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Investigation of Beam Forming Algorithms Using Smart Antenna for Modern Wireless Communication

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Abstract: In Recent wireless communications especially for mobile phones the effectiveness of the system depends on how well the signal is received, with signals coming from several service providers and radio users, the wireless channels grow crowded. Enhancing a signal's quality is important under these fictitious circumstances Additionally, the current generation of services, like 5G, will use a higher frequency range and require a broader bandwidth and more channel capacity for high-speed data transfers.

One of the technologies that can improves the wireless communication system is smart antenna with respect to enhancing quality, coverage, and capacity of networks while increasing efficiency.

The biggest issue in a noisy setting is getting the most signal reception in the desired direction. Therefore, Adaptive algorithms contributes a key factor in obtaining the optimum signal quality with improving efficiency.

In this paper we considered uniform linear array with 15 elements and performance can be investigated using adaptive beam forming algorithms Recursive Least Square (RLS), Least Mean Square (LMS) The results of simulations are carried out by using MATLABR2023A.

Our focus is to improves the system efficiency with high gain towards the desired direction without any side lobes. This can be obtained by using the N-LMS algorithm

Keywords: *Adaptive beamforming, smartantenna,RLS LMS, NLMS*

1. Introduction

A system of elevated conductors known as an antenna, which connects or aligns the transmitter or receiver with empty space. In order to transmit or receive radio waves, antennas act as interfaces between photons in space and electrons on conductors. An antenna array is a collection of related antennas those are all pointed in the same general direction. The two types of antenna array systems are as follows: They are a non-uniform linear array where the current excitation coefficients vary and a uniform linear array where each element is given an equal amount of current with the phase shift along the line is uniform.

A smart antenna system integrates digital signal processing methods with array antenna components. A technique for manipulating signals can created on an array antenna's elements is known as array signal processing. Mobile communication services are increasingly requiring smart antennas in a noisy environment so that they can achieve the spatial dimensions of a wireless channel [1].

The Direction of arrival (DOA) and beamforming techniques are generally developed at signal processing technology. All incoming signals have their direction of arrival determined by the DOA algorithm. The system settings are then updated using the adaptive beam forming technique. In order to reduce the phase shift in the received signal, the main beam is aimed in the direction of the intended signal, while nulls are aimed in the direction of interference [2], with the weights of the elements affecting both phase shift and amplitude attenuation. In an adaptive smart antenna system, a maximum-intensity beam can be formed in any desirable direction while a Smart antenna produces a beam based on the estimated DOA.

This paper organized into following sections: Section II Shows the description about antenna arrays, Smart antenna system was described in section III. Beam forming algorithms Recursive Least Square, Least Mean Square and Normalized -LMS techniques in section IV. The Section V presents the simulations findings. In section VI, Concluding Remarks are made.

2. Linear Arrays

The spatial locations of antenna elements in various forms called antenna array geometry, we consider the linear array in our case with 15elements for simplicity and ease of operation and implementation [3][4] and it is shown in fig1

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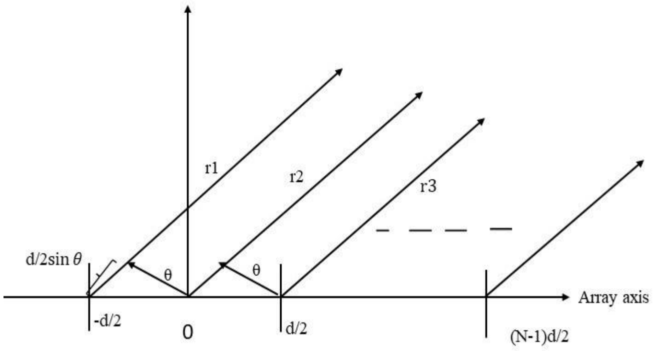

Fig 1: Linear Array Model

In linear array geometry the spatial configuration of elements are located along the axis of the array, λ.is considered as one wave length between them .we assume that the interelement spacing is equal and excitation with equal amplitudes. The array factor for far fields considerations as r >>d given by

$$AF = 1 + e^{j(k\, d \cos\theta + \delta)} + e^{j(2k\, d \cos\theta + 2\delta)}$$

Where d is considered as inter element spacing and it should be in terms of wavelengths, k is the phase constant owing to propagation and it is related to wavelength is given by 2π/λ and θ is the angle of incidence along the array axis and δ is the phase shift from element to the element.

The above equation easily can be represented as follows

$$AF = \sum_{n=1}^{N} e^{j(N-1)(kd\cos\theta + \delta)} \quad (1)$$

$$AF = \sum_{n=1}^{N} e^{j(N-1)(\psi)} \quad (2)$$

Where ψ is total phase shift due to propagation and from the equation (2) it is clear that the

1. There is a direct relationship between the phase ψ and the element spacing in wave length that means one of the control parameter is wavelength, if we change the spacing between antenna elements from 0.1 λ to 0.5λ and from 0.5λ to 1.λ wavelength the resultant radiation pattern gets controllable moreover in this case there are more grating lobes will be the another problems.

2. The phase ψ also dependent on number of antenna elements N that means if we change the array elements then the radiation pattern gets modified and it will be affected on radiation characteristics.

3. Finally, the phase ψ also directly proportional to the phase difference δ that means if we choose the different values of phase shifts then the radiation pattern gets sectorized into more directional towards the desired direction this will be discussed in results section vi.

4. From the above all three conditions, it is observed that the progressive phase shift is the most controllable parameter for providing good directional properties and this can be proven by using various methods for adaptive beam forming for modern wireless communication for smart antenna system.

3. Smart Antenna System

Traditional antenna arrays (Scanned arrays) uses the technique called electronic beam steering where each antenna element phase of the current changes directly and which are implemented at RF Frequencies as a result the main beam steered in the user desired direction. Certain adaptive beam forming algorithms, such as RLS, LMS, and others, are developed nowadays for modern wireless communications based on technological improvement in order to make antenna systems smarter. The advantage of these antenna-based systems is that they provide better coverage area, lower interference levels, and further enhance capacity augmentation.

An intelligent antenna system(smart) with beam forming is also capable of changing its radiation pattern according to the signal environment by adapting its directional properties according to it. In addition, beam forming requires less energy than traditional omnidirectional antennas and other conventional antennas when the beam is released.

To distinguish between the desired signal and the interference signal, smart antenna systems utilize adaptive beam forming algorithms while also estimating their direction of arrival (DOA). In order to track a desired user with major beam and null placing in other unwanted user locations, the direction of arrival process regularly adjusts to accommodate continuous changes in desired and interference signal locations.

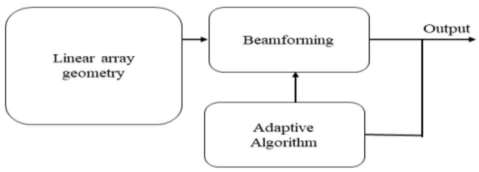

Fig 2: Block Diagram of Smart Antenna System

Based on the above figure 2. The estimated output at the array is given by:

$y(n) = W^{H}.X(n)$ (3)

where

$W^{H} = [w_0\ w_1\ w_2 \ldots w_{n\ 1}]^{T}$ is a weighted matrix of antenna array

and

$X(n) = [x_1(n)x_2(n)\ldots x_n(n)]^T$ is signal vector matrix.

Due to the noise environment in modern wireless communications systems, the required signals angles arrival changes over time. As a result we need to continuously adapt the weights of individual element of an antenna array which is accomplished by adaptive algorithms, This is one of the methods used to recursively calculate the array weights in order to find the ideal weight solution..

4. Adaptive Beam Forming Algorithms

A collection of antennas is created in order to implement smart antenna beam forming techniques, and after that, each antenna element is given the array weights, in order to enhance the primary beam targeted at signal of interest (SOI) and lessen nulls in the direction of signal not of interest (SNOI).

In this work we considered linear array with 15 elements and considered Recursive Least Square Algorithm (RLS), Least Mean Square Algorithm (LMS), and Normalized Least Mean Square Algorithm(N-LMS)

A) Recursive least square algorithm:

With respect to equation 3 let us consider x be the received signal vector matrix and α be the exponential weighting vector, then as per RLS algorithm the correlation matrix and correlation vector of length k are then represented by R_{xx}, r_k respectively.

The following steps involved to updated the array weights in recursive manner

- Step 1. The equation to update the correlation matrix R_{xx} given by

$$R_{xx}(k) = \alpha R_{xx}(k-1) + x(k)x^H(k)$$

Step 2: The equation to update for correlation vector r_k

$$r(k) = \alpha r(k-1) + x(k)\, d^*(k)$$

- Step 3:The inversion of correlation matrix is given by

$$R_{xx}^{-1}(k) = [\alpha R_{xx}(k-1) + x(k)x^H(k)]^{-1}$$

Step 4:the equation to find out the gain vector

$$g(k) = R_{xx}^{-1}(k)x(k)$$

step5: The equation for recursive updating of array weights

$$\omega(k) = w(k-1) + g(k)\, d(k) - x^H(k)w(k-1)g(k)$$

The matrix inversion lemma [1] approach may be utilized to simplify the process

B)Least Mean square algorithm:

The Least Mean square algorithm is a gradient based approach and the array weight updated equation for LMS is given by

$$\omega(n+1) = \omega(n) + \mu x(n)[d(n) - w^H x(n)]$$

Where W(n)=weight vector of nth antenna element

e=error signal $= d(n) - W^H.X(n)$

$y(n) = W^H.X(n)$

d=expected or desired signal

μ=step size

$W^H = [w_0\, w_1\, w_2 \ldots w_{n-1}]^T$ is matrix of antenna array weights,

the flow chart for Least Mean Square Algorithm was given by

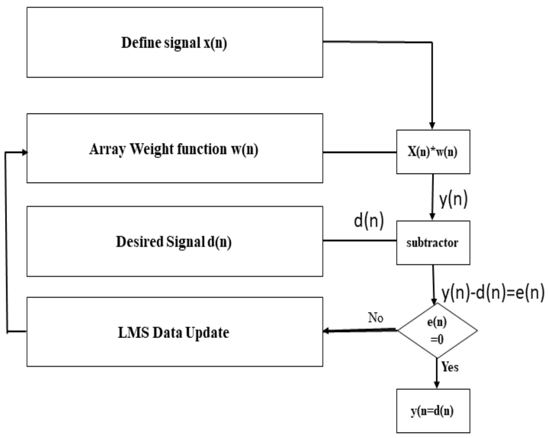

Fig 3: Flow Diagram of LMS Algorithm

C) Normalized Least Mean square algorithm(N-LMS):

In Normalized Least Mean Square Algorithm (N-LMS) the step size is divided with normalized input signal in such a way that the gradient noise amplification due to x(n)is avoided which results fast convergency is achieved.

In general the array updating equation for N-LMS given by

$$w(n+1) = w(n) + \frac{\mu}{\|x(n))^2\|} x(n)\, e^* n \quad (5)$$

From eqn(5) it can be stated that the N-LMS has fast convergence rate and more stable due to reduction in step size and it prevents the updated weight vectors from diverging rather than LMS algorithms[4]

In general, For Normalized Least Mean Square Algorithm

For each value of n

{

$e(n) = d(n) - W^H.X(n)$

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

}

5. Simulation Results & Observations

Fig4.Describes the Graphical representation of Radiation pattern that is the array factor vs Direction of Arrival for linear array with consideration of 15 elements, in which the user desired location at 60^0 and interference signal at -100^0 with maintaining 0.5 wavelength space between elements. From the figure it is clear that the beam getting towards the desired direction with broader half power beam width which means the directivity is less with introducing more no.of side lobe levels.

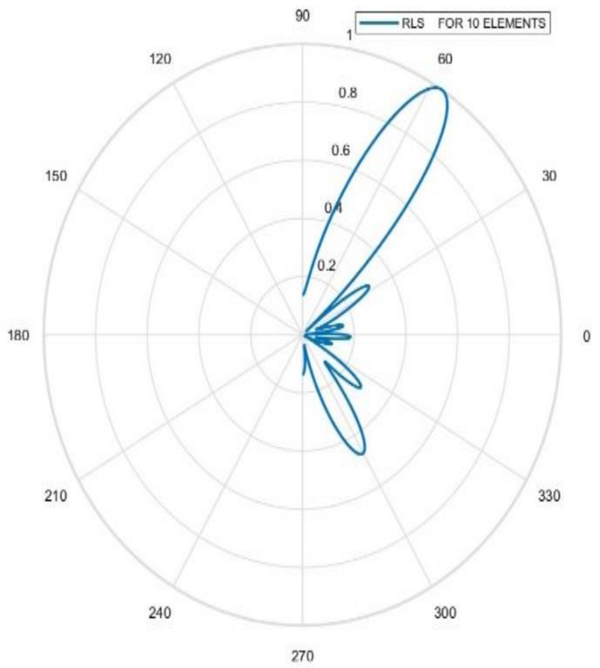

Fig 4. DOA Vs Array Factor For 15 Elements

Figure 5 shows variation in mean square error as the no.of iteration changes , it is evident that at initial conditions the mean square error is not convergent but as the number of iterations increases up to 30 iterations, before a precise beam pattern forms, RLS methods achieve speedy convergence by approaching the mean square error to zero.

Table 1.General Parameters For RLS Algorithms		
S. No	Description	Parameter
1	Array Configuration	Linear
2	Antenna Elements	15
3	Spacing Between Elements	0.5ƛ
4	Signal of interest	60 °
5	Interreference	-100 °

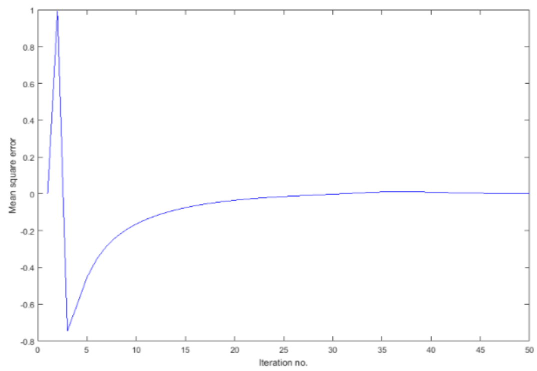

Fig 5. Variation of iterations with respect to mean square value using RLS algorithm.

Table2. General Parameters For LMS Algorithms		
S. No	Description	Parameter
1	Array Configuration	Linear
2	Antenna Elements	15
3	Spacing Between Elements	0.5ƛ
4	Signal of interest (DOA)	60 °
5	Interreference	-100 °

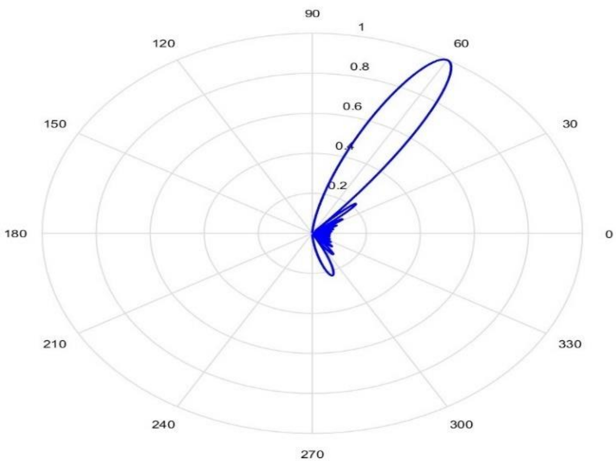

Fig 6. DOA Vs Array Factor For 15 Elements FOR LMS

From fig 6 it is clear that using LMS Algorithm the directivity is improved because of of the beam gets narrower when compared to RLS algorithm.

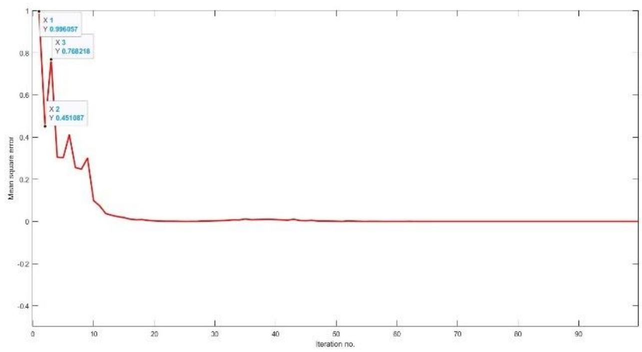

Fig 7. variation of iterations with respect to mean square value LMS algorithm.

From fig 7 it is also clear that the mean square value using LMS technique convergence to its minimum value within 20 iterations as the array weights are updated using equation (4)

Table 3 General Parameters For N-LMS Algorithms		
S. No	Description	Parameter
1	Array Configuration	Linear
2	Antenna Elements	15
3	Spacing Between Elements	0.5λ
4	Signal of interest (DOA)	60 °
5	Interreference	-100 °

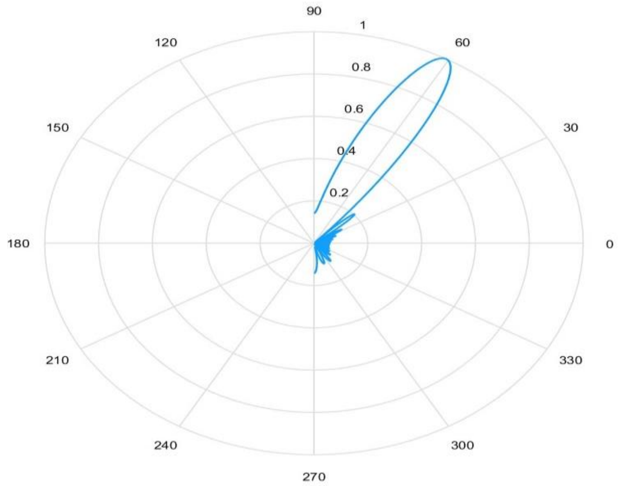

Fig 8. DOA Vs Array Factor For 15 Elements FOR N-LMS

From fig 8. It is observed that using N-LMS algorithms the directivity is slightly improved with reduction of side lobe levels further when compared to LMS Algorithms.

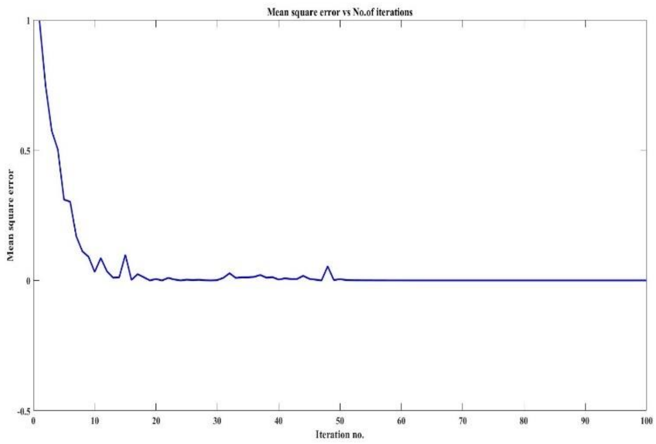

Fig 9 variation of mean square value against Number of iterations using N-LMS algorithm.

Form fig 9 it is observed that Using N-LMS Algorithm the mean square value convergence within 10 to 15 iterations.

6. Conclusions

Using a smart antenna, we looked at its performance and analysis with the help of Adaptive beam forming algorithms by considering linear antenna array. Based on the obtained simulation outcomes for improving the directivity and reducing side lobe levels we can conclude that the at 0.5 wavelength the N-LMS algorithm will give the best results with respect to directivity and improving system efficiency.

Author contributions

Narayanadas Mallaiah: developed the theory and perform the computations using algorithms and generated the MATLAB Code and simulated the results and developed the initial manuscript.

N. V. Koteswara Rao: validated the data, verified the algorithms and improved the documentation quality.

D. Ramakrishna: Providing all the necessary software tools and

helping in execution

Conflicts of interest

The authors declare no conflicts of interest

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