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Analysis and Comparison of Adaptive Beamforming Algorithms for Smart Antenna

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Abstract—Smart Antenna systems is one of the emerging technology for future wireless communication technology. Smart antenna uses one of its functions that is beamforming for directional signal transmission and reception. Now-a-days there is an increasing demand on RADAR, satellite communication, mobile communication and broadcasting. Beamforming performs an important role in all these applications. Electronic scanning of lobe and placing the nulls in any directions is possible, changing the phase and amplitude of existing currents in each antenna elements. Smart Antenna is nothing but an adaptive array antenna which uses beamforming to adopt the antenna pattern dynamically .In this paper the performance analysis of LMS and NLMS algorithms is presented in terms of beam pattern and mean square error .for this purpose different cases of direction of arrival and signals are used .Smart antenna incorporates these adaptive algorithms in coded form which adjusts complex weights according to input signal environment.

Index Terms—**Beamforming, Beam pattern, Mean Square Error, Direction of Arrival.**

I. INTRODUCTION

The technology of smart or adaptive antennas for mobile communications has received enormous interest worldwide in recent years. The principle reason for introducing smart antennas is the possibility of a large increase in capacity and other advantages include increased range and potential for new services .There is enormous increase in traffic due to increased number of users and introduction of high bit rate data services.One of the most promising technique to overcome these problems is to use smart or adaptive antennas .Smart antennas dynamically adapts to the changing traffic requirements. Smart antennas are the antenna arrays with smart signal processing algorithms to identify spatial signal signature such as Direction of Arrival of the signal and use it to calculate beamforming vectors to track and locate antenna beam on the mobile targets .It is an antenna system that can modify its beam pattern by means of internal feedback control while it is operating.

In this paper main focus is given on beamforming concept. Different direction of arrivals are provided. Based upon that current amplitudes are adjusted by a set of complex weights using adaptive beamforming. A smart antenna contains several antenna elements whose signal is processed adaptively in order to exploit spatial domain of the mobile radio channel. Generally they are co-located with the base station and their smart system combines an antenna array with a digital signal processing capability to transmit and receive in an adaptive spatially sensitive manner .It can automatically change directionality of their radiation pattern in response to signal environment.

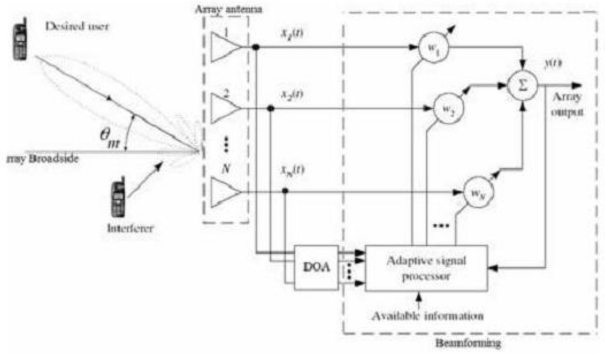

Fig 1. Functional Block Diagram of Smart Antenna System

A smart antenna system at the base station of a cellular mobile system is depicted in Fig 1. It consists of a uniform linear antenna array for which the current amplitudes are adjusted by a set of complex weights using an adaptive beamforming algorithm. The adaptive beamforming algorithm optimizes the array output beam pattern such that maximum radiated power is produced in the directions of desired mobile users and deep nulls are generated in the directions of undesired signals representing co-channel interference from mobile users in adjacent cells. In this paper adaptive beamforming is employed because it controls radiation pattern by minimizing mean square error and maximizing signal to noise ratio and minimizing variance [1]

II. ADAPTIVE BEAMFORMING

Adaptive beamforming is a technique in which array of an antenna is exploited to achieve maximum reception in a specified direction by estimating the signal direction [2] .It not only direct the beam in desired direction but also introduces nulls at interfering directions.Adaptive arrays are able to update their weights to the changing signal conditions.Thus the weights are computed according to the characteristics of the received signal ,which are periodically sampled.The ability to self update is extremely desirable in many applications where the signals change such as in a mobile communication system,radar target tracking etc.In beamforming each user's signal is multiplied by complex weight that adjust the magnitude and phase of the signal to and from each antenna.Adaptive beamforming is used to describe the application of weight to the inputs of an array of antennas to focus the reception of an antenna array in a certain direction called the main lobe.More importantly signals of the same carrier frequency from other directions are rejected.It achieves directional signal transmission and reception.

It is the process of altering the complex weight on-the-fly to maximize the quality of the communication channel. Fig.3 [4] shows a generic adaptive beamforming system which requires a reference signal.

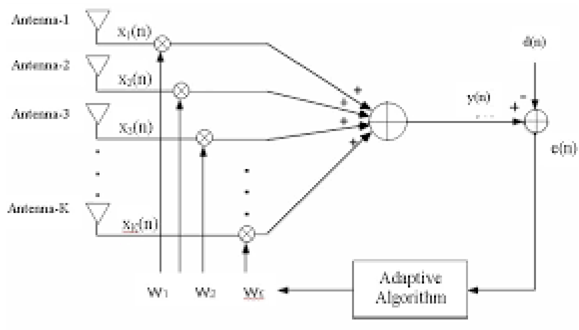

Fig.2.Block Diagram of Adaptive Beamforming

The signal x(n) received by multiple antenna elements is multiplied with the coefficients in a weight vector ‘w’ which adjust the phase and amplitude of the incoming signal accordingly. This weighted signal is summed up, resulting in the array output, y(n). An adaptive algorithm is then employed to minimize the error e(n) between a desired signal d(n) and the array output y(n).The complex weights wk for the antenna elements are carefully chosen to give the desired peaks and nulls in the radiation pattern of the array. The weights could then be slowly varied to steer the beam until maximum signal strength occurs and the direction to the signal source is found [3]

Adaptive beam forming can be accomplished using beamforming algorithms. It has profound effect on the performance of a smart antenna system. The adaptive algorithm gives smart antenna system its intelligence. Without an adaptive algorithm two original signals can no longer be extracted. The adaptive beamforming algorithm depends on its performance and convergence rate .In this paper we deal with non blind adaptive beamforming algorithms are analysed comparatively on the basis of beam pattern and mean square error .The criteria for choosing the adaptive beamforming algorithm depends on its performance and convergence rate .In this paper we deal with LMS and NLMS and both algorithms are analysed on the basis of beam pattern and mean square error.

III. LEAST MEAN SQUARE (LMS) ALGORITHM

It is a non blind adaptive algorithm which need training sequence .LMS algorithm is introduced by Widrow and Hoff in 1959 which uses gradient based method of steepest descent. LMS uses the estimate of the gradient vector from the available data .It incorporates an iterative procedure that makes successive corrections to the weight vector in the direction of negative of the gradient vector which leads to minimum mean square error. Compared to other algorithms LMS algorithm is relatively simple; it does not require correlation function calculation nor does it require matrix inversions.

$$x(t) = s(t)a(\theta_0) + \sum_{i=1}^{N_u} u_i(t)a(\theta_i) + n(t) \quad (1)$$

Consider a Uniform Linear Array (ULA) with N isotropic elements, which forms the integral part of the adaptive beamforming system as shown in the figure 4 [2] below. The output of the antenna array is given by, s(t) denotes the desired signal arriving at angle θo and ui(t) denotes interfering signals arriving at angle of incidences θi respectively. a(θo) and a(θ i) represents the steering vectors for the desired signal and interfering signals respectively.

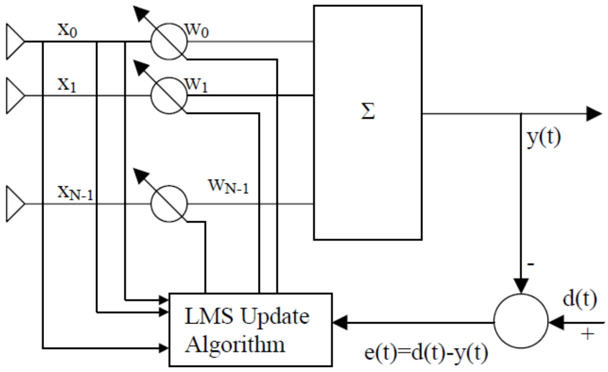

Fig.3 LMS Adaptive Beamforming Network

Therefore it is required to construct the desired signal from the received signal amid the interfering signal and additional noise n(t) [4].As shown above the outputs of the individual sensors are linearly combined after being scaled using corresponding weights such that the antenna array pattern is optimized to have maximum possible gain in the direction of the desired signal and nulls in the direction of the interferers. The weights here will be computed using LMS algorithm based on Minimum Squared Error (MSE) criterion. Therefore the spatial filtering problem involves estimation of signal from the received signal (i.e. the array output) by minimizing the error between the reference signal , which closely matches or has some extent of correlation with the desired signal estimate and the beam former output y(t) (equal to wx(t)). This is a classical Weiner filtering problem for which the solution can be iteratively found using the LMS algorithm [2].

From the method of steepest descent, the weight vector equation is given by,

$$w(n + 1) = w(n) + 1/2\, [\nabla(E\{e^{2}(n)\})] \quad (2)$$

Where μ is the step-size parameter and controls the convergence characteristics of the LMS algorithm;

$e^2(n)$ is mean square error between the beam former output y(n) and the reference signal which is given by,

$$e^2(n) = [d^*(n) - w^h x(n)]^2 \quad (3)$$

The gradient vector in the above weight update equation can be computed as,

$$\nabla w\,(E\{e^2(n)\}) = -2r + 2Rw(n) \quad (4)$$

This method of steepest descent algorithm involves computational complexity in the calculation of r and R matrices.LMS algorithm simplifies it with the instantaneous values of covariance matrices r and R instead of actual vales. These values are given by the equations,

$$R(n) = x(n)\, x^h(n) \quad (5)$$

$$r(n) = d^*(n)\, x(n) \quad (6)$$

so, weight update equation is given by,

$$w(n+1)= w(n) + \mu\, x(n)[d^*(n)-x^h(n)\, w(n)] \quad (7)$$

since ,$e^*(n)= d^*(n)-x^h(n)\, w(n)$

Therefore,

$$w(n+1)= w(n) + \mu\, x(n)\, e^*(n) \quad (8)$$

LMS algorithm is initiated with an arbitrary value w(0) for weight vector at n=0.Successive corrections of weight vector gives minimum mean square error. It can be summarized as follows,

Output $y(n)= w^h x(n)$

Error $e(n)= d^*(n)-y(n)$

Weight, $w(n+1)=w(n) +u\, x(n)\, e^*(n)$

The weight vector is seen to converge and remains stable at,

$$0 < \mu < 1/\lambda max$$

Where λmax is the largest eigenvalue of the correlation matrix *R*.If μ is chosen to be very small then the algorithm converges very slowly. A large value of μ may lead to a faster convergence but may be less stable around the minimum value .Convergence of algorithm is inversely proportional to the eigenvalue spread of correlation matrix R and these are widespread values but with slow convergence. Ratio of largest eigenvalue estimates the eigenvalue spread of matrix R.If μ is small then slow convergence speed and it is large given fast convergence but less stable for minimum value.

IV. NORMALIZED LEAST MEAN SQUARE (NLMS) ALGORITHM

The drawback of LMS algorithm is that it is sensitive to scaling of its input x(n).So, it is difficult to choose the step size μ.It guarantees algorithm stability. NLMS algorithm is an extension of LMS algorithm which resolves this problem by normalizing the power of input. NLMS algorithm developed by Haykin in 2002.It is used for wide ranges of step sizes.

NLMS algorithm is superior than LMS algorithm if we consider convergence parameters .It is formulated as modification in LMS algorithm. NLMS algorithm is implemented in MATLAB. The step size parameter is selected based on current input values. Its practical implementation is very similar to that of LMS algorithm. For Each iteration following steps can be carried out,

I) Output of adaptive filter is calculated.

$$y(n) = \sum_{i=0}^{N-1} w(n)x(n-i) = \mathbf{w}^T(n)\mathbf{x}(n)$$

II) An error signal is calculated as the difference between the desired signal and the filter output

$$e(n)= d(n) - y(n)$$

III) Step size value for input vector is given by,

$$\mu(n) = \frac{1}{x^T(n)\, x(n)}$$

IV) The filter tap weights are updated in preparation for next iteration.

$$w(n+1) = w(n) + \mu(n)\, x(n)e^*(n)$$

In LMS algorithm the adaptation of weight vector at iteration n+1 is the product of estimation error ,tap input vector x(n) and step size parameter μ..This adaptation depends upon the tap input vector x(n).When x(n) is greater, LMS filter suffers from gradient noise amplification. To cope up with this problem we use NLMS algorithm .The weight vector update equation is normalized by the squared Euclidean norm of the input vector x(n) at iteration n .LMS differs from NLMS only in terms of weight updating mechanism. In NLMS coefficient updating equation is normalized by factor which is equal to the product of input vector x(n) and its transpose.

$$w(n+1)= w(n) + \frac{\mu\, x(n)\, e^*(n)}{x^h(n)\, x(n)} \quad (9)$$

Some modifications done to the LMS algorithm results in NLMS algorithm. The gradient noise amplification problem can be solved by normalized product vector at each iteration n+1 with square of Euclidean norm of the input vector x(n) at iteration n. The final weight vector is given by ,

$$w(n+1)=w(n) + \frac{\mu}{a + \|x(n)^2\|}\, x(n)\, e^*(n) \quad (10)$$

Where NLMS algorithm reduces step size μ to make the changes in the update weight vector. This avoids divergence of weight vectors make algorithm more stable and increases convergence for fixed step size .In NLMS algorithm ,step size is divided by the norm of the input signal to avoid gradient noise amplification due to x(n).That is calculated gradient estimate is divided by sum of the squared elements

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of data vector [5] .This algorithm proves to be advantageous for two reasons :

1. Increases convergence speed and
2. Improves stability for known range of parameter values.

Computational complexity is also less as it requires minimum mathematical operations.

V. SIMULATION RESULTS

The two algorithms are implemented and simulation results are observed. This is nothing but the performance analysis of these algorithms i.e. LMS and NLMS. The simulation results are carried out for different cases of multiple paths and multiple signals and the behavior of these algorithms under these conditions is analyzed. The user can input the various parameters such as number of array elements, distance between the array elements with number of input samples, signal to noise ratio (SNR) and interference to noise ratio (INR).

The two algorithms are compared on the basis of radiation pattern and mean square error (MSE).Radiation pattern decides the directivity i.e maximum gain in the direction of desired user .It is nothing but the efficiency in transmission and reception. The mean square error decides the convergence performance of the respective algorithm.

I] Radiation Pattern for LMS and NLMS Algorithms
Rectangular plots are given, which are plotted (-180^0 00 180)
DOA1 $=60^0$, DOA 2 $=30^0$,DOA 3= 330^0
Number of Samples =600
Number of Array Elements N = 8
Element Spacing d =0.3 λ

Case 1: 1 Signal 1 Direction of Arrival(DOA)

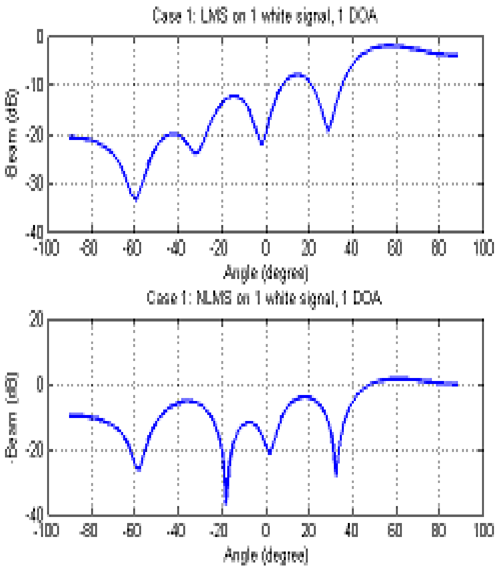

Fig 4. Radiation Pattern for Case 1

Case 2 : 1 Signal 3 Direction of Arrivals

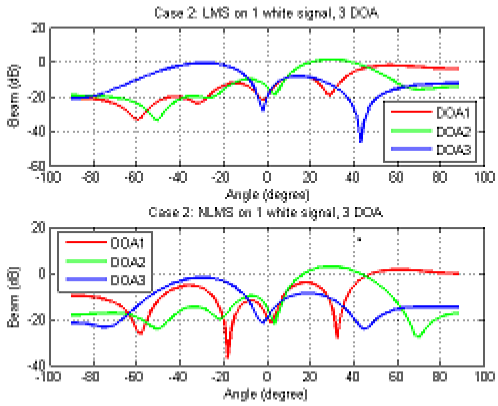

Fig 5. Radiation Pattern for Case 2

Case 3: 2 Signals and 1 Direction of Arrival

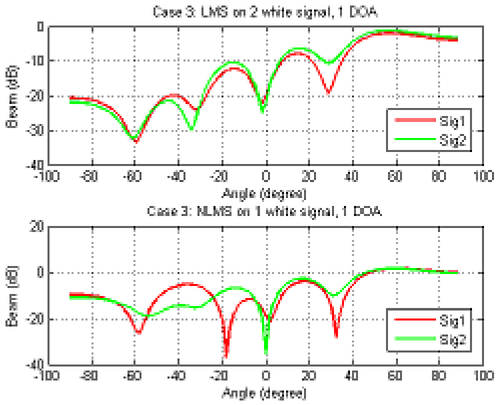

Fig 6 . Radiation Pattern for Case 3

Case 4: 2 Signals and 3 Direction of Arrivals

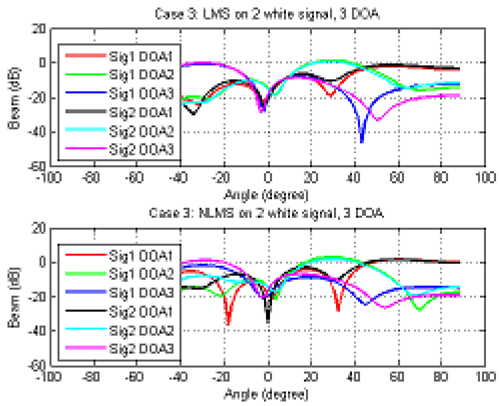

Fig.7 Radiation Pattern for Case 4

The above graphs shows radiation pattern for the users arriving at different angle of arrivals. For LMS algorithm it shows signal strength maximum about 0 dB and for NLMS it is better than maximum. Also the abilty to reject interference and other side lobes is maximum in NLMS algorithm than LMS algorithm. More deep nulls are observed for LMS algorithm than LMS algorithm. NLMS algorithm shows better signal strength as compared to LMS .LMS and NLMS algorithms both sows maximum signal power in the direction of given direction of arrivals.

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II) Plots of Mean Square Error (MSE) for LMS and NLMS
Number of Samples = 600
Number of Antenna Elements N=8
Element Spacing d= 0.3 λ

Case 1: 1 Signal 1 Direction of Arrival

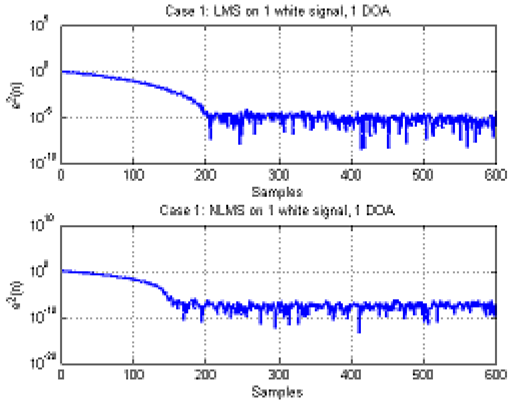

Fig.8 Mean Square Error for Case 1

Case 2 : 1 Signal 3 Direction of Arrivals

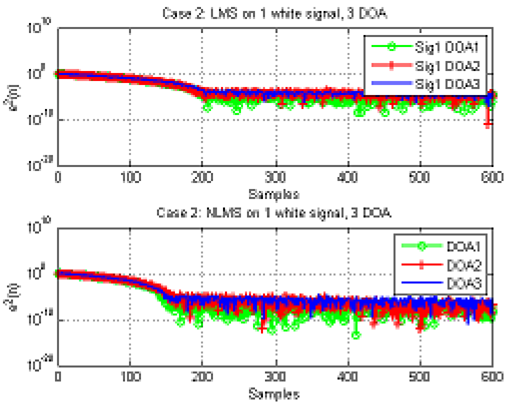

Fig.9 Mean Square Error (MSE) for Case 2

Case 3: 2 Signals and 1 Direction of Arrival

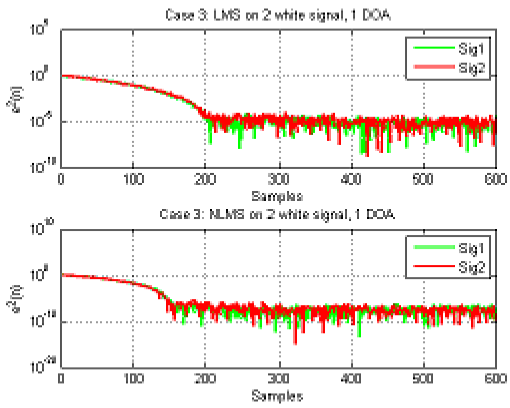

Fig.11 Mean Square Error for Case 3

Case 4: 2 Signals and 3 Direction of Arrivals

Here, first white signal 1 is considered and then white signal 2 is considered.

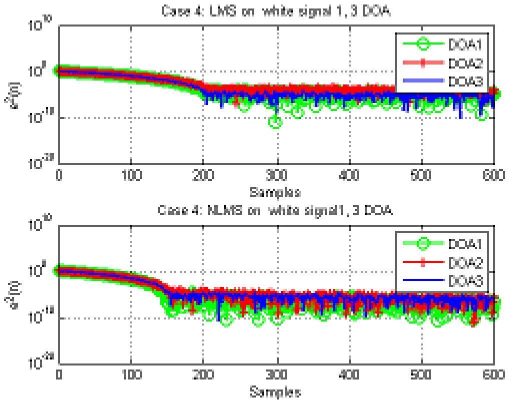

Fig .11 Mean Square Error for Case 4 (Signal 1)

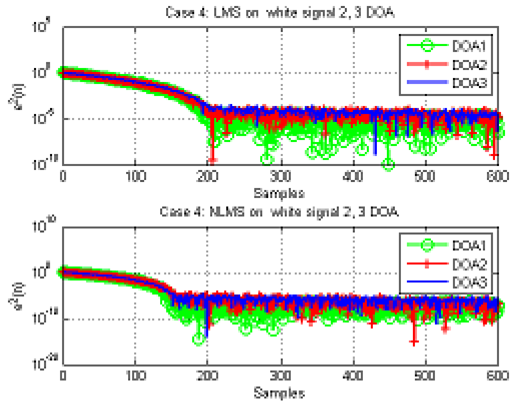

Fig.12.Mean Square Error for Case 4(Signal 2)

The mean square error for various algorithms is shown in above graphs. From the graphs is clear that the error amplitude decreases as we are moving from LMS to NLMS algorithm. It also shows that convergence starts for LMS approximately after 200th sample, where as for NLMS algorithm it is approximately after 150th sample. Hence, NLMS has better convergence than LMS algorithm.

VI. CONCLUSION

In this paper, LMS and NLMS beamforming algorithms are compared on the basis of radiation pattern and mean square error (MSE).As far as radiation pattern is concerned ,NLMS algorithm shows better signal strength as compared to MS algorithm .The ability of NLMS algorithm to steer the beam in desired direction and placing nulls in unwanted direction is good than LMS algorithm. NLMS algorithm shows minimum mean square error (MSE) value as compared to LMS algorithm and it is observed for reduced number of samples. Thus, NLMS converges faster than LMS algorithm. However, LMS algorithm is simple in terms of computational complexity but still NLMS algorithm proves to be superior than LMS in performance point of view.

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VII. FUTURE SCOPE

Adaptive beam forming algorithms improves the directivity of antenna. In future, these beamforming algorithms can be implemented for Cognitive Radio Architecture and results can be analyzed .Also these algorithms can be implemented for real time applications such as echo cancellation, anti jamming etc. Further, simulation results can be tested for different channels such as Racian channel, Rayleigh Channel.

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