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Sequential Studies of Beamforming Algorithms for Smart Antenna Systems

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Abstract: Smart antenna is the most efficient leading innovation for maximum capacity and improved quality and coverage. A systematic comparison of the performance of different Adaptive Algorithms for beamforming for Smart Antenna System has been extensively studied in this research work. Simulation results revealed that training sequence algorithms like Recursive Least Squares (RLS) and Least Mean Squares (LMS) are best for beamforming (to form main lobes) towards desired user but they have limitations towards interference rejection. While Constant Modulus Algorithm (CMA) has satisfactory response towards beamforming and it gives better outcome for interference rejection, but Bit Error Rate (BER) is maximum in case of single antenna element in CMA. It is verified that convergence rate of RLS is faster than LMS so RLS is proved the best choice. The effect of changing step size for LMS algorithm has also been studied.

Key words: Smart Antenna System · Beamforming · Training sequence algorithms · Bit error rate

INTRODUCTION

Smart antenna for mobile communication has received enormous interests worldwide in recent years. In the last decade wireless cellular communication has experienced rapid growth in the demand for provision of new wireless multimedia services such as Internet access, multimedia data transfer and video conferencing. In order to meet this demand and to overcome the limited capacity of conventional single input single output (SISO) systems, the use of multiple element antennas (MEAs) has been under consideration [1,2]. A multiple input multiple output (MIMO) system offers greater capacity than SISO counterparts. The multiple antennas can be used to increase the communication reliability by diversity or to increase the data rate by spatial multiplexing or a combination of both. Smart antennas refer to a group of antenna technologies that increase the system capacity by reducing the co-channel interference and increase the quality by reducing the fading effects. Co-channel interference is the limiting factor to the communication systems [3,4]. Array containing M identical elements can steer a directional beam to maximize the signal from desired users, signals of interest (SOI), while nullifying the signals from other directions, signals not of interest (SNOI) [5,6]. Multiple antennas have performance and capacity enhancements without the need for additional power or spectrum. Many practical algorithms for MIMO have been proposed in recent years. The techniques of placing nulls in the antenna patterns to suppress interference and maximizing their gain in the direction of desired signal have received considerable attention in the past and are still of great interest using evolutionary algorithms such as genetic algorithms (GA) [7-10].

A smart antenna has the potential to reduce noise, to increase signal to noise ratio and enhance system capacity. Several approaches have been studied to introduce smart antenna technology into GSM, IS-136 and third generation systems. They have been considered mostly for base stations so far. Recently, they have been applied to mobile stations or handsets. Also, one of the third generation wireless personal communication systems, 3GPP (third generation partnership project), requires antenna diversity at base stations and optionally at mobile stations but cost of fabrication increases with the number of array elements [11-14].

Smart antennas involve processing of signal induced on an array of antennas. They have application in the

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areas of radar, sonar, medical imaging location based application and communications. Smart antennas have the property of spatial filtering, which makes it possible to receive energy from a particular direction while simultaneously blocking it from another direction. This property makes smart antennas as a very effective tool in detecting and locating radiation from other sources [15, 16]. Smart antennas are characterized into switched beam system and adaptive arrays. In this paper adaptive arrays are investigated and used for smart antenna model. In adaptive beamforming, the goal is to adapt the beam by adjusting the gain and phase on each antenna element such that a desirable pattern is formed.

MATERIALS AND METHODS

The output response of the uniform linear array is given by LMS as follows:

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

where w is the complex weights vector and x is the received signal vector
Optimal weights are calculated as follows:

$$w (n+1) = w(n)- \mu\, g(w(n)) \tag{2}$$

where w(n+1) denotes new weights computed at (n+1) iteration. ì is gradient step size that controls the convergence characteristics of the algorithm, that is how fast and close the estimated weights approach the optimal weights g(w(n)) is estimate of gradient of the Mean Square Error (MSE);

$$MSE(w(n))=E[Ir(n+1)ï^2]+ w^H (n)R\, w(n)-2\, w^H(n)z \tag{3}$$

Errors between reference signal and array output have been calculated using standard methods. In RLS, I from LMS is replaced by gain matrix, weight vector and error signal are calculated using standard methods. In CMA we don't have any reference signal as it is blind beamforming algorithm, so error signal is defined as follows;

$$\varepsilon(n) = \frac{y(n)}{|y(n)|} - y(n) \tag{4}$$

Weights have been updated using standard methods of CMA.

RESULTS AND DISCUSSION

Simulation for 8 elements Antenna Array is performed on Matlab 7.0, using input Signal consisting of user signal at 0 degree, three Gaussian Interferers at -60, -30 and 60 degree and White Gaussian Noise at each element with SNR of 10 dB is added. Modulation environment is MSK (Minimum Shifting Key). User signal is taken from randint and normnd commands of Matlab that have an equal probability of having 0's and 1's.

The beampattern is obtained by first calculating an Array factor for the array from -180 to 180 degrees and then multiplying the weights with it. The response of every input user signal and interfering signal is shown in the form of a graphical user interface in Figure 1. It can be seen that main lobe is formed towards user at angle 0 and interfering signals at -60, 30 and 60 degrees are being rejected as nulls are placed towards them. Response is calculated for LMS, RLS and CMA. It is also revealed that by selecting larger array of antenna elements, element spacing increases. Major drawback of this approach lies in appearance of replicas of main lobe in undesired directions, referred to as grating lobes.

Amplitude response is obtained by taking 20log10 of the values obtained during beam pattern (Figure 2). From Amplitude response it is also clear that main lobe is formed best from RLS and LMS Algorithms as it has maximum signal strength in user direction. While interference rejection is better in CMA as it can be seen that it is producing nulls towards interfering signals. By giving different angles to user signal and interference the amplitude response changes accordingly.

The BER is obtained by first demodulating the output signal (that was modulated in Minimum Shifting Keying environment) to obtain the bits that were present in demodulated signal. Then these bits have been subtracted from the bits of original signal values. Modulus of this subtraction gives the BER values.

The high error rate in single antenna element is due to the fact that it would have to provide coverage to enhanced number of users, which are much more than its capacity so error rate increases. CMA is Blind Sequence algorithm that does not require any training bits and it gives relatively less BER.

LMS is training sequence Algorithm that requires reference signal to compare with input signal so it lessons BER. It has been revealed from different simulation measurements that RLS gives best results. It can be seen that BER is maximum for a single antenna element and BER reduces by using smart antenna system having Adaptive Algorithms.

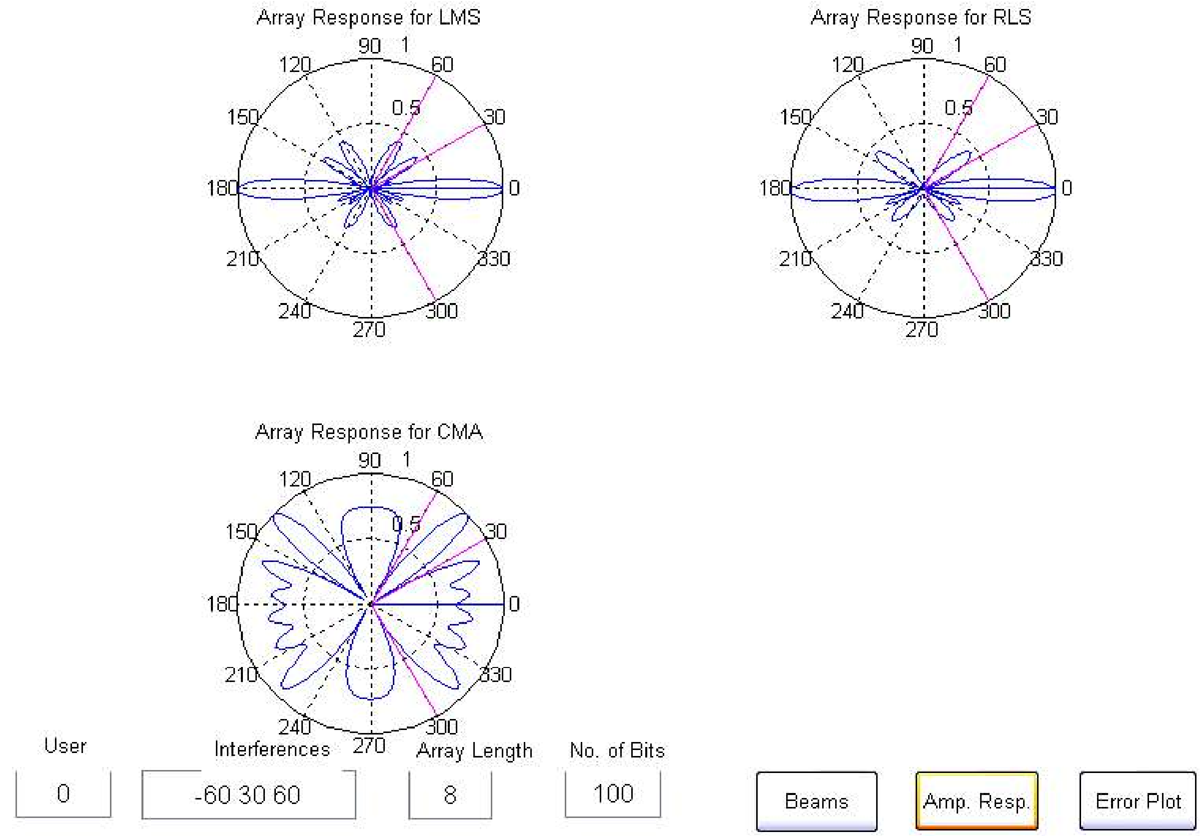

Fig. 1: Beampattern, User at Angle 0, and Interferers at Angles 60, 30, 60

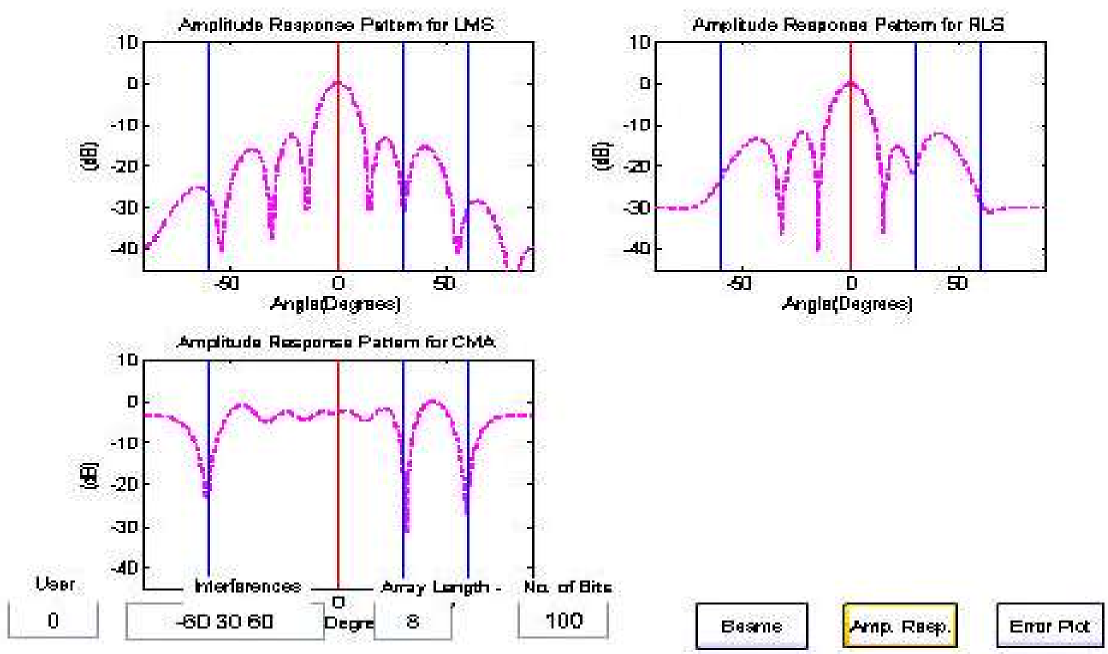

Fig. 2: Amplitude Responses, User at Angle 0, Interferers at -60, 30, 60

The error plot is drawn by subtracting original signal from output signal. Its magnitude has been calculated to draw the plot. It has been observed that increasing the value of SNR error decreases. Minimum error has been noticed from RLS and maximum error from CMA. Many algorithms may perform poorly or fail completely in the field because the assumptions made in the mathematical models do not accurately represent the real physics of the problem at hand. So it is further recommended for operators to verify performance in real life also. By increasing the number of elements in the Antenna Array (from 8 to 12 in this case) the Beams become narrow.

The most exciting contribution of smart antennas in communication technology lies in its narrow beam features that enhances directional gain and intensity and the user can be facilitated with maximum signal strength. On operator end it also saves power because a narrow beam consumes less power than a broad beam. By comparing amplitude responses from Figure 2, it is ascertained as well that beam size is reduced when we increase antenna array. The worst condition of SNR for performance comparison has been considered as well. The SNR has been reduced from 10 to 2 db, interference and user signals have been given angles quite close to each other that is a performance limiting factor for smart antenna system.

The simulation results revealed that CMA and LMS give maximum BER when user and interference are quite close to each other which is not affordable in practical Base Station installations. In LMS algorithm weights are updated using a reference signal mostly and no knowledge of the direction of signal is utilized. Under certain conditions for example when the eigen value spread is large, convergence rate of LMS Algorithm slows down. This leads to development of RLS algorithm, which replaces the step size. CMA doesn't use any reference signal but automatically selects one or several of the multipaths as the desired signal.

When array vector is updated it does not need to know the arrival timings of the incident rays. It does not need to synchronously sample the received signal with the clock timing. RLS algorithm has been designed to cater with any change in environment and considering all the other key parameters. Also probability of this so close co channel interference is equally likely in real world. So on commercial scale it is not desirable to implement such problematic technique. It is evident as well that best performance promise in all conditions is duly accomplished by RLS only.

CONCLUSION

In a comprehensive comparison among adaptive algorithms, the parameters of beampattern, amplitude response, error plot and BER have been studied. The system has also been analyzed in strict SNR environment. The significance of LMS algorithm cannot be ruled out in generating better main lobe in a specified direction of user but to nullify co channel interference it plays very unsatisfactory response. CMA bears maximum error but focusing on co channel interference it gives more reliable results than LMS and RLS. Results obtained from simulation assert that capability to reject the interfering signal by placing nulls in undesirable direction is really accomplished by CMA. But when angle of arrival of interference and user were quite close to each other then CMA had BER even more than single antenna element. RLS algorithm involves more computations than LMS, it provides safe side towards main lobe and have better response towards co channel interference. It has been revealed as well that convergence rate of RLS is faster than LMS. RLS Algorithm is found to have minimum BER and error signal magnitude, therefore it has been proved the best algorithm for implementation on Base Station Smart Antenna System.

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