Simulation of Reduced Complexity Beamforming Algorithms for Mobile Communication

Kishore M, Ashwini V.R. Holla, H .M. Guruprasad

Abstract— ***Interference reduction is vital for being able to effectively communicate with mobile users. In order to provide line of sight communications and continual coverage to the remote users. one approach to increasing capacity and coverage zones for the servicing wireless station is to use smart antennas. Sophisticated adaptive beam forming techniques can be applied to point the array's beam in the desired look direction while simultaneously nulling out the interfering signal. This paper explains the approaches for beam formation that reduce the computational complexity of conventional Least Mean Square algorithm.***

IndexTerms—Smartantenna, Beam Forming, Interference, Least Mean Square Algorithm

I. INTRODUCTION

Smart antenna systems employing multiple antennas provide for increased system capacity, extended radio coverage and improved quality of service through the ability to steer the antenna pattern in the direction of desired user while placing nulls at interferer locations. Adding more antennas to the array gives higher angle resolution while steering the beam and more degrees of freedom in placing the nulls, but it results in increase of computational complexity and latency in calculating the weight vectors, which are used to process the received signals at the antennas. In Switched-beam where approach a set of weight vectors (vectored weights of phase shifts used to steer the beam) are pre-calculated and stored for different angles, there is lesser computational complexity. In fully adaptive systems, however, a new weight vector is calculated adaptively with the change in the angle of the user and/or an interferer, therefore offers accurate tracing of the user angle at the cost of increased computational complexity. Among the basic adaptive filters used for beam steering, Least Mean Square (LMS) algorithm is the one that is most prolifically used.

The computational requirements of conventional LMS algorithm is high, therefore methods reducing complexity of beam forming algorithms without degrading the performance are sought.

In this paper the LMS algorithm is modified, reducing the complexity in the weight vector updation functions that follow signum and sinusoidal shapes.

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BEAM FORMATION

A. Smart Antenna

The smart antenna consists of Down Converter, Analog to Digital Converters and Digital Signal Processor. Based on Direction of Arrival (DOA), and the antenna array the Adaptive Beam Forming (ABF) algorithms dictate the beam patterns for which the necessary calculations are done by the processor. The uniform linear antenna array for which the current amplitudes are adjusted by a set of complex weights using an adaptive beam forming algorithm. The adaptive beam forming algorithm optimizes the array output beam pattern such that maximum radiated power is produced in the direction of desired mobile user and deep nulls are generated in the direction of undesired signals representing co-channel interference from mobile users in adjacent cells. Two basic functions that any smart antenna are supposed to perform for providing a reliable link are:

(a) Direction of Arrival (DOA) Estimation and

(b) Adaptive Beam forming (ABF).

DOA estimation is necessitated with moving transmitter/ recievers as in mobile communication systems. Direction of Arrival is defined as the direction along which the desired signals arrive. The function of the DOA algorithms is to work on the signal received at the antenna array elements and compute the direction of arrival of all incoming signals that include desired user signal, interfering signals and multipath signals.

B. Beam Formation

A Beam former is a set of sensors or antennas arranged in a linear fashion with outputs that can be steered electronically. The signal received at these sensors is sent for computation of complex weight vectors. In essence, beam forming is spatial-temporal filtering where signals are separated according to their directional characteristics and frequency content.

ABF is a technique in which beam is steered along the direction of the desired signal, while a null is generated along the direction of the interfering signal. This is done by ABF by dynamically updating the complex weights with the help of adaptive algorithms.

C. Adaptive Beamforming

Adaptive Beam forming is a technique in which an array of antennas is exploited to achieve maximum reception in a specified direction while rejecting signals of the same/different frequency from other directions. The weight vectors are computed and adaptively updated in real time based on signal samples.

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The adaptive process permits narrower beams in look direction and reduced output in other directions, which results in significant improvement in Signal to Interference Noise Ratio (SINR).

II. COMPLEX WEIGHTS

The weight updation equation can be represented as

$$w(n+1) = w(n) + \Delta w(n)$$

Where $w(n)$ is the weight vector computed at the given instant with, $\Delta w(n)$ the correction applied to calculate new weights. Each of the beams forming algorithm varies in terms of computation of weights. In a practical case, if $s(n)$ is the signal samples that correspond to a look direction specified, $i(n)$ represents interfering signal samples corresponding to jamming directions and $n_0(n)$ the noisy signal samples due to receiver components. The composite received signal is given by

$$x(n) = s(n)a(\theta_0) + \sum_{i=1}^{M} i_i(n)a(\theta_i) + n_0(n) \quad \text{.................(1)}$$

Where, M is number of jamming sources, $a(\theta_0)$ is desired steering vector and $a(\theta_i)$ is the steering vector corresponding to i^{th} interference signal. Since jamming signals (or interfering signals) are of no interest, it is assumed $i(n)_1 = i(n)_2 ...... = i(n)_M = i(n)$ with this modification equation (1) can be written as

$$x(n) = s(n)a(\theta_0) + i(n)\sum_{i=1}^{M} a(\theta_i) + n_0(n)$$

In matrix notation, induced signal can be written as

$$X = A_{\theta_0} S + A_{in} I_i + N$$

X is an L x N_s induced signal matrix, with - N_s the total number of samples, 'L'- number of array elements,

S Represents reference signal samples and A_{θ_0} the desired steering vector of order Lx1, I_i represents interference signal samples matrix of order 1xN_s, N represents Gaussian noise matrix of order LxN_s and A_{in} is Lx1 column vector obtained by adding all columns of array manifold vector as shown (3.8)

$$A_{in} = \begin{bmatrix} 1 \\ e^{ix_1} \\ \vdots \\ e^{iy_1} \end{bmatrix} + \begin{bmatrix} 1 \\ e^{ix_2} \\ \vdots \\ e^{iy_2} \end{bmatrix} + \ldots\ldots\ldots\ldots\ldots + \begin{bmatrix} 1 \\ e^{ix_m} \\ \vdots \\ e^{iy_m} \end{bmatrix}$$

X1=2ndsin θ_1 *, X2=2ndsin* θ_2*, Xm=2ndsin* θ_m

Y1=2nd(L-1)sin θ_1*, Y2=2nd(L-1)sin* θ_2

Ym= Ym=2ndsin θ_m

Where,'d' is the distance between antenna elements, $\theta_1, \theta_2, ..., \theta m$ are directions of jamming signals and M is number of jamming signals.

III. SIMULATION METHODOLGY OF ADAPTIVE BEAM FORMING

1. Compute the Lx1 steering vector for desired direction θ_0 .
2. Compute the LxM array manifold vector corresponding to M interference source directions $\theta_1, \theta_2, ..., \theta_M$.
3. Obtain signal samples 'S' by sampling continuous time signal of baseband frequency. (For simulation sine wave samples is considered).
4. Compute the autocorrelation matrix R_{xx} .
5. Compute the step size
6. Compute the following for all signal samples $0 \le n \le N_s$.

   Where, N_s is the total number of signal samples.
7. The array factor is computed
8. Array factor versus angles are plotted.

IV. NEWLY PROPOSED SIGNUM ALGORITHMS

A. Signum Data Least Mean Square(Sd-Lms)

The LMS algorithm is the most widely used adaptive beam forming algorithm, being employed in several communication applications. It has gained popularity due to its low computational complexity and proven robustness. The LMS algorithm changes the weight vector $w(n)$ along the direction of the estimated gradient based on the steepest descent method. In employing the LMS algorithm, it is assumed that sufficient knowledge of the reference signal is present.

The Least Mean Square (LMS) algorithm is one of the most popular algorithms in adaptive signal processing, due to its simplicity and robustness. Many different modifications were proposed to improve performance of the LMS and a large number of results on its steady state misadjustment and its tracking ability has been obtained.

Despite computational efficiency, LMS algorithms need additional simplifications in applications such as high speed digital communication. The weight coefficient in LMS algorithm is modified by applying the signum operator to the data and hence leads to Signum Data algorithm.

The weight vector for Sign Data Least Mean Square (SD-LMS) is given by

$$w(n+1) = w(n) + \mu \operatorname{sgn}(x(n))\, e(n)$$

Where, sgn(x(n)) is sign of data vector given by

$$\operatorname{sgn}(x(n)) = \frac{x(n)}{|x(n)|}$$

Where, μ is the step siz , $x(n)$ is the induced signal and $e(n)$ is the error signal. Sign Data LMS (SD-LMS) individually normalizes each coefficient of weight vector.

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B. Signum Signum Least Mean Square(Ss-Lms)

Quantizing both the error and data will lead to development of Signum Signum LMS algorithm. The weight update equation for (SS-LMS) is given by.

$$w(n+1) = w(n) + \mu \operatorname{sgn}(x(n)) \operatorname{sgn}(e(n))$$

Where, $\operatorname{sgn}(x(n))$ is sign data operator, μ is the step size and $\operatorname{sgn}(e(n))$ is sign error operator.

$$x(n) = a(\theta_0)s(n) + i(n)\sum_{i=1}^{M} a(\theta_i) + n_0(n)$$

$$y(n) = w(n)^T x(n)$$

$$e(n) = s(n) - y(n)$$

$$\operatorname{sgn}(x(n)) = \frac{x(n)}{|x(n)|},$$

$$\operatorname{sgn}(e(n)) = \begin{cases} 1 & e(n) > 0 \\ 0 & e(n) = 0 \\ -1 & e(n) < 0 \end{cases}$$

C. Signum Error Least Mean Square(Se-Lms)

The weight coefficient of LMS is modified by applying sign operator to error e(n).

The weight vector for Sign Error Least Mean Square (SE-LMS) is given by

$$w(n+1) = w(n) + \mu x(n) \operatorname{sgn}(e(n))$$

$$x(n) = a(\theta_0)s(n) + i(n)\sum_{i=1}^{M} a(\theta_i) + n_0(n)$$

$$y(n) = w(n)^T x(n)$$

$$e(n) = s(n) - y(n)$$

$$\operatorname{sgn}(e(n)) = \begin{cases} 1 & e(n) > 0 \\ 0 & e(n) = 0 \\ -1 & e(n) < 0 \end{cases}$$

y(n) is the output beam, w(n) is the complex weight vector.

Here the signum error varies from +1 to -1 as shown above, it becomes +1 when error signal is greater than zero and -1when error signal e(n) is less than zero and zero when error signal is zero which is ideal case.

V. SIMULATION RESULTS

Table 1.gives the input data to the following algorithms

Algorithms	No of antenna elements	Desired direction	Jammer direction
LMS	100	45	10,60,70
SD-LMS	100	45	10,60,70
SS-LMS	100	45	10,60,70
SE-LMS	100	45	10,60,70

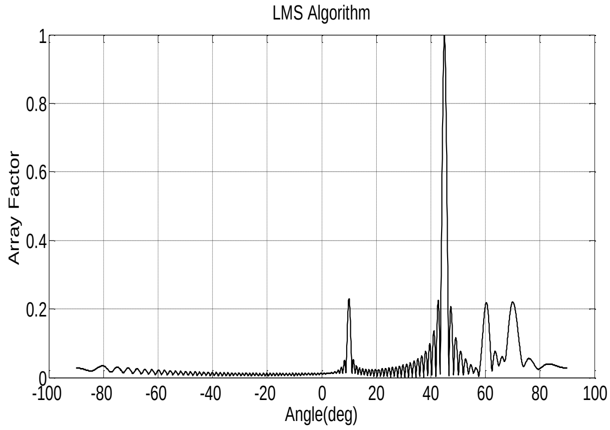

Figure1:Beam plot of LMS algorithm

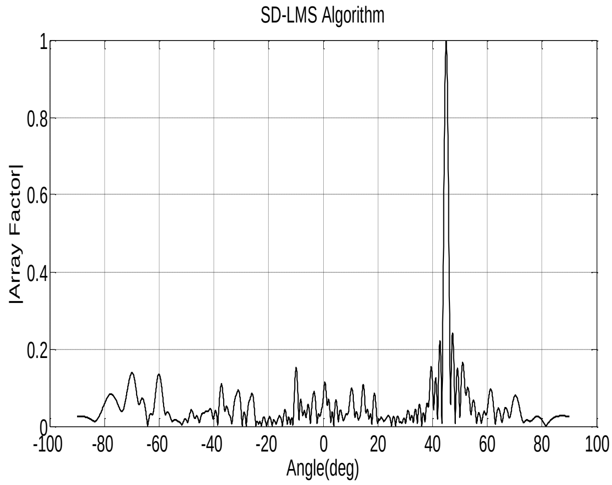

Figure2:Beam plot of SD-LMS algorithm

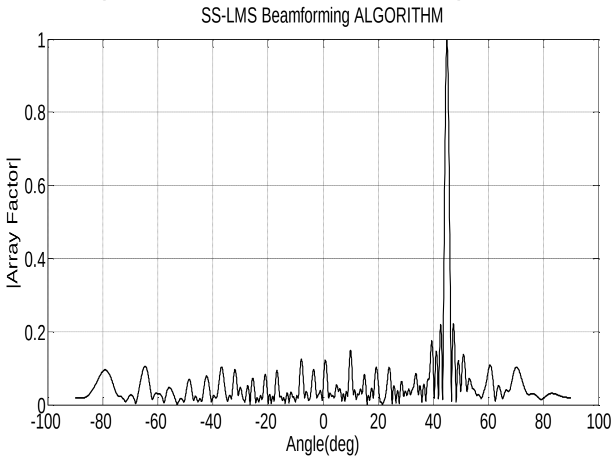

Figure3:Beam plot obtained using SS-LMS algorithm

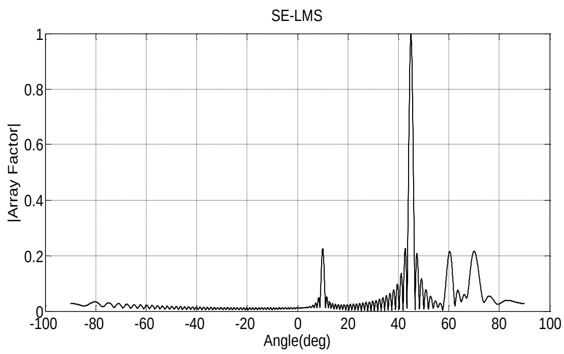

Figure 4:Beam plot of SE-LMS algorithm

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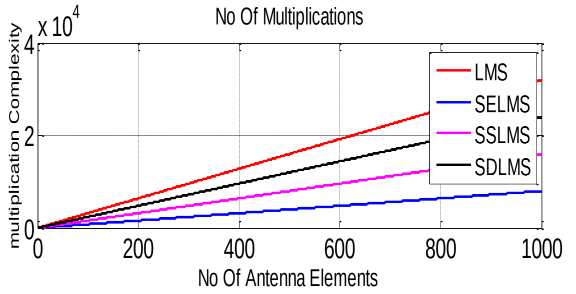

Figure5:Graph of multiplication complexity with respect to number of antenna elements

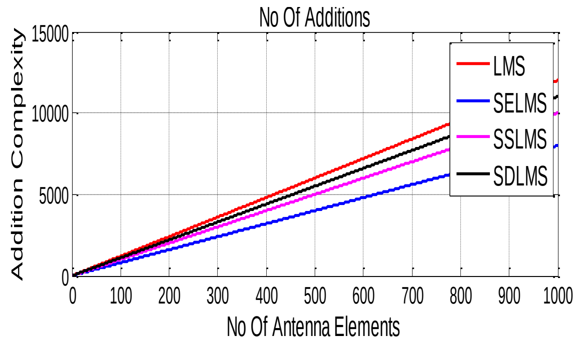

Figure6: Graph of addition complexity with respect to number of antenna elements.

VI. DISCUSSION

The simulation tool primarily used for this project was Math work's Mat lab software 7.0. The simulation simulates a maximum of 100-element linear array with equal element spacing at $\lambda/2$. The sensor outputs will be pure tone sinusoids with changed amplitudes and phases, and for each element in the array there is a time delay at which the signal arrives at each element. The main objective of beam forming is to point the beam in the direction of the signal of interest and listen. The beam pattern is obtained by first calculating an Array factor for the array from -90 to 90 degrees and then multiplying the weights with it. The response of every input user signal and interfering signal is shown in the results. The above capability of adaptive / smart antennas clearly indicates without doubts that smart antenna can be easily replaced with traditionally used existing antennas (Omni directional, sectored antenna with diversity concept). Use of adaptive antenna in existing systems will reduce power consumption and interference while enhancing spectral density in wireless system which is the dire need of wireless communication systems. Health hazard is being considered the main factor in RF communication which will also be taken care of by use of smart antenna as less RF pollution is created with the use of smart / adaptive antenna.

VII. CONCLUSION

A newly proposed adaptive algorithm for beam forming called sdlms,sslms,selms along with conventional lms algorithm is presented and analyzed. The proposed method works well to form the main beam in the desired user and reduced interferences in the undesired direction as shown in the figure(1-4)and also the newly proposed algorithm reduces the computational complexity of lms algorithm with respect to number of multiplications and additions as shown in the figure(5-6).

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