Comparative Analysis of Adaptive Beamforming Algorithm LMS, SMI and RLS for ULA Smart Antenna

Dhaval N. Patel, B.J.Makwana, P.B. Parmar

Abstract—**The challenge of a modern day wireless system is to provide reliable and extensive service, which provide the desired capacity for communication. It is necessary to increase the capacity and channel bandwidth at the same time minimize the channel interference. Smart antenna is one of the best techniques to improve the capacity of the wireless communication system by improving the gain of main lobe in a direction of arrival (DOA) and null generation towards the interfere. The smart antenna adaptive algorithms Least Mean Square (LMS) achieve the best weight vector of antenna array elements for beamforming by iterative process. In this paper we analyzed the performance of LMS, Sample Matrix Inversion (SMI), Recursive least square (RLS) algorithms by varying the number of elements in the uniform linear array (ULA), and simulations results are carried out using MATLAB.**

***Index Terms*—Beam forming, LMS, RLS, SMI, Smart antenna, ULA**

I. INTRODUCTION

In modern era, there are many inventions related to the applications of wireless services increases all over the world, hence the number of users are rises day by day. This has resulted the need of wider service area and higher data rates to satisfy the each users need. Demanding coverage and data rates can be achieved using smart antenna (SA) system.[1] SA system consist of array antenna and signal processing ability to reject interfere signal. In the view of fact that today's evolution of powerful digital signal processor and ingenious software based algorithms makes the smart antenna systems accepted commercially.

In SA system the optimum weights for array antenna elements are computed using algorithm for different parameters. According to the processed and calculated weights array antenna generates the radiation pattern in which the main lobe of radiation pattern is in the direction of the desired user and generate the null in the direction of the other users. Thus smart antenna eliminate the interfere and enhancing the desired user by providing the gain. The interference arises due to the fact that the antenna might be serving multiple users. In this paper, LMS (Least Mean Square), SMI (Sample Matrix Inversion) and RLS (Recursive Least Square) algorithms are used to achieve the complex optimum weights of the array elements. The performance of the algorithms are investigated in terms of parameters related to radiation pattern like side lobe level and beam width for uniform linear array antenna in distinct signal environment [2-4].

Section II gives Smart antenna. In Section III discuss Adaptive beamforming algorithms, Section IV gives Simulation setup and Results, Section V gives Conclusion.

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II. SMART ANTENNA

Historically the term "Smart Antenna" appear from the adaptive antenna. The term adaptive antenna initially used by Van Atta in the year 1959, to describe the self-phased array. Meantime Howells proposed the first adaptive technique sidelobe cancelation, it is used for the automatic interference nulling[5].Until current technology era, there are enormous progress arises for the improvement in the field of Smart Antennas.

Smart antenna consists of more than one antenna elements, which are organized spatially and interconnected to each other in the terms of feeding to produce a radiation pattern which is directed to the desired user. In uniform linear array (ULA) antenna all the elements are identical. Many consider the SA system as smart antenna, but actually antenna are not smart. It has the digital signal processor which have the complex processing capabilities, along with the array antenna and processor the system becomes smart antenna system. There are basically two types of smart antenna, switched beam antenna and adaptive array antenna. Switched beam system have several available fixed patterns. These antenna systems detect signal strength, choose one of predetermined beam pattern and switch from one beam to another as the user moves from its position.

Adaptive antenna technology represents the most advanced smart antenna approach [6]-[9]. This method using signal-processing algorithms for beamforming, which track the desired signals adequately and dynamically minimize interference. The adaptive antenna system gives

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required gain while simultaneously generate the null for minimizing interfering signals generated by other users.

Direction of Arrival (DOA) estimation and Beamforming are two goal in smart antenna systems. In DOA estimation, first find the direction of the all incoming signals then classify desired user's direction as well as the other interfering signal's direction. Smart Antenna system is shown in the figure. An effective design of an adaptive array antenna depends on the selection of the DOA estimation algorithm. [6]

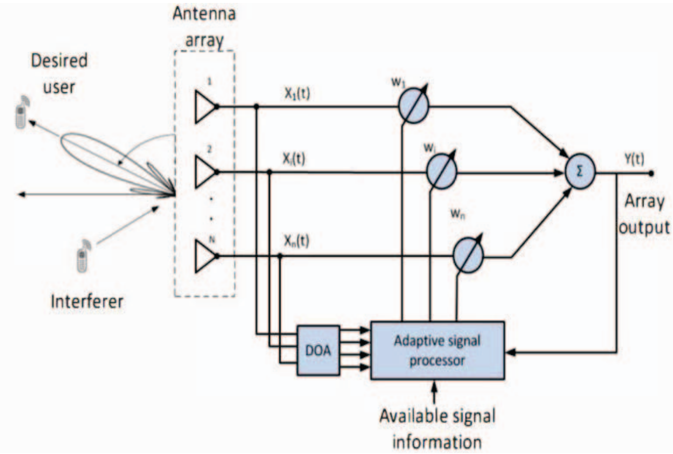

Fig. 1. Functional Block Diagram of Smart Antenna System

In second goal, adaptive beamforming algorithms are used to compute the complex weights $W_1, W_2 \ldots W_n$.[11] which are multiplied with the incoming signals and produce the radiation pattern which locate the desired user and minimize the power at the interfere as shown in the Fig. 1.

III. ADAPTIVE BEAMFORMING ALGORITHMS

In adaptive beamforming weights to change or adapt, depending on the received data to achieve a certain goal. Many adaptive algorithms exists which are used for increase the signal to interference ratio (SIR) and reduce the mean square error (MSE). Algorithm is steering main lobe toward a signal of interest to control the smart antenna pattern.[10]

A. Least Mean Square Algorithm

The LMS algorithm was introduced by Dr. Bernard Widrow. In LMS algorithm calculation of the weight vector is based on Minimum Squared Error (MSE) criterion shown in Fig. 2. This algorithm is non-blind type algorithm, so it uses the reference signal.[1-2] In the course of training session training signal is transmitted and received at other side, used this received signal to find error signal. Minimum error is achieved through the use of a gradient based method of steepest decent. This method of LMS is iterative that makes continues corrections of the weight vector by small amount according to the gradient vector, known as step size, which eventually present the minimum mean square error. Comparatively the LMS algorithm is straightforward because it does not require any complex computation of correlation function and matrix inversions.[7]

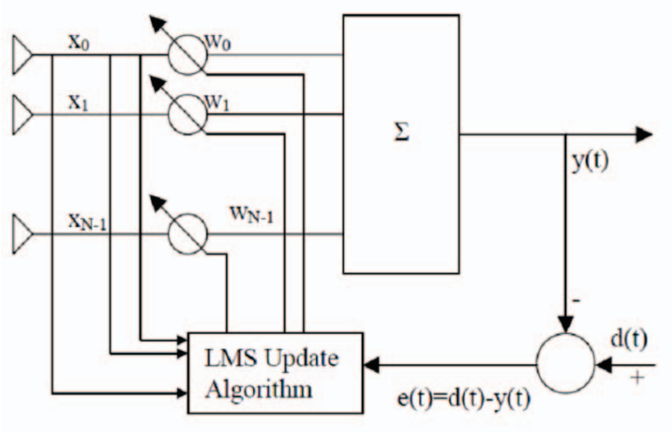

Fig. 2. LMS adaptive beamforming network

Array antenna receive the incoming signal x(t) and multiplied with the weight factors W, which basically modify the phase and amplitude of incoming signal. This modified weighted signals are added together and give the output signal y(t). Then adaptive algorithm is used to observe the error between output signal y(t) and reference signal d(t), minimizing this error by updating the weight vector.[4]

$$y(n) = w^H * x(n) \tag{1}$$

The weight vector w shown in the above eq^n is a complex vectors. The LMS algorithm update the weight vector according to the instantaneous gradient vector $\nabla J(n)$. The updated value of the weight vector is written as,

$$w(n+1) = w(n) + \frac{1}{2}\mu[-\nabla J(n)] \tag{2}$$

Where μ is the step size which regulate the speed of convergence. Value of step size is very small generally varies between 0 and 1. Initial value of both the covariance matrix R and the cross-correlation vector r requires to compute the precise value of instantaneous gradient vector. Gradient vector is given by,

$$\nabla J(n) = -2r(n) + 2R(n) * w(n) \tag{3}$$

Where $$R(n) = x(n) * x^H(n) \tag{4}$$

And $$r(n) = d^*(n) * x(n) \tag{5}$$

The weight vector can be found by,

$$w(n+1) = w(n) + \mu[-r(n) + R(n) * w(n)]$$

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

$$= w(n) + \mu[x(n) * e^*(n)] \quad (6)$$

The union velocity of LMS calculations relies upon step size μ and remains stable at,

$$0 < \mu < \frac{1}{\lambda_{max}}$$

Maximum eigen value of the correlation matrix R is take as λ_{max}, which is the boundary for step size value. If the value of step size μ is very small then the speed of algorithm is slow. Vice versa for large value of μ speed of convergence is fast but it may be less stable around the minimum value.[11]

B. Sample Matrix Inversion Algorithm

Main limitation of the LMS adaptive algorithm is that for decent convergence it requires many iterative steps. If the signal parameters are changing rapidly than sufficient tracking of the desired signal becomes difficult in the LMS algorithm. The control of the rate of convergence of the weights depends on the eigen value of the array correlation matrix. Slow convergence problem of the LMS algorithm is overcome by using sample matrix inversion (SMI). Weight of the array in this algorithm is calculated by using its estimated value instead of correlation matrix R. An estimate of R for the array signals of N samples may be obtained as follows,[2-3]

$$R_{xx}(n) = \frac{1}{n}\sum_{n=0}^{N-1} x(n) * x^H(n) \quad (7)$$

The value of correlation vector is given by,

$$r(n) = \frac{1}{n}\sum_{n=0}^{N-1} x(n) * d(n) \quad (8)$$

The weights in the SMI algorithm can be calculated by the given formula,

$$w_{SMI} = R_{xx}(n)^{-1} * r(n) \quad (9)$$

In abruptly fast changing environment this algorithm is most favorable for beamforming because the speed of convergence is higher compared to the LMS algorithm.[9-10]

C. Recursive Least Squares Algorithm

In SMI algorithm has the advantage over the LMS algorithm but it has the several limitation, computational complexity and matrix singularities. In RLS algorithm correlation matrix and correlation vectors are calculated recursively. Write the correlation matrix and the correlation vector

$$R_{xx}(n) = \sum_{n=0}^{N-1} x(n) * x^H(n) \quad (10)$$

$$r(n) = \sum_{n=0}^{N-1} x(n) * d(n) \quad (11)$$

We might want to nullify the effect of the earliest data samples and highlights the most recent signal data Because the signal may be vary with the time.[2] This desired method can be achieved by modifying the eq^n (10-11),

$$R_{xx}(n) = \alpha^{(N-1)-n} \sum_{n=0}^{N-1} x(n) * x^H(n)$$

$$r(n) = \alpha^{(N-1)-n} \sum_{n=0}^{N-1} x(n) * d(n)$$

Where α is the exponential weighting factor and its value is between 0 and 1, range of α is $0 \le \alpha \le 1$. At long last mathematical statements for the weights are derived as,

$$w(k) = w(k-1) - g(k) * x^H(k) * w(k-1) + g(k) d^*(k)$$

$$= w(k-1) + g(k)[d^*(k) - x^H(k) * w(k-1)] \quad (12)$$

Value of the previous error is evaluated straightforwardly in RLS algorithm. Conditions in which the parameters are change or alter the use of RLS algorithms gives the best performance [9-11].

IV. SIMULATION SETUP AND RESULTS

In this section, MATLAB platform is used to process the results of the adaptive beamforming algorithms discussed in section III. For the task of simulations consider the uniform linear array antenna with M number of element and inter element spacing in terms of wavelength.

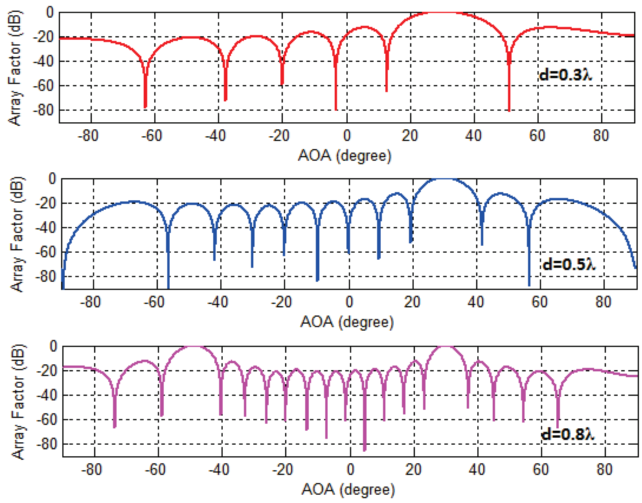

Fig. 3. Beamforming for different spacing between the antenna elements.

Simulation results for different inter element spacing is shown in the Fig. 3. As spacing of elements increased, beam width becomes narrower but for higher values sidelobe level increased. So consider the most appropriate separation distance between two antenna elements is 0.5 λ for all algorithms.

A. LMS Algorithm

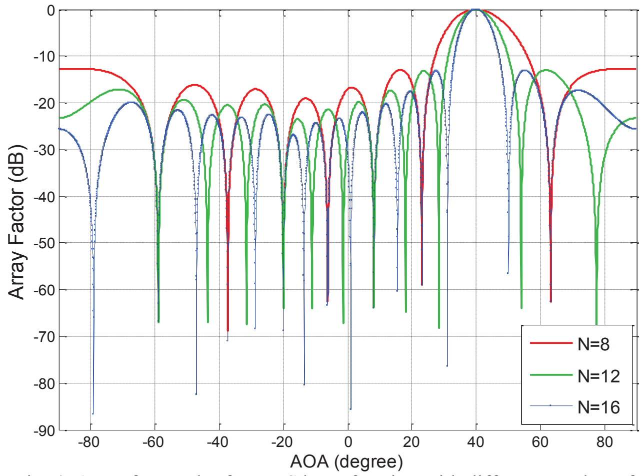

Fig. 4. Array factor plot for LMS beamforming with different number of array elements.

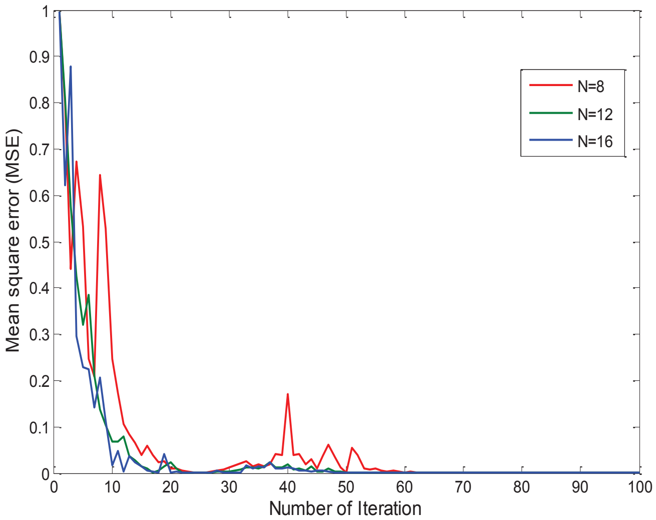

Fig. 5. MSE v/s No. of iteration plot for LMS beamforming with different number of array elements.

Simulation is carried out for different cases, number of elements of array are considered as N=8, 12 and 16. The inter-element spacing is considered to be half wavelength and step size is μ=0.01. Signal of desired user is arriving at an angle of 40 degrees and interfere signal is arriving at an angle of -20 degrees. Outcomes are carried out for 100 iteration process. The result shown in Fig. 4 is of Array factor for angle of different arriving angel. Fig.5 is shown the result of MSE v/s number of iteration.

B. SMI Algorithm

Number of elements of array are considered as N=8, 12 and 16. The inter-element spacing is 0.5λ and step size is μ=0.01. AOA of desired user signal is at an angle of 30 degrees and interfere signal is arriving at an angle of -20 degrees. Process run for 100 iteration steps. The result shown in Fig. 6 is of Array factor for angle of different arriving angel.

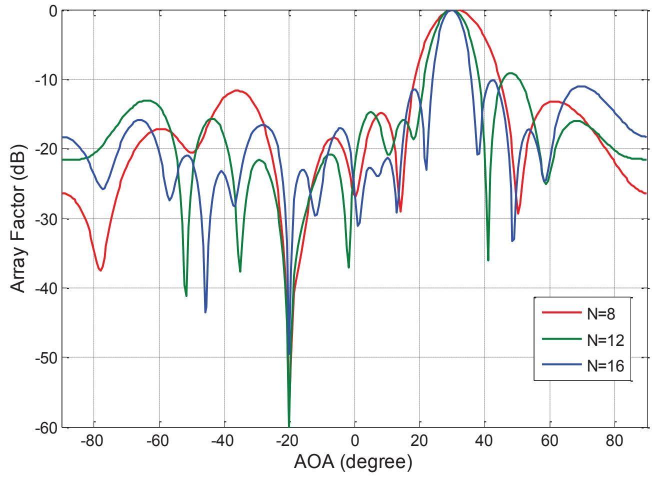

Fig. 6. Array factor plot for SMI beamforming with different number of array elements.

C. RLS Algorithm

When the desired signal has been taken at 30° and the signal not of interest is taken at -20°. Fig. 7 shows the array factor obtaining by using RLS algorithm. It has been obtained for various cases, i.e. N=8, N=12 and N=16. And it has been noticed that the radiation pattern obtained for N=16 elements is the best.

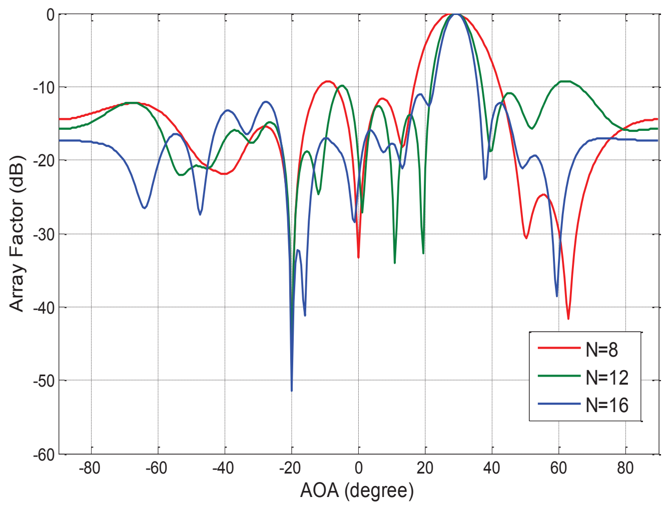

Fig. 7. Array factor plot for RLS beamforming with different number of array elements.

TABLE I
SIMULATION RESULTS

Algorithm	N	Side Lobe Level (db)	Null Depth (db)
LMS	8	-12.92	-47.76
	12	-13.14	-63.91
	16	-13.20	-68.88
RLS	8	-9.25	-47.14
	12	-9.86	-47.47
	16	-11.02	-51.46
SMI	8	-11.65	-57.84
	12	-9.68	-61.92
	16	-10.17	-49.61

V. CONCLUSION

All three adaptive algorithms LMS, SMI and RLS are simulated and analyzed the performance of algorithms from the obtained radiation pattern. Number of elements of ULA antenna is variable, and it has been observed that as the number of elements increases, the improvement in terms of narrow beam width and deepest null at interfere becomes superior. Enhanced radiation pattern has been resulted for spacing of array element at half of the wavelength. The radiation pattern achieved by using LMS algorithm is finest. Convergence speed is one the drawback of LMS algorithm as it is directly depends on the step size value. Convergence is low for small value of step size and for large value of step size it becomes unstable. SMI overcomes the limitation of LMS but it increase the complex computation of correlation matrix. In RLS algorithm array weights are updates very quickly because the variation of convergence is determined by the knowledge of eigen value of the correlation matrix of signal.

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