SIMULATION AND COMPARISON OF ADAPTIVE ALGORITHMS FOR OPTIMAL WEIGHTING OF ARRAY ELEMENTS IN SMART ANTENNAS

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ABSTRACT : *The most important task of an antenna is producing an appropriate radiation pattern in order to construct optimal communication channel between base station and user. Processing of received signal in various elements of antenna array may results in access to different data in identification of massage and user position as well as received direction and/or angle of transmitted signal toward antenna. In this paper, several algorithms, including RLS, LMS, and CMA, are proposed in order to obtain optimum weighting of appropriate radiation pattern. Furthermore, LMS simulation is carried out and the obtained results are compared with that of RLS and CMA algorithms. By increasing sample number of received signals, the estimated values approach real values and weights reach the optimum weights.*

Keywords: Constant Modulus Algorithm (CMA), Least Mean Square (LMS), Recursive Least Square (RLS), Smart antenna.

1. INTRODUCTION

The task of a smart/array antenna is to produce specific pattern in order to receive optimum signal and eliminate interference. The interference can be brought out by other user or multi-path routes. Various methods are exists to form beam, each of which is used considering the desired aspect as well as radiated signal characteristics to the array.

With this antenna architecture, the weights of the antennas are adapted to point the main beam in the desired direction and place nulls in the interference directions. Different algorithms are used to adjust the weights in Smart Antenna Systems [1].

An adaptive antenna array combines the outputs of antenna elements but controls the directional gain of the antenna by adjusting both phase and amplitude of the signal at each individual element [2,3]. The combined relative amplitude and phase shift for each antenna is called a complex weight. These weights are calculated using different algorithms [4-9]. The weighted signals are summed and the output is fed to a controller that adjusts the weights to satisfy an optimization criterion.

Adaptive antennas have the ability of separating automatically the desired signal from the noise and the interference signals and continuously update the element weights to ensure that the best possible signal is delivered in the look direction. It not only directs maximum radiation in the direction of the desired mobile user but also introduces nulls at interfering directions while tracking the desired mobile user at the same time [10,11].

2. CONSTRUCTION OF BEAM AND ADAPTIVE ALGORITHMS

Array coefficients are usually obtained by direct solving of the equation related to the correlation matrix. Instead of solving direct equation, adaptive algorithms can be utilized which obtain weights in several iterations. The noticeable advantage of these algorithms is their application in noisy environment. Since these algorithms utilize previous weights, they reduce noise impact in order to update weights. A comparison of Least Mean Square (LMS) and Recursive Least Square (RLS) algorithms for smart antennas in a Code Division Multiple Access (CDMA) mobile communication environment has been presented in [12].

2.1 LMS Algorithm

LMS algorithm is one of the most used algorithms in weighting arrays. This algorithm is based on weight change with regard to an objective function. Weight update relation is given in Eq. 1.

$$\vec{w}(n+1) = \vec{w}(n) - \mu \vec{g}(\vec{w}(n)) \qquad (1)$$

Where, $\vec{w}(n+1)$ is (n+1)th weights and μ is a positive scalar named gadient step which controls algorithm convergence. $\vec{g}(\vec{w}(n))$ is an estimation of mean square error (MSE) gradient given by Eq. 2.

$$MSE(\vec{w}(n)) = E[|r(n+1)|^2] + \vec{w}^{\dagger}(n) R \vec{w}(n) - 2\vec{w}^{\dagger}(n)\vec{z} \qquad (2)$$

Where, R is the correlation matrix of array signals, $\vec{z}$ is the correlation vector of reference signal with arrived signal to the array and $r(n+1)$ is the reference signal. MSE gradient in *n*th iteration is expressed by Eq. 3.

$$\nabla_{\vec{w}} MSE(\vec{w})\big|_{\vec{w}=\vec{w}(n)} = 2R\vec{w}(n) - 2\vec{z} \qquad (3)$$

It should be noted that *n*th weights are used for calculation in (n+1)th iteration. Output of the array is given by Eq. 4.

$$y(n) = \vec{w}(n)\vec{x}(n+1) \qquad (4)$$

Where, $\vec{x}(n+1)$ is the vector of array signals. The estimation of MSE gradient is performed by replacing R and $\vec{z}$ with their estimations. This in (n+1)th iteration is expressed by Eq. 5.

$$g(\vec{w}(n)) = 2\vec{x}(n+1)\vec{x}^{\dagger}(n+1)\vec{w}(n) - 2\vec{x}(n+1)r(n+1)$$

$$= 2\vec{x}(n+1)\varepsilon^{*}(\vec{w}(n)) \qquad (5)$$

Where, $\varepsilon(\vec{w}(n))$ is the error between array output and reference signal expressed by Eq. 6.

$$\varepsilon(\vec{w}(n)) = \vec{w}^{\dagger}(n)\vec{x}(n+1) - r(n+1) \qquad (6)$$

As expressed by Eq. 5, estimation of MSE gradient is the array output multiplied by array signal in (n+1)th iteration. An important issue in LMS algorithm is the algorithm convergence. If $\lambda_{\max}$ is the highest eigenvalue of R and $\mu < 1/\lambda_{\max}$, LMS algorithm will converge. Mean value of weights also converge toward optimum weights.

Convergence speed of the algorithm is expressed by the time weights reach optimum weights. An important parameter which can be used to measure LMS algorithm convergence is time constant of the eigenvalues given by Eq. 7.

$$\tau_l = \frac{1}{2\pi\lambda_l} \qquad (7)$$

λ_l is the lth eigenvalue of matrix R. As seen, these time constants are related to the amount of eigenvalues. The more the eigenvalues, the less the time constants are. High eigenvalues are usually related to sources with high power, while low eigenvalues correspond to the small received power or environment noise. Thus, when eigenvalue of the matrix R is highly scattered, the algorithm convergence time increases. Convergence is a vital issue in the application of an algorithm in system. For example, due to its convergence time, LMS algorithm is not recommended to be used in mobile communication network since. Moreover, convergence speed should be considered due to the used signal states such as each user presence time, each time interval in TDMA system.

2.2 RLS Algorithm

LMS algorithm convergence is related to eigenvalues of correlation matrix. LMS algorithm convergence is less in environments where eigenvalues of correlation matrix is high. This problem is solved in RLS algorithm where inverse of correlation matrix is used instead of step size, μ. Thus, update relation of weights is demonstrated by Eq. 8.

$$\vec{w}(n) = \vec{w}(n-1) - R^{-1}(n)\vec{x}(n)\varepsilon^{*}(\vec{w}(n-1)) \qquad (8)$$

Where, R(n) is given by:

$$R(n) = \delta_0 R(n-1) + \vec{x}(n)\vec{x}^{\dagger}(n) = \sum_{k=0}^{n} \delta_0^{n-k}\vec{x}(k)\vec{x}^{\dagger}(k)$$

(9)

Where, δ_0 is a positive scalar less than unity and very close to it. RLS algorithm needs correlation matrix inverse, and the recursive relation for calculation of this matrix is given by:

$$R^{-1}(n) = \frac{1}{\delta_0}\left[R^{-1}(n-1) - \frac{R^{-1}(n-1)\vec{x}(n)\vec{x}^{\dagger}(n)R^{-1}(n-1)}{\delta_0 + \vec{x}^{\dagger}(n)R^{-1}(n-1)\vec{x}(n)}\right]$$

(10)

Initial value of correlation matrix inversion is $R^{-1}(0) = \frac{1}{\varepsilon_0} I$ where $\varepsilon_0 > 0$.

RLS algorithm minimizes mean square error (MSE). MSE is expressed by $J(n) = \sum_{k=0}^{n} \delta_0^{n-k}\left|\varepsilon(k)\right|^2$. The main advantage of RLS algorithm is that its convergence is independent on eigenvalues of correlation matrix dissipation. RLS and LMS algorithms, among the algorithms work based on gradient, have the highest and lowest convergence speed, respectively.

2.3 CMA Algorithm

CMA algorithm is another algorithm based on gradient calculation. It is assumed in this algorithm that the interference signals change signals level. Weights are achieved through minimizing fitness function as:

$$J(n) = \frac{1}{2}E\left[\left(\left|y(n)\right|^2 - y_0^2\right)^2\right] \qquad (11)$$

Weights updating relation is expressed by:

$$\vec{w}(n+1) = \vec{w}(n) - \mu\vec{g}(\vec{w}(n)) \qquad (12)$$

Where, $y(n) = \vec{w}^{\dagger}(n)\vec{x}(n+1)$ is the array output at the nth instant, and y_0 is the array output in the absence of interference. $\vec{g}(\vec{w}(n))$ is an estimation of fitness function gradient. It should be noted that in this algorithm, like LMS algorithm, fitness function gradient is used instead of its real value.

$$\vec{g}(\vec{w}(n)) = 2\varepsilon(n)\vec{x}(n+1) \qquad (13)$$

Where, $\varepsilon(n) = (\left|y(n)\right|^2 - y_0^2)y(n)$. Thus, weights updating relation becomes as:

$$\vec{w}(n+1) = \vec{w}(n) - 2\mu\varepsilon(n)\vec{x}(n+1) \qquad (14)$$

Similar to LMS algorithm, this algorithm is along with reference signal $\varepsilon(n) = d(n) - y(n)$. CMA algorithm is proper for elimination of correlated receiving and it is efficient in modulated signals by constant push such as GSMK and QPSK. Regarding CDMA systems need power control, this algorithm is not used.

3. ANALYSIS AND SIMULATION RESULTS

For simulation purposes, a linear array of concentric elements is considered. The distance between the elements is half of the wavelength. In addition, a sequence signal, up to 5000 samples with binary values of 1 and -1, is sampled and used as the input. Although 5000 instantaneous samples are exists, the obtained results reveal that the system converges up to 150 samples. The parameter μ is 0.008. Moreover, in order to reach real results, in particular for more than one multi-pad, signals in each route have different gains. The gains included amplitude and phase components. The former has a significant impact on system, while the latter has no effect on it.

Frequency carrier signal is set to 400 MHz. Thus, λ=0.75 m. the distance between array elements is d=λ/2 and equal 0.375m. Propagation delay for the signal to reach the first element of μ is 100 seconds. In simulation with two signals, propagation delay of the second signal to reach the first element of μ is 150 seconds.

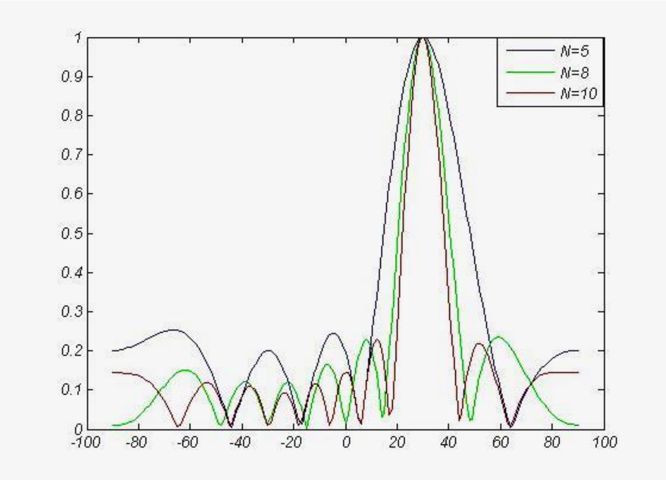

Fig. 1 Array pattern for AOA=30 and d=λ/2 and interference 60 using LMS algorithm

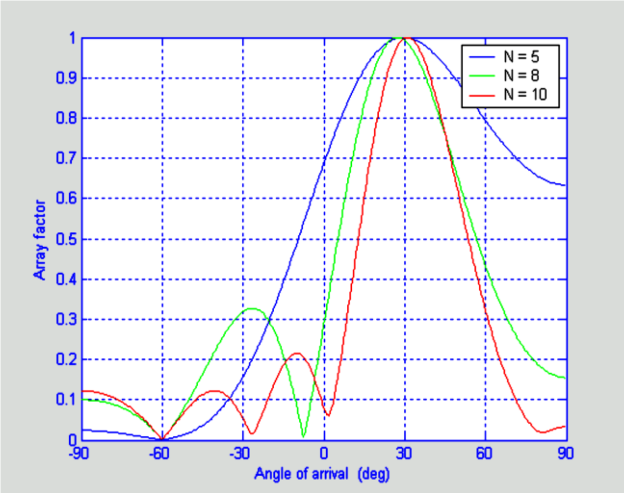

Fig. 2 Array pattern for AOA=30 and d=λ/4 using RLS algorithm

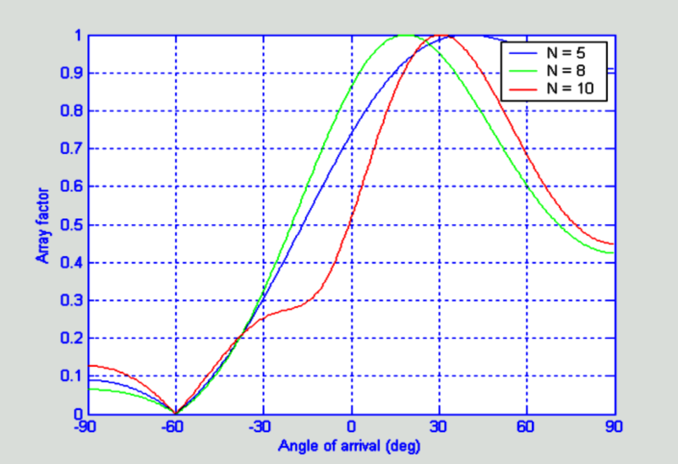

Fig. 3 Array pattern for AOA=30 and d=λ/8 using RLS algorithm

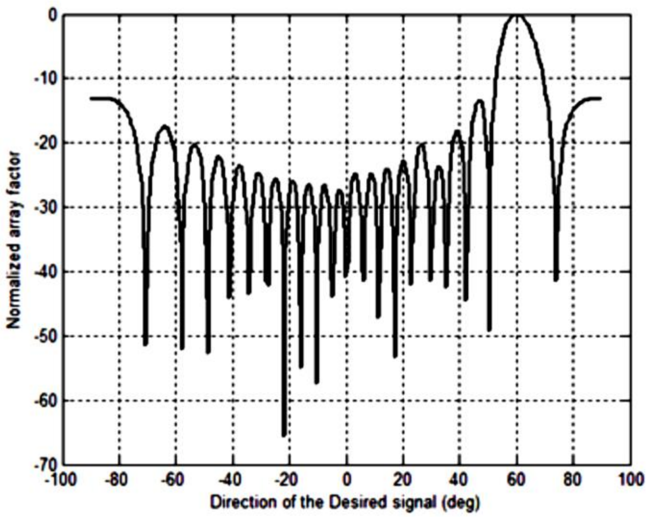

Fig. 4 Radiation pattern of the linear array of 21 elements with the direction of arrival at 60^0 using CMA

Figure 1 depicts diagram obtained by LMS algorithm. As can be seen, weak beams are generated in the path of interference. Figures 2 and 3 show array pattern diagram when elements distance is 1/4 and 1/8 of wavelength, respectively. Obviously, simulations prove that the optimal value between the elements is half of the wavelength.

4. COMPARISON OF SIMULATION RESULTS OBTAINED BY LMS, CMA, and RLS ALGORITHMS

In a wide comparison among adaptive algorithms, parameters of antenna pattern, amplitude response, error diagram and BER are studied. LMS algorithm importance in constructing the best main lobe in the direction of user cannot be ignored. However, it is not completely satisfactory in neutralizing interference signals.

CMA algorithm has the highest error. However, it leads to reliable solutions compared to LMS and RLS algorithm in elimination of interferences. Obtained results by simulations in Figure 5 indicate that inserting zero in interference routes, in the CMA algorithm, actually results in interference signal omission. Whereas in the case the signal receiving angle of user and interference is very close to each other, BER in this algorithm is higher than that of array elements signals.

RLS algorithm is more computationally complex than LMS. RLS algorithm convergence is higher than that of LMS. RLS has the minimum error signal and minimum BER.

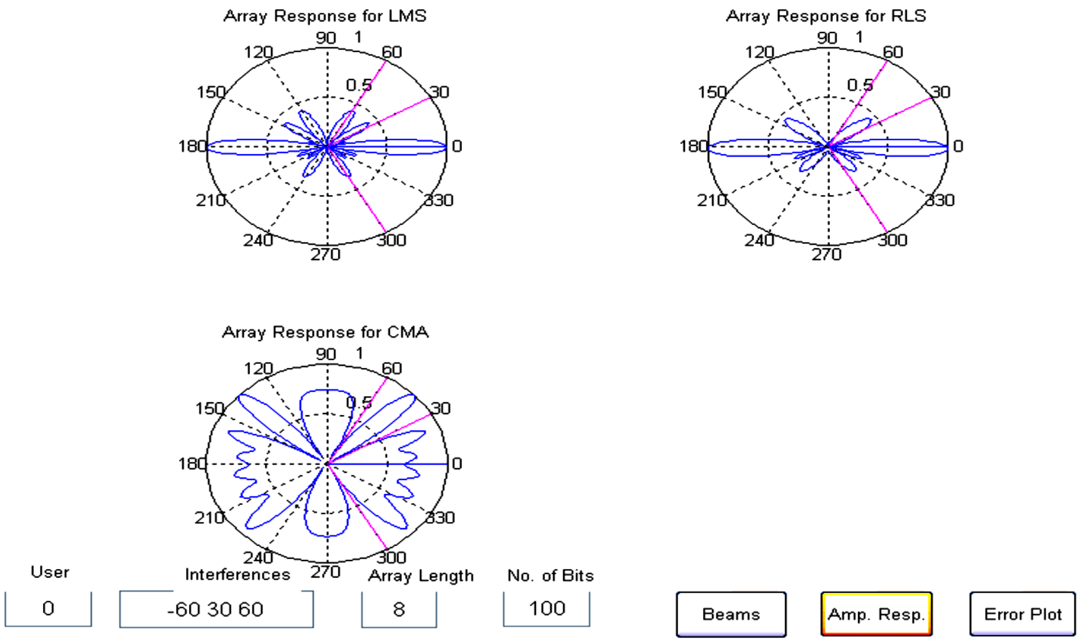

Fig. 5 Array antenna pattern for the user in angle of 0 and interferences of 60, -30 and 60

5. CONCLUSION

In this paper, various algorithms, including LMS, RLS, and CMA, producing adaptive beam in smart antennas were addressed. Convergence speed of LMS algorithm is dependent on eigenvalues of array correlation matrix. In environment where eigenvalues expansion of correlation matrix is high, the algorithm expands with low convergence speed. This problem is resolved in LMS algorithm by substituting inversion of matrix R with gradient step size of μ. Simulation results provide better understanding of convergence, stability, and adaptability method of algorithm. The obtained results by simulations indicate that LMS algorithm has low speed compared with RLS algorithm. However, LMS put forward less computation on system processor in the case it converges in load channel conditions. While its convergence speed id high, RLS algorithm needs initial estimation of inversion of matrix R. In addition, it is much more complicated than LMS algorithm in terms of computations.

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