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Adaptive Beamforming Algorithm for Smart WiMAX Antenna

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Abstract: The estimation of high spatial resolution of the desired signal is the main problem in wireless communication (mainly in Wimax antenna application). In this paper, the smart antenna for Wimax application is analyzed by detecting the main beam towards the desired source signal (by adjusting the weighted array values) using adaptive beamforming algorithms like Least Mean Square (LMS) algorithm, Normalized Least Mean Square (NLMS) algorithm, Recursive Least square (RLS) Algorithm, Constant Modulus Algorithm (CMA) and CMA-NLMS Algorithm based on 3.5 GHz, which is a WiMAX standard frequency and it also deals with the generation of deep nulls in the direction of interference signals by using MATLAB software. The algorithm for smart Wimax antenna provides best quality of the desired signal with maximum convergence rate. Adaptive beamforming algorithms are also used to find the mean square error of the signal. Finally, the mean Square error and the desired output of the signal comparison of the entire adaptive beamforming algorithm will be done and best output of the algorithm will be chosen for the application.

Keywords: LMS, NLMS, RLS, CMA, CMA-NLMS, beamforming, Smart Antenna, Wimax.

I. INTRODUCTION

Wireless is the most important communication technology in recent trends technology. WiMAX is the next generation of wireless communication, which provides high speed rates of communication signals for long distance. The error is the main problem in communication of the signals. The detection of the exact arrival signal angle and number of signals arrival is done through MUSIC and ESPRIT algorithm, but this estimation leads to minimize the signal to noise ratio due to the more noise present and also increase the computation. The noise is eliminated by using preprocessor in ESPRIT. Hence it tends to increase in manufacturing cost [1]. The MUSIC (Multiple Signal Classification) algorithm determines the multiple array of signal elements of various terms like polarization, elements count used, signal direction. Spatial estimation is done through MUSIC, but it does not reduce the interference problems [8]. ESPRIT (Estimation of Signal Parameters via Rotational Invariant Techniques) applied to various problems like presence of noise in the signal, estimation of accurate detection. This technique also includes the problem of interference and the convergence rate [9].

In this paper, the adaptive beamforming algorithms are chosen in order to provide a better performance of ULA antenna than comparable with the MUSIC and ASPRIT algorithms..This paper contains mainly six captions. First caption contains thesis of the project. Second caption contains the explanation of smart antenna and WiMAX, and it also explains the integrated system of both smart antenna and WiMAX technique. Third caption contains the information of adaptive beamforming and their conditions to form a beam at desired angle and effects of reducing the interference noise signal. Fourth caption contain the details about the determination of beamforming output, Mean Square error, optimal weight vectors using adaptive beamforming algorithms. Fifth caption contains simulation results for the implementation of smart Wimax antenna isshown. Finally, conclusion caption deals with the summary of this paper.

II. SMART WIMAX ANTENNA

The adaptive antenna technology integrated with the WiMAX technique for more convenient wireless communications for high speed rates of the signal communication.

A. *Smart Antenna*

Smart antenna is one of the important technologies for the overall wireless communication system performance. Adaptive antenna array, which is an array of multiple antenna elements, with the weighted received signals and combines to produce maximum signal to interference and noise power ration. The adaptive antenna array forms a main beam towards the desired signal and nullifies the interference signal patterns with the advantages as, it excessively reduces the interference pattern, increases the system capacity, increase in power efficiency and reduce the construction cost of the system.

B. *WiMAX*

WiMAX (Worldwide Interoperability for Microwave Access) is an upgrading a wireless communication standard designed to provide 30 to 40 Mbps data rates. It is classified in two categories and they are, First is Fixed WiMAX provides for a fixed-line connection with the antenna within the 2-11 GHz frequency range and the other one is Mobile WiMAX allows the mobile machine to be connected to the internet within the range 2-6 GHz frequency range.

III. ADAPTIVE BEAMFORMING

Beamformingis the process of differentiating the spatial properties between signal and noise. The system which is used for beamforming is beamformer, which is mainly used in antenna. The system receives a desired source signal radiating from a specific direction and attenuate signals originating from other directions.

$$\theta = (2\pi d) * \sin \Phi / \lambda, \quad -\pi/2 \leq \theta \leq \pi/2 \qquad (1)$$

Where d is the distance between adjacent arrays, ($d<(\lambda/2)$) and λ is the wavelength of the incident wave. The adaptive beamforming can be achieved by different adaptive algorithms like LMS, NLMS, RLS, CMA, CMA_NLMS, etc. These are also called smart antenna algorithms.

IV. ADAPTIVE ALGORITHMS

Adaptive Beamforming algorithms based on the approach to adjust the weights as the incoming data is sampled and keep updating it such that it converges to an optimal solution.

A. Mathematical Model of CMA Algorithm

Constant Modulus Algorithm (CMA) exploits the constant modularity of the signalfor adapting the parameters. To construct a receiver weight vector **w** such that the output signal is

$$y_k = w^H x_k \qquad (2)$$

and the stochastic weight vector is,

$$\mathbf{w}(k+1) = \mathbf{w}(k) - \mu \mathbf{x}_k \left(|y_k|^2 - 1\right)^2 y_k \qquad (3)$$

Similar to LMS, but with update error $(|y_k|^2-1)y_k$.

B. Mathematical Model of LMS Algorithm

The LMS algorithm consists of two basic processes. First is the filtering process, which computes the output of the filter and generates the error by comparing the output with the desired inputs. Second, an Adaptive process which automatically adjust the parameters in order to estimate the error from the output. The step size is

$$0<\mu<2/(M\, S_{max}) \qquad (4)$$

where M is the number of array elements and S_{max} is the power spectral density of the signal.

The error signal (e(n)) is determined by the difference between the original signal and output of the beamformer.

$$e(n) = d(n)-w^H(n)u(n) \quad (5)$$

where d(n) is the desired signal and the tap-weight vectors are calculated for each iteration and it is mentioned as below equation.

$$w(n+1) = w(n)+\mu u(n)e^*(n) \quad (6)$$

Finally, the mean square error is estimated as

$$J(n) = E(|e(n)|^2) \quad (7)$$

C. Mathematical Model of NLMS Algorithm

The Normalized LMS is as similar as LMS Algorithm but it differs only in the process of weight controller mechanism. LMS algorithm creates gradient noise amplification problem if the tap unit vector increases. The step size (μ) is a constant for each iteration values to estimate the optimal weights is given below,

$$0<\mu<2E[|u(n)|^2]D(n)/ E[|e(n)|^2] \quad (8)$$

Where $E[|e(n)|^2]$ is the error signal power , $E[|u(n)|^2]$ is the input signal power and D(n) is the Mean Square deviation.

D. Mathematical Model of CMA-NLMS Algorithm

CMA-NLMS is the combination of both CMA and NLMS algorithm. To construct a receiver weight vector **w** such that the output signal is

$$y_k=w^H x_k \quad (9)$$

and the stochastic weight vector is,

$$0<\mu<2E[|u(n)|^2]D(n)/ E[|e(n)|^2] \quad (10)$$

$$\mathbf{w}(k+1) = \mathbf{w}(k) -\mu \mathbf{x}_k (|y_k|^2-1)^2 y_k \quad (11)$$

Similar to LMS, but with update error $(|y_k|^2-1)y_k$.

E. Mathematical Model of RLS Algorithm

An important feature of RLS algorithm is that its rate of convergence is typically an order of magnitude faster than that of the simple LMS Algorithm.

For each instant of iteration to compute,

$$\Pi(n)= P(n-1)u(n) \quad (12)$$

$$K(n)= \Pi(n)/(\lambda+u^H(n)\, \Pi(n)) \quad (13)$$

$$\Xi(n)= d(n)-w^H(n-1)u(n) \quad (14)$$

$$w(n)=w(n-1)+k(n)\, \Xi^*(n) \quad (15)$$

and

$$P(n)=\lambda^{-1}P(n-1)[1-k(n)u^H(n)] \quad (16)$$

V. Simulation Analysis

Simulation analysis for an adaptive WiMAX smart antenna is done through MATLAB software. This simulation dealt with the radiation pattern (beamforming), mean square error and desired signal output for various adaptive beamforming algorithms like CMA, LMS, NLMS, CMA-NLMS and RLS.

A. Analysis of the Results

In table I, it describes the parameter used in the simulation process in order to get the desired output from the desired input. And the parameters are number of array elements, which is used to get the input and output signal into it, WiMAX frequency value is used for WiMAX antenna application, Step size, a constant parameter is used in order to estimate the optimal weights, Desired signal angle and interference angles are used to estimate the direction of the arrival angle and the angle ofother signal should be nullified for different adaptive algorithms. Simulation result figures shown below describe the optimal output of the beamforming and convergence of the signal for adaptive algorithms.

Table I
Simulation Parameters

S.No	Parameter Used	Range				
		CMA	LMS	NLMS	CMA NLMS	RLS
1	Number of array elements	16	16	16	16	16
2	WiMAX frequency	3.5GHz	3.5GHz	3.5GHz	3.5GHz	3.5GHz
3	Step size (μ)	0.0025	0.0026	0.1273	0.1273	_
4	Desired Signal Angle	0^0	0^0	0^0	0^0	0^0
5	Interference Signal Angle (I_1)	$\pm 30^0$	$\pm 30^0$	$\pm 30^0$	$\pm 30^0$	$\pm 30^0$
6	Interference Signal Angle (I_2)	$\pm 60^0$	$\pm 60^0$	$\pm 60^0$	$\pm 60^0$	$\pm 60^0$

In table II, Uniform Linear array (ULA) / weights vector for each iteration is given. The weight vectors for various adaptive beamforming algorithms are different and it is clearly shown in the table II. The output of the desired signal is changed due to these weight vector and the step size value. And the weight value changes due step size, input signal parameters. In this table , detailed value of the weight vector for each array is shown.

Table II
ULA Values for all Algorithms

No. of ULA	CMA	LMS	NLMS	CMA-NLMS	RLS
1	1	1	1	1	1
2	0.51609+4.5579i	0.97949-0.014012i	0.98998-0.021021i	1.0048-0.037433i	0.98973-0.021198i
3	0.51609+4.5579i	0.99605-0.018392i	1.0055-0.016769i	1.0222-0.018052i	1.0054-0.016992i
4	0.51609+4.5579i	0.99151-0.015517i	1.0004-0.016576i	1.0151-0.022204i	1.0003-0.016767i
5	0.51609+4.5579i	1.0024-0.011206i	1.0072-0.0079678i	1.0168-0.0045396i	1.0072-0.0081026i
6	0.51609+4.5579i	0.98191-0.0028176i	0.98667-0.010809i	0.99132-0.026427i	0.98645-0.010849i
7	0.51609+4.5579i	0.98926-0.02762i	1.0043-0.027444i	1.03-0.033603i	1.0042-0.027781i
8	0.51609+4.5579i	1.0015-0.0098658i	1.0058-0.0073022i	1.0144-0.004822i	1.0059-0.0074211i
9	0.51609+4.5579i	0.99096-0.012294i	0.99847-0.014222i	1.0104-0.020719i	0.99836-0.014374i
10	0.51609+4.5579i	0.99276-.0064826i	0.99719-0.008666i	1.0038-0.014276i	0.9971-0.0087468i
11	0.51609+4.5579i	0.98086-0.019841i	0.99384-0.025101i	1.0136-0.039606i	0.99361-0.025347i
12	0.51609+4.5579i	1.006-0.0204i	1.0144-0.013722i	1.0317-0.006015i	1.0145-0.013966i
13	0.51609+4.5579i	0.99117-.0008432i	0.99324-0.004846i	0.99504-0.012538i	0.99313-0.0048597i
14	0.51609+4.5579i	0.9879-0.016852i	0.99813-0.019361i	1.0144-0.028017i	0.99799-0.019569i
15	0.51609+4.5579i	0.98953-0.012364i	0.99734-0.014953i	1.0095-0.022704i	0.99722-0.015106i
16	0.51609+4.5579i	0.99499-0.02368i	1.0071-0.021551i	1.0286-0.023129i	1.007-0.021839i

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B. Simulation Result

In figure 1,2,3,4 and 5, the main beam at 0^0 is the desired signal angle and deep nulls are formed at the direction of $\pm 30^0$ and $\pm 60^0$ in both axis with respect to the absolute array weight factors for each iteration. It rejects the other signals and also describes the main beam towards being the desired signal angle which has a strong arrival the signal is detected. By comparing all the figures (1 to 5), CMA has a wide beam width which results in high noise signal and other algorithms(LMS, NLMS, CMA-NLMS,RLS) has a narrow beam width which also has high gain except LMS by comparing with others.

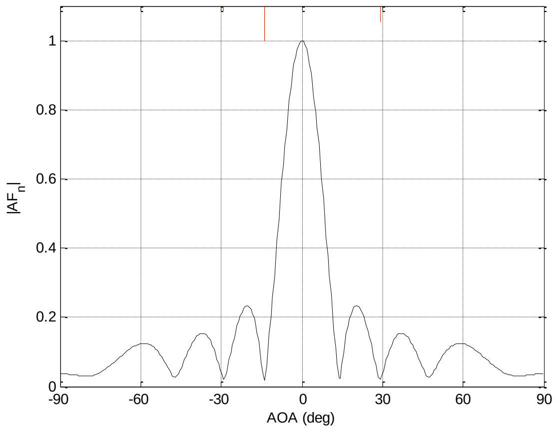

Figure 1. Main beam formation towards the source signal and deep nulls at interferences of CMA

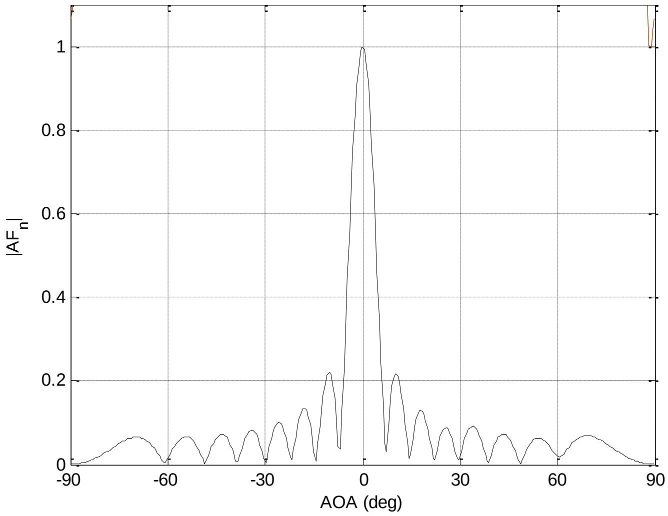

Figure 2. Main beam formation towards the source signal and deep nulls at interferences of LMS

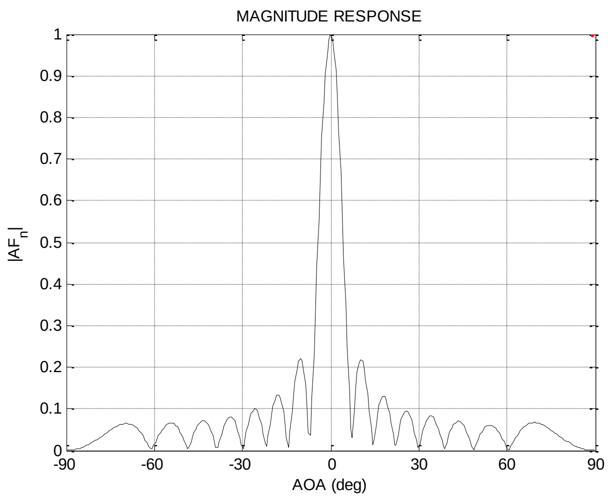

Figure 3. Main beam formation towards the source signal and deep nulls at interferences of NLMS

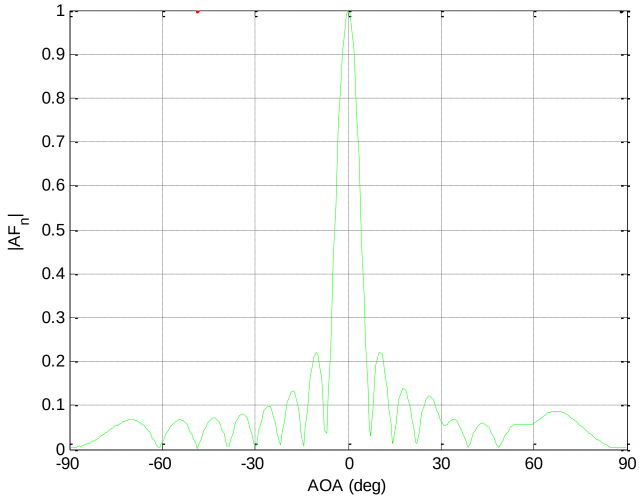

Figure 4. Main beam formation towards the source signal and deep nulls at interferences of CMA-NLMS

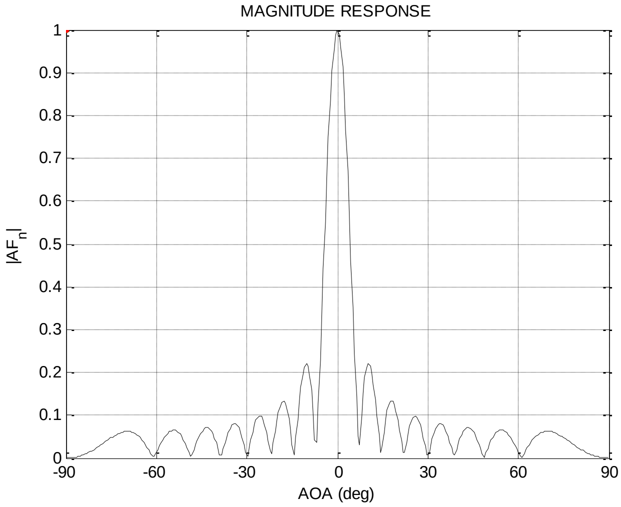

Figure 5. Main beam formation towards the source signal and deep nulls at interferences of RLS

In figure 6 to 10, the output signal with respect to the input signal is given for all adaptive algorithms like CMA, LMS, NLMS, CMA-NLMS and RLS respectively. The legends for desired signal , Array output yy and yy1 are shown for each iteration. From these figures, it is clearly seen array output signals are not exactly as the input signal (desired signal). Hence, errors are present in output signals of CMA, LMSNLMS, CMA-NLMS and RLS algorithm respectively. From these figures, desired signal output is merely same for both NLMS and RLS algorithms, but there is a slight difference in their output signal. Hence, RLS has nearly same desired signal as output signal.

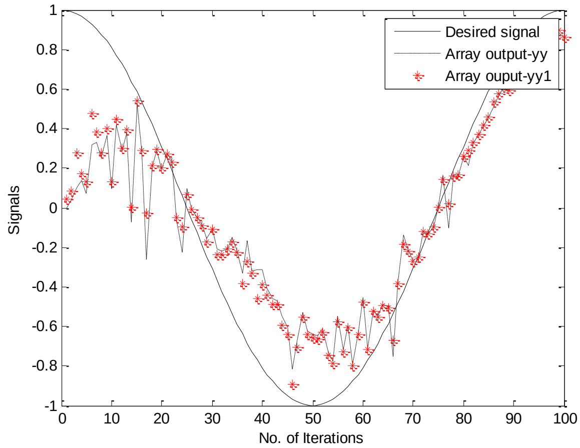

Figure 6: Desired Input and Output signal of CMA

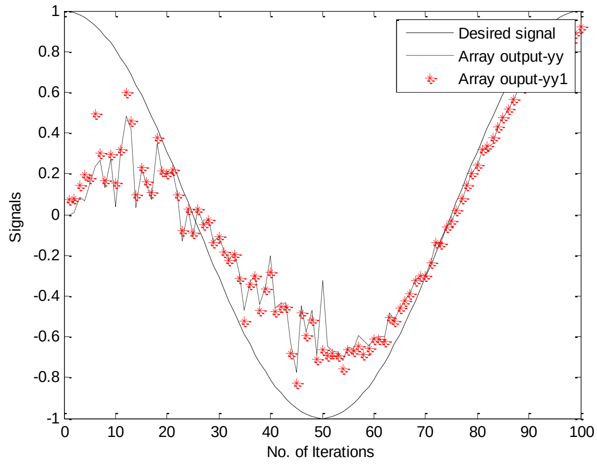

Figure 7: Desired Input and Output signal of LMS

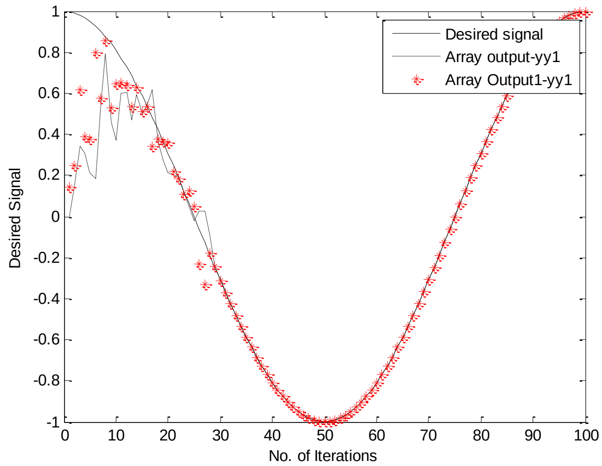

Figure 8: Desired Input and Output signal of NLMS

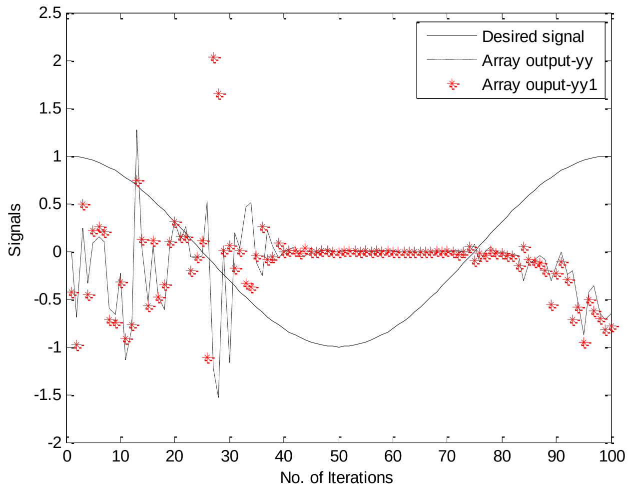

Figure 9: Desired Input and Output signal of CMA -NLMS

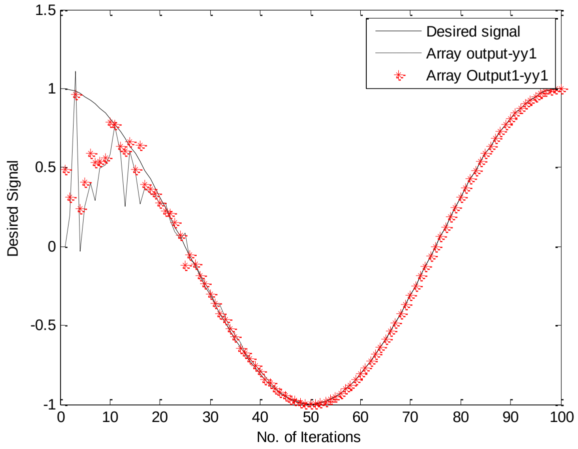

Figure 10: Desired Input and Output signal of RLS

In figure 11 to 15, the signal over the axis dealt with the mean square error, which is based on ensemble averaging of the squared estimation error $|e(n)|^2$, which is used to estimate the convergence rate of the signal for each iteration weight value. This curve is also called as mean square error learning curve, which is based on ensemble averaging of the squared estimation error and it is plotted versus iterations. It also dealt with noise produced after Smoothening the signal after the ensemble averaging. By comparing figures (11 to 15), the error is greater in CMA algorithm than others and smaller in RLS algorithm than LMS, NLMS, CMA-NLMS.

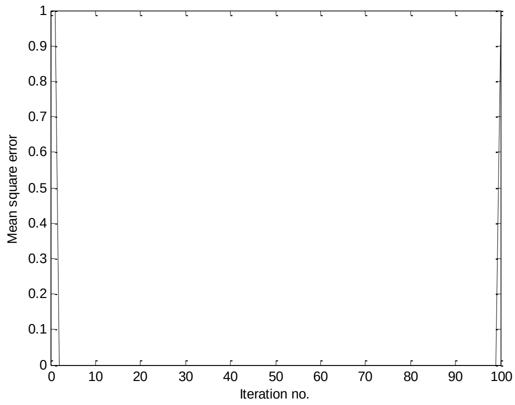

Figure 11. Mean Square Error analysis of CMA

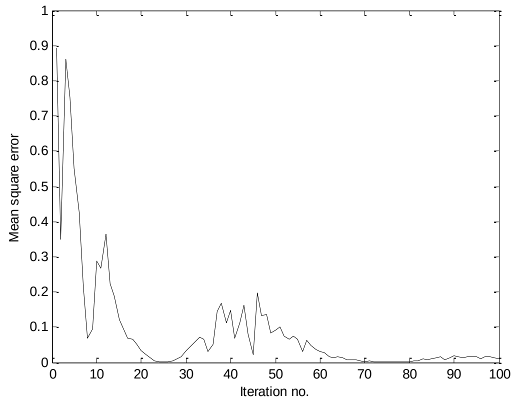

Figure 12. Mean Square Error analysis of LMS

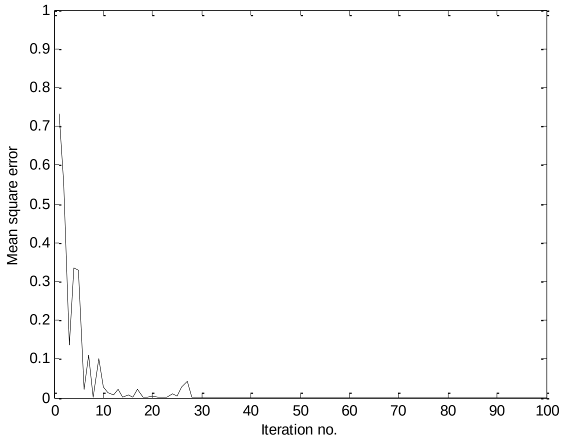

Figure 13. Mean Square Error analysis of CMA

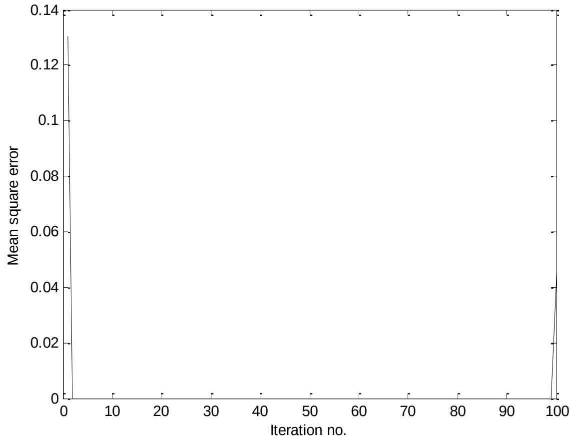

Figure 14. Mean Square Error analysis of CMA-NLMS

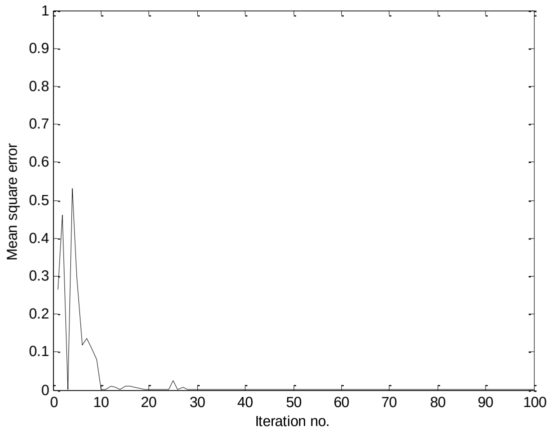

Figure 15. Mean Square Error analysis of RLS

VI. Conclusion

The adaptive beamforming for both directions of desired angle and the interference signal angle is estimated by using LMS , NLMS , RLS, CMA and CMA-NLMS algorithms and also dealt with the convergence by the estimation of mean square error for Wimax application by using all mentioned adaptive algorithms. Finally the results of all mentioned algorithms are compared since only weight vector value changes with a step size value. The error value of RLS is 0.5,NLMS is nearly 0.7 , in LMS is 0.9 , in CMA is 1 . Hence by comparing all adaptive beamforming algorithm, the error is less in RLS & CMA-NLMS algorihtm than LMS, NLMS and CMA algorihtm for WiMAX application. Eventhough the error value is less in CMA-NLMS algorithm , the desired signal ouput is less compared with desired signal input. Hence RLS provide better output signal than other algorithms. Finaly, the magnitude gain factor is more in RLS and NLMS than LMS. It also considered the equations dealt for the application of beamforming for wimax application in order to get better communication.

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