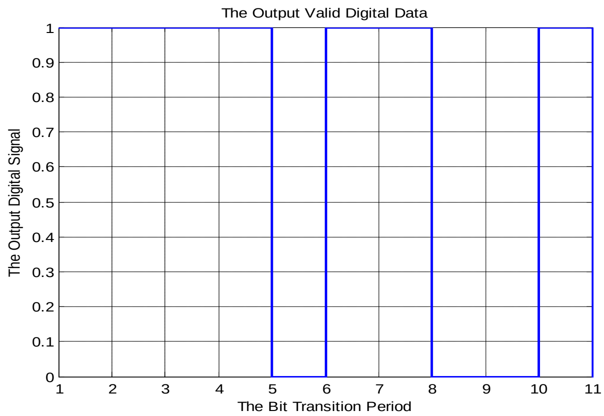

Fig 12. The valid output data at 30º phase angle for SNR=10.

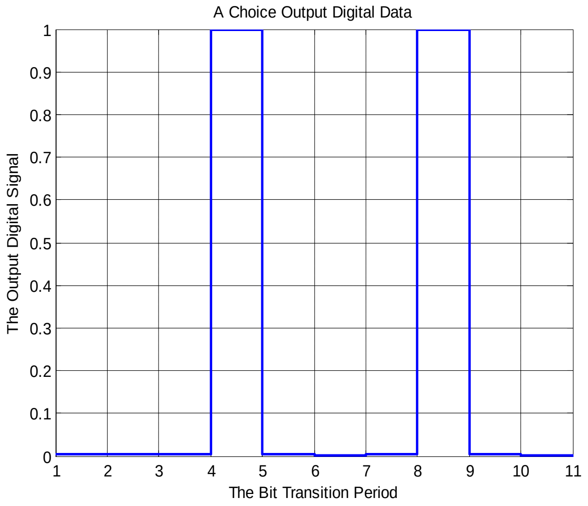

Fig 13. The choice output data at 30º phase angle for SNR=100

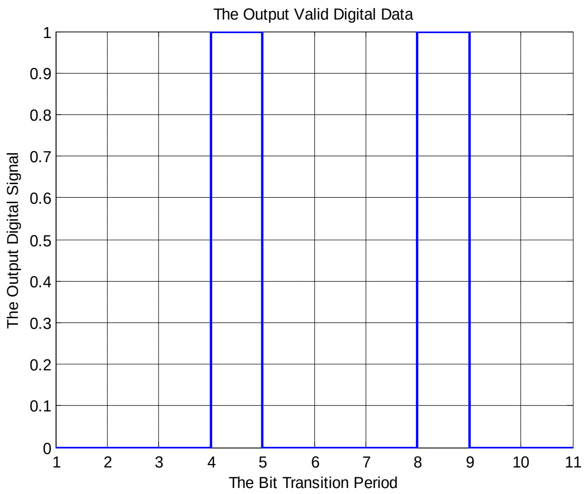

Fig 14. The valid output data at 30º phase angle for SNR=100.

As SNR increases, the choiced output digital data equals the valid output digital data.

6. CONCLUSIONS

The presented study reveals that the result of DoA estimation using MUSIC algorithm have greater resolution and accuracy. The simulation results reveal that their performance improves with high SNR. These improvements are seen in the form of the sharper peaks. Clearly, this shows that MUSIC algorithm provides high resolution and adds new possibility of user separation and can be widely used in the design of Smart Antenna systems

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