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COMPARATIVE ANALYSIS OF ADAPTIVE BEAM FORMING (ABF) ALGORITHMS FOR SMART ANTENNA SYSTEM (SAS)

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Abstract - Due to the latest big development in the subject of cellular communication, there is a need to maximize spectral efficiency so that the sizeable boom in visitors can be accommodated efficiently. The smart antenna gadget is a major supply to maximize the spectral efficiency and capacity of wi-fi networks. It consists of an adaptive antenna array that continuously adjusts its radiation characteristics (beam-width of the primary lobe, side-lobe degrees, and function of nulls) to supply narrow beam in the course of arrival (DOA) of the favored sign and to vicinity nulls inside the DOA of interferer signals in order that maximum SINR (signal to Interference and Noise Ratio) is received. Smart antennas are getting more popular now a days because of massive advancement inside the area of virtual sign processing and real-time implementation of adaptive signal processing strategies. These adaptive beam forming algorithms use extraordinary standards to adapt the system for higher overall performance and steer the principle beam toward the signal of hobby. Basically, adaptive beam forming is a technique in which an array of antennas is exploited to obtain most reception in a selected path. A set of rules with small complexity, low computation fee, correct convergence fee typically desired. In this paper we analyze various adaptive beam forming algorithms including LMS (Least Mean Squares), NLMS, CMA (Constant Modulus Algorithm), and RLS (Recursive Least Squares) through simulating different parameters like radiation pattern, amplitude response, mean square error and absolute weights of an N-element array for a certain number of iterations. The obtained simulation results are very helpful to evaluate performance and quality of adaptive beam forming algorithms.

Keywords – LMS, NLMS, RLS, CMA, SINR, ABF, Smart Antenna, Signal Processing

I. INTRODUCTION

Smart antenna technology gives a significantly stepped forward approach to reduce interference levels and enhance the device potential. Each consumer's signal is transmitted and received by using the base station best within the direction of that unique user. This notably reduces the general interference level inside the machine. A smart antenna gadget includes an array of antennas that collectively directs specific transmission or reception beams towards each user within the antenna device. This technique is known as beam forming that is a signal processing method used in sensor arrays for directional signal transmission or reception of sign. This is executed via combining elements within the array in a way where alerts at specific angles enjoy positive interference and whilst others revel in damaging interferences. The beam forming procedure may be used at each the transmitting and receiving ends with a view to achieve spatial selectivity. It has been observed numerous programs in wireless communications, radio terminology, speech analogy, acoustics, and biomedicine.[1-2] The smart antenna systems can normally be categorized as both switched beam and adaptive array structures. In a switched beam machine multiple constant beams in predetermined guidelines are used to serve the users. On this technique, the base station switches between numerous beams that supply the nice performance as the mobile user moves via the cellular. Adaptive beam forming makes use of antenna arrays backed with the aid of robust signal process capability to mechanically exchange the beam sample according with the changing signal surroundings. It no longer only directs most radiation inside the course of the desired cellular user but additionally introduces nulls at interfering instructions even as monitoring the desired cellular user on the identical time.[2] The model carried out by multiplying the incoming sign with complicated weights and then summing them together to gain the desired radiation sample. These weights are computed adaptively to evolve to the modifications within the signal environment. The complicated weight computation based totally on distinctive standards and included inside the sign processor within the form of software program algorithms.[1]

II. ADAPTIVE BEAM FORMING (ABF) TECHNIQUE

The adaptive beam forming algorithms can be categorized into various classes: non-blind adaptive and blind adaptive algorithms. Non-blind algorithms use training series d(n) to replace the complex weight vectors while blind algorithms do no longer but use a few properties of the preferred sign. LMS, NLMS, and RLS are non-blind algorithms whilst CMA is a blind algorithm. Basically, Adaptive beam forming is a way wherein an array of antennas is exploited to acquire maximum reception in a particular direction via estimating the sign arrival from the desired course. It no longer handiest directs the principle beam in preferred guidelines but additionally introduces nulls at interfering directions. Adaptive antenna arrays are able to alter dynamically update their weights to the changing signal conditions [3] hence weights are usually computed in line with the characteristics of the acquired indicators, which might be periodically sampled. The switched beam system is as shown in Figure-2.1.

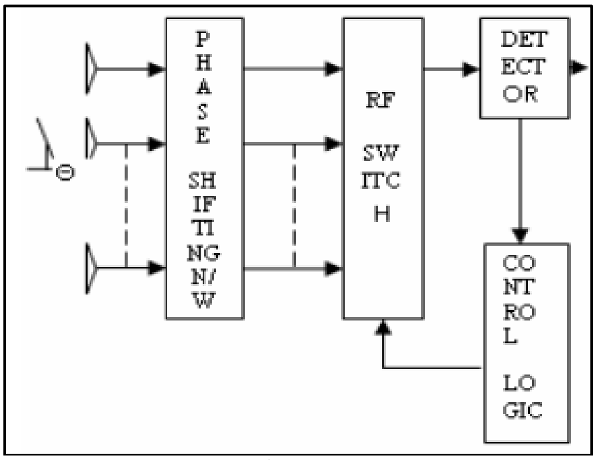

Figure 2.1 Block diagram of Switched Antenna System (SAS).

A normal switched beam machine for the bottom station could encompass more than one arrays with every array overlaying a positive phase inside the cell. It includes a phase shifting network, which paperwork a couple of beams looking in sure guidelines. The manipulate logic selects the right beam. The manage good judgment is ruled with the aid of an set of rules that scans all of the beams and selects the only receiving the most powerful signal primarily based at the size made with the aid of the detector. The array factor for N element equally spaced linear array is given by

$$AF(\emptyset) = \sum_{n=0}^{N-1} A_n e^{jn\left(\frac{2\pi d}{\lambda}\cos\phi + \alpha\right)} \ldots\ldots\ldots (i)$$

The inter element phase shift α is given by

$$\alpha = -\frac{2\pi d}{\lambda_0}\cos\phi_0$$

Where ϕ – desired beam direction and λ_0 is the wavelength

The method is easy in operation but is not suitable for high interference regions. For this reason switched beam systems offer restrained performance enhancement when as compared to traditional antenna structures in wireless communique [4-5]. However, more performance upgrades can be carried out via imposing advanced sign processing strategies to process the statistics received via the antenna arrays. The adaptive array structures are smart because they are able to dynamically react to the changing RF surroundings. The adaptive array uses antenna arrays but it's miles controlled by using signal processing. Figure 2.2 shows the block diagram for Antenna Array System.

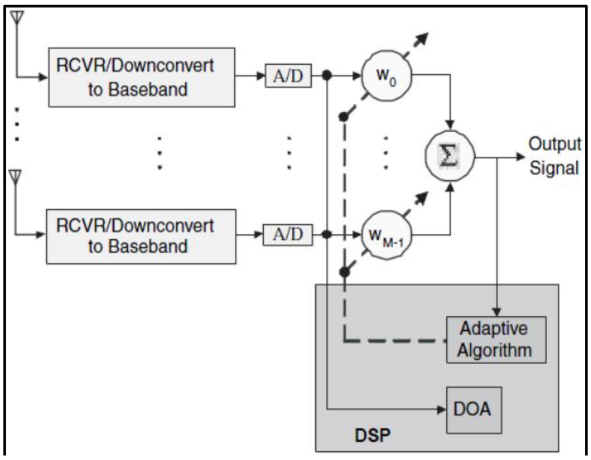

Figure 2.2 Functional block diagram: Adaptive Antenna Array System (AAAS)

III. ALGORITHMS

3.1 Least Mean Square (LMS) Algorithm

The Least mean square (LMS) algorithm is the famous adaptive filtering algorithm wherein the Gradient-primarily based technique is employed. It accommodates very recent observations and decreases the mean rectangular error iteratively. The course of the gradient vector is contrary to that of the steepest descent (SD). Window propounded SD approximation in phrases of weights using the LMS technique is mathematically written as.

$$w(n+1) = w(n) + \mu x(n) e^{*}(n) \dots \dots .. (ii)$$

Where, $0 \leq \mu \leq 1/2\lambda_{max}$, μ is the step size which is always positive and controls the speed of adaptation. λ_{max} is the largest eigen value and is trace of auto-correlation matrix. LMS algorithm depends on three element step size parameter, eigen value of correlation matrix of the input data and number of weights [5-6]. As LMS algorithm uses principal of weight adaptation, LMS algorithm has least computational complexity, high stability with simple implementation but its applications are limited due to its slow convergence, sometimes it may require more than thousands of iterations for convergence. The main advantage of LMS is its low computational complexity and disadvantage is slow convergence rate.

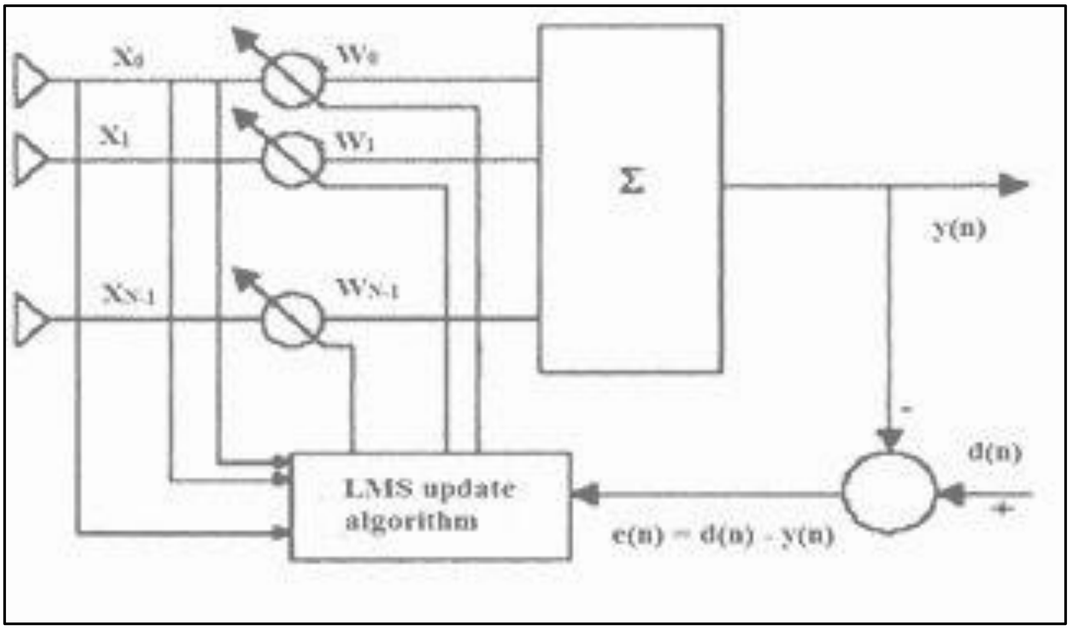

Figure 3.1 LMS Adaptive Beam Forming Network

3.2 NLMS Algorithm

It is formulated as an extension of the LMS approach [6]. It could persist over a huge variety of step sizes. The normalized least imply rectangular (NLMS) algorithm has advanced convergence homes than the least suggest square (LMS) set of rules. However, the weight noise impact of the NLMS set of rules is massive so that the regular-nation residue electricity is greater than that for the LMS set of rules. A generalized NLMS algorithm is evolved primarily based upon the pseudo inverse of an anticipated covariance matrix. A initial assessment indicates improved performance may be attained but the implementation complexity might be excessive [7-8]. Theoretically, the LMS technique is the most primary approach for calculating the load vectors. But, in practice, an advanced LMS method this is Normalized-LMS (NLMS) is used to reap solid calculation and faster convergence[11-12]. The NLMS set of rules can be formulated as a herbal modification of the LMS set of rules based totally on a stochastic gradient set of rules. Gradient noise amplification problem occurs in the preferred form of the LMS algorithm. The final weight vector can be updated by

$$w(n+1) = w(n) + \frac{\mu}{a + |x(n)|^2} x(n) e^{*}(n) \dots \dots .. (iii)$$

In which the NLMS set of rules reduces the step length μ to make the large adjustments within the replace weight vectors. This prevents the update weight vectors from diverging and makes the set of rules greater strong and quicker converging than when constant step length is used. Equation (iii) represents the normalized model of LMS (NLMS), due to the fact step size is split by using the norm of the input sign to avoid gradient noise amplification because of x(n). Right here the gradient estimate is split by the sum of the squared elements of the data vector.[9-10]

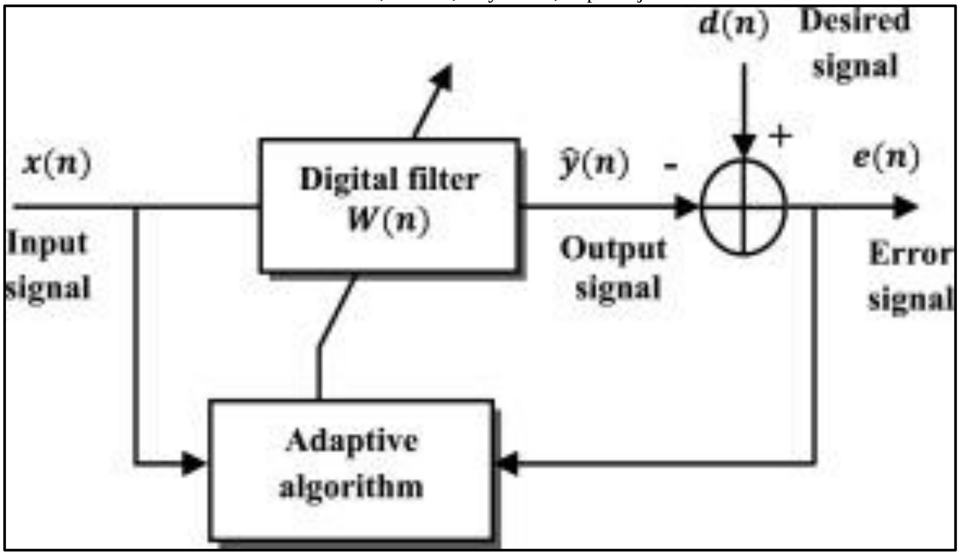

Figure 3.2 NLMS Adaptive Beam Forming Network

3.3 Recursive Least Square (RLS) Algorithm

RLS adaptive algorithm makes use of the method of Least Squares in approximating weight vector w(k) [13]. In LMS, the weight vector is selected to lessen the averaged blunders squares while in RLS, it is to lessen the cost function which includes the sum of error squares over a time window. The weights may be calculated the usage of following equations:

$$w(n) = (n-1) - R^{-1}(n)x(n)e^{*}\big(w(n-1)\big) \ldots\ldots (iv)$$

Where, $R^{-1}(0) = \delta^{-1}I$, δ small positive constant and I the N × N identity matrix. RLS has maximum signal strength in desired direction and therefore has the best formation of main lobe. It has narrowest beam width, total rejection of interference, more power in side lobes but atIn comparison to LMS, RLS has a quicker fee of convergence. This greater performance is achieved at the rate of massive computational complexity. the cost of computational complexity. RLS is used when fast tracking of is signal is needed.[11-12]

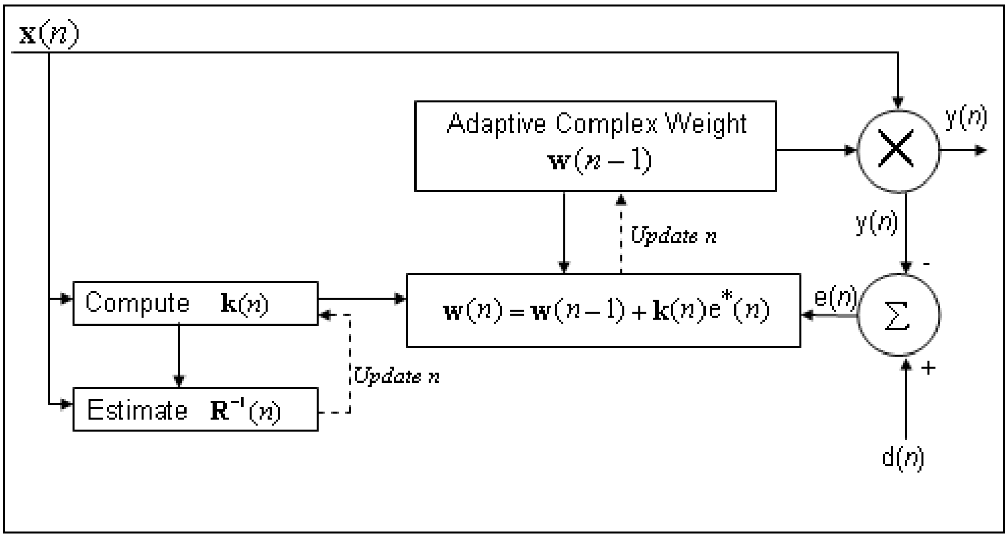

Figure 3.3 RLS Beam Forming Network

3.4 Constant Modulus Algorithm (CMA)

CMA is a famous algorithm of adaptive beam forming of blind variation. This set of rules is derived retaining in view the consistent complicated envelope (amplitude) property of the signal [15-16]. These signals normally encompass FM, FSK, PSK, QAM, and PAM. If the arrival sign has regular amplitude then this set of rules keeps and restores the amplitude of the favored signal [13-14]. CMA seeks a beam former weight vector which minimizes a cost function. The weights are calculated using given equations:

$$w(n+1) = w(n) + \mu\, e * (n)\, x(n) \ldots\ldots\ldots (v)$$

Error signal,

$$e(n) = (y(n) / |y(n)|) - y(n) \ldots\ldots\ldots\ldots (vi)$$

Motive is to reduce the error e(n) between the signal output y(n) and the reference signal y(n), d(n) is known as hard limit of y(n) and given as

$$d(n) = e(n) + y(n) \dots\dots\dots\dots\dots\dots\dots \text{(vii)}$$

The signal from each element is multiplied with weights and are all combined linearly and is given as,

$$y(n) = wH\ (n)\ x(n) \dots\dots\dots\dots\dots\dots\dots \text{(viii)}$$

$w = [w_1, w_2, w_3, w_4, \dots\dots\dots\dots w_n]$; known as complex weight vector, x(n) is an input signal.

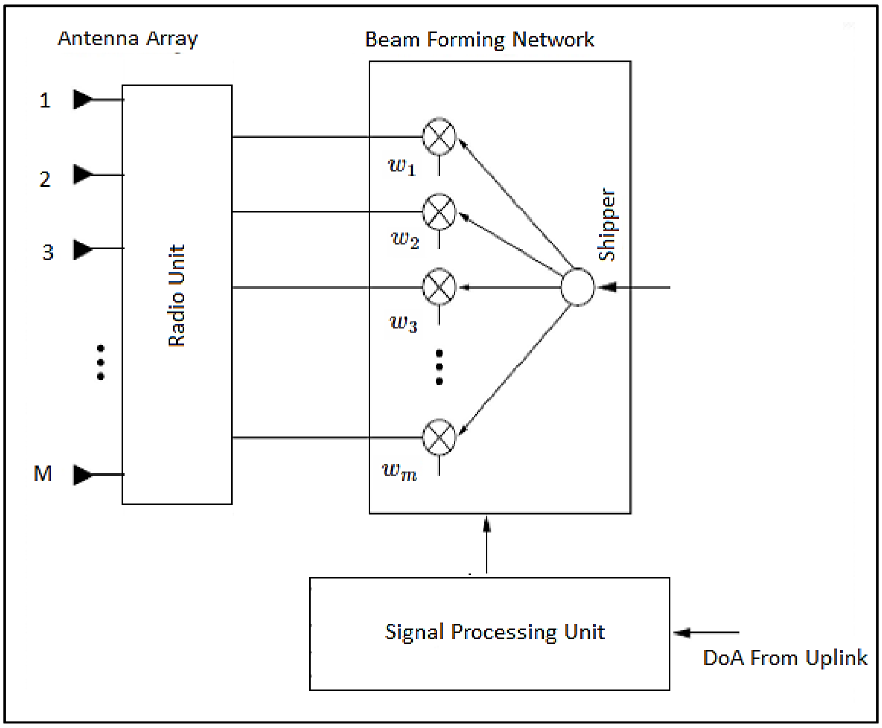

Figure 3.4 CMA Beam Forming Network

IV. RESULTS & DISCUSSION

4.1 Performance Evaluation for LMS Algorithm.

For simulation purpose the uniform linear array with N number of elements is considered. The spacing between the individual elements is considered to be half wavelength $(\frac{\lambda}{2})$. The array factor plots and how the LMS algorithm places deep nulls in the direction of interfering signals and maximum in the direction of the desired signal.

Table 1. Variation in AOA of Desired Signal

Angle of arrival for desired signal	30^0	0^0	-45^0
Angle of Arrival (AOA) for interfering signal	60^0	60^0	60^0
Angle of Arrival (AOA) for interfering signal no. of Element	N=5, 8 and 10	N=5, 8 and 10	N=5, 8 and 10
Inter-element spacing - d	λ/2	λ/2	λ/2

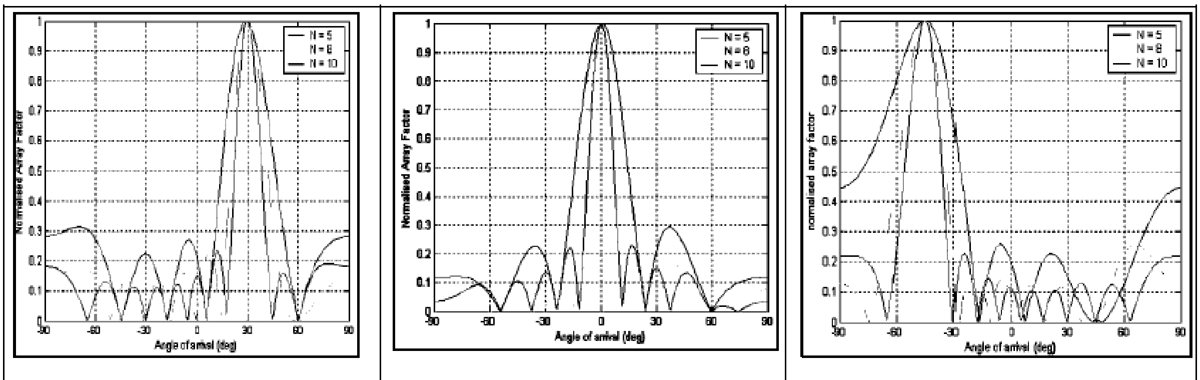

Figure 4.1 Array factor (AF) Plot for (a) AOA for user - 30^0 (b) AOA for user - 0^0 (c) AOA for user - -45^0

Variation in Inter-element Distance, d in Antenna Array: The array factor for the number of elements N = 5, 8 and 10 for the spacing between elements equal to λ/2, λ/4 and λ/8 is computed. The simulation result shows that as the number of array elements increases, the main lobes and the side lobes become narrower increasing the resolution and accuracy of the LMS algorithm.

Table 2. Variation in inter element distance of Desired Signal

Angle of arrival for desired signal	30^0	0^0	-45^0
Angle of Arrival (AOA) for interfering signal	60^0	60^0	60^0
Angle of Arrival (AOA) for interfering signal no. of Element	N=5, 8 and 10	N=5, 8 and 10	N=5, 8 and 10
Inter-element spacing - d	λ/2	λ/4	λ/8

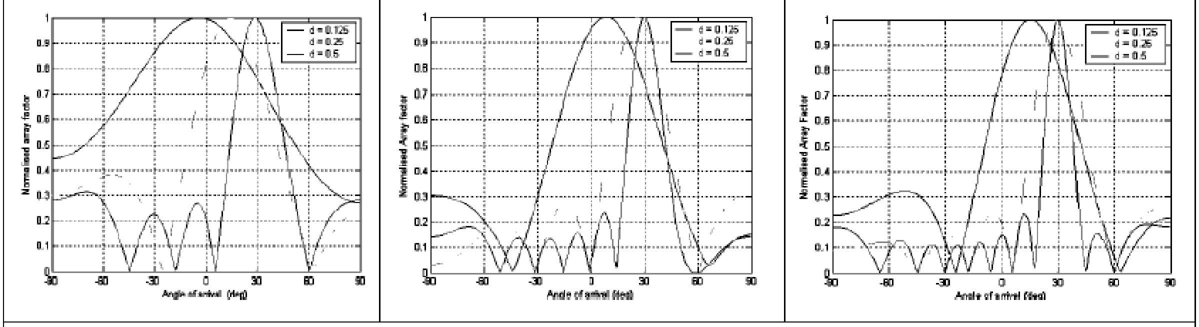

Figure 4.2 Array factor (AF) Plot for inter distance d = λ/2 , λ/4 , and λ/8 for different no.of element (a) N = 5 (b) N =8 (c) N = 10

4.2 Performance Evaluation for RLS Algorithm

For simulation purpose the uniform linear array with N number of elements is considered. The spacing between the individual elements is considered to be half wavelength (λ/2) . The array factor plots and how the RLS algorithm places deep nulls in the direction of interfering signals and maximum in the direction of the desired signal.

Variation in Inter-element Distance, d in Antenna Array: The array factor for the number of elements N = 5, 8 and 10 for the spacing between elements equal to λ/2, λ/4 and λ/8 is computed.

Table 3. Variation in inter element distance of Desired Signal

Angle of arrival for desired signal	30^0	0^0	-45^0
Angle of Arrival (AOA) for interfering signal	60^0	60^0	60^0
Angle of Arrival (AOA) for interfering signal no. of Element	N=5, 8 and 10	N=5, 8 and 10	N=5, 8 and 10
Inter-element spacing - d	λ/2	λ/4	λ/8
Step-size μ	0.5		

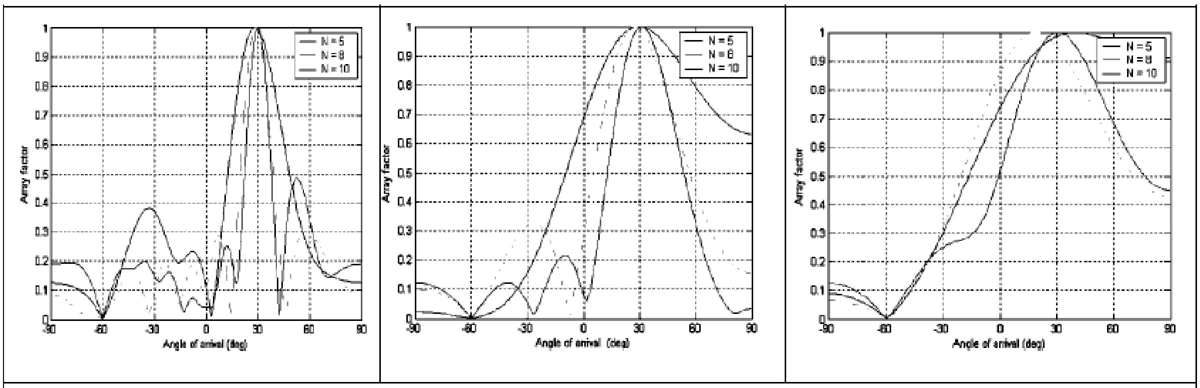

Figure 4.3 Array factor (AF) Plot for inter distance d = λ/2 , λ/4 , and λ/8 for different no.of element (a) N = 5 (b) N =8 (c) N = 10

4.3 Performance Evaluation for NLMS Algorithm

For simulation purpose the uniform linear array with N number of elements is considered. The spacing between the individual elements is considered to be half wavelength (λ/2) . The array factor plots and how the NLMS algorithm places deep nulls in the direction of interfering signals and maximum in the direction of the desired signal.

Table 4. Variation in AOA of Desired Signal

Angle of arrival for desired signal	30^0	0^0	-45^0
Angle of Arrival (AOA) for interfering signal	60^0	60^0	60^0
Angle of Arrival (AOA) for interfering signal no. of Element	N=5, 8 and 10	N=5, 8 and 10	N=5, 8 and 10
Inter-element spacing - d	λ/2	λ/2	λ/2

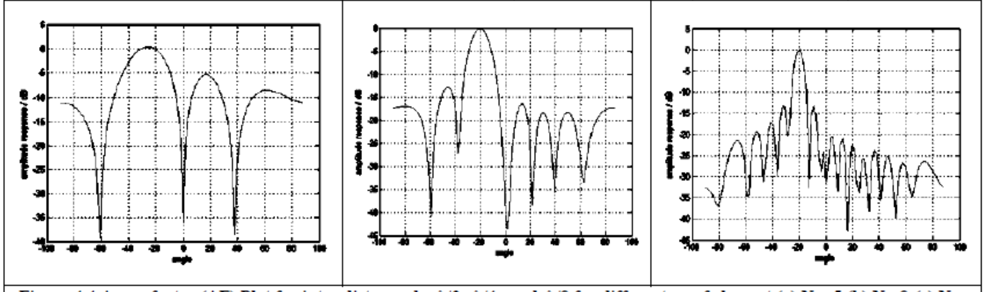

Figure 4.4 Array factor (AF) Plot for inter distance d = λ/2 , λ/4 , and λ/8 for different no.of element (a) N = 5 (b) N =8 (c) N = 10

The results show that the response is better when using higher number of elements. The response is showing amplitude of approximately 0.4 at some undesired angles of arrival. Such values are considered as drawbacks of the algorithm. The results of N=10 were better in the case of d=0.5λ; however, this was not the case when using d=0.25λ and d=0.125λ. The case of N=8 has given better performance. The performance in term of passing band has shown better performance for smaller inter-element distance.

4.4 Performance Evaluation for CMA

For simulation purpose the uniform linear array with N number of elements is considered. The spacing between the individual elements is considered to be half wavelength (λ/2) . The array factor plots and how the CMA algorithm places deep nulls in the direction of interfering signals and maximum in the direction of the desired signal.

Variation in Inter-element Distance, d in Antenna Array: The array factor for the number of elements N = 5, 8 and 10 for the spacing between elements equal to λ/2, λ/4 and λ/8 is computed.

Table 5. Variation in inter element distance of Desired Signal

Angle of arrival for desired signal	30^0	0^0	-45^0
Angle of Arrival (AOA) for interfering signal	60^0	60^0	60^0
Angle of Arrival (AOA) for interfering signal no. of Element	N=5, 8 and 10	N=5, 8 and 10	N=5, 8 and 10
Inter-element spacing - d	λ/2	λ/4	λ/8
Step-size μ	0.5		

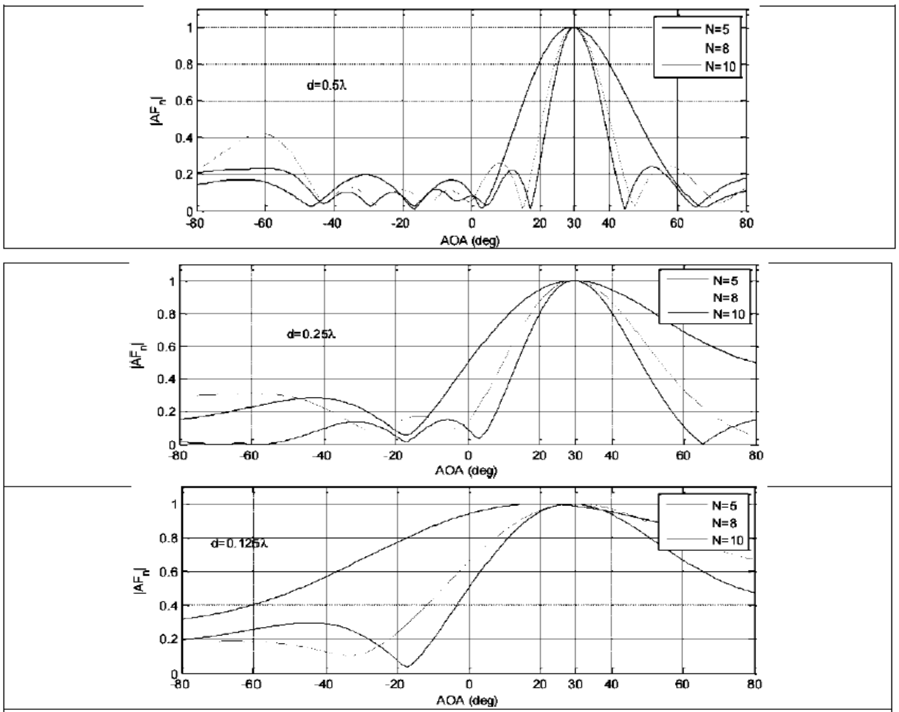

Figure 4.5 Array factor (AF) Plot for inter distance d = λ/2 , λ/4 , and λ/8 for different no.of element (a) N = 5 (b) N =8 (c) N = 10

Moreover it is obvious that in order to choose distance between element in antenna array eighth wavelength (d=0.125 λ), the number of elements must be increased to achieve a reasonable system performance by comparing the performance of the algorithms in terms of suppressing unwanted signal, it is evident from the figures that LMS , NLMS , CMA and RLS algorithms place adaptively the maxima radiation pattern in the desired direction of signal which arrives at 30^0 and nulls at the AOA of the interferer signal at -60^0, however, CMA algorithms did not succeed in suppressing the signal completely. Moreover, RLS algorithm can be considered the best algorithm in terms of suppression of unwanted signals even with angles arriving from Convergent direction. In order to increase the characteristic of distinction between the AOA’s even they close in values, the width of main lobe must be narrow enough to truck desired signal, this is done by increasing the number of element N in antenna array as it is shown in the figures. But the bad impact in increasing the number of elements lies in the increasing of side lobes number, which leads to increase the level of interference due to the radiation of power in unwanted directions. It is also observed from the pictures that the optimum value for distance between element in antenna array is half wavelength (d=0.5 λ) Where the algorithms still have reasonable performance with the changes in the values of rest parameter.

V. COMPARISON BETWEEN ALGORITHMS

From the simulation consequences, it's far pretty clean that all the algorithms carry out properly for an inter-detail spacing (d) of 1/2 the wavelength. Additionally for nice performance of all of the algorithms at least eight number antenna array factors are required. In the case of LMS and CMA algorithms alterations inside the step size inside its limits can be used for bringing the development inside the performance. LMS, NLMS and RLS algorithms require a reference signal while the CMA does not require a reference sign. LMS has gained popularity due to its low computational complexity and robustness. One of the drawbacks encountered in LMS algorithm is its gradual convergence under high eigen price spread.

Sl. No.	Parameter	LMS	NLMS	CMA	RLS
1	Usage of reference signal	Yes	Yes	No	Yes
2	Complex in Computation	Low	Low	Moderate	High
3	Convergence Time Period	More	More	Slow	Less
4	Rejection of Co-channel Interference	Low	Medium	Low	Satisfactory
5	Beam Width	Narrow lesser Side lobe levels	Narrow lesser Side lobe levels	Wider	Narrow with more side lobe levels

Table 6. Comparison of Algorithms

VI. CONCLUSION

In adaptive beam forming, the radiation sample of the clever antennas is controlled via diverse adaptive algorithms. An adaptive set of rules dynamically optimizes the radiation pattern consistent with the converting electromagnetic environment. Right here we analyze four famous adaptive techniques including LMS, NLMS, CMA, and RLS via simulation of diverse parameters like radiation sample, amplitude response, mean square errors, and absolute weights. Comparative analysis of the 4 algorithms LMS is the most effective and more suitable desire as it has the narrowest beam width inside the preferred direction, least energy interior lobes, and complete rejection of interferer alerts but it has gradual convergence which limits its software in case of quick various channel situations and in which short taking pictures of the sign is required. Even as CMA has the widest beam width within the favored direction, suppresses interference to a point and volatile conduct in case of convergence due to which CMA can be utilized in applications where the complex envelope of the sign ought to ideally be consistent. Within the case of RLS we've got the narrowest beam width, complete rejection of interference, and quickest convergence at the price of excessive computational burden but have greater electricity interior lobes compared to LMS. RLS is the great desire and has additionally its application in which brief tracking of the sign is required.

For all of the above algorithms, foremost spacing between antenna array factors is determined to be half of the wavelength. Additionally for great performance of all the algorithms as a minimum eight antenna array elements are required. At ultimate it is able to be without problems concluded that the RLS set of rules has the upper hand over LMS, NLMS and CMA algorithms. It finds its application in mobile communication where it is used to eliminate multipath fading.

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