Smart Antenna system design using adaptive beamforming algorithms to minimize Noise

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Abstract*—Wireless communication is one of the most rapidly growing industries. The high demand for wireless communication services had led to an increase in system capacity. Then most elementary solution would be to increase bandwidth; however, this becomes ever more challenging as the electromagnetic spectrum is becoming increasingly congested. The ever-increasing demand for increased capacity in wireless communications services has led to developments of new technologies that exploit space selectivity. This is done through smart-antenna arrays and the associated adaptive beamforming algorithms. Smart-antenna systems provide opportunities for higher system capacity and improved quality of service among other things In this paper, two non-blind algorithms: Least Mean Square (LMS) and Normalized Least Mean Square (NLMS) algorithms were compared for a robust smart antenna system. It has been found that NLMS performs better in many respects than LMS and so we propose NLMS to be used by mobile companies when they will use smart antenna. Our findings are explained in details in the result and analysis section with graphs. Our comparison and findings were simulated using MATLAB.

***Index terms*—Smart Antenna, Beamforming, LMS and NLMS.**

1.INTRODUCTION

Basic idea of "smart" concept used for antenna systems, which are simple hardware elements, is the use of a digital signal-processing capability to transmit and receive in an adaptive, spatially sensitive manner. In other words, such a system can automatically change the directivity of its radiation patterns in response to its signal environment. In comparison with other antenna systems this technology can dramatically increase the performances (such as power consumption, capacity etc.) of a wireless system [1].

There are two techniques to estimate the position of a mobile phone; they are Triangulation method, and Received Signal Strength method (RSS). For Triangulation method, there are many approaches such as, Cell Identification (CI) combined with Timing Advance (TA), Angle of Arrival (AoA), Time of Arrival (ToA) and Time Difference of Arrival (TDoA) [2]. These methods need synchronization of the network and complexity of the separated architectures, the second technique is desired. Received Signal Strength method is a technique that estimates the position of a mobile phone by matching the signal strength with the neighboring reference points [2].

Section 2 discusses the mobile station antenna array along with its necessary equations. Section 3 discusses adaptive beamforming with LMS and NLMS Algorithms. In Section 4, simulation results are presented and discussed. Finally, conclusions are given in Section5.

2.MOBILE STATION ANTENNA ARRAY

A two elements array antenna is formed by using two infinitesimal dipoles separated by distance **d** as shown in Fig.1. Element 2 of the array antenna includes a weight component that provides the phase shift δ necessary for steering the beam of the antenna in any desired direction.

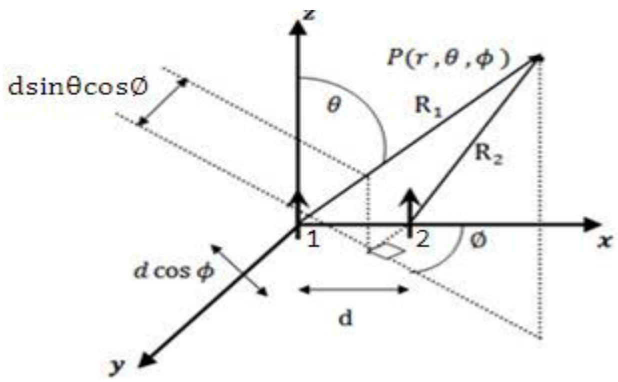


Fig.1: Two element array antenna.

The resultant field at far field point *(P)* can be expressed as:

$$E_T = {}^{\mu_0}/_{4\pi}\,[R_1 - R_2]\frac{d[I]}{dt}\left[e^{j\psi/2}2\cos\left(\frac{\psi}{2}\right)\right] \quad (1)$$

Where

$$[I] = Re\left(I_0\, e^{jw(t-R/c)}\right) \quad (2)$$

$$R_1 = (z_j - z_1)\Big/\left(\sqrt{r^2 + (z_j - z_1)^2}\right) \quad (3)$$

$$R_2 = (z_j - z_2)\Big/\left(\sqrt{r^2 + (z_j - z_2)^2}\right) \quad (4)$$

$$\psi = kd\sin\theta\cos\phi + \delta \quad (5)$$

The beamforming signal processor operates only on the magnitude of the measured electric field strength. Hence (1) is reduced to

$$E_T = E_0[R_1 - R_2]\left|2\cos\left(\frac{\psi}{2}\right)\right|$$

$$E_T = E_0[R_1 - R_2] \times AF \quad (6)$$

Where

ISSN: 2278 – 7798

$$E_0 = \mu_0 w I_0 / 4\pi = 10^{-7} w I_0 \qquad (7)$$

$$I_0 = \sqrt{\frac{P_r}{R_r}} \qquad (8)$$

$$AF = 2\cos\left(\frac{\psi}{2}\right) \qquad (9)$$

The total output of an N-element array with complex weight is given by.

$$E_T = \sum_{i=1}^{N} w_i E_i \qquad (10)$$

3. Adaptive Beamforming Algorithms

3.1 Least Mean Square

One of the simplest algorithms that is commonly used to adapt the weights is the Least Mean Square algorithm (See Fig.2). The LMS algorithm is a low complexity algorithm that requires to direct matrix inversion and no memory [3]. Moreover, it is an approximation of the steepest descent method using an estimator of the gradient instead of the actual value of the gradient, since computation of the actual value of the gradient is impossible because it would require knowledge of the incoming signals a prior. Therefore, the error can be defined as desired signal minus output of array weight.

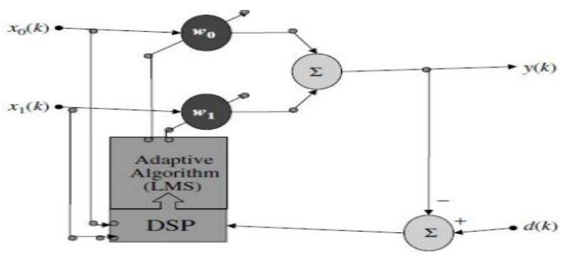


Fig.2: Block diagram of LMS algorithm.

$$\varepsilon(k) = d(k) - \bar{w}^H \bar{x}(k) \qquad (11)$$

The Squared error is

$$|\varepsilon(k)|^2 = |d(k) - \bar{w}^H \bar{x}(k)|^2 \qquad (12)$$

The cost function is defined as:

$$J(\bar{w}) = D - 2\bar{w}^H \bar{r} + \bar{w}^H \bar{R}_{xx} \bar{w} \qquad (13)$$

Where $\bar{R}_{xx}$ and $\bar{r}$ are the covariance and cross correlation respectively and can be defined as

$$\bar{R}_{xx} = X(k) X^H(k) \qquad (14)$$

$$\bar{r} = d^*(k) X(k) \qquad (15)$$

To minimize the cost function, the gradient of (13) is set to zero, and the solution for weights is the optimum weiner solution is given as [4].

$$\bar{w}_{opt} = \bar{R}_{xx}^{-1} \bar{r} \qquad (16)$$

Hence the smart antenna weights can then be updated as follows:

$$w(k+1) = w(k) + \mu X(k)[\, d^*(k) - x(k)\, \bar{w}(k)\,]$$

$$w(k+1) = wk + \mu X(k)\, \varepsilon^*(k) \qquad (17)$$

Where μ is the step size parameter that control rate of adaptation.

3.2 Normalized Least Mean Square

The normalized least-mean-square (NLMS) algorithm which is also known as the projection algorithm, is a useful method for adapting the coefficients of a finite-impulse response (FIR) filter for a number of signal processing and control applications. It can persist over a wide range of step-sizes. Theoretically, LMS method is the most basic method for calculating the weight vectors. However, in practice, an improved LMS method, the Normalized-LMS (NLMS) is used to achieve stable calculation and faster convergence. The NLMS algorithm can be formulated as a natural modification of the LMS algorithm based on stochastic gradient algorithm.

Gradient noise amplification problem occurs in the standard form of LMS algorithm. This is because the product vector $\mu\mathbf{x}(k)\varepsilon^*(k)$, k applied to the weight vector $\mathbf{w}(k)$ is directly proportional to the input vector $\mathbf{x}(k)$. This can be solved by normalized the product vector at iteration k +1 with the square Euclidean norm of the input vector $\mathbf{x}(k)$ at iteration n. The final weight vector can be updated by,

$$W(k+1) = w(k) + \frac{\mu}{x(k)^2}\, x(k)\varepsilon^*(k) \qquad (18)$$

where the NLMS algorithm reduces the step size μ to make the large changes in the update weight vectors. This prevents the update weight vectors from diverging and makes the algorithm more stable and faster converging than when a fixed step size is used. Equation (18) represents the normalized version of LMS (NLMS), because step size is divided by the *norm* of the input signal to avoid gradient noise amplification due to $x(n)$ [10]. Here the gradient estimate is divided by the sum of the squared elements of the data vector.

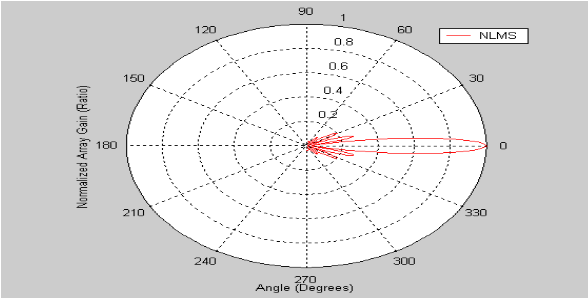
4. RESULTS AND ANALYSIS

A. RADIATION PATTERN AND CONVERGENCE

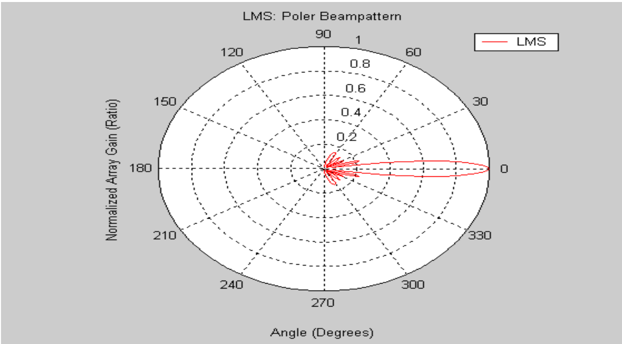
The performance of the algorithm is evaluated through radiation pattern and convergence analysis which are particularly attractive measurement of the wireless communications. The comparison between two training based

ISSN: 2278 – 7798

algorithm is investigated by computer simulations using MATLAB® 7.0. A system equipped with eight antennas with half wavelength spacing is considered for this purpose. The modulation scheme and radio channel used for this simulation are BPSK and AWGN respectively.



(a) NLMS



(b)LMS

Fig 3.Radiation pattern of LMS and NLMS algorithm (When N = 10)

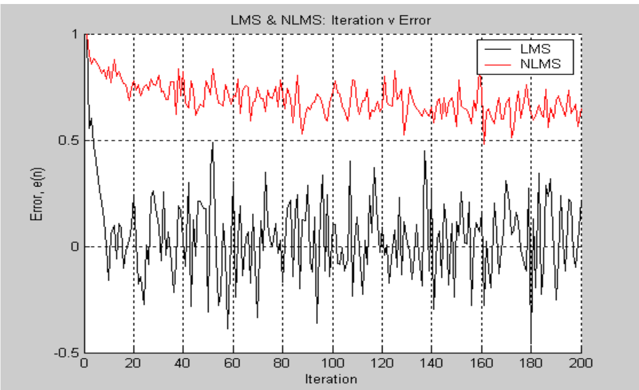


Fig 4. Error convergence performed by LMS and NLMS

We compared between LMS and NLMS in this section for smart antenna. From Fig.3, we can see that both main beams of NLMS and LMS are directed to the desired angle but LMS have a narrower beamwidth and higher gain. Also, NLMS generates significant two side lobes while LMS has many side lobes. From Fig. 4, we can see that the number of iterations needed for errors of NLMS to converge is much less than LMS. Here the red lines in the top part of the Fig. 4 converges early and is very stable and less fluctuation. This is caused by the complex algebra in deriving NLMS for each iteration in generating a more optimal step size which will give a better radiation pattern. On the other hand, LMS shows unstable result and convergence compare to the performance of NLMS.

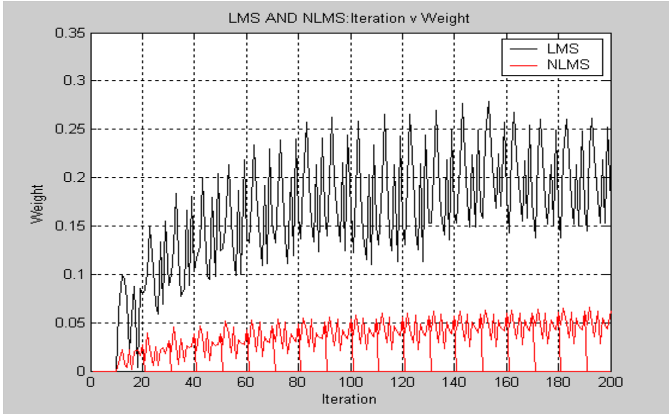


Fig 5. Weight vector convergence perfomed by LMS and NLMS

The red line in Figure 5 shows that NLMS performs better than LMS algorithm for smart antenna systems. Though it has some spikes but it is not so much compare to the black lines for LMS where the variation of weight values is more and so LMS is less stable in converging weights. NLMS need more time to complete iteration. Since NLMS always update the optimal step size in each iteration, less iteration are needed for NLMS to converge and that is the reason for NLMS algorithm to converge quickly. So we can conclude that NLMS has a better performance than LMS algorithm.

B.LOADING OF ANTENNA

The effect of interferers on the loading of the smart antenna and its accuracy in generating the desired radiation pattern is studied. Fig.6 shows the changes in the BS smart antenna beam when the number of interferers increases. The smart antenna was also tested for an interfering signal that is angularly near to the desired signal. The beam obtained was not as accurate for the previous test with the same number of elements. This is due to the fact that the is unable to null the interference and point to the desired signal with the restricted degree of freedom. In addition, the direction of the main beam will be slightly shifted if the direction of any interferers is too close to the direction of the desired signal.

ISSN: 2278 – 7798

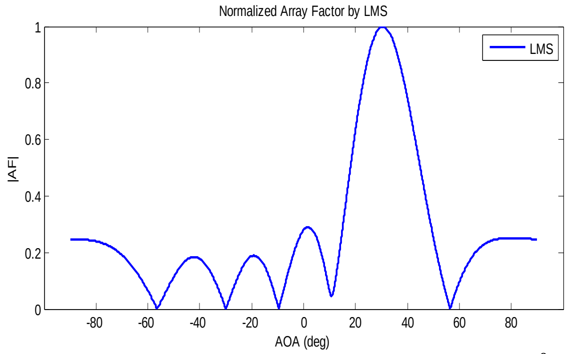


Fig.6. Antenna loading to interference when θ = 30^0

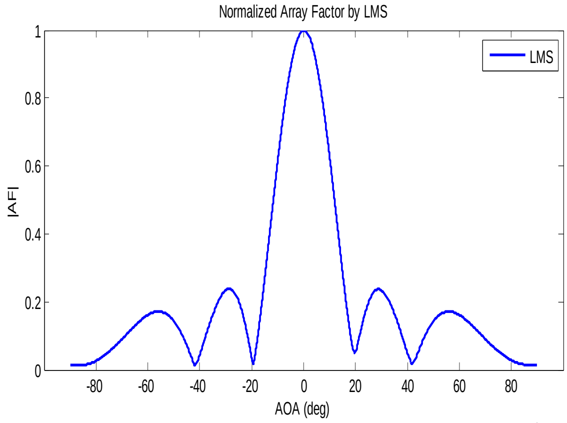


Fig.7. Antenna loading to interference when θ = 0^0

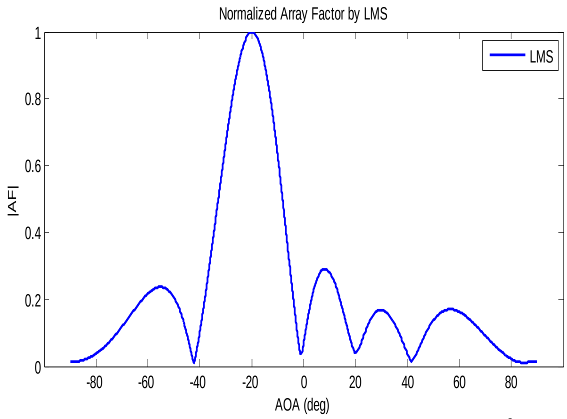


Fig.8. Antenna loading to interference when θ = -20^0

5.CONCLUSIONS

The proposed algorithms are used to achieve the adaptive beamforming. We compare LMS and NLMS algorithms for robust smart antenna system. It was noticed that increasing the number of elements of the antenna array ensures better performance. Both LMS and NLMS algorithms perform better when the numbers of antenna array elements are more. We have analyzed in the above chapter that normalized-LMS performs better than LMS algorithm. The error convergence is more stable and shows quick convergence for NLMS algorithm, while the LMS algorithm shows output with more fluctuations and less stable and convergence takes more time in the case of LMS than NLMS. Also, the radiation pattern is better and more directed when we implement NLMS algorithm. These are shown using linear beam pattern and polar beam pattern formats in the graphs. NLMS outperforms LMS for weight convergence and NLMS shows more stable and quick convergence. However, it is shown that the computational cost to run NLMS is a bit higher than LMS. The reason is evident from the extra step of NLMS equations to update the step size of the NLMS equation. And this time is very small and unnoticeable. And in overall issues, NLMS is very good algorithm to implement for Smart Antenna systems.

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ISSN: 2278 – 7798