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EIGHT ELEMENT ADAPTIVE ARRAY SMART ANTENNA

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Abstract— The sectorized antennas or switched beam smart antennas have less interference rejection capability due to scalloping. To circumvent this problem adaptive array smart antennas are very suitable. These adaptive array smart antennas involve the array processing to manipulate the signal induced on various antenna elements in such way that the main lobe of an antenna directs towards the desired signal and nulls in the direction of interference. In these smart antennas to locate desired signal, MUSIC algorithm is used as it is highly accurate, stable and provides high angular resolution. Further typical beam forming algorithm used is RLS algorithm as it is faster in its convergence. With use of MUSIC and RLS algorithms eight element adaptive array smart antennas add new possibility of accurate user separation which can improve the capacity of wireless communication system such as 3G cellular system.

Keywords- Smart antennas, Adaptive array, MUSIC algorithm, RLS algorithm

I. INTRODUCTION

3G cellular networks are designed to provide high bit rate services, multimedia traffic in addition to voice calls. 3G technology utilizes W-CDMA as radio access technology which provides digitally efficient spectrum utilization and variable user data rates. The dedicated pilot is presented in the structure of uplink W-CDMA frame of IMT-2000 physical channels and this dedicated pilot supports the use of adaptive array smart antenna.

Adaptive array smart antenna is one of the smart antennas which consists of array of multiple antenna elements. This smart antenna estimates the angle of arrival of the desired signal and essentially puts its main beam in the direction of desired signal and nulls in the direction of interference.

II. ADAPTIVE ARRAY SMART ANTENNA

As stated earlier it is an array of multiple antenna elements which estimates the AOA (Angle of Arrival) of the desired signal using algorithms such as MUSIC (Multiple Signal Classification). The estimated AOA is used for beam forming in which the received signal of each antenna element is weighted and combined to maximize the desired signal to interference plus noise power ratio which essentially puts a main beam of an antenna in the direction of desired signal and nulls in the direction of interference. The weights of each element of an array may be changed adaptively and used to provide optimal beam forming in the sense that it reduces MSE (Mean Square Error) between desired signal and actual signal output of an array. Typical algorithms used for this beam forming is RLS algorithm. That is adaptive array smart antenna utilizes sophisticated signal processing algorithms to continuously distinguish between desired signals and

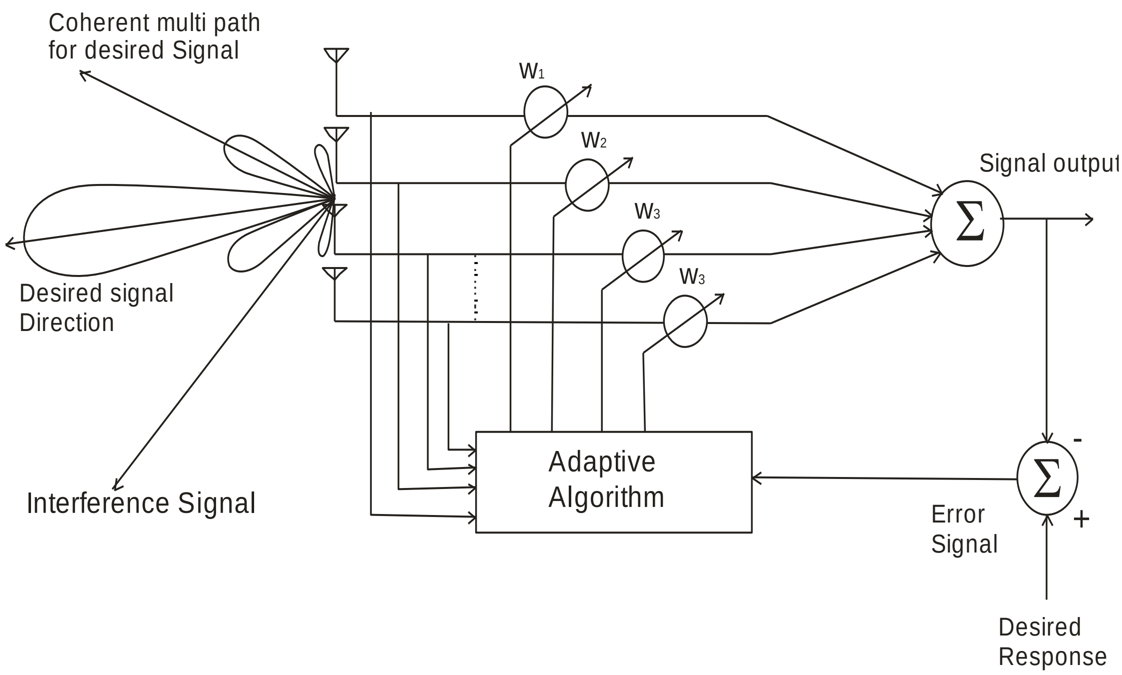

Figure 1 Adaptive array smart antenna

multipath and interfering signals as well as calculates their directions of arrival and tracks the moving users smoothly with main lobes in the direction of desired user and the nulls along the direction of interferers. That is beam pattern of an adaptive array changes as the desired user and the interference move. As shown in Figure 1, this smart antenna generates narrower beams. It creates less interference to neighboring users than switched beam approach. Adaptive array smart antennas provide interference rejection and spatial filtering capability which has the effect of improving capacity of wireless communication system.

A. ADAPTIVE SIGNAL PROCESSOR

The input signals induced in each antenna element of the antenna array $x_1(k), x_2(k), x_3(k), \ldots\ldots\ldots x_N(k),$ are the signals that are applied to the multiplying weights $w_{1,} w_{2,} w_{3,} \ldots\ldots\ldots w_N$. The array output signal is,

$$y(k) = \sum_{i=1}^{N} x_i(k) w_i \tag{1}$$

Using vector notation, the array output is given as,

$$Y(k) = W^T X(k) \tag{2}$$

where W^T is the transpose of the weight vector *W*,

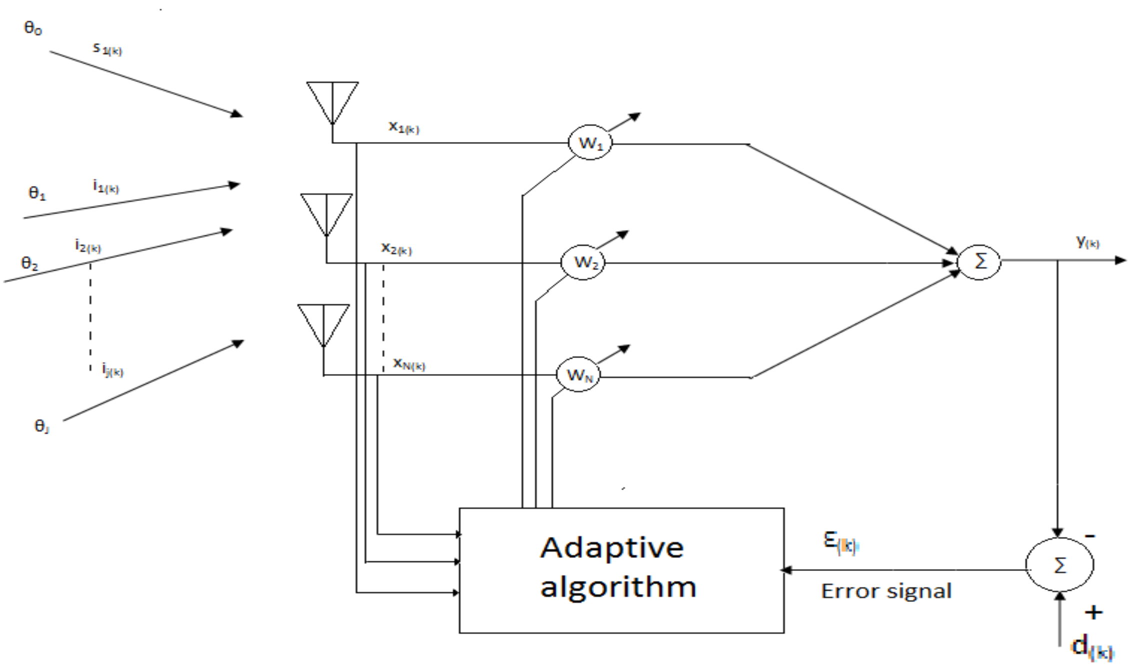

Figure 2 Adaptive signal processor.

$$W = \begin{bmatrix} w_1 \\ w_2 \\ w_3 \\ : \\ w_N \end{bmatrix}$$

And the antenna array input signal vector is given as,

$$X(k) = \begin{bmatrix} x_1(k) \\ x_2(k) \\ x_3(k) \\ : \\ x_N(k) \end{bmatrix}$$

As shown in Figure 2, in order that adaption takes place, a desired response signal *d(k)* when continuous or sampled must be supplied to the adaptive element. The difference between the desired response and the output response forms the error signal as,

$$\varepsilon(k) = d(k) - W^T X(k) \qquad (3)$$

where k is the k^{th} sampling instant

The signal $\varepsilon(k)$ is used as the control signal for the weight adjustment circuits. The purpose of weight changing process is to find a set of weights that will permit the output response of adaptive element at each instant of time to be equal to or as close as possible to desired response. For each input signal vector $X(k)$, the error $\varepsilon(k)$ would be made as small as possible. Finally we can have,

$$W_{opt} = R_{xx}^{-1} r_{xd} \tag{4}$$

Where,

$$R_{xx} = E[XX^T] = E\begin{bmatrix} x_1x_1, x_1x_2, \ldots\ldots x_1x_N \\ x_2x_1, x_2x_2, \ldots\ldots x_2x_N \\ : \\ x_Nx_1, x_Nx_2, \ldots\ldots x_Nx_N \end{bmatrix} \tag{5}$$

= Array correlation matrix.

Array correlation matrix is the matrix of cross-correlation and auto-correlation of input signals to the adaptive array elements.

And r_{xd} is the signal correlation vector and is given by,

$$r_{xd} = E[Xd\ ] = E\begin{bmatrix} x_1d \\ x_2d \\ : \\ x_Nd \end{bmatrix} \tag{6}$$

The optimum weight vector W_{opt} is the one that gives the least mean square error. The equ.(4) is the Wiener equation and is the equation for multichannel least square filter used in the processing of digital array data.

III. ADAPTIVE BEAMFORMING ALGROTHMS

A . Recursive Least Square (RLS) Algorithm

Since signal sources can change with time, we want to de-emphasis the earliest data samples and emphasis the most recent ones and this can be accomplished by modifying the array correlation matrix and correlation vector equations used in such way that we forget the earliest time samples. Thus the array correlation matrix,

$$R_{xx}(k) = \sum_{i=1}^{k} \alpha^{k-i} X(i) X^H(i) \tag{7}$$

and signal correlation vector is given as,

$$r_{xd}(k) = \sum_{i=1}^{k} \alpha^{k-i} d*(i) X^H(i) \tag{8}$$

where α is the forgetting factor and it is positive constant such that

$$0 \le \alpha \le 1$$

The recursive equations allow for easy updates of inverse of the co-relation matrix. The RLS algorithm also converges much more quickly than the LMS algorithm.

B. DOA Estimation MUSIC Algorithms for Adaptive Array Smart Antennas

The purpose of DOA (Direction of Arrival) estimation is to use the data received by the array to estimate the direction of arrival of the signal. MUSIC is one of the DOA algorithms. It is high resolution technique based on exploiting the eigenstructure of array input covariance matrix. MUSIC makes assumption that the noise in each channel is uncorrelated making correlation matrix diagonal. The incident signals are somewhat correlated creating non diagonal signal correlation matrix.This array correlation matrix has N eigenvalues $\lambda_1, \lambda_2, \ldots \lambda_N$ along N associated eigenvectors V. If the eigenvalues are sorted from smallest to largest we can divide the matrix V into two subspaces such that $V=[V_{no}\ V_s]$. The first subspace V_{no} is noise subspace associated with smallest eigenvalues and second subspace V_s is signal subspace associated with largest eigenvalues of R_{xx}. Here array correlation matrix R_{xx} has D eigenvectors associated with D signals and $N - D$ eigenvectors associated with the noise. We can then construct the $N \times (N-D)$ subspace spanned by the noise eigenvectors such that,

$$V_{no} = [v_1, v_2, v_3 ----v_{N-D}] \qquad (9)$$

The noise subspace eigenvectors are orthogonal to array steering vectors at the angles of arrivals $\theta_1, \theta_2, \theta_3, \ldots \theta_D$ and the MUSIC Pseudospectrum is given as,

$$P_{MUSIC(\theta)} = 1/abs(a_i^H V_{no} V_{no}^H a_i) \qquad (10)$$

IV. DEVELOPMENT OF EIGHT ELEMENT ADAPTIVE ARRAY SMART ANTENNA

. The macrocell base stations require maximum number of eight elements in its array. Hence eight element adaptive array smart antenna is developed using MUSIC and RLS algorithms

A. Simulation results of MUSIC algorithm for eight element linear adaptive array

For simulation of MUSIC algorithm equ(10), MATLAB is used and the array used is eight element linear array with, (i.e. N=8).

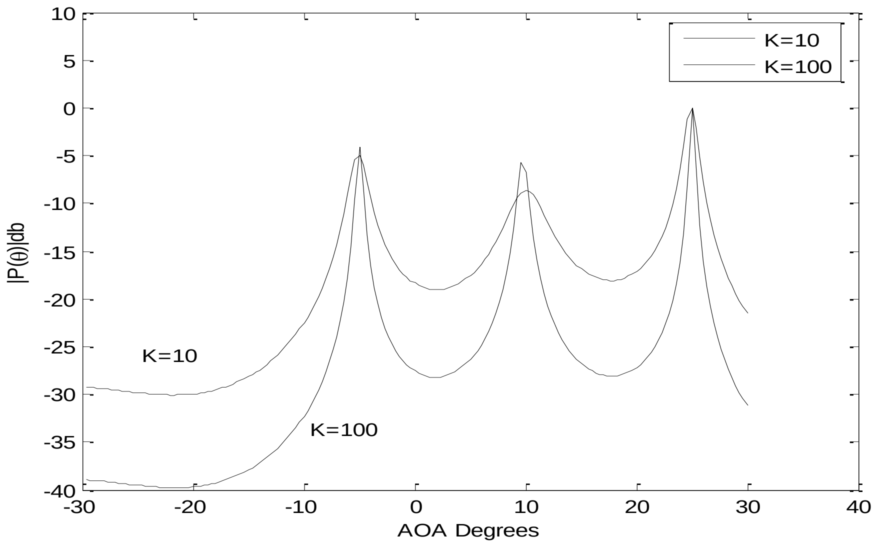

Figure 3 MUSIC Spectrum for N = 8 and DOA = -5^0, 10^{0}and 25^0.

* Spacing between array elements d =0.5λ
* DOAs of desired signals : -5^0, 10^0 and 25^0.

Figure 3 shows the MUSIC spectrum of eight element adaptive array smart antenna obtained for snapshots equal to 10 and 100 and direction of arrivals of desired signals are -5^0, 10^0 and 25^0. Increased snap shots leads to sharper MUSIC spectrum peaks indicating more accurate detection of desired signals and better resolution.

B. Simulation results of RLS algorithm for eight element linear array

For simulation of RLS algorithm eight element linear array is used with;

* Spacing between array elements d = 0.5λ
* DOA of desired signal = 25^0
* DOA of Interfering Signals = - 45^0 and +45^0.

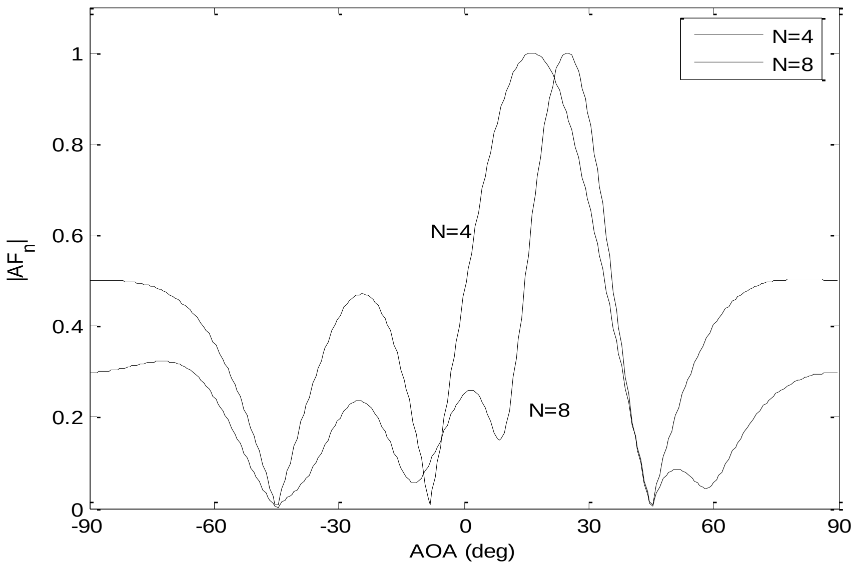

Figure 4 Adaptive beam forming using RLS algorithm

Table 1 Weights obtained by RLS algorithm for eight element adaptive array

w_1	0.9975-0.0707i
w_2	0.1263+1.0937i
w_3	-1.0818+ 0.4495i
w_4	-1.0863-0.7004i
w_5	0.8311-1.2168i
w_6	0.6919+0.4618i
w_7	-0.5959+1.2168i
w_8	-0.9304+0.4994i

Figure 4 shows the eight element adaptive array smart antenna with MUSIC and RLS algorithm which puts the main beam in the DOA of 25^o of desired signal and nulls in the direction of interfering signals at - 45^o and 45^o i.e. this array accepts the signal at 25^o and rejects the signals at $\pm$ 45^o and thus improves the SINR of the wireless system. Figure 4 also shows that as the number of elements in the array are increased from four to eight DOA detection and beam forming in the desired direction becomes more accurate and highly stable.

V. CONCLUSIONS

In Eight element adaptive array smart antenna with MUSIC and RLS algorithm the side lobe level is reduced to insignificant magnitude. Further the adaptive array smart antennas with MUSIC DOA estimation algorithm and RLS beam forming algorithm rejects the interfering signal completely. When such Eight element adaptive array smart antenna is employed in 3G CDMA wireless cellular mobile system it may improve the system capacity significantly.

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