Performance of Variable Step-Size LMS Algorithm for Beamforming of Smart Antenna of Dipole Array

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Abstract. This paper describes a performance comparison of least mean square (LMS) and variable least mean square (VSLMS) technique for beam formation for smart antenna of dipole array. In 4G and 5G cellular communication, 'smart antenna is one of the important technologies'. Due to increased traffic densities, accurate beam formation and interference reduction in a cellular area became one of the tasks of the cell site antenna system. After determining direction of arrival (DOA) of user's signal smart antenna forms beam toward the user and null toward the interferer using some effective digital signal processing algorithm. In this paper, investigation on the performance of VSLMS algorithm for adaptive beamforming of smart antenna of dipole array is presented. It is found that for interference reduction lower side lobe level (SLL) can be obtained using VSLMS algorithm compared to LMS algorithm. Maximum 3 dB lower SLL is achieved using VSLMS compared to LMS algorithm. The investigation, presented here, is useful for cellular network.

Keywords: Smart antenna · Beamforming · Dipole array · Variable step-size LMS algorithm · Side lobe level

1 Introduction

To improve the channel capacity and enhance the spectrum utilization, optimization of the system is obligatory. A smart antenna has the property of spatial filtering of forming beam toward a particular direction and of suppressing radiation in other directions. The use of smart antenna also helps in cancellation of an unwanted jamming signal produced by the transmitter apart from the desired signal direction. Adaptive smart antenna is capable of beam steering in any direction according to the DOA and generating a null in the interferer's direction [1–4]. Various beamforming algorithms are used for the signal and null generation [5–7]. Most popular algorithm for adaptive beamforming is LMS algorithm. In a variable step-size algorithm, step-size varies with number of iteration and various types of variable step-size algorithms are found in literature [8–12]. But most of these cases, algorithms are applied for smart antenna of isotropic

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elements. Some papers reported beam-forming of smart antenna of dipole array using LMS and other algorithms [13–17]. But still investigations on performances of variable step-size algorithms for smart antenna of dipole array are relatively less. In this paper, VSLMS algorithm is used for forming radiation of smart antenna of dipole array. Dipole arrays of 16 elements and 20 elements are considered here and the array is a co-linear dipole array where dipoles are oriented along the line of array. The simulation results for beamforming using VSLMS algorithm are compared with those obtained using LMS algorithm. Better results for VSLMS algorithms are achieved. MATLAB is used for simulation.

2 Variable Step-Size Least Mean Square Algorithm

In adaptive signal processing 'Least mean square (LMS)' algorithm is the simplest technique used for updating the weights during iteration. It is used to determine the minimum error e(n) between desired signal d(n) and array output y(n), as [9].

$$e(n) = d(n) - y(n) \tag{1}$$

In LMS algorithm weight updating equation is

$$w(n + 1) = w(n) + \mu x(n)\, e^*(n) \tag{2}$$

Where, μ denotes the step size parameter and the complex conjugate of e(n) is denoted as e*(n) with the received signal by the antennas as $x(n) = [x_1(n), x_2(n), \ldots, x_N(n)]$

In VSLMS algorithm, in every iteration, during weight updating, step-size parameter varies as [10].

$$\begin{aligned} \mu(n+1) &= \alpha\, \mu_n + \delta \varepsilon_n, \ \text{if } 0 < \mu_{n+1} < \mu_{max} \\ &= \mu_{max}, \qquad \text{otherwise} \end{aligned} \tag{3}$$

maximum value of convergence parameter, μ_{max} is defined as $\mu_{max} < 2/\lambda_{max}$ and is the largest λ_{max} is the maximum eigen value of the correlation matrix of the signal. Here, 'α' and 'δ' are constant parameters and in simulation, the best results are found for $\alpha = 0.95$ and $\delta = 0.0003$.

The factor ε_n in (3) is related to the weight vectors as

$$\varepsilon_n = ||w(n+1) - w(n)|| / ||w(n+1)|| \tag{4}$$

VSLMS algorithm updates weight according to the relation [10].

$$w(n+1) = w(n) + \mu_{n+1} x(n) e * (n) \tag{5}$$

The range of step size μ is

$$0 < \mu < 1/\lambda_{max} \tag{6}$$

Where λ_{max} is calculated from array correlation matrix R, i.e. λ_{max} = tr[R], where tr [R] denotes the trace of R.

3 Beamforming of Smart Antenna of Dipole Array

The half-wave dipole antennas with uniform linear array of ‘d’ inter-element spacing is shown below in Fig. 1. In this array the dipole array is a co-linear dipole array.

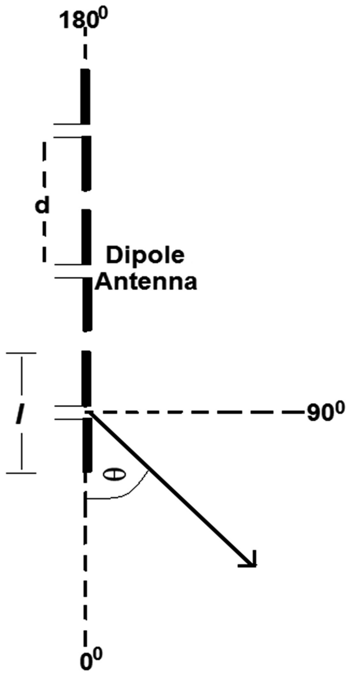


Fig. 1. Co-linear dipole array

For a dipole antenna of length ‘l’, the radiated electric field is expressed as [18]

$$E(\theta) = j\eta \frac{I_0 e^{-j\beta r}}{2\pi r} \left[\frac{\cos\left(\frac{\beta l}{2} cos\theta\right) - \cos\left(\frac{\beta l}{2}\right)}{sin\theta} \right] \tag{7}$$

Where

$\beta = 2\pi/\lambda$ is the propagation constant, I_0 is current amplitude fed to the dipole antenna, η is the free space impedance (120 πΩ), r is the distance of the observation point from the antenna array.

For N number of dipole antennas, the total radiated field, is given by

$$E_{total} = E(\theta)\ AF(\theta) \tag{8}$$

where, E(θ) is expressed by Eq. (7) and array factor is given by

$$AF(\theta) = \sum_{n=1}^{N} I_0 e^{j(n-1)\left(\frac{2\pi d}{\lambda}cos\theta + \alpha\right)} \tag{9}$$

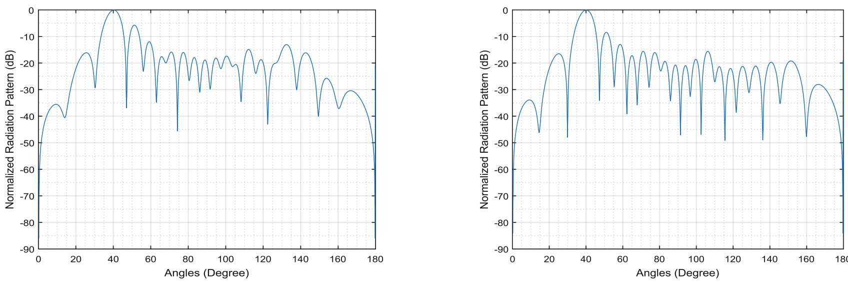
where λ is the wavelength, α is the progressive phase shift of the array and I_0 is the current fed to the antennas and it is assumed that all the antennas are fed by equal current I_0.

Above equation for $E_{total}(\theta)$ is the cost function for adaptive beamforming and normalized radiation pattern is

$$RP_{norm} = 20log_{10}\left[\frac{E_{total}(\theta)}{maxE_{total}(\theta)}\right] \tag{10}$$

For beamforming Eq. (10) with Eq. (7) are considered using adaptive signal processing algorithm.

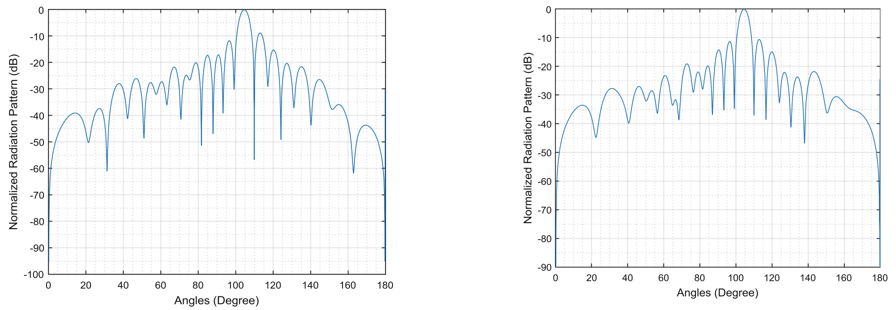
Adaptive beamforming results for smart antenna of λ/2 dipole array in various beam directions (BD) null directions(ND) are plotted in Fig. 2 and in Fig. 3 with number of dipoles 20 (N = 20).



(a)LMS Algorithm (b)VSLMS Algorithm

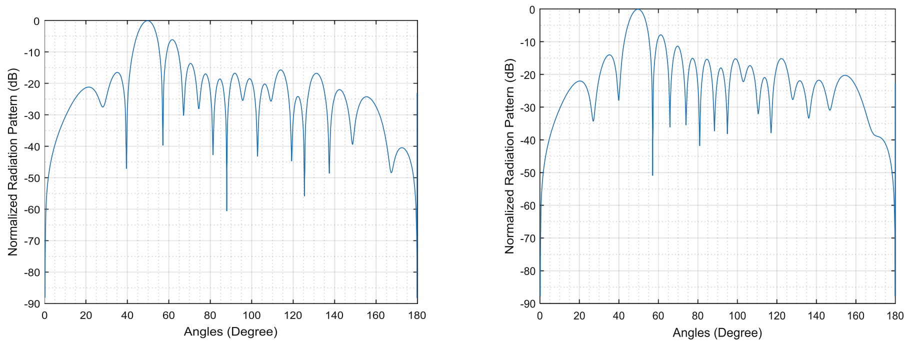
Fig. 2. Radiation pattern for N = 20, BD = 40°, ND = 47°, d = 0.5λ

Similarly, adaptive beamforming results for smart antenna of λ/2 dipole array in various beam directions (BD) null directions(ND) are shown in Fig. 4 and in Fig. 5 with number of dipoles 16 (N = 16).



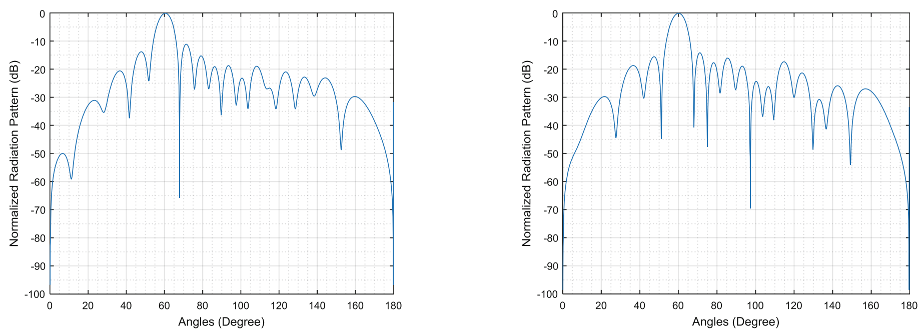
(a)LMS Algorithm (b) VSLMS Algorithm

Fig. 3. Radiation pattern for N = 20, BD = 105°, ND = 110°, d = 0.5λ



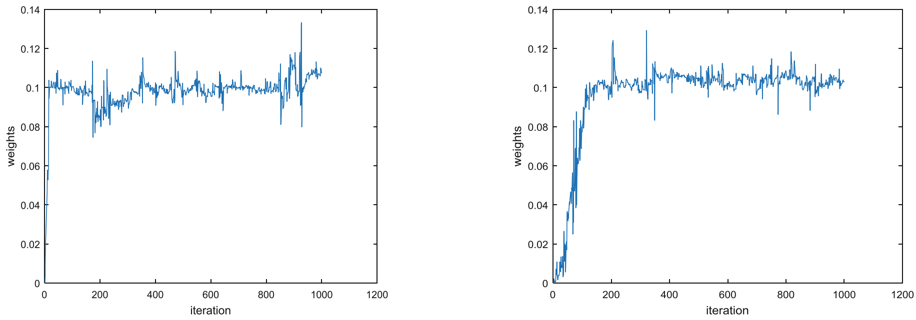
(a) LMS Algorithm (b) VSLMS Algorithm

Fig. 4. Radiation pattern for N = 16, BD = 50°, ND = 57°, d = 0.5λ



(a) LMS Algorithm (b) VSLMS Algorithm

Fig. 5. Radiation pattern for N = 16, BD = 60°, ND = 68°, d = 0.5λ

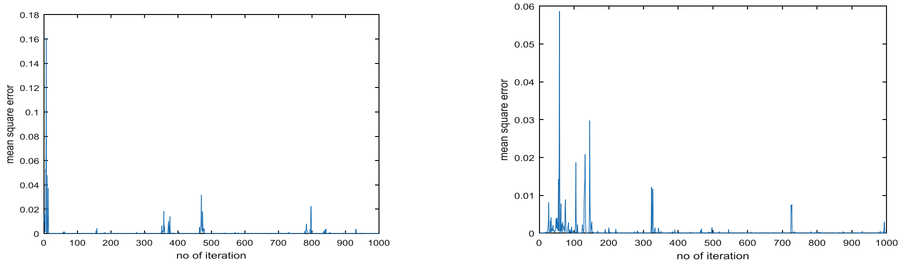


(a) LMS (b) VSLMS

Fig. 6. Variation of weight for N = 20, BD = 40°, ND = 47°, d = 0.5λ

The variation of weight for LMS and VSLMS algorithms are shown in Fig. 6(a) and in Fig. 6(b).

Simulated error plots for LMS and VSLMS algorithms are shown in Fig. 7(a) and in Fig. 7(b) respectively.



(a) LMS (b) VSLMS

Fig. 7. Mean square error for N = 20, BD = 40°, ND = 47°, d = 0.5λ

The variations of step-size with iteration number are shown in Fig. 8 and in Fig. 9.

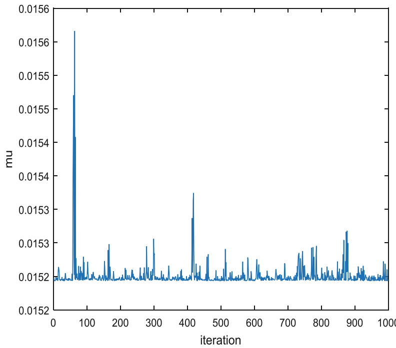


Fig. 8. Variation of step size for N = 16, BD = 60°, ND = 68°, d = 0.5λ

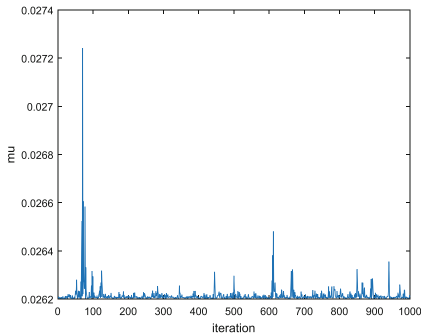


Fig. 9. Variation of step size for N = 20, BD = 40°, ND = 47°, d = 0.5λ

Simulated results with spacing of 0.5λ are compared in Table 1 for different beam direction (BD) and null direction (ND).

Table 1. Comparison of simulated results

Comparison of simulated results	LMS			VSLMS		
Desired angles (Deg)	Obtained angle (Deg)	Obtained Null (Deg)	SLL_{max} (dB)	Obtained angle (Deg)	Obtained Null (Deg)	SLL_{max} (dB)
N = 20, BD = 40, ND = 47	40.2	46.9	−5.7	40.0	47.3	−8.3
N = 20, BD = 105, ND = 110	104.6	110	−8.8	104.6	110.	−10.6
N = 16, BD = 50, ND = 57	49.6	57	−6.0	49.5	57	−7.9
N = 16, BD = 60, ND = 68	60.54	68.1	−11.0	60.2	68	−14.0

From the above table it is evident that in lower SLLs are achieved using VSLMS algorithm compared to LMS algorithm. Maximum SLL (SLL_{max}) difference between VSLMS and LMS algorithm is 3 dB.

4 Conclusion

The adaptive beamforming of smart antenna of co-linear dipole array is presented in this paper using VSLMS algorithm. In this simulation, resonant frequency of the array is taken to be 1800 MHz and wavelength is 16.66 cm. Number of iteration in all the cases is 1000. Performance of VSLMS algorithm is better than LMS algorithm. Since in both the adaptive algorithms, weight updating is random, therefore, the best results after a large number of run are presented in this paper. Also it is observed in both the algorithms that the desired beam directions cannot be achieved towards the angles very close to extreme ends 0° and 180. This is due to the inherent property of radiation field of dipole antenna. The investigation, presented here, may be useful for adaptive smart antenna design for the application in cellular network.

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