

Comparative Study Of Least Mean Square And Recursive Least Square Adaptive Beamforming Algorithms On CDMA Based Networks For Improved Performance

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Abstract

This paper aimed at a comparative study of the performance of the Least Mean Square (LMS) and Recursive Least Square (RLS) algorithms of the adaptive beam forming antenna on the CDMA based network. The smart antenna test-bed used include a single input multiple output system which consists of one transmitter and six receivers. During experimentation, the interference and noise reduction capabilities of the adaptive antenna were investigated using the LMS and RLS algorithms. Also, the two adaptive algorithms were simulated and evaluated for a 6 uniform linear array elements with inter-element spacing of 0.5λ on the CDMA based network using MATLAB version 7.5. In the simulation, the angle of arrival of the desired signal and the interfering signal were at 30° and 60° respectively. The desired signal was assumed to be a complex sinusoidal phase modulated and the interfering signal assumed as random signal. Results obtained showed that the recursive least square algorithm started to converge from iteration number 20 while least mean square algorithm started to converge from iteration number 50. Result also showed that the recursive least error was 0.001 at 20 iterations, while least square error was 0.025 at 20 iterations. Result obtained also showed that RLS algorithm has lower bit error rate of order 10^{-3} compared to LMS algorithm.

Keywords: Smart antenna, adaptive beamforming, RLS algorithm, LMS algorithm, adaptive antenna, antenna

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I. Introduction

An antenna is a transducer that transmits or receives electromagnetic waves and converts electromagnetic radiation into electric current or vice versa. There are two types of antenna directional patterns with reference to two dimensional plane. These patterns are Omni directional which radiates equally in all direction and directional which radiates more in one direction than other (Rappaport, 2002). Omni-directional antennas were in use in the early days of wireless communication. This type of antenna consists of a simple dipole which radiates and receives electromagnetic waves in form of signal in all directions. Omni-directional antennas are adequate for radio frequency environment where no specific knowledge of the user's whereabouts is available. The Omni-directional antenna ensures that only a small percentage of the scattered signals reach the desired user. As the number of users increases, the signals that miss the intended user become interference for those in the same or adjoining cells. Omni-directional antennas offer no preferential gain for the signals of served users, rather, users compete over the signal energy and the Omni-directional antenna approach cannot selectively reject signals interfering with those of several users nor has no spatial multipath mitigation or equalization capabilities. These limitations of Omni-directional antenna regarding the quality, capacity and coverage of the wireless network led to the evolution of the conventional sector antenna in use today.

The conventional sector antenna is a directional microwave antenna with a sector-shaped radiation pattern designed to have certain fixed preferential transmission and reception directions (Rappaport, 2005). Sectorized antenna takes a traditional cellular area and subdivides it into sectors that are covered using directional antennas looking out from the same base station. The sector antenna broadcast signals in one particular direction and the coverage range is greater than in Omni-directional case, but they are used for limited-range distances of around 4 to 5km. Also, sectorized antenna system increases the possible reuse of frequency channel in a cellular system by reducing potential co-channel interference across the original cell which the Omni-directional antenna system could not reduce. One of the limitations of the sector antenna system is that since each sector uses a different frequency to reduce co-channel interference, handoffs between sectors always results and this leads to poor quality of service as witnessed today. Another limitation is that the

conventional sectorized antenna system has no capability to send maximum beam to intending user and suppress the unwanted users. Based on these limitations of the sector antenna systems in use today, smart antenna systems were introduced in mobile communication networks.

Smart antenna is an array of antennas that is capable of changing its radiation pattern dynamically to adjust to noise, interference and multi-paths in the channel (Tsoulos, 2009). Smart antenna techniques are used in acoustic signal processing, tracking, radio astronomy, radio telescopes and mostly in cellular systems like Wide band Code Division Multiple Access (W-CDMA) and CDMA20001x (Garg, 2000). Switched beam antenna and adaptive antenna arrays are the classification of smart antennas (Boukalov, 2009). Switched beam antennas are directional antennas deployed at base station of a cell. They have only a basic switching function between separate directive antennas.

Adaptive antenna arrays are antenna arrays with smart signal processing algorithm that can change their radiation pattern dynamically to adjust to the noise, interference in the channel and mitigate multipath fading effects on the signal of interest (Boukalov, 2009). Adaptive antenna uses the principle of adaptive beamforming.

Adaptive beamforming is the process of altering the complex weights to maximize the quality of the communication channel (Wells, 2006). In the adaptive beamforming process, the digital signal processor interprets the incoming data information, determines the complex weights (amplification and phase information) and multiplies the weights to each element output to optimize the array pattern. There are different beamforming algorithms which include Least Mean Square (LMS), Recursive Least Square (RLS) algorithm, Direct Matrix Inversion (DMI) algorithm (Santhi, 2009) But, this paper focused on the comparative analysis between the least mean square and recursive least square algorithms on the CDMA network.

II. Review of Related Literatures

2.1 Least Mean Square (LMS) Algorithm

The least mean squares algorithm uses the gradient based approach of beamforming. This algorithm does optimization by minimizing the mean square error while iterating the array weights. The LMS algorithm can also employ an iterative technique called the method of steepest descent to approximate the gradient of the cost function. The method of steepest descent can be approximated in terms of the weights using the LMS method. The steepest descent iterative approximation is given as (Ifeagwu, et al., 2015):

$$w(k+1) = w(k) + \mu e^*(k) x(k) \tag{1}$$

Where the error signal $e(k)$ is given by:

$$e(k) = d(k) - w^H(k)x(k) \tag{2}$$

$w(k+1)$ denotes the weighted vector to be computed at iteration $(k+1)$, $w(k)$ is the complex weight, μ is the LMS gradient step size (gain constant), $x(k)$ is the received signal vector, $d(k)$ is the desired signal at the receiver, equal to the transmitted signal. LMS gradient step size controls the convergence characteristics of the algorithm, that is, how fast and close the estimated weights approach the optimal weights. The smaller the step size the longer it takes the LMS algorithm to converge. In order to ensure the stability and convergence of the algorithm, the adaptive step size should be chosen within the range specified as:

$$0 < \mu < \frac{1}{2\lambda_{\max}} \tag{3}$$

Where λ_{\max} is the maximum eigenvalue of the input covariance matrix. The LMS algorithm requires knowledge of the desired signal $d(k)$. This can be done in a digital system by periodically transmitting a training sequence that is known to the receiver, or by using the spreading code in the case of a direct-sequence CDMA system. The LMS algorithm is important because of its simplicity and ease of computation and because it does not require off-line gradient estimations or repetition of data.

2.2 Recursive Least Square (RLS) Algorithm

This algorithm solves the problem of slow convergence rate associated with the LMS algorithm (Pettersen, 2009). Recursive Least Square algorithm has fast convergence rate especially in an environment that is changing rapidly. The dependency of this algorithm on a specific air interface decreases because it has the ability to process the input signal before demodulation. However, in RLS algorithm, the required correlation matrix and the required correlation vector can be recursively calculated. Since the signal sources can change or slowly move with time, RLS algorithms tend to deemphasize the earliest data samples and emphasize the most recent ones i.e. forgetting the earliest time samples. In RLS, μ from LMS is replaced by gain matrix. Thus, in RLS algorithm, the weights $w(k)$ are updated by equation (4) given as (Shaukat, Hassan, 2009):

$$w(k) = w(k - 1) + q(k)(e^* (k)) \tag{4}$$

where, $w(k - 1)$ is weight to be computed at iteration, $k - 1$, $q(k)$ is gain vector, and $e(k)$ is the error signal. The error signal in RLS algorithm is given as (Nwalozie et al, 2013).

$$e(k) = d(k) - w^H (k - 1)x(k) \tag{5}$$

The step required in the implementation of the LMS and RLS algorithms are summarized in Table 1

Table 1: Comparison of steps involved in the implementation of LMS and RLS algorithms

Steps taken to implement algorithms	LMS algorithm	RLS algorithm
Initialize : Compute initial weight $w(0)$	$w(k) \text{ at } k = 0$	$w(k) \text{ and } R_{xx}^{-1}(k) \text{ at } k = 0$
Compute beamformer output, $y(k)$	$w^H (k)x(k)$	$w^H (k - 1)x(k)$
Compute the error signal, $e(k)$	$d(k) - w^H (k)x(k)$	$d(k) - w^H (k - 1)x(k)$
Compute the weight at different iterations starting with $k = 0$	$w(k) = w(k + 1) - \mu e^* (k) x(k)$	$w(k) = w(k - 1) + q(k)e^* (k)$
Update the inverse correlation matrix	Not needed	$R_{xx}^{-1}(k) = \gamma^{-1} [R_{xx}^{-1}(k - 1) - q(k)x(k)$
Compute the gain $q(k)$	Not needed	$\frac{\gamma^{-1} R_{xx}^{-1}(k - 1)x(k)}{[1 + \gamma^{-1} x^H (k) R_{xx}^{-1}(k - 1)x(k)]}$

III. Materials And Method

3.0 Materials

The materials used in this paper include a practical setup of adaptive beamforming antenna system for the performance comparison of LMS and RLS of adaptive beamforming algorithms and the adaptive antenna system itself. The adaptive antenna test-bed include a single input multiple output system which consists of one transmitter and six receivers as shown in Figure 1. The major components used in the experimental setup of an adaptive antenna at 800MHz include: Functional generators TG-550 which generates the signal to be process, Transmitters TXM-918-ES, Antennas (transmitting and receiving) ANT-918-CW-QW, Receivers RXM-918-ES, data acquisition board (hardware) PCI-6502E (peripheral component Interconnect [PCI] interface module) and data acquisition tool (software) in MatLab (in a PC). The data acquisition hardware was used in acquiring the signal from the receiver and uploading to the PC for post processing.

The hardware part was used to collect real data measurements of the signals incident on the smart antenna sensor array. The signal was generated at the transmitter (single) as an input signal at 800 MHz and sent to the receiver (multiple antenna system) wirelessly. The receivers (six), were spaced apart at half wavelength to reduce the effect of inter-element coupling and situated horizontally to receive the incoming signal. The information signal was captured using a Data Acquisition board (DAQ) and then uploaded to a PC for post-processing. The measured data were processed in MATLAB which were used to predict the performance of various adaptive algorithms and the smart antenna system being investigated. The transmitters, antennas and receivers used operate at 800MHz.

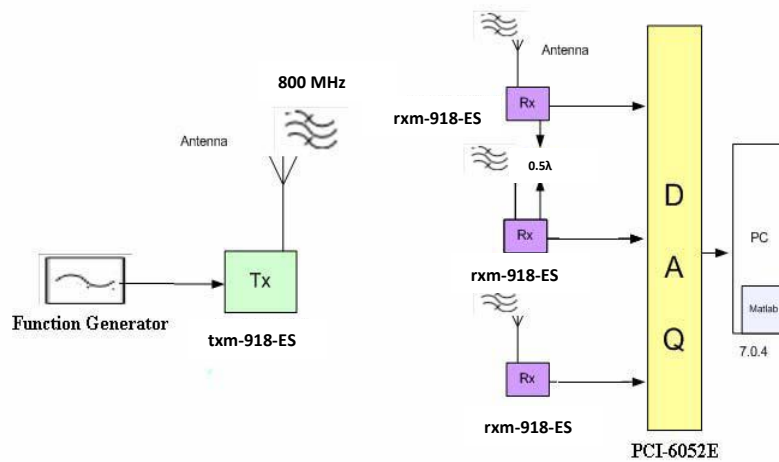


Figure 1: The developed adaptive beamforming antenna hardware system

3.2 Method

In order to have a comparative study of the performance of the LMS and RMS adaptive beamforming algorithms on the CDMA based network, the two adaptive algorithms were simulated and evaluated for 6 uniform linear array elements in MATLAB version 7.5. In the simulation, 6 uniform array elements with inter-element spacing $d=0.5\lambda$ were used on a CDMA based network. In the simulation, the angle of arrival of the desired signal and the interfering signal were at 30° and -60° respectively. The desired signal was summed to be a complex sinusoidal phase modulated and the interfering signal was assumed as random signal. For simplicity, the reference signal was assumed to be the same as the desired signal. Simulations were also done to observe the number of iterations it took both the LMS and RLS algorithm to converge. The steps required in implementing the LMS and RMS algorithms during simulation are shown in Table 1.

IV. Results And Discussion

4.1 Results

The weights of six antenna elements obtained from the implementation of the LMS and RLS adaptive beamforming algorithms are as shown in Table 2. Figure 2 shows the mean square error versus number of iterations plot for LMS algorithm while Figure 3 shows the Mean square error versus number of iterations for RLM algorithm. Figure 4 shows array factor against the angle of arrival using the LMS algorithm. Figure 5 shows array factor against the angle of arrival using the RLS algorithm.

Table 2: The weight updates for 6 uniform linear array antenna elements

Elements (N)	Weight update (LMS)	Weight update (RLM)
1	$1.2053 - 0.16i$	1.0000
2	$0.060383 + 0.78118i$	$0.2853 - 1.2732i$
3	$-0.69623 - 0.058965i$	$-0.4089 + 0.0238i$
4	$0.27167 - 0.54308i$	$0.4875 + 0.6410i$
5	$0.62374 + 0.45644i$	$0.7568 - 0.5431i$
6	$-0.543016 + 0.85068i$	$-0.4253 - 0.9647i$

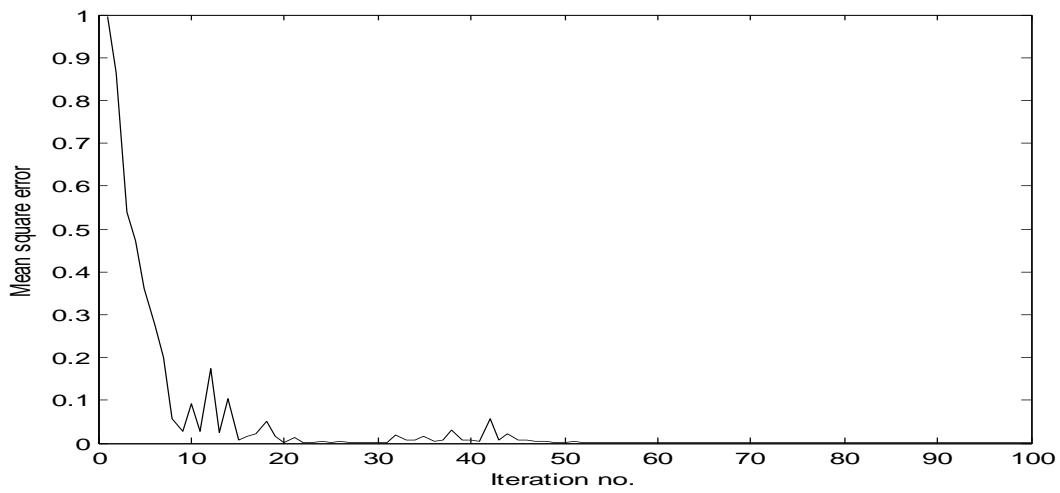


Figure 2: Mean square error versus number of iteration plot for LMS algorithm.

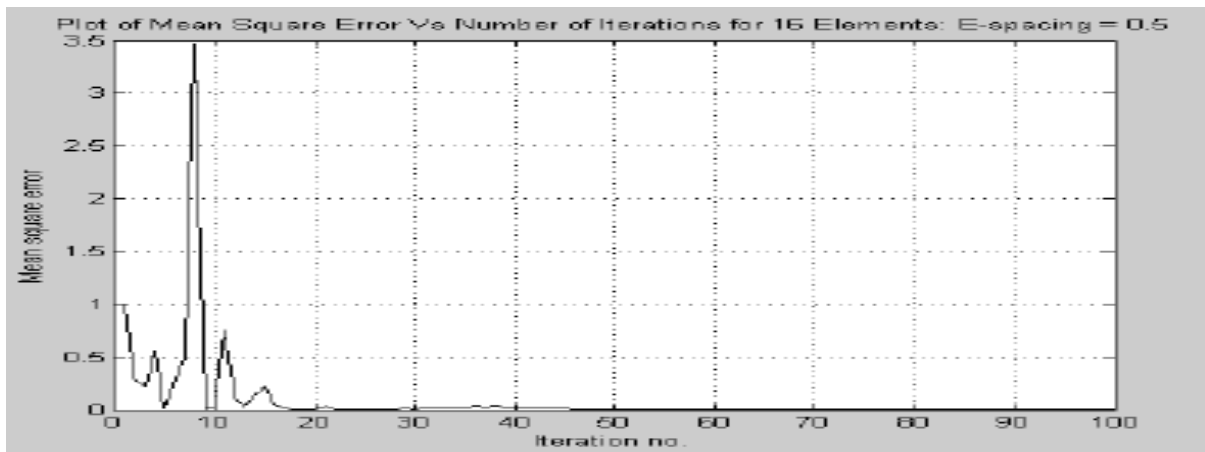


Figure 3: Mean square error versus number of iterations for RLM algorithm.

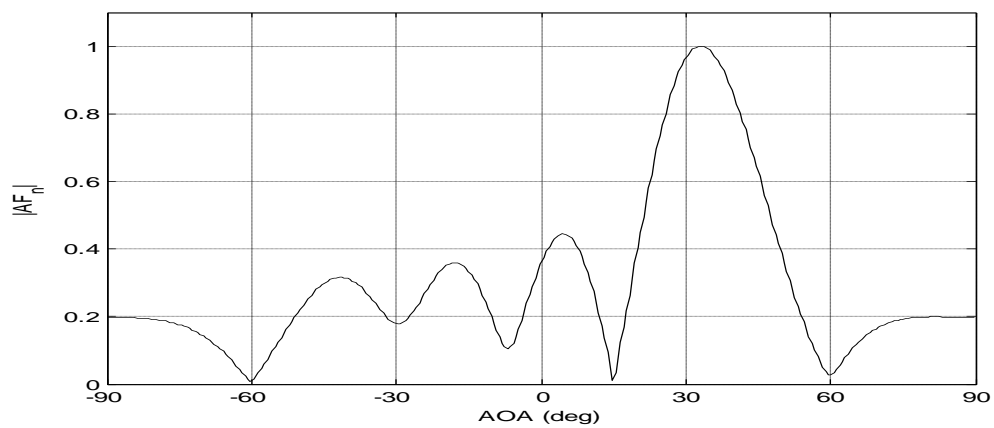


Figure 4: Array factor against the angle of arrival using the RLS algorithm

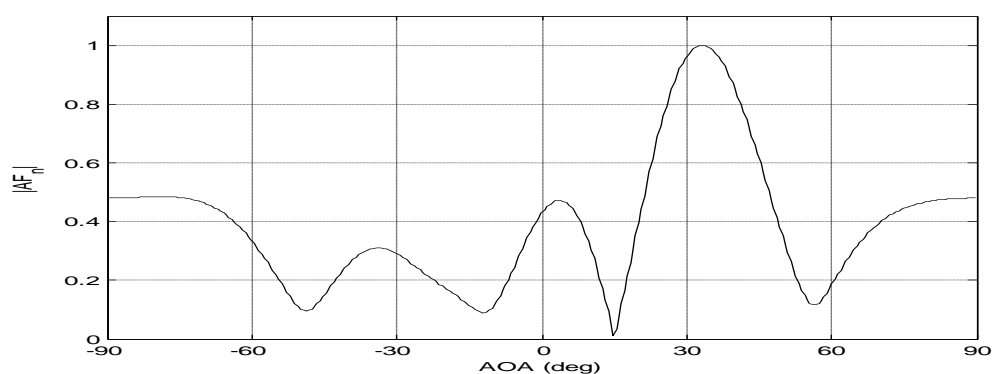


Figure 5: Array factor against the angle of arrival using the LMS algorithm

4.2 Discussion

In Figure 2, the LMS algorithm starts to converge from iteration number 50 while in Figure 3, the RLS starts to converge from iteration number 20. That showed that the RLS adaptive beamforming algorithm can achieve faster convergence than the LMS. Also, the recursive least Square error was almost 0.001 at 20 iterations, while LMS error was almost 0.025 at 20 iterations. The fast convergence of RLS proves that RLS algorithm has lower bit error rate and error signal magnitude and therefore can perform better than the least mean square algorithm on a CDMA network in reducing network interference.

Figures 4 and 5 showed that the beam (main lobe) was formed in the direction of the desired user at 30° . As noticed in Figure 5, no null was formed towards the direction of the interferer at -60° with LMS algorithm, but in Figure 4, a complete null was formed in the direction of the interferer at -60° using RLS algorithm.

V. Conclusion

This paper has shown a comparative study of the two adaptive algorithms on a CDMA network. In this paper, the beamforming algorithms were successfully simulated using MATLAB version 7.5. Simulation results were obtained for array outputs versus the angle of arrival and plots of mean square error versus number of iterations. Results showed that LMS algorithm can be used in updating the combining weights of the antenna. But, its slow convergence provides acquisition and tracking problems for cellular systems. Although the LMS algorithm has easy computation, simplicity in implementation, requires power control but does not require repetition of data. Thus, the fast convergence rate of RLS algorithm enables satisfactory services with less latency on the communication network. The advantage of RLS over LMS is that it allows for easy updates of the inverse of the correlation matrix.

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