PERFORMANCE BASED COMPARISON OF ADAPTIVE BEAMFORMING ALGORITHMS FOR SMART ANTENNA

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ABSTRACT

Smart Antennas are the most prominent technologies used in the field of wireless communication. They are most widely used to improve the performance of wireless communication system by increasing coverage area ,system capacity and Quality of Service. Smart antenna describes multiple antennas which increases directivity of antennas by ensuring directional signal transmission and reception .Adaptive beamforming technique of smart antenna described in this paper is used to provide maximum signal strength in the direction of desired user and zeroing or nulling the interference. Using various adaptive beamforming algorithms such as LMS, NLMS and BBNLMS maximum possible directivity is achieved. These techniques are compared on the basis of beam pattern in terms of signal strength and MSE .The results are analyzed for multiple DOAs and multiple signals.

Keywords: Adaptive Beamforming, Direction of Arrival (DOA), LMS, NLMS ,BBNLMS.

I. INTRODUCTION

There is significant research and development on smart antennas for wireless systems all over the world. Because smart antennas keeps potential to enhance the performance of future generation wireless systems and they are deployed in many systems. Smart antenna technology have a significant effect on many important parameters in the wireless communication system. Bandwidth, interference rejection, bit rates, reliability and power economy are the areas where benefits must be achieved .Much work have been carried out in the field of smart antenna since 1950's introducing various adaptive beamforming algorithms. In this paper main focus is given on adaptive beamforming concept and related algorithms .Different criterion are used by these algorithms for better system performance and to direct the beam in a signal of interest. Many non blind and blind adaptive algorithms are implemented .These algorithms are analysed for different parameters such as mean square error, beam pattern, signal to noise ratio, signal to interference ratio ,steady state error etc.

This paper investigates non blind algorithms such as LMS, NLMS and BBNLMS. These algorithms are implemented in MATLAB and analysed for parameters such as beam pattern and mean square error. The convergence performance of all three algorithms is decided by the value of mean square error. Also magnitude and phase deviation for these algorithms is plotted. The smart antenna incorporates these algorithms in coded form which calculates complex weights according to the signal environment. LMS algorithm is very simple and has very low computational complexity and most commonly used algorithm .BBNLMS and NLMS algorithms are implemented in order to improve convergence rate. BBNLMS algorithm shows better convergence performance as compared to LMS and NLMS algorithms. Magnitude deviation plotted describes the deviation of actual signal amplitude from the desired value and phase deviation is deviation of the actual angle from desired angle for all the three algorithms .

II. SMART ANTENNA

2.1 Introduction

Smart antennas implies the multiple antenna elements with smart signal processing algorithms which are exploited to get maximum directivity. Two basic types of smart antennas comprises of phased array or multi beam antennas and adaptive array antennas . Phased array antenna consists of either a number of fixed beams with one beam turned on towards the desired signal and the adaptive antenna array is a multiple antenna element array in which the received signals are weighted as well as they are combined to maximize the desired signal to interference and noise power ratio. This results a main beam in the direction of the desired signal and generation of nulls in the direction of the interference.

A smart antenna is hence called as a phased or adaptive array antenna as it adjusts to the environment. It mean that for the adaptive array antenna, the beam pattern change depends on the movement of desired user and the interferer; and in the phased array antenna as the desired user moves the beam is selected or different beams are selected. Smart antenna using direction of arrival estimation find outs the angle of desired user and then it employs beamforming technique to direct the signal in desired user direction and rejects the interferer signal. Direction of arrival estimation finds peaks of the spatial spectrum and estimates desired user angle. Beamforming is generally an adaptive signal processing technique which is used to direct the beam in a particular direction with no mechanical steering the antenna element. The main aim of the beamforming technique is to increase the directivity in terms of transmission and reception .

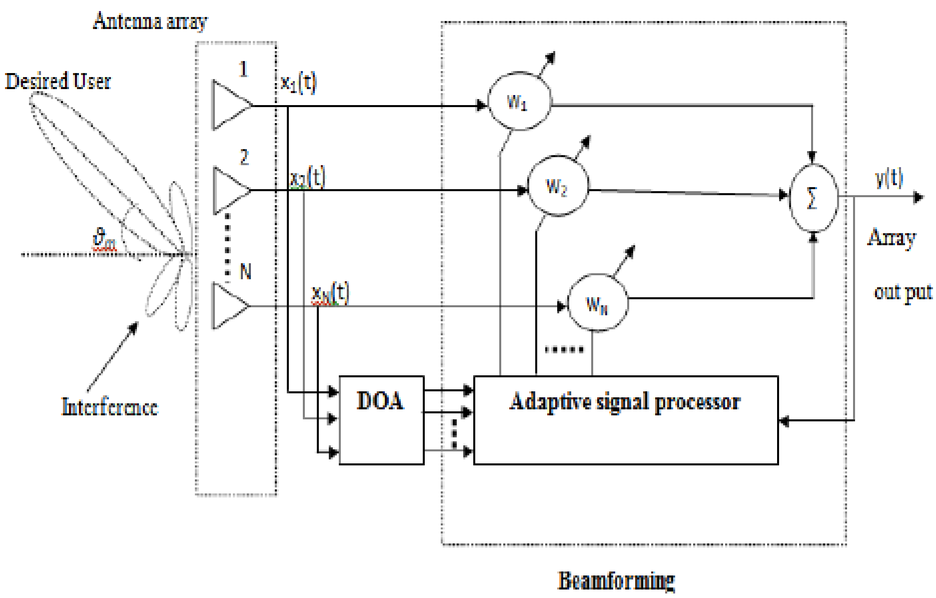

Fig.1 Block Diagram of Smart Antenna System

A smart antenna system situated the base station of a cellular mobile system is described in Figure 1[5]. It consists of a uniform linear array of antenna . The current amplitudes are adjusted by a set of complex weights using an adaptive beam forming algorithm. It optimizes the array output beam pattern in such a way that maximum power is radiated in the directions of desired users with generation of deep nulls in the directions of an undesired signals which represents the co-channel interference from mobile users in the adjacent cells. Before performing adaptive beamforming, the directions of users and also interferes must be obtained using a direction-of- arrival (DOA) estimation algorithm. By using the data received on the downlink which is at the base-station sensor array

the direction of arrival(DOA) estimation algorithm finds the directions of the signals from the desired mobile users and from the directions of interference signals.

2.2 Adaptive Beamforming

Beamforming is implies each user's signal is multiplied of a complex weight to each user's signal which adjusts not only magnitude but also the phase of the signal to and from each antenna. The phases and amplitudes are adjusted to optimize The received signal is optimized by adjusting the magnitude and phase. This results in the output of the arrays of antenna can transmit or receive in a particular direction and it minimizes the output in unwanted direction [4]

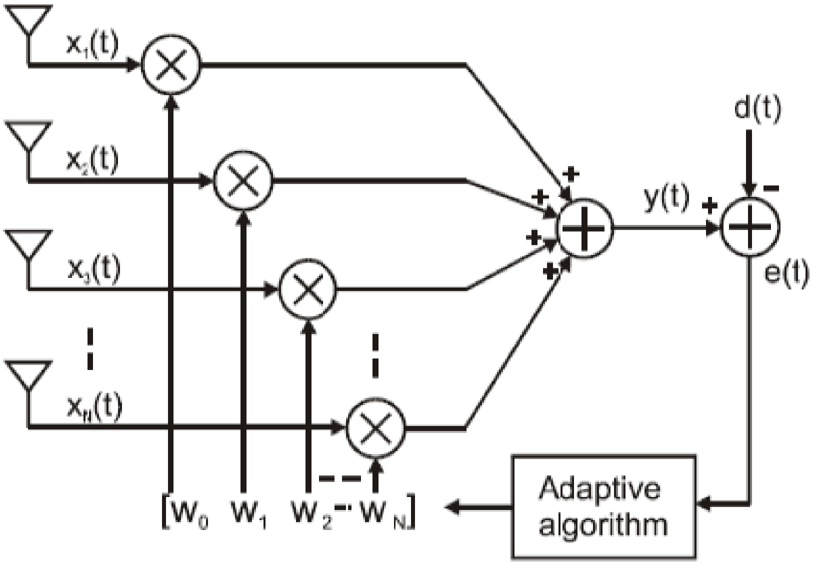

Fig.2 Block Diagram of Adaptive Beamforming

A generic adaptive beam former is shown in fig.2[4]. The weight vector *w* is calculated using the statistics of signal x(t) arriving from the antenna array. An adaptive processor will minimize the error *e* between a desired signal d(t) and the array output y(t). The computational power of many systems is limited and should be managed wisely[4]. Adaptive beamforming is a technique which uses an array of antennas in order to achieve maximum reception in the direction of desired user while signals having same frequency from the other directions are reject which is achieved by the variation of the weights of the each of antenna used in the array. Multiple antennas have great ability to enhance the capacity and also the performance without using an additional power or spectrum.

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In a smart antenna system with (Ne) elements equally spaced (d) and user's signal arrives from desired angle Φ_o. Adaptive beamforming scheme which is used to control weights adaptively optimizes signal to noise ratio (SNR) of the desired signal into the look direction Φ_o.

The array factor is given by,

$$AF(\Phi_o) = \sum_{n=0}^{N-1} A_n . e^{(jn(\frac{2\pi d}{\lambda}\cos\Phi+\alpha))} \qquad (1)$$

Where ,inter element phase shift α is given by,

$$\alpha = \frac{-2\pi d}{\lambda_o}\cos\Phi_o$$

III. ADAPTIVE BEAMFORMING ALGORITHMS

Adaptive beamforming computes the optimum weights are iteratively by using complex algorithms depending upon different criteria. The criteria for choosing the adaptive beamforming algorithm is based on it's performance as well as convergence rate. Adaptive beamforming algorithm is categorized as Non blind adaptive algorithms and blind adaptive algorithms. Non blind adaptive algorithms requires the statistical knowledge of transmitted signal to converge to an optimum weight solution. A pilot training sequence is sent over the channel to receiver which helps to identify the desired user . No training sequence is used for blind algorithm hence called as blind algorithm, hence the term 'blind'. They restores some characteristic of the transmitted signal to separate it from the other users present in the surrounding environment. In this paper the concentration is given on non blind LMS,NLMS and BBNLMS algorithms.

3.1 Least Mean Square (LMS) Algorithm

The Least Mean Square (LMS) algorithm is introduced by Widrow and Hoff in 1959.It is an adaptive algorithm which uses a gradient-based method of steepest decent LMS algorithm makes use of the estimates of the gradient vector from the available data. LMS algorithm also incorporates an iterative procedure which makes successive corrections to the weight vector and it is in the direction of the negative of the gradient vector that eventually leads to the minimum mean square error.

Uniform Linear Array of Antenna is used with N number of antenna elements having equal spacing d between the elements,the output of antenna array is given by,

$$x(t) = s(t)a(\theta_o) + \sum_{i=1}^{N_u} u_i(t)a(\theta_i) + n(t) \qquad (3)$$

s(t) denotes the desired signal arriving at angle θo and $u_i(t)$ denotes interfering signals arriving at angle of incidences θi respectively. a(θo) and a(θi) represents the steering vectors for the desired signal and interfering signals respectively. Therefore it is required to construct the desired signal from the received signal and the interfering signal and additional noise n(t) [5]

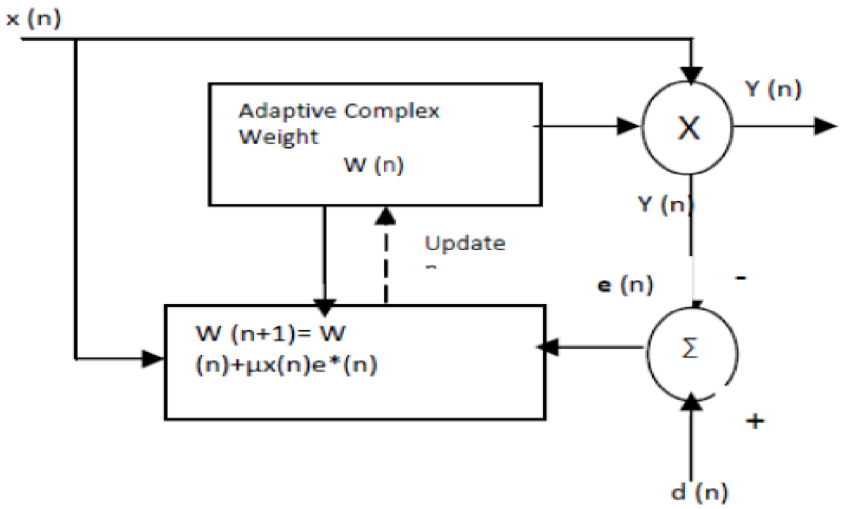

Fig.3 Block Diagram of LMS algorithm

LMS beam former configuration is shown in fig.2[2].By using the method of steepest descent the equation for weight vector is given by,

$$w(n+1) = w(n) + 1/2\ \mu[-\nabla(E\{e\ 2\ (n)\})] \quad (4)$$

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

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

$$e^2(n) = [d^*(n)- w^h x(n)]^2 \quad (5)$$

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

$$\nabla w\ (E\{e^2(n)\}) = -\ 2r + 2Rw(n) \quad (6)$$

$$\text{Output signal, } y(n) = w^h x(n) \quad (7)$$

$$\text{Error, } e(n) = d^*(n) - y(n) \quad (8)$$

Weight vector equation is given by,

$$w(n+1) = w(n) + \mu x(n)e^*(n) \quad (9)$$

In the method of steepest descent the main problem is the computation which is involved in finding the values r and R matrices in real time condition .However, the LMS algorithm simplifies this by using the instantaneous values of covariance matrices *r* and *R* instead of using their actual values i.e.

$$R(n) = x(n)\ x^h(n) \quad (11)$$

$$r(n) = d^*(n)\ x(n) \quad (12)$$

Hence ,equation for updating weights is given by,

from (11) and (12)

$$w(n+1) = w(n) + \mu x(n)[d^*(n) - x^H(n)w(n)\ ] \quad (13)$$

$$w(n+1) = w(n) + \mu x(n)e^*(n) \quad (14)$$

The LMS algorithm is initiated with an arbitrary value *w*(0) for the given weight vector at *n*=0.Finally,the successive corrections of the weight vector eventually leads to the minimum value of the mean squared error,

3.2 Normalized Least Mean Square (NLMS) Algorithm

It is an extension provided to the LMS algorithm. The adjustment of weight vector is directly proportional to the step size μ(n). Therefore, when value of u(n) is large, the LMS algorithm suffers from the problem of gradient noise amplification . To mitigate this difficulty, normalized LMS algorithm. In particular, the adjustment which is applied to the weight vector at iteration n+1 is normalized with respect to the squared Euclidean norm of μ(n) at iteration and hence it is called as normalized .It shows more stability than LMS algorithm as step size is chosen based on the current input values It is employed in following three steps ,

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) Error signal is given as the difference between desired signal and filter output

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

iii) Step size is calculated in normalized form as,

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

iv) Filter weights are adjusted by using following equation

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

hence,

$$w(n+1)= w(n) + \frac{\mu(n)}{p + \| x(n)^2\|}\, x(n)\, e^*(n) \qquad (15)$$

LMS algorithm have variable step size which indicates better convergence.

3.3 Block Based Normalized Least Mean Square (BBNLMS) Algorithm

More better convergence than LMS and NLMS algorithm is achieved by using BBNLMS algorithm .BBNLMS shows less computational complexity than NLMS algorithm. NLMS shows complexity in the calculation of step size .But BBNLMS algorithm calculates step size μ by partitioning input data into a number of blocks. It then computes maximum magnitude of data in each block .Maximum magnitude of data in each block decides step size μ. It gives low steady state error value. The equation for BBNLMS algorithm is given by,

$$w(n+1)= w(n) + \frac{\mu}{xm * xm}\, x(n)e^*(n) \qquad (16)$$

where, xm ≠ 0 ,it is a maximum of the x_m in the block and p=0 in (15)

IV. SIMULATION RESULTS AND DISCUSSION

LMS ,NLMS and BBNLMS algorithms are implemented in MATLAB .These are analysed to check their performance on the basis of beam pattern ,mean square error , magnitude deviation and Convergence comparison Beam pattern and MSE plots for multiple signals and multiple paths cases are observed.

Number of Antenna Elements N=8

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Number of Samples = 600

Element Spacing = 0.3 lambda

DOA 1= 300, DOA 2 = 600, DOA 3 = 3300

Interference Angle =900

4.1 Beam Pattern

Beam pattern is observed for multiple paths and multiple signals cases.

Case 1: 1 Signal 3 DOAs

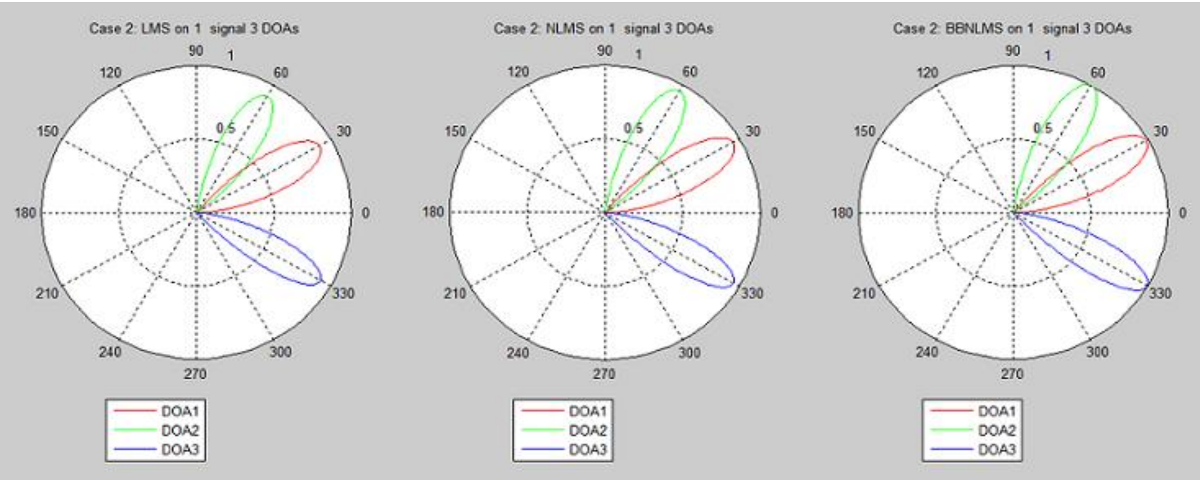

Fig.4 Beam Pattern Polar Plots of Case 1 for LMS,NLMS and BBNLMS Algorithms

The above graph shows polar plot for beam pattern in terms of field strength under the condition of 1 signal with 3 DOAs. . A gain of amplitude 0.5 is introduced as it is propagated through an antenna. BBNLMS shows maximum gain of amplitude 1 in the direction of desired user as compared to LMS and NLMS algorithms. It means , it has maximum field strength in that particular directions given. Null is produced in the direction of interference angle.

Case 2: 2 Signals 1 DOA

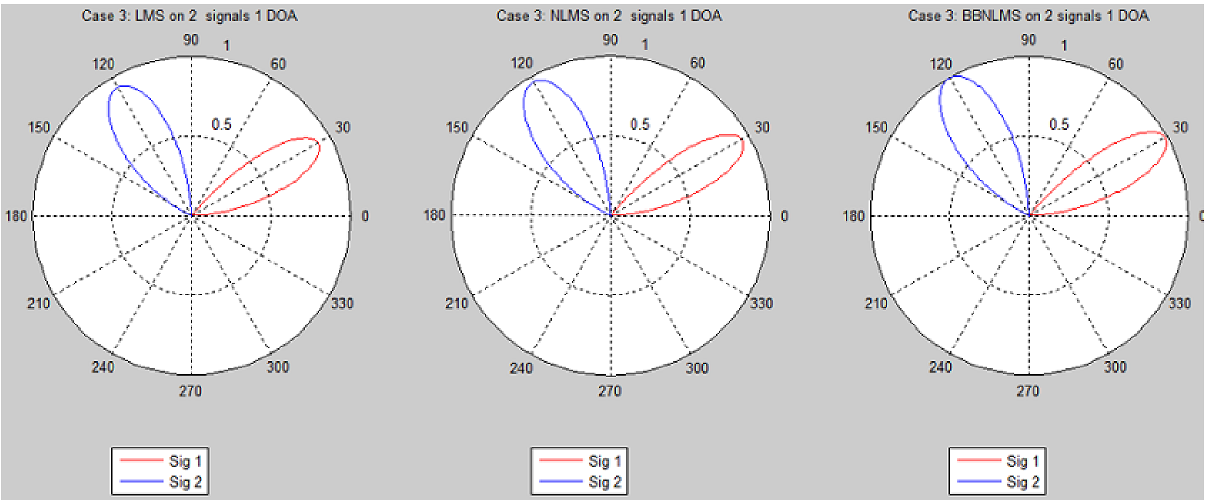

Fig.5 Beam Pattern Polar Plots of Case 2 for LMS,NLMS and BBNLMS Algorithms

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Fig.5 reveals polar plot for beam pattern for which 2 different signals are used with 1 DOA .Again ,LMS algorithm shows minimum gain than NLMS algorithm and NLMS algorithm shows minimum gain than BBNLMS algorithm. . BBNLMS has good ability to steer the beam in the desired direction. The transmission of two different signals with one DOA each is same as sending one signal with two multipath which are separated by at least one sample period. Because in both situations the two signals are uncorrelated with each other.

4.2 Mean Square Error (MSE)

Case 1: 1 Signal 3 DOAs

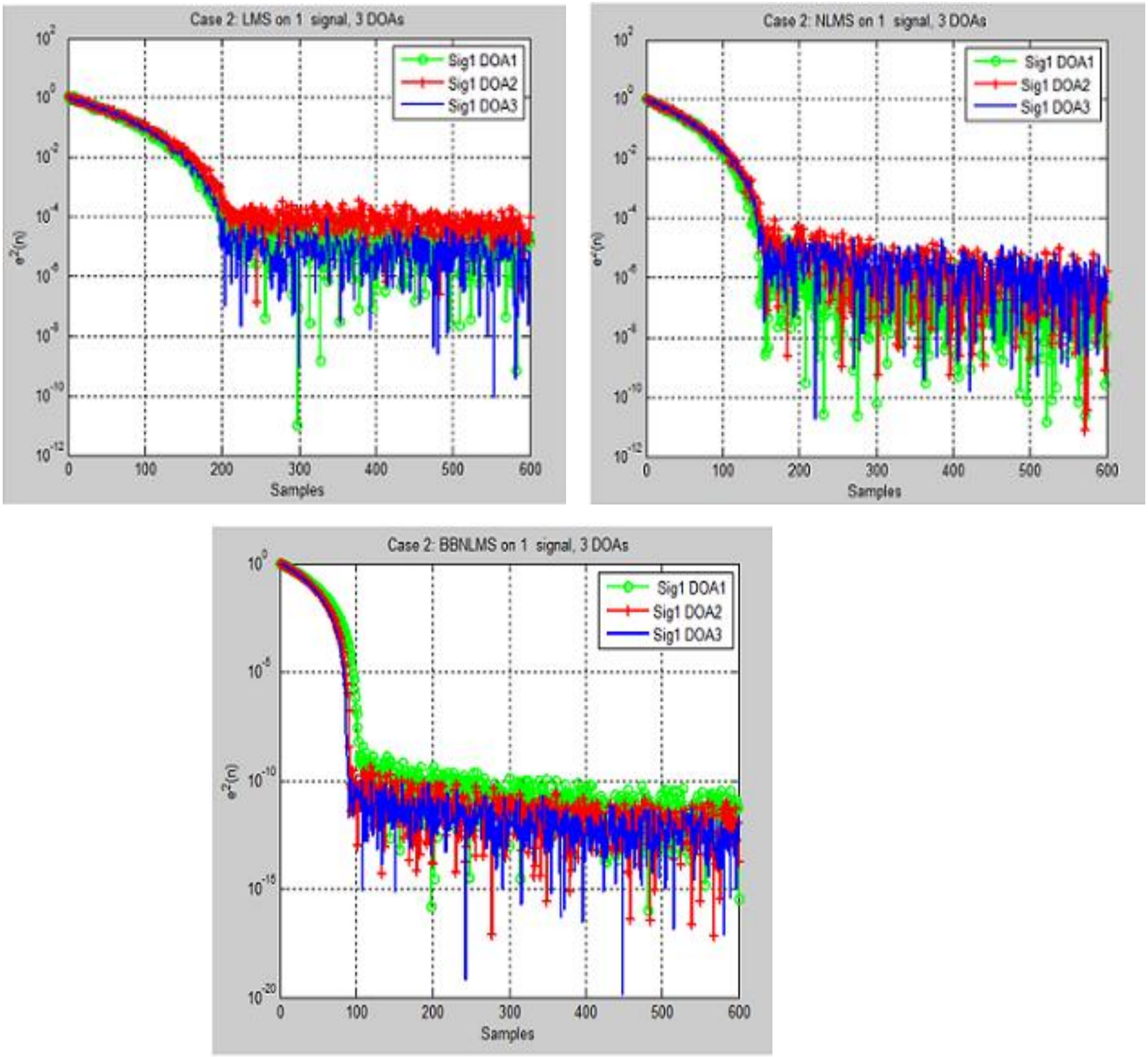

Fig.6 Mean Square Error Plot of Case 1 for LMS,NLMS and BBNLMS Algorithms

In fig.6 ,1 signal and 3 DOAs have been used. The value of Error is10^{-5}, 10^{-8} , 10^{-10} for LMS,NLMS and BBNLMS respectively. The value of error decreases from LMS to BBNLMS. Ideally, the minimum mean square error value will have better convergence. So BBNLMS shows minimum mean square error value. So,it

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have better convergence performance than LMS and NLMS. Also if we observe the samples on X axis. LMS algorithm starts its convergence after 200th sample. NLMS starts its convergence after 150th sample and BBNLMS starts its convergence after 100th sample. It means that, the number of samples are reduced with reduction in the error value on Y axis from LMS,NLMS and BBNLMS algorithms.

Case 2: 2 Signals 1 DOA

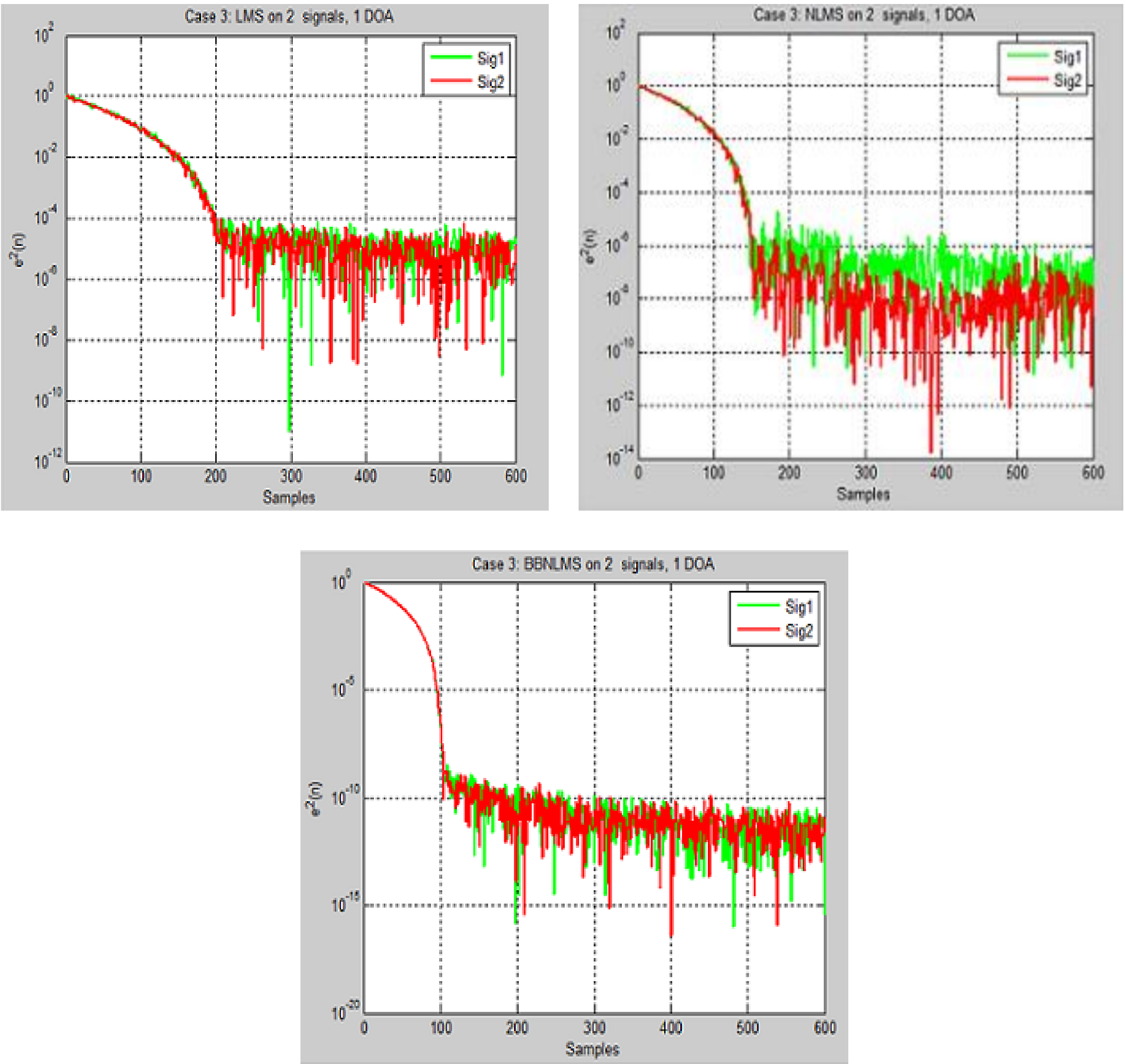

Fig.7 Mean Square Error Plot of Case 2 for LMS,NLMS and BBNLMS Algorithms

Above fig .7 shows MSE plot for 2 signals and 1 DOA .It is same as in case 1 and case 2.Again it shows improved convergence for BBNLMS algorithm as it has minimum MSE value than LMS and NLMS. Two different signals are coming through their respective DOA towards the antenna array.

4.3 Magnitude Deviation

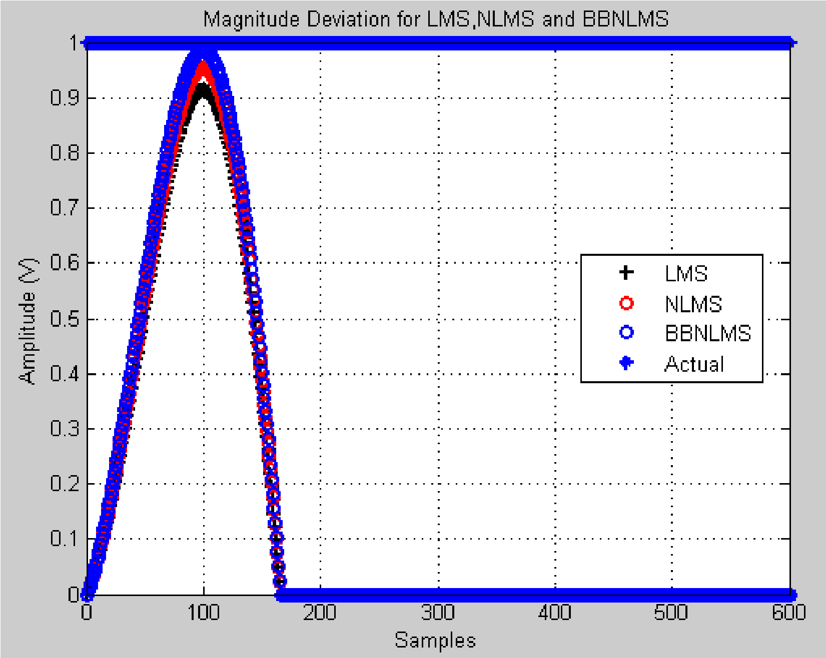

Fig 8 Plot of Magnitude deviation for LMS,NLMS and BBNLMS Algorithm

Above plot shows that magnitude deviation for BBNLMS algorithm is better than LMS and NLMS algorithm. The amplitude value for BBNLMS algorithm matches closely with actual value than for LMS and NLMS algorithm.

4.4 Convergence Comparison for LMS,NLMS and BBNLMS Algorithms

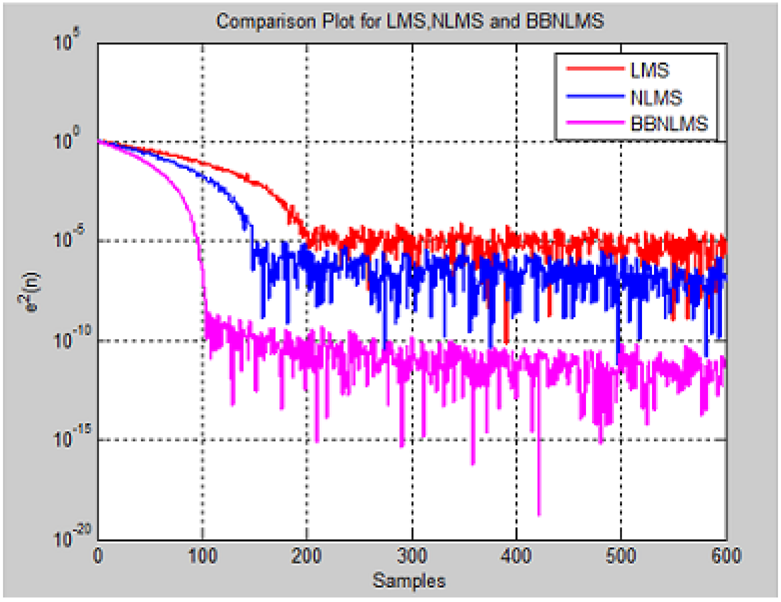

Fig.9 Plot of Convergence Comparison for LMS ,NLMS and BBNLMS Algorithms

From fig 9,it is revealed that BBNLMS shows faster convergence as compared to LMS and NLMS algorithms.NLMS sows somewhat better results than LMS on the basis of MSE value and number of samples.BBNLMS shows minimum value of MSE for least number of samples .

V.CONCLUSION

In this paper ,several Adaptive beamforming Algorithms were implemented and their simulations are carried out. LMS ,NLMS and BBNMLS algorithms are compared and analyzed on the basis of beam pattern , mean square error(MSE),magnitude deviation and convergence comparison.It is noted that, magnitude deviation for BBNLMS algorithm is better than LMS and NLMS algorithm .Convergence rate is faster for BBNLMS algorithm than LMS and NLMS algorithm. As far as radiation pattern is concerned ,BBNLMS algorithm shows better signal strength as compared to NLMS algorithm and LMS algorithm. BBNLMS algorithm shows minimum mean square error (MSE) value as compared to NLMS and LMS algorithm and it is observed for reduced number of samples. Thus, BBNLMS converges faster than NLMS and LMS algorithm and proves to be superior than NLMS and LMS.

In future same simulations can be performed for blind adaptive algorithms .It can be implemented for Rayleigh and Racian channels. Also cognitive radio architecture can be used instead of smart antenna .It can be used in applications like anti jamming and echo cancellation.

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