Investigation of Adaptive Beam-forming Algorithms for Smart Antennas System

Simrandeep Kaur¹, Naresh Kumar², Subhash Dubey³

¹,²University Institute of Engineering and Technology, Panjab University, Chandigarh 160014, India
³Government College of Engineering and Technology (GCET), Jammu

¹simrandeepk95@gmail.com, ²naresh_uiet@yahoo.com, ³subrag11121@gmail.com

Abstract: Smart antennas are examined as a promising technology in wireless communication systems. In the development of smart antenna technology, Adaptive beam-forming is the most important aspect. Adaptive beam-forming uses various algorithms to identify the signals in the desired direction and separate the interference from the undesired/unwanted direction. In this paper, Proposed Adaptive Beam-forming Algorithm offers the better solution for reducing interference and improves the system capacity. The main objective of this paper is to analyze the different approaches used for designing the smart antennas to track the desired signal and put perfect null towards the interferer signal.

Keywords: Beam-forming, Adaptive Algorithms, Smart Antennas, Antenna Array.

1. INTRODUCTION

In communication systems, smart antennas system has become the hour of need as they permit for maximal use of frequency band by delivering service to the maximal/required users. The smart antenna system includes an antenna elements array, a powerful processing of signal hardware and software attempting to implement appropriate Direction of Arrival (DOA) and Beam-forming algorithms [1]. Such algorithms provide smart antennas with the possibility to offer provision of assistance to the desired users and to eliminating unwanted users. Such algorithms often assist in reducing effects of multipath and noise fading [2]. As a consequence, the overall improvement of the communication system is achieved by enhancing the efficiency of the signal and providing the service to maximal users. Beam-forming is considered as a technique to change the signal’s phase and magnitude from each antenna element through use of the product from each signal (signal of the user) and vectors of weight. If the angle of arrival (AOA) of the desired signal is the same, the Fixed Beam-forming is used, but when the AOA varies over time, an optimization scheme needs to be devised which iteratively changes the weights of the arrival signals. Such a concept is known as Adaptive Beam-forming which adapts the weight in time [3]. Accordingly, Adaptive Beam-forming is used to separate the desired signal from the interferer signal by adapting the weight in terms of time though maximize the Signal to Noise Ratio (SNR), array output and reduces error [4]. This can be done by using the Adaptive Beam-forming Algorithms. In this paper, the Adaptive Beam-forming Algorithms results will be analyzed and discussed by varying the antenna elements (N) and separation distance (d) in MATLAB.

1.1. ALGORITHM TYPES OF ADAPTIVE BEAM-FORMING

There can be two types (Non-blind & Blind) of Adaptive Beam-forming algorithms [5]. In the Non-Blind Adaptive Algorithms, training or reference signal should be employed but in Blind Adaptive Algorithms, no reference signal should be utilized. They seek to restore certain kind of characteristics of the transmitted signal to distinguish the desired user from several other users in the environment surrounding them.
Fig. 1: Algorithm Types of Adaptive Beam-forming.

whereas under Non-Blind category in Fig. 1, Least Mean Square (LMS), Sample Matrix Inversion (SMI), Constant Gradient Algorithm (CGA) and Recursive Least Square (RLS) and under the Blind category Decision Directed (DD) and Constant Modulus Algorithm (CMA). Some basic parameters related to Antenna are discussed in Table 1.

**Table 1: Some parameters related to Antenna:**

| Parameters     | Formulas                                                                 | References |
|----------------|---------------------------------------------------------------------------|------------|
| Directivity:   | The ratio of intensity of radiation from the antenna to the intensity of radiation in a given direction measured all over. | [6]        |
|                | \( D = \frac{4\pi U}{P_{\text{rad}}} \) (Dimension-less) where \( U = \text{Intensity of radiation (W per unit solid angle)}. \) \( P_{\text{rad}} = \text{total radiated power (W)}. \) |            |
| Gain:          | The gain from antenna is considered as a measure of the intensity ratio in the direction is given. Moreover, Gain is described as the multiple of 4 times the intensity ratio in a specific direction to the power accepted by the uniformly radiated antenna, the antenna that radiated throughout all directions equally. | [7]        |
|                | \( G = \frac{4\pi U(\theta, \phi)}{P_{\text{in}}} \) where \( U(\theta, \phi) = \text{given direction’s intensity}. \) \( P_{\text{in}} = \text{power accepted by the antenna}. \) |            |
| Beam-width:    | The angular separation evaluated among two similar points where the maximum pattern is acquired on the opposite direction. | [6-7]      |
|                | \( \text{FNBW} = \frac{\text{HPBW}}{2} \) where \( \text{FNBW} = \text{First Null Beam width}. \) \( \text{HPBW} = \text{Half Power Beam width.} \) (measured in degrees and radians) |            |

2. **ARRAY FACTOR**

Adaptive array system uses an antenna array that is managed by a powerful signal processing capability to directly manipulate the radiation pattern according to the changing signal environment [8]. Adaptive array system, offer optimum radiation in user’s direction and additionally simultaneously reject the interferences.
The Array Factor (AF) is a characteristic of the weights, positions and steerage vector used with inside the antenna array or the phased array [9-10]. The array factor without taking the component specific radiation characteristics, estimates the impact of merging radiating array elements. The array factor and element factor product assigns the antenna array radiation’s pattern [11-12]. Radiation’s pattern is equal to the array factor, if we presume all elements radiate equally throughout every direction. The antenna elements (N) and separation distance (d) between them is shown in Fig. 2. The array factor can be derived as:

For \( i = 1: \text{Number of Antennas}(N) \),

\[
AF = AF + w(i)^* \exp(j \times (i - 1) \times (2 \times pi) / \lambda \times d \times \sin(theta))
\]

where \( d \) = distance among antenna elements, \( \lambda \) = wavelength, \( w(i) \) = \( i \)th element weight coefficient, \( \theta \) = angle of incidence.

3. ADAPTIVE BEAMFORMING ALGORITHMS

At the base station, an adaptive algorithm is used in manner ensuring that the system has able to find out the optimal radiation pattern for each user [13]. As of the process of training each of the users delivers a short - term training sequence to the base station [14]. The algorithm then uses this information from a user by comparing each received signal to the original sequence to determine the appropriate pattern of radiation for that user [3,15]. With this approach, each antenna element uses all received signals and is optimally combined to maximize the desired signal and cancel unwanted interference. At the base station a lot of number crunching is required during the training process. But in the past it was unpopular due to the high cost of computing power [16]. However, intensive signal processing is no longer a problem when low cost, extremely fast processors are available. When interference from other users happens it is more complicated. The block diagram is shown in Fig. 2 of the adaptive beam-forming.

**Fig. 2: Adaptive Beam-forming.**

**LMS Algorithm:** LMS Algorithm comes under the category of non-blind adaptive algorithms and it is gradient basis technique of steepest decent. The weight vector update involves an iterative technique, resulting in attempting to reduce the mean square error among both the desired signal and the array output, just so the array output is almost approximately equivalent to the desired signal [8,14]. Based upon the step size (\( \mu \)), the convergence of LMS Algorithm is estimated. Thus the appropriate step size (\( \mu \)) has to be selected. The equations of the LMS Algorithm are as follows:

Output signal: \( y_{LMS}(i + 1) = w_{LMS} \times signal_{ns}(i, i + 1) \)  

Error signal: \( e(i + 1) = signal_{x}(i + 1) - y_{LMS}(i + 1) \)
Weight: \( \text{wlms} = \text{wlms} + \mu \times e(i+1) \times (\text{signal}_{\text{ns}}(:,i+1)) \)  

(4)

where \( \text{signal}_{\text{ns}}(:,i+1) = \) Total received signal.

**CMA Algorithm:** CMA Algorithm is a well known blind adaptive algorithm. The algorithm is introduced to keep in focus the signal’s constant complex envelope (amplitude) property amongst other signals like FSK, PSK, MSK, and QAM [17]. If the signal arriving is of constant amplitude, this algorithm should maintain and reestablish the desired signal amplitude. CMA Algorithm is used to suppress the undesired signal but not completely cancel it. Due to slow convergence of CMA Algorithm, tends to put performance limits during which signals shift gradually and those signals also have to be identified quickly. The equations of the CMA Algorithm are as follows:

**Output signal:** \( y_{\text{CMA}}(i+1) = w_{\text{CMA}} \times \text{signal}_{\text{ns}}(:,i+1) \)  

(5)

**Error signal:** \( e_{\text{CMA}}(i+1) = \frac{y_{\text{CMA}}(i+1)}{\text{norm}(y_{\text{CMA}}(i+1))} - y_{\text{CMA}}(i+1) \)  

(6)

**Weight:** \( w_{\text{CMA}} = w_{\text{CMA}} + \mu \times e_{\text{CMA}}(i+1) \times (\text{signal}_{\text{ns}}(:,i+1))^T \)  

(7)

where \( \text{signal}_{\text{ns}}(:,i+1) = \) Total received signal.

**RLS Algorithm:** One of the non-blind adaptive algorithms, the RLS Algorithm. The LMS algorithm's convergence speed relies upon the array correlation matrix's Eigen values. With slow speed, the algorithm converges with large Eigen value distribution and this problem is fixed by RLS algorithm by updating Gradient step size \( \mu \) at \( n^\text{th} \) iteration with the gain matrix \( (\mu^{-1}(n)) \) [18-19]. RLS algorithm is performance-wise better over LMS and CMA Algorithm [20]. RLS algorithm shows the high convergence rate and side lobes are not entirely eliminated [21]. RLS must have narrower beam widths, adequate rejection of Interference and convergence faster. High computational complexity is becoming a major drawback. The equations of the RLS Algorithm [22] are as follows:

**Output signal:** \( y(n) = w^T(n) \times x(n) \)  

(8)

**Error signal:** \( e(n) = d(n) - y(n) \)  

(9)

**Weight:** \( w(n) = r^{-1}(n) \times p(n) \)  

(10)

where \( d(n) = \) desired signal, \( r(n) = \sum_{k=0}^{K} \lambda^{k-1} x(n)x^T(n) \) (input signal correlation) and \( p(n) = \sum_{k=0}^{K} \lambda^{k-1} x(n)d(n) \) (input and desired signal correlation).

**Proposed Algorithm:** Proposed Algorithm is a combination or hybrid of two non-blind adaptive algorithms, LMS and RLS. The result of the proposed is better as relative to the LMS and CMA Algorithm. In this, the reference signal is used to update the weight vector equation. It suppresses the interference or noise signal better as compared to the both LMS and CMA Algorithm. The equations of the Proposed Algorithm are as follows:

**Output signal:** \( \text{yd}(i) = \sum(w(:,i)^T \times \text{signal}_{\text{ns}}1(:,i)) \)  

(11)

where \( z = R \times \text{signal}_{\text{ns}}1(:,i) \)

\( u = \text{signal}_{\text{ns}}1(:,i)^T \times z \)

\( v = \frac{1}{1 + u} \)

\( zz = v \times z \)

\( w(:,i) = w(:,i) + (e(i) \times zz) \)

\( R = R - zz \times z \)
Error signal: \( e(i) = \text{signal}_x(i) − y_1(i) \)

where \( y_1(i) = w(:,i)' \ast \text{signal}_ns1(:,i) \)

Weight: \( w = \text{repmat}(\text{wlms}',1,\text{length}(t)) \)

\[ \text{(12)} \]

\[ \text{(13)} \]

### 4. SIMULATION RESULTS & DISCUSSION

For different antenna elements (N) and different distances between the successive antenna elements (d), the simulation results are shown in this section and are performed in MATLAB. The desired incoming signal is 35° and two interference or noise signals are -20° and 0°. The antenna elements 4,8,16 and distance among successive antennas are \( \lambda/8, \lambda/4, \lambda/2 \) are taken into consideration. To avoid spatial aliasing, the maximum distance between the two elements was restricted to \( \lambda/2 \) or 0.5\( \lambda \).

**LMS Algorithm:**

![Fig. 3: Linear Array Beam-forming Pattern at d=0.5\( \lambda \) of LMS for N=4,8,16.](image3.png)

![Fig. 4: Linear Array Beam-forming Pattern at N=4 of LMS for d=\( \lambda/8, \lambda/4, \lambda/2 \).](image4.png)
The amplitude response comparison of LMS Algorithm by varying number of the antenna elements and antenna’s distance are shown in Fig. 3 and Fig. 4. In Fig. 3, for N=8 original signal is extracted which is 35° and N=4,8 places approximate null at 0°. In Fig. 4, at N=4 for d= λ/8, λ/4, λ/2 the better result obtained at d= λ/8 as places a null at 0° and d= λ/4, λ/2 also places a close null at 0°. The waveform gets broadened as the distance decreases so it is difficult to extract the original signal.

CMA Algorithm:

Fig. 5: Linear Array Beam-forming Pattern at d=0.5λ of CMA for N=4,8,16.

Fig. 6: Linear Array Beam-forming Pattern at N=4 of CMA for d= λ/8, λ/4, λ/2.

The amplitude response comparison of CMA Algorithm by varying number of the antenna elements and antenna’s distance are shown in Fig. 5 and Fig. 6. In Fig. 5, the better result is obtained for N=16 i.e. almost sharp lobe is at 35° and null at -20°. In Fig. 6, at N=4 for d= λ/8, λ/4, λ/2 the better result obtained at d= λ/2 because places a null at close to 0°.
Proposed Algorithm:

Fig. 7: Linear Array Beam-forming Pattern at d=0.5λ of Proposed for N=4,8,16.

Fig. 8: Linear Array Beam-forming Pattern at N=4 of Proposed for d=λ/8, λ/4, λ/2.

The amplitude response comparison of Proposed Algorithm by varying number of the antenna elements and antenna’s distance are shown in Fig. 7 and Fig. 8. In Fig. 7, the better result is obtained for N=16 i.e. almost a perfect null at -20°, N=8 places almost a close null at 0° and for N=4,8 almost extract desired incoming signal at 35°. In Fig. 8, at N=4 for d=λ/8, λ/4, λ/2 the better result obtained at d=λ/2 and λ/4 because places a null at 0°. Thus the better results are obtained for higher value of N i.e. N=16 and d=λ/2 is taken as maximum distance between two antenna elements.

5. CONCLUSION AND FUTURE SCOPE

The performance improves with the more numbers of antenna elements in the array and large distance between the antennas i.e. λ/2 as in simulation results of LMS, CMA and Proposed Algorithm. Compared with both LMS and CMA, RLS Algorithm is better. RLS Algorithm exhibits higher convergence rate, narrow beam width and lateral lobes are not totally eliminated. These algorithms are used to steer the beam in desired direction and places a null in the unwanted or interferer direction. The results of Proposed Algorithm as compared to LMS and CMA Algorithm are better because it places a null towards the interferer signal i.e. 0° and -20° and extract
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desired incoming signal at 35°. Thus, the convergence of CMA and LMS is slower than the Proposed Algorithm. For beam steering implementation, the future research approach will investigate the time-varying desired user and undesired / interferer locations, as well as other unique weight estimation algorithms.

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