Comparative Analysis of Adaptive Beamforming Algorithms for Wireless Communication

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Abstract— The field of wireless communication has shown a tremendous growth with the increase of mobile and wireless services in recent past. Adaptive antenna plays an important role in improving wireless services in urban and densely populated areas. An array of antenna combined with digital signal procesor is known as adaptive antenna. Adaptive antenna optimizes the array pattern according to the changing electromagnetic environment. In this article, the signal processing aspect of adaptive antenna i.e. adaptive beamforming is studied and compared. The performance of Least mean square (LMS), Constant modulus (CM), Conjugate gradient (CG) and Quasi newton (QN) algorithm are compared in terms of their beam pattern characteristics and their rate of convergence. The simulation result shows that beamwidth decreases with the increase of array elements. The LMS and CG have more null depth compared to CM and QN algorithm. CG algorithm have the fastest rate of convergence among the other three algorithms.

Index Terms — Adaptive antenna, adaptive beamforming, LMS, RLS, CMA, CGM, QNA, wireless communication.

1 INTRODUCTION

In the modern era of wireless communication there has been a substancial increase in the wireless internet and cellular services. With the introduction of LTE (long tern evolution) network and 5G technology in near future, it is foreseen that in the future an enormous rise in traffic will be experineced for mobile and personal communication systems. This has become a challenging task for service providers to meet the requirement of present wireless communication. Adaptive antenna [1, 2, 3] has emerged as one of the leading technologies which achieves higher data rate, higher capacity, improved quality and coverage. In the last few years worldwide researchers have shown more interest in the area of adaptive antenna and multiple input and multiple output (MIMO) technology. The two signal processing aspects of adaptive antenna are direction of arrival (DOA) estimation and adaptive beamforming (ABF). There exists numerous DOA estimation algorithms such as capon, multiple signal classification (MUSIC), estimation of signal parameters via rotation invariance technique(ESPRIT), matrix pencil, maximum likelihood technique. In [4, 5] authors have compared the performance of all related DOA estimation technique. ABF technique optimizes the weights (amplitude and phase) of antenna array so as to focus the pattern maxima in the direction of intended user and nulls in the direction of interfering signals. ABF techniques takes the fixed beamforming approaches one step further and calculates the array weights on the fly basis. In [6, 7] authors have analyzed the performance of ABF algorithms. The ABF algorithms are categorised on the basis of their working principle. Some algorithms alter the radiation pattern characterisitcs i.e. their side lobe level, null depth, direction of main beam and nulls, beamwidth on the basis of minimizing the mean square error between the desired signal and the array output while some algorithms utilizes the property of refernce signal. The ABF techniques recalculate the antenna array weights on the basis of the dierction of incoming signals, means as the direction of incoming signal changes the weights of antenna array are optimized. Figure 1 shows the adaptive beamforming network.

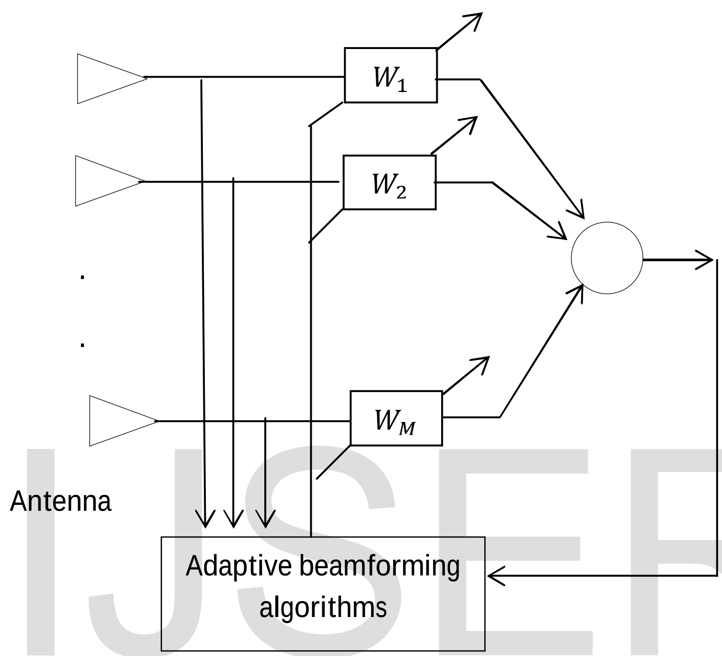

Figure 1. Adaptive beamforming network

The paper is organised in the following man-ner. Section 2 briefly discusses the adaptive beamforming algorithms. Section 3 presents the simulation results and comparative analysis of all the discussed ABF algorithms. Section 4 con-cludes the paper.

2 ADAPTIVE BEAMFORMING ALGORITHMS

The term adaptive array was first coined by Van Atta in 1959 which defines a self phased array. It basically reflects all the incident signal back in the arrival direction using clever phasing scheme. In 1959 Howell proposed sidelobe cancellor (SLC) while in Applebaum developed fully adaptive antenna array based on maximization of signal to noise ratio (SNR) at the array output. The beamforming algorithms are classified as fixed weight beamforming and adaptive beamfomring algorithms. Adaptive beamforming algorithms continuosly updates the array weights based on certain optimization criteria in the changing signal environment. This section briefly discusses least mean square, recursive least square, conjigate gradient algorithm and quasi newton algorithm.

2.1. Least Mean Square Algorithm

In 1959 Widrow and Hoff [8, 9] formulated least mean square algorithm for use in adaptive switching circuits. The algorithm finds wide application in the field of wireless communication due to its less complexity and proven robustness. The algorithm is based on the method of steepest descent in which the weights are updated in the negative direction of gradient of cost function. The weight update equation is given by:

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

where, $e(k) = d(k) - \bar{w}^{H}(k)\bar{x}(k)$

where μ is the step size parameter and it controls the rate of convergence of the algorithm. The algorithm gives satble results when the step size lies in the following range:

$$0 \le \mu \le 1/\lambda_{max}$$

where λ_{max} is the largest eigen value of the array correlation matrix.

2.2. Constant Modulus Algorithm

In the field of wireless communication there exits many signals which are frequency and phase modulated. Frequency modulated (FM), Frequency shift keying (FSK), Phase shift keying (PSK), Quadrature amplitude modulation (QAM) are some of the examples of phase and frequency modulated signals. These signals have constant amplitude. When these signal travels in fading channels than these signals loses their constant amplitude property. Godard utilizes this concept and introduced a blind equalization algorithm. The weight update equation is given by:

$$\bar{w}(k+1) = \bar{w}(k) + \mu e^{*}(k)\bar{x}(k) \quad (2)$$

where, $e(k) = (y(k) - y(k)/|y(k)|)$

2.3. Conjugate gradient Algorithm

The CGA finds its roots to find the solution of system of linear equations. It is an iterative algorithm which finds the optimum solution by choosing the perpendicular path for each new iteration. Since the algorithm find the solution by choosing the perpendicular path for each new iteration thus the algorithm has the fastest rate of convergence. The general weight update equation is given by:

$$\bar{w}(n+1) = \bar{w}(n) - \mu(n)\bar{D}(n) \quad (3)$$

where, μ(n) and $\overline{D}$(n) are the step size and the direction vector and is given by:

$$\mu(\mathrm{n}) = \frac{\overline{r}^{H}(n)\overline{A}\overline{A}^{H}\overline{r}(n)}{\overline{D}^{H}(n)\overline{A}^{H}\overline{A}\overline{D}(n)} \quad (4)$$

$$\overline{D}(n+1) = \overline{A}^{H}\overline{r}(n+1) - \alpha(n)\overline{D}(n) \quad (5)$$

where, $\overline{r}$ is the residual and is given by:

$$\overline{r}(n+1) = \overline{r}(n) + \mu(n)\overline{A}\overline{D}(n) \quad (6)$$

$$\alpha(n) = \bar{r}^{H}(n+1)\bar{A}\bar{A}^{H}\bar{r}(n+1) / \bar{r}^{H}(n)\bar{A}\bar{A}^{H}\bar{r}(n) \quad (7)$$

2.4. Quasi Newton Algorithm

Quasi Newton algorithm[10] is an efficient optimization technique which finds its application in the field of wireless communication. The algorithm has good convergence speed comparable to RLS algorithm and provides stable solution under high signal correlation condition. The weight vector is updated as:

$$\overline{w}(k+1) = \overline{w}(k) + \mu(k)h(k) \quad (8)$$

where μ(k) is the step size and h(k) is the direction of the update and is given by:

$$h(k) = -R^{-1}(k-1)\,\partial J_{w,w^*} / \partial w^* \quad (9)$$

The cost function and the step size is given by,

$$J_{\mathrm{w,w^*}} = |e(k)|^2 \quad (10)$$

$$\mu(k) = 1/2x^{H}(k)R^{-1}(k-1)x(k) \quad (11)$$

where, x(k), R-1(k-1) and e(k) are the input vector, inverse of the correlation matrix and the error vector.

3 SIMULATION RESULTS

In this section simulation results of adaptive beamforming algorithms are discussed. All the algorithms are simulated in MATLAB. Uniform linear array of omnidirectional antenna elements with half of the wavelength spacing between the elements have been considered. The desired signal is a cosine signal and the undesired signals are the random signals. The performance of the algorithms are analyzed with the variation of antenna elements. The direction of desired signal and undesired signals are {0^0, -40^0, 60^0} and the noise variance is 0.01 while the elements which are varied are {9, 12, 15}.

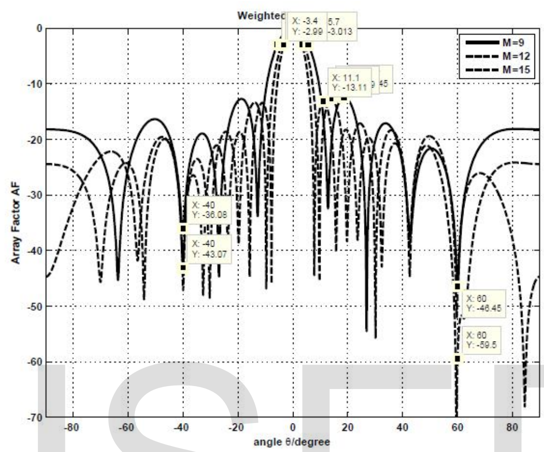

Figure 2 Normalised array factor plot of LMS algorithm

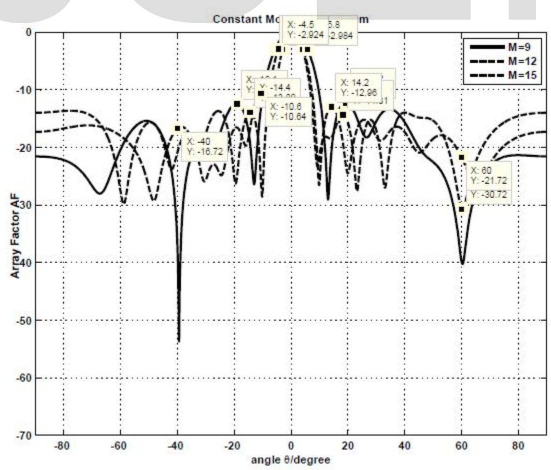

Figure 3. Normalised array factor plot of constant modulus algorithm

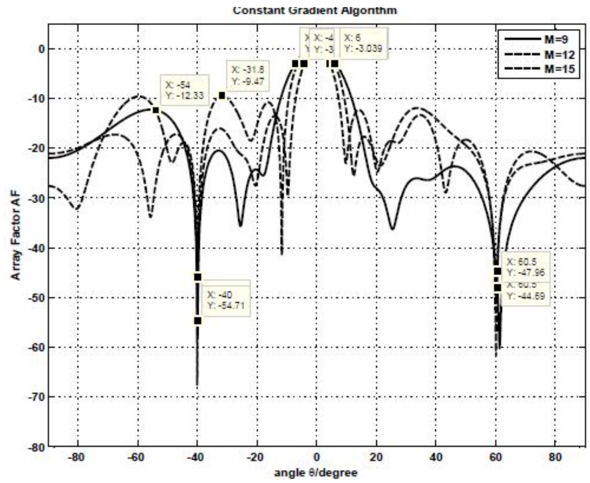

Figure 4. Normalised array factor plot of conjugate gradient algorithm

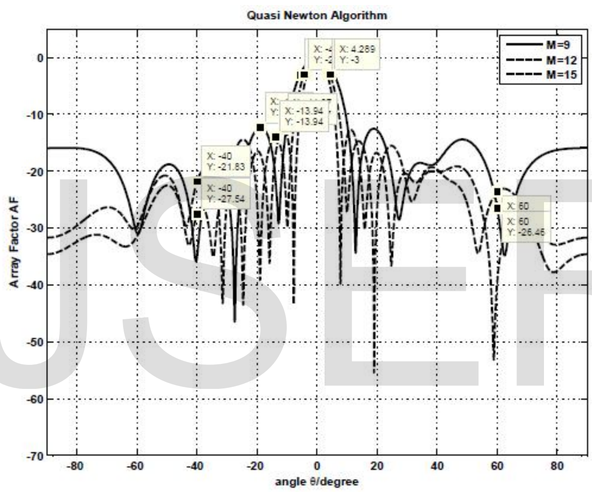

Figure 5. Normalised array factor plot of quasi newton algorithm

Table 1. Radiation pattern characteristics with the variation of antenn elements for LMSalgorithm

S. No.	Number of antenna elements	Beamwidth (degree)	Maximum SLL (dB)	Null depth at 40^0(dB)	Null depth at 60^0(dB)
1.	9	11.3	-12.45	-36.08	-46.45
2.	12	8.5	-12.69	-47.15	-45.94
3.	15	6.8	-13.11	-43.07	-59.50

Table 2. Radiation pattern characteristics with the variation of antenn elements for CMalgorithm

S. No.	Number of antenna elements	Beamwidth (degree)	Maximum SLL	Null depth at 40^0 (dB)	Null depth at 60^0 (dB)
1.	9	11.5	-12.24	-37.4	-30.72
2.	12	8.8	-13.89	-16.72	-21.72
3.	15	7.1	-10.64	-20.85	-39.87

Table 3. Radiation pattern characteristics with the variation of antenn elements for CGalgorithm

S. No.	Number of antenna elements	Beamwidth (degree)	Maximum SLL	Null depth at 40^0(dB)	Null depth at 60^0 (dB)
1.	9	13.6	-12.33	-58.33	-47.96
2.	12	12.4	-12.32	-54.71	-44.69
3.	15	8.6	-9.47	-45.84	-45.48

Table 4. Radiation pattern characteristics with the variation of antenn elements for QNalgorithm

S. No.	Number of antenna elements	Beamwidth (degree)	Maximum SLL (dB)	Null depth at 40^0 (dB)	Null depth at 60^0 (dB)
1.	9	11.369	-12.35	-34.93	-26.46
2.	12	8.689	-13.94	-21.83	-39.47
3.	15	6.85	-12.57	-27.54	-23.62

Figure 2-4 shows the variation of radiation pattern characteristics (beamwidth, SLL and maximum null depth) of LMS, CM, CG and QN algorithm with the variation of antenna array elements. Table 1-3 presentsthatbeamwidth decreases with the increase of antenna elements. This verifies that a directive beam is obtained when the number of array elements are increasing in ascending order. The four algorithms shows similar variation of beamwidth and maximum SLL with the increase of array elements. The results also presents that LMS and CG algorithm have larger null depth as compare to CM and QN algorithm.

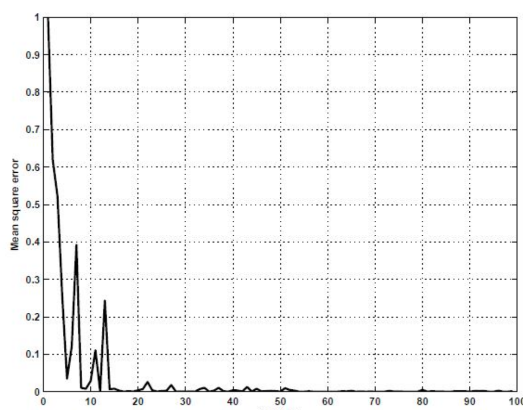

Figure 6. Mean square convergence plot of LMS algorithm

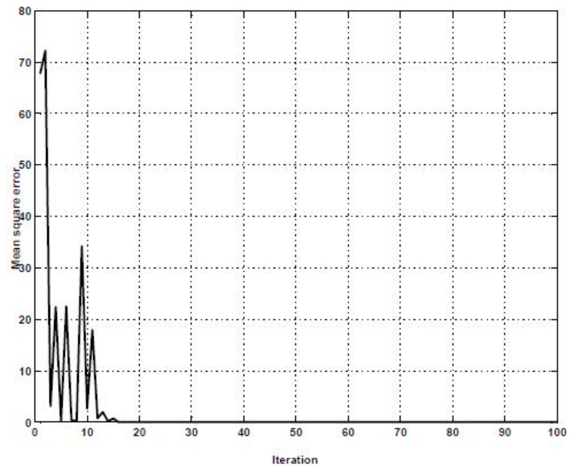

Figure 7. Mean square convergence plot of CM algorithm

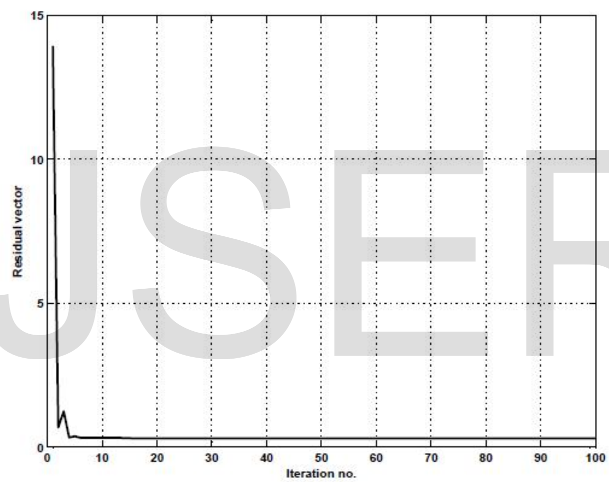

Figure 8. Residual vector convergence plot of CG algorithm

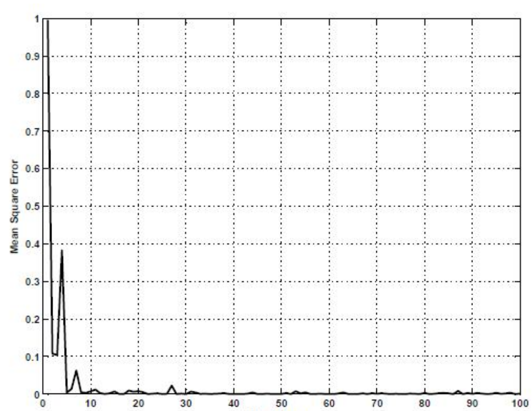

Figure 9. Mean square error convergence plot of QN algorithm

Figure 6-9 presents the convergence plot for all the discussed algorithms. The results shows that QN algorithm have slow rate of convergence while LMS and CM algorithm has moderate rate of convergence. The residual vector of CG algorithm converges after 6 iterations, thus this algorithm have the fastest rate of convergence and finds applications in wireless communication.

4 CONCLUSION

In this article the raidation characteristics of LMS, CM, CG and QN algorithm are discussed and compared. The simulation results presents that beamwidth decreases with the increase of array elements. The LMS and CG algorithm have more null depth as compared to CM and QN algorithm.

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