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Design and Analysis of Radiation Pattern of Smart Antenna for various Adaptive Algorithms

Harpreet Kaur Saini, Isha Puri

Abstract— **Adaptive beamforming techniques are used for the design and implementation of the adaptive smart antenna. The beamforming techniques are based on the angle of arrival of the signal. Various beamforming techniques such as LMS (Least Mean Square), RLS (Recursive Least Square) and SMI (Sample Matrix Inversion) are employed and the results are discussed and analyzed. These beamforming techniques performance is studied in accordance with the varying element spacing and the number of array antenna elements used for the designing of antenna. All the techniques used are compared on the basis of their side lobe level and the null depth of the interfering signals. From all the results, it is observed that the maximum radiation pattern of array structure is better for the LMS algorithm as compared to the other two. The desired radiation pattern is present in the direction of the desired signals hence creating nulls in the direction of interfering signals. With decrease in side lobes level and the beam width decrease, there is a gradual increases in the directivity of the signal.**

Index Terms— Smart antenna, LMS, RLS, SMI, Beamforming, antenna array.

I. INTRODUCTION

Antenna is a passive structure, which serves as a passage between a transmission line and air used to transmit or receive the electromagnetic waves. With development in technology and its use, there has been a rapid increase in number of users due to wide use. Bandwidth has to be the important factor in designing of a communication system as for more number is user, demand of bandwidth by cellular systems increased. As the frequency spectrum is limited and it is expensive to purchase carriers, there is an urge that within the same frequency spectrum, more users should be supported. The use of antenna array along with the adaptive techniques known as smart antenna will improve the signal quality at the receiver and hence will improve the bandwidth utilization. The designing of the adaptive smart antennas is based on the beam forming technique. Beam forming is an adaptive technique, in which beam is bend towards the desired signal direction and the nulls are created in the direction of the interfering signals. The mobiles or receiver devices at which the signals are to be sent are first look after and then the signal phases are added to create a radiation pattern of the antenna array. The mobiles which will not need the signal will be out of pattern.

Harpreet Kaur Saini, *Department of ECE, Lovely Professional University, Phagwara, India.*
Isha Puri, *Department of ECE, Lovely Professional University, Phagwara, India.*

II. ADAPTIVE TECHNIQUES

A. *LMS ALGORITHM:*

Least mean squares (LMS) algorithms are basic classes of adaptive filter used to fetch a desired signal from the noisy and distorted signal by finding the filter coefficients, which are related to the production of the least mean squares of the error signal that is the difference between the desired and the actual signal. The basic operation of the least mean squares (LMS) algorithms to adjust the filter coefficients in order to minimize the cost function. In comparison to the recursive least squares (RLS) algorithms, the LMS algorithms techniques do not involve any matrix operations [7]. Therefore, the LMS algorithms require fewer computational resources and less memory than the RLS algorithms. Moreover, the implementation and computations of the LMS algorithms is less complicated than the RLS algorithms.

The standard LMS algorithm performs the following operations to update the coefficients of an adaptive filter:

1) Calculates the output signal y(n) from the adaptive filter.
2) Calculates the error signal e(n) by using equation:

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

3) Updates the filter coefficients by using the following equation:

$$\vec{w}(n+1) = \vec{w}(n) + \mu . e(n) . \vec{u}(n) \tag{2}$$

Where, μ is the step size of the adaptive filter, is the filter coefficients vector, and is the filter input vector which is provided to meet the following condition:

$$0 \le \mu \le \frac{1}{2\lambda_{\max}} \tag{3}$$

Where, $\lambda_{\max}$ is the largest Eigen value of the correlation matrix R_{xx}

$$R_{xx}(k) = E[x(k)x^H(k)] \tag{4}$$

Where, $x(k)$ is the received signal vector and 'E' denotes the expected value of input signal and its hermitian transpose.

B. *RLS (RECURSIVE LEAST SQUARE) ALGORITHM*

The Recursive least squares (RLS) is an adaptive filter algorithm, which recursively finds the filter coefficients that minimizes a weighted linear least squares cost function relating to the input signals. In comparison with LMS algorithm, RLS algorithm have a faster convergence speed and it does not exhibit the problem of Eigen value spread. But it consists of more complicated mathematical computations as compared to LMS algorithm.

For the operation of updating of filter coefficients of adaptive filter, following operations are performed by RLS algorithm:

1) Calculate the adaptive filter output signal y(n).
2) Calculates the error signal 'e(n)' using equation 1
3) Update the filter coefficients using the following equation:

$$\vec{w}(n+1)=\vec{w}(n)+e(n).\vec{k}(n) \tag{5}$$

Where, $\vec{w}(n)$ is the filter coefficients vector and $\vec{k}(n)$ is the gain vector and $\vec{k}(n)$ is defined by the following equation:

$$\vec{k}(n)=\frac{P(n).\vec{u}(n)}{\lambda+\vec{u}^{T}(n).P(n).\vec{u}(n)} \tag{6}$$

Where, λ is the forgetting factor and P(n) is the inverse correlation matrix of the input signal. Refer to the book Adaptive Filter Theory for more information about the inverse correlation matrix.

P(n) has the following initial value P(0):

$$P(0)=\begin{pmatrix} \delta^{-1} & & 0 \\ & \delta^{-1} & \\ 0 & & \delta^{-1} \end{pmatrix}$$

Where, δ is the regularization factor. The standard RLS algorithm uses the following equation to update this inverse correlation matrix.

$$P(n+1)=\lambda^{-1}P(n)-\lambda^{-1}\vec{k}(n).\vec{u}^{T}(n).P(n) \tag{7}$$

C. SMI (SAMPLE MATRIX INVERSION) ALGORITHM

SMI is also known as DIRECT MATRIX INVERSION is a type of algorithm which is used to estimate the adaptive weights of the antenna arrays by replacing the correlation matrix by its estimated value. It is a block based adaptive technique which uses block for the computation of correlation matrix and hence accelerating its matrix convergence speed. The output signal of the adaptive techniques is the multiplication of the transpose of weight matrix and the input vector matrix given as:

$$y(n)=w^{H}x(n) \tag{8}$$

where , weight matrix is given as:

$$w(n)=R_{xx}^{-1}(n)x(n) \tag{9}$$

And the correlation matrix is given for 'n' number of samples of input signal $x(n)$ where n=1,2,3,............K-1 , where K is the number of blocks used for the computation and is known as observation interval. The correlation matrix is given as:

$$R_{xx}^{-1}(n)=\frac{1}{K}\left(\sum_{n=1}^{K}x(n)x^{H}(n)\right) \tag{10}$$

This algorithm is suitable for the rapid in change in environment as it has fast convergence speed than the LMS algorithm in the direction of the desired signal while it has more computational complexities.

III. ANTENNA GEOMETRY

The antenna IS designed at 2.4 GHz frequency and the desired signal is taken at 30 degree (0.52 radians) while the interfering signals are taken at 10 degree (0.17 radians) and at 50 degree (0.87 radians). The comparison is taken for number of antennas equal 4 and 8 all with antenna array elements spacing of 0.5 of wavelength.

A. STRUCTURE WITH 4 ANTENNA ELEMENTS

The number of antenna elements N=4 for the array structure is made and the results are discussed comparing their radiation patterns based on the spacing between antenna elements [6]. A uniform linear array with operating frequency of 2.4 GHz is considered for simulations. The desired signal is taken as a cosine signal at an angle of 30°. Two interfering signals are considered at angles of 10° and 50°.

a) SPACINGS OF 0.5

Antenna elements spacing with 0.5 of wavelength that is the distance between two antenna elements of 62.5mm is taken for the designing of array antenna with each antenna element of dimensions 30.272mm x 44.1 mm.

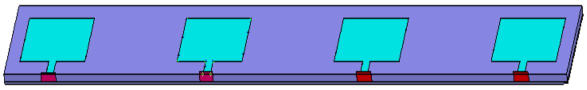

Fig.1: N=4 with elements spacing, d=0.5

b) SPACINGS OF 0.3

Antenna elements spacing with 0.3 of wavelength that is the distance between two antenna elements of 37.5MM is taken for the designing of array antenna with each antenna element of dimensions 30.272mm x 44.1 mm.

The structure of the above description is shown below.

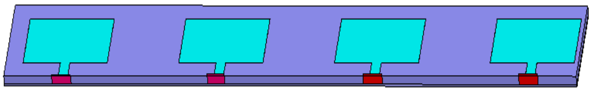

Fig. 2: N=4 with elements spacing, d=0.3

c) SPACINGS OF 0.8

Antenna elements spacing with 0.3 of wavelength that is the distance between two antenna elements of 37.5MM is taken for the designing of array antenna with each antenna element of dimensions 30.272mm x 44.1 mm.

Fig 3: N=4 with elements spacing, d=0.8

B. STRUCTURE WITH 8 ANTENNA ELEMENTS

An antenna structure with elements spacing of 0.5 of wavelength and total of 8 elements is taken for the simulation of the ration pattern. The structure drawn is shown below:

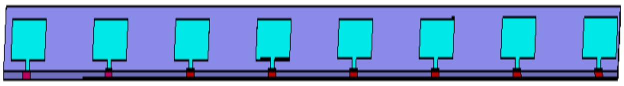

Fig.4: N=8 with elements spacing, d=0.5

IV. RESULTS AND DISCUSSIONS

The results on the antenna structures derived aboveare obtained for the antenna spacing of 0.5 of wavelength and number of antennas 4 and 8. These results were obtained for the LMS, RLS and SMI algorithms. And the following results were obtained based on all the parameters.

A. RADIATION PATTERN FOR 4 ELEMENTS ANTENNA

The respective radiation representing the array factors is observed for different elements spacing. The elements spacing is the distance between the two consecutive antenna array elements. These spaces are taken as:

- d=0.5 of wavelength i.e. 62.5mm.
- d=0.3 of wavelength i.e. 37.5mm.
- d=0.8 of wavelength i.e. 100mm.

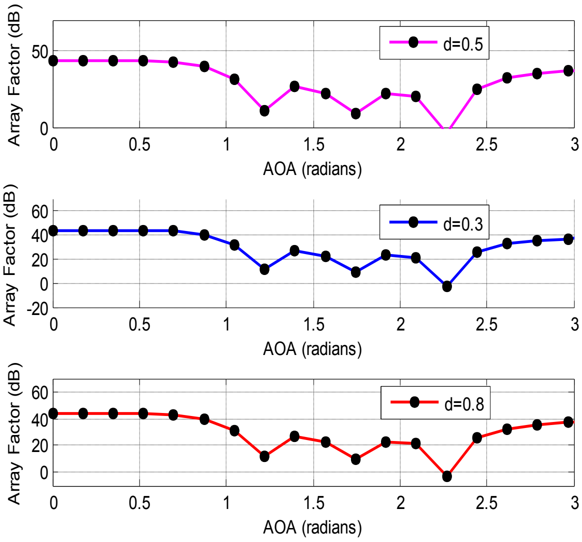

Fig. 5: Effect on beamforming with the variation of antenna array spacing.

From the results obtained for the radiation pattern plotted as array factor shows that when the distance between the two consecutive antenna elements is equal to 0.5 of the wavelength, then it has minimum value of side lobe and minimum beam width is analyzed as compared to the array factor obtained when the distance between elements of the array structure, d is less than or greater than the 0.5 of wavelength. For $d = 0.5\lambda$, for decreasing beam width it results in higher directivity. And moreover the null depth also decreases with $d = 0.5\lambda$ as compared to the null depths obtained for further changes in distance between the elements

B. COMPARISION OF ALGORITHMS FOR BEAMFORMING

A uniform structure with elements spacing, d=0.5 is taken. The beam for the desired signal direction is steered at the angle or arrival of as 30 degree (0.52 radians) and the interference signal is taken in the direction of 10 degree (0.17 radians) and at 50 degree (0.87 radians). The following section shows the effect of variation of the number of antenna elements (M) on the beamforming of LMS, SMI and RLS algorithms.

a) LMS BEAMFORMING

When the LMS algorithm was applied the following results were obtained. These results obtained shows the better radiation pattern when number of antenna array elements were eight (8) instead of four (4). These radiation patterns are in the form of array factor in decibels (dB). The figure below shows the simulated results of LMS algorithm on the received signal consisting of noise as well as the radiated signal. The nulls are created in the direction of unwanted signals. While main lobe is enhanced i.e. obtained in the direction of the desired signal that is in the angle of arrival of 30 degree.

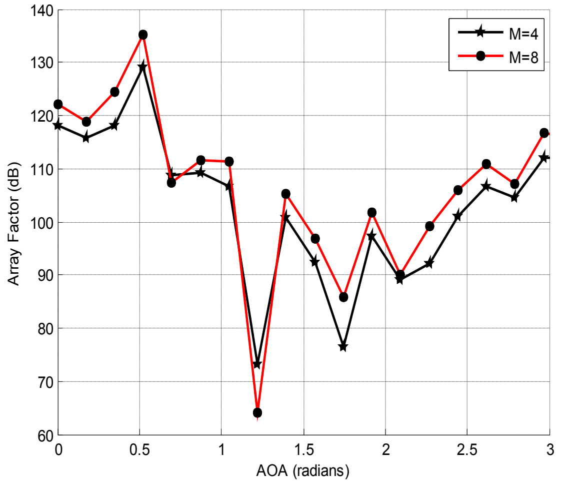

Fig. 6: The normalized Array Factor Plot for the LMS algorithm

b) RLS BEAMFORMING

When the Recursive Least Square algorithm technique is applied on the received distorted signal at the receiver, the following results were obtained. These results obtained shows the better radiation pattern when number of antenna array elements were eight instead of four. While main lobe is enhanced that is obtained in the desired signal direction that is in the angle of arrival of 30 degree.

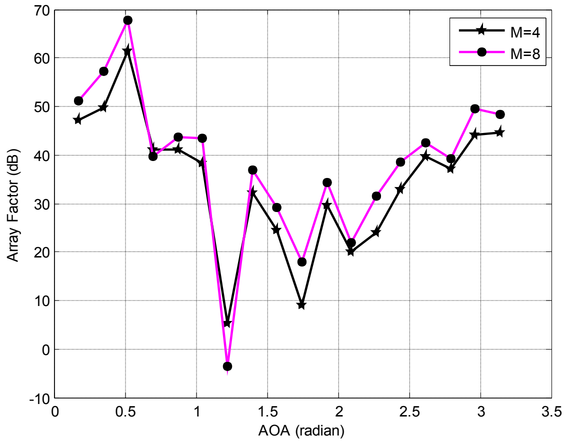

Fig. 7: The normalized Array Factor Plot for the RLS algorithm

c) SMI BEAMFORMING

When the Sample Matrix Inversion algorithm technique is applied on the received distorted signal at the receiver, the following results were obtained. These results obtained shows the better radiation pattern when number of antenna array elements were eight instead of four. The figure below shows the simulated results of LMS algorithm on the received signal consisting of noise as well as the radiated signal. The nulls are created in the direction of unwanted signals. While main lobe is enhanced that is obtained in the direction of the desired signal that is in the angle of arrival of 30 degree.

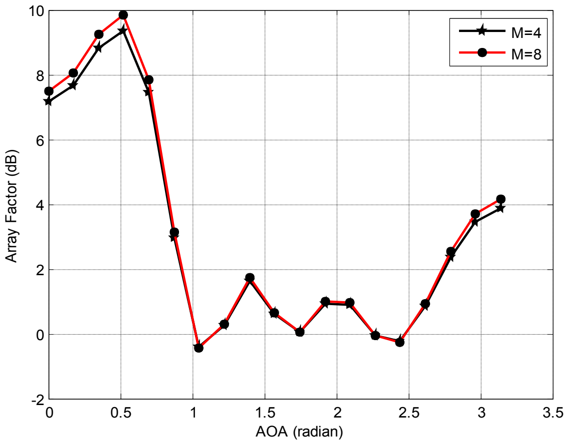

Fig 8: The normalized Array Factor Plot for the SMI algorithm

With increase in the number of antenna elements increases, the Side lobe level increases hence decreasing the beam width of the antenna array and thus increasing the directivity of the antenna array. The SLL decreases with increase in the number of antenna array elements and the unwanted signals directions have minimum lobe levels.

V. CONCLUSION

Smart antennas are the intelligent antenna systems that extremely improve the efficiency of the wireless transmissions and for the use of the connections between the wireless devices they are most likely to become the standard. Smart antenna is used for the removal of noise component from the signal received at the receiver array and for estimating its spectrum. The removal of noise components will gradually increase the signal to noise ratio and hence increasing the capacity of the system. Hence substantial increasing the signal processing power at the decreasing costs with wider range for wireless broadband systems. The smart antennas are not actually smart rather these are the use of adaptive techniques that make the antenna smart. The various beamforming techniques when applied vary with different parameters such as beam width, array factor, null depth. Use of adaptive beamforming techniques can detect the message signal from the noisy distorted signal. Moreover, with increase in number of antenna elements, the radiation pattern of antenna increases and hence increasing the directivity of the signal.

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Ms. Harpreet Kaur Saini is currently pursuing M. Tech in electronics and communication engineering from Lovely Professional University (LPU), Phagwara, Punjab. Her specialization is Wireless Communication. Her area of interest is Antenna Engineering, Digital Signal Processing and Satellite Communication.

Mrs. Isha Puri is currently working as an assistant professor in Department of Electronics and communication engineering at Lovely Professional University, Phagwara. She had many international publications. Her area of interest is Antenna Designing and Microwave application designing.