

# Design and Simulation of a Novel Multistage Beamforming Algorithm for Mobile Communication

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**ABSTRACT:** Adaptive arrays are antenna arrays with smart signal processing techniques, which are used in many wireless communication applications. Many signal processing techniques have been used to steer the array pattern in look direction by adjusting the weights of the signal without user intervention. Weights of signal processor can be automatically adjusted by simple adaptive beamforming techniques. One of the most commonly used beamforming technique is least mean square (LMS) algorithm. LMS algorithm has low computational complexity. However, its convergence rate is slow. In this paper a novel implementation scheme for LMS algorithm is simulated, which decreases the mean square error (MSE) and increases convergence speed. This proposed algorithm is called four stage LMS algorithm. Four stage LMS algorithm for beamforming is simulated using MATLAB and compared with existing LMS and dual stage LMS algorithm. From simulation results we infer that the convergence of proposed algorithm is better compared to LMS and dual stage LMS algorithms.

**Keywords:** Adaptive arrays, Beamforming, LMS algorithm, Convergence

## I. INTRODUCTION

Wireless networks face ever-changing demands on their spectrum and infrastructure resources. Increased number of wireless subscribers and introduction of high rate data services increases the wireless traffic in the network. This becomes a major challenging problem for the service provider to solve. The deployment of smart antennas or adaptive antennas for wireless communications [1], [2], has emerged as one of the leading technologies for achieving high efficiency networks that maximize capacity and improve quality and coverage. Adaptive antennas combine many antenna elements with signal processing strategies that vary the way in which those elements are used. Beamforming is the method used to create the radiation pattern of antenna array by adding constructively the phases of the signals in the direction of the target or desired user nulling the pattern in the direction of undesired or interference target. Both relative amplitude and phase shift called complex weight are adjusted to control the array pattern. Altering the complex weights for maximum power dissipation in desired direction is done by using several adaptive signal processing techniques.

The most commonly used signal processing technique for adaptive beamforming is LMS algorithm [3]. Several modifications were made to the basic LMS algorithm the most recent being the dual stage LMS algorithm [4]. Though LMS and dual stage LMS algorithms have low computational complexities, they have lower convergence rate. Hence, in this paper a modified dual stage LMS called four stage LMS algorithm is proposed which provides excellent convergence compared to LMS and dual stage LMS algorithms.

## II. GENERAL METHODOLOGY OF BEAMFORMING

The general methodology of beamforming is shown in Fig. 1, which consists of an array of M antenna elements or beamformer. A beamformer is a collection of sensors or antennas which are linearly arranged so that their output can be steered electronically. The received signal at these sensors is used to compute the complex weights which are adaptively updated based on signal samples.

As shown in Fig.1, the output of the array  $y(n)$  is the weighted sum of the received signals  $X_k(n)$  at the array elements and the array weights  $W_k(n)$ , where  $k=1,2, \dots, M$  and M is number of antenna elements. The array weights  $(W_1, W_2, \dots, W_M)$  are iteratively computed based on array output  $y(n)$ , a reference signal  $d(n)$  that approximates the desired signal and previous weights. The array output is given by

$$y(n) = W^H(n) x(n) \quad (1)$$

where,  $W^H$  denotes the hermitian transpose of the weight vector  $W$ .

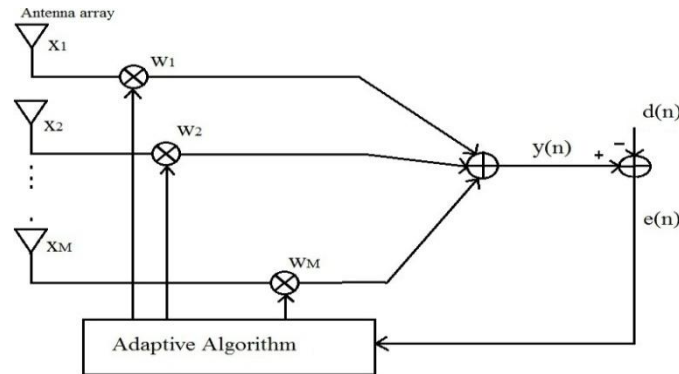


Fig.1 Smart antenna receiver.

The received signal  $x(n)$  is given by

$$x(n) = a_{\theta} d(n) + \sum_{k=1}^M a(\theta_k) i(n) + n_k(n) \quad (2)$$

where,  $a_{\theta}$  is the desired steering vector,  $d(n)$  is the reference signal,  $a(\theta_k)$  is the interference steering vector,  $i(n)$  is the interference signal and  $n_k(n)$  is the noise signal. The error  $e(n)$  is used to calculate new weights and is given by

$$e(n) = d(n) - y(n) \quad (3)$$

### III. DUAL STAGE LMS ALGORITHM

Dual stage LMS beamforming algorithm [4], comprises two LMS algorithm sections, LMS1 and LMS2. An array image factor  $F$  of the desired signal is sandwiched between the two LMS algorithm blocks as shown in Fig. 2. The incoming signal is multiplied with the weights generated by LMS1 processing section resulting in  $y_{LMS1}$ . The intermediate output yielded from LMS1 is multiplied with the array factor  $F$ , of the desired signal. Array factor  $F$ , is used to calculate the weights of LMS2. The resultant filtered signal is further processed by second LMS or LMS2 algorithm section. As shown in the figure common external reference signal is used for both the LMS processing sections, i.e.,  $d_1$  and  $d_2$ . The difference between the LMS1 output  $y_{LMS1}$  and the reference signal  $d_1$  results in error signal  $e_{LMS1}$ . Similarly, the error signal  $e_2$  is the difference between LMS2 algorithm section output  $y_{LMS2}$  and reference signal  $d_2$ . For the purpose of adaptation error signal of LMS2 algorithm section is fed back to combine with that of LMS1 algorithm, to form the overall error signal  $e_{LMS}$ . As a result the dual stage LMS algorithm converges in less number of iterations.

The received signal or array input to LMS1 section is given as

$$X_1(t) = [x_{1,1}(t), x_{1,2}(t), \dots, x_{1,M}(t)]^T \\ = A_d S_d(t) + A_i S_i(t) + n(t) \quad (4)$$

where  $S_d(t)$  is desired signal,  $S_i(t)$  is interference signal and  $n(t)$  is noise,  $A_d$  and  $A_i$  are factor for the desired and interference signal respectively.

LMS1 section output at  $k^{th}$  iteration is given as

$$y_{LMS1}(k) = W_1^H(k) X_1(k) \quad (5)$$

where  $W_1^H(k)$  represents the hermitian of weight vector of LMS1 algorithm section. The update equations of LMS processing blocks is given as

$$W_i(k + 1) = W_i(k) + \mu e_i(k)X_1(k) \quad (6)$$

where  $i=1$  for LMS1 algorithm and  $i=2$  for LMS2 algorithm,  $\mu$  is the step size and  $e_i(k)$  is the error signal given as

$$e_1(k) = d_1(k) - y_{LMS1}(k) \quad (7)$$

where  $y_{LMS1}$  is the output of LMS1 algorithm section and is given as

$$y_{LMS1}(k) = W_1^H(k)X_1(k) \quad (8)$$

The error signal  $e_2$  is given as

$$e_2(k) = d_2(k) - W_2(k)X_2(k) \quad (9)$$

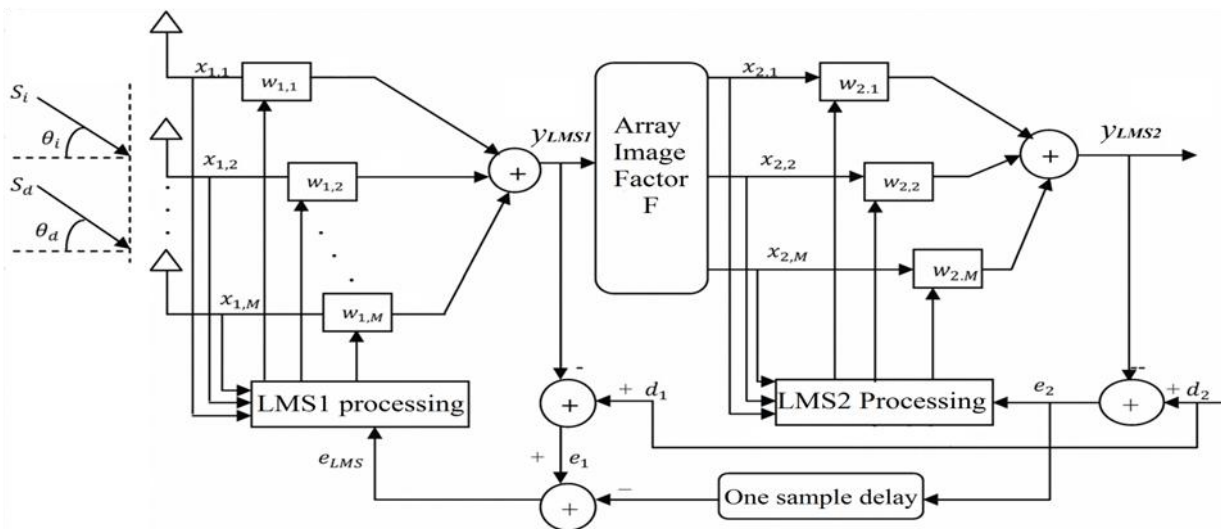


Fig.2 Dual stage LMS algorithm for beamforming.

where  $X_2(k)$  is the input to LMS2 and is given as

$$X_2(k) = Fy_{LMS1}(k) = FW_1^H(k)X_1(k) \quad (10)$$

The array image factor  $F$  is calculated by the equation

$$F = \frac{x'_{1,k}(t)}{w_{1,k}(t)y_{LMS1}(t)+c} \quad (11)$$

where  $c=0.0001$  a constant. The overall error  $e_{LMS}$  of dual stage LMS algorithm at  $k^{th}$  iteration is given as

$$e_{LMS}(k) = e_1(k) - e_2(k - 1) \quad (12)$$

This overall error  $e_{LMS}$  is fed back to LMS1, as a result number of iterations required by dual stage LMS algorithm to converge is reduced.

#### IV. THE PROPOSED ALGORITHM

This section presents a modified dual stage LMS algorithm for beamforming. The proposed scheme is called four stage LMS algorithm as shown in Fig.3, it consists of two LMS blocks LMS1 and LMS2 along with two more blocks namely LMS1 speediness module or simply speediness module (SM) and LMS2 speediness module or simply converge

speediness module (CSM). Both LMS1 and LMS2 employs conventional LMS algorithm using array weights update equation given by

$$w(k + 1) = w(k) + 2\mu x(k)e(k)$$

$$e(k) = d(k) - x^H w(k) \tag{13}$$

where  $x(k)$  is the input signal vector,  $\mu$  is the step size,  $w(k)$  is the weight vector,  $e(k)$  is the error signal and  $d(k)$  is the reference signal.

The LMS section is used to find the proper weight vector  $w_k$ , which reduces the mean square error of the system output and reference signal. When LMS algorithm reaches stable state, the weight vector  $w_k$  or  $w_{LMS}$  would be stable i.e. ,

$$\lim_{k \rightarrow \infty} \frac{w_{k-1} - w_s}{w_k - w_s} = \text{const}, k = 1, 2, \dots \tag{14}$$

where  $k$  is number of iterations, and  $w_s$  is the stable weight vector. We choose Aitken method for LMS1 speediness module or speediness module (SM) because the restrictive condition of Aitken method is satisfied by (14) which results in good performance and quick convergence.

#### A. Principle of Operation

As shown in Fig.3, LMS1 section and LMS2 section are operating in parallel. The converse speediness module (CSM) calculates the weight vector  $w_{CSM}$  by taking into account the weight vector  $w_{LMS1}$  of LMS 1. Then the weight vector  $w_{CSM}$  is forwarded to LMS2. The weight vector of CSM  $w_{CSM}$  is much closer to the stable state vector  $w_s$  than the weight vector  $w_{LMS2}$ . Again the weights of LMS2 are given to speediness module, which helps in increasing the convergence of LMS1 algorithm. As a result the overall convergence is greatly increased.

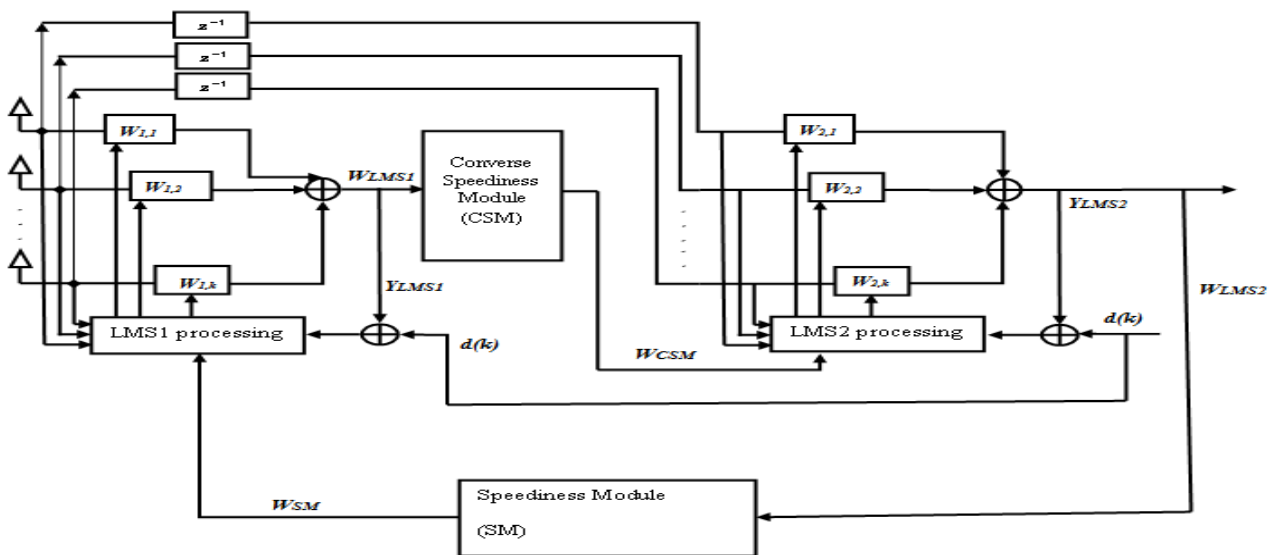


Fig.3 Four stage LMS algorithm.

#### 1) LMS2 Speediness Module or Converse speediness module

Using equation (13) and simplifying we get

$$w(k + 1) = [I - 2\mu x x^H] w(k) + 2\mu x d(k) \tag{15}$$

let  $R_k = x x^H$  and  $p_k = d(k)x$ , then equation (15) becomes

$$w(k + 1) = [I - 2\mu R_k]w(k) + 2\mu p_k \tag{16}$$

Defining  $M_k = I - 2\mu R_k$  and  $N_k = 2\mu p_k$  we get

$$w(k + 1) = M_k w(k) + N_k \tag{17}$$

Formulating from (17) and replacing  $w(k + 1)$  with weight vector  $v(k + 1)$ , which are weights of LMSII also denoted as  $w_{LMS2}$  we get

$$w_{csm}(k + 1) = w_{csm}(k) + ([I - 2\mu_{csm} R_k]^{-1}[v_k - 2\mu p_k]) \tag{18}$$

where  $w_{csm}(k + 1)$  are  $L \times 1$  updated array weights,  $I$  is  $L \times L$  identity matrix,  $\mu$  is the step size.

## 2) SpeedinessModule(SM)

In speediness module to calculate the array weights we use Aitkin method [5], given by

$$w_{sm} = \psi(\psi(w_k)) - \frac{\text{power}\{\psi(\psi(w_k)) - \psi(w_k)\}}{\psi(\psi(w_k)) - 2\psi(w_k) + w_k} \tag{19}$$

where

$$\psi(w_k) = M_k w_k + N_k \tag{20}$$

substituting equation (20) in equation (19) and simplifying we get

$$w_{sm} = v_{value} - \frac{N_{value}}{D_{value}} \tag{21}$$

where

$$N_{value} = M_k (M_k w_{LMS1} + N_k - w_{LMS1}),$$

$$D_{value} = M_k (M_k w_{LMS1} + N_k - 2w_{LMS1}) - N_k + w_{LMS1},$$

$$\text{and } v_{value} = M_k (M_k w_{LMS1} + N_k) + N_k.$$

## B. Implementation Methodology

The implementation methodology for four stage LMS algorithm consists of two modules of LMS as well as two new modules executing in parallel with different method of array weights calculation as summarized in Table. I

TABLE I  
FOUR STAGE LMS ARRAY WEIGHTS ESPRESSIONS

Modules of Four Stage LMS	Weight Equations
CSM	$w_{csm}(k + 1) = w_{csm}(k) + ([I - 2\mu_{csm} R_k]^{-1}[v_k - 2\mu p_k])$
LMS1	$w(k + 1) = w(k) + 2\mu x(k)e(k)$
SM	$w_{sm} = v_{value} - \frac{N_{value}}{D_{value}}$
LMS2	$w(k + 1) = w(k) + 2\mu x(k)e(k)$

### V. SIMULATION RESULTS

The evaluation of beamforming algorithms is done by means of MATLAB simulations. LMS and dual stage LMS algorithms for beamforming are simulated in MATLAB and results obtained are compared with proposed algorithm. The simulation parameters are as shown in Table. II, with the assumptions that look direction and jammer directions are known a prior and distance between antenna elements is  $0.5\lambda$  to avoid grating lobes.

TABLE II  
SIMULATION PARAMETERS

Type of antenna elements	Uniform linear array
Number of antenna elements in array	50
Look direction	$40^0$
Jammer directions	$10^0, 60^0$
Spacing between antenna elements	$0.5\lambda$
Directional range of beamformig	0 to $\pm 90^0$

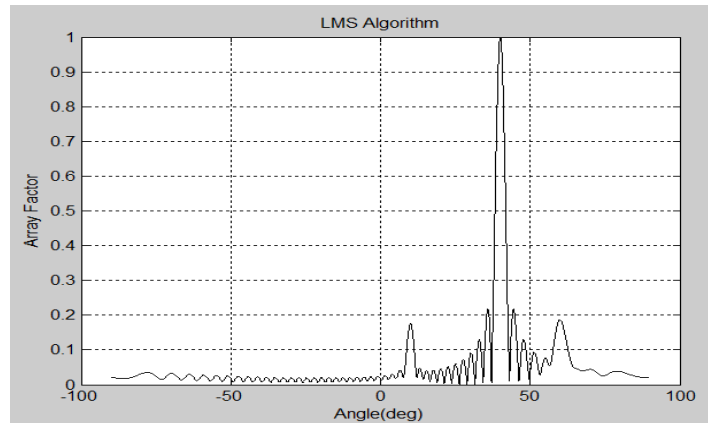


Fig. 4 Beam plot of Dual stage LMS algorithm.

From Fig.4 it is evident that dual stage LMS is able to form main beam in desired direction ( $40^0$ ) and small radiations in jammer directions.

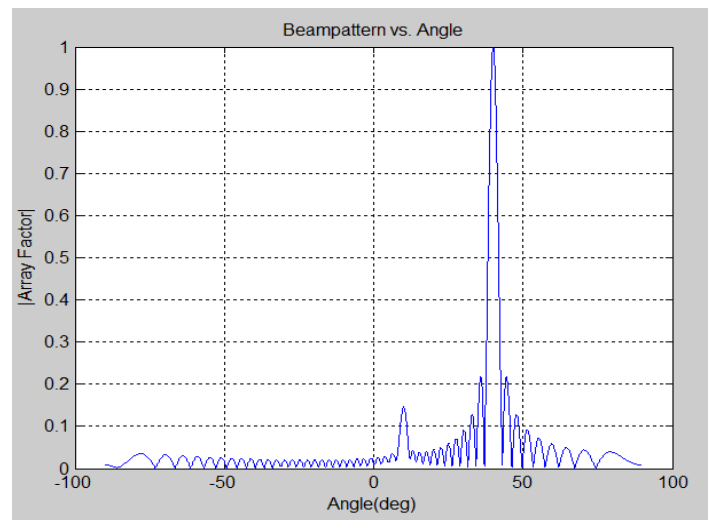


Fig. 5 Beam plot of Four stage LMS algorithm.

From Fig.5 it is evident that Four stage LMS algorithm is able to form main beam in desired direction ( $40^{\circ}$ ) and relatively small radiations compared to dual stage LMS in jammer directions.

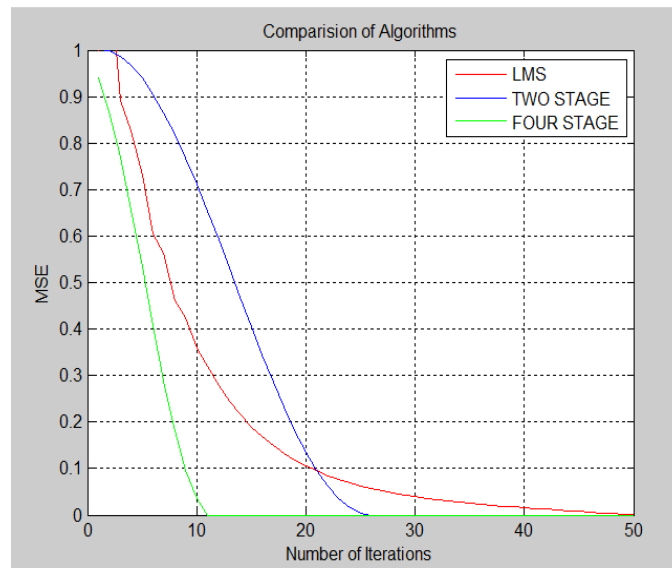


Fig. 6 Convergence behaviour of LMS, Dual stage LMS and Four stage LMS beamforming algorithms.

According to Fig.6 it is clear that the MSE cure of LMS algorithm takes 50 iterations to converge and dual stage LMS takes 25 iterations, while the proposed four stage LMS takes around 11 iterations to converge. Hence the proposed algorithm is efficient in terms of convergence compared to conventional beamforming algorithms.

## VI. CONCLUSION

The proposed algorithm for beamforming called Four stage LMS algorithm is simulated and analysed. The proposed algorithm is does well in forming main beam in look direction and nulls in jammer directions. The proposed algorithm also have high rate of convergence compared to dual stage LMS and conventional LMS algorithm. Therefore, the proposed algorithm is best suited for beamforming as it can track the desired signal in less number of iterations, than the conventional beamforming algorithms.

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## BIOGRAPHY

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