Comparison and performance evaluation of different adaptive beam forming algorithms in wireless communications with smart antenna

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Abstract-Many current modern wireless communication applications still rely on older electronic scanning technologies. Recent efforts are being exerted to modify wireless communication systems to include digital beam forming and adaptive beam forming techniques.The fixed beam forming approaches, which included the maximum SIR, the ML methods, and the MV method, were assumed to apply to fixed direction of arrival angle emitters.If the desired direction of arrival angles change with time, it is necessary to devise an optimization scheme that keeps recalculating the optimum array weights.The receiver signal processing algorithm then must allow for the continuous adaptation to an ever-changing electromagnetic environment.The adaptive algorithm allows for the calculation of continuously updated weights. The popular optimization techniques like LMS(least mean square), SMI(sample matrix inversion) andRLS(recursive least square) algorithms can take into consideration, it is desired to find their adaptive weights and finally comparison of performance evaluation needs to be considered with suitable plots.

Keywords-LMS, RLS, SMI, Adaptive beam forming, smart antenna, Digital Signal Processing.

1. INTRODUCTION

Adaptive Beam forming is a technique in which an array of antennas is exploited to achieve maximum reception in a specified direction by estimating the signal arrival from a desired direction (in the presence of noise) while signals of the same frequency from other directions are rejected. This is achieved by varying the weights of each of the sensors (antennas) used in the array. It basically uses the idea that, though the signals emanating from different transmitters occupy the same frequency channel, they still arrive from different directions. This spatial separation is exploited to separate the desired signal from the interfering signals. In adaptive beam forming the optimum weights are iteratively computed using complex algorithms based upon different criteria.

When the algorithms used are adaptive algorithms, this process is referred to as adaptive beam forming. Adaptive beam forming is a subcategory under the more general subject of digital beam forming. The chief advantage of digital beam forming is that phase shifting and array weighting can be performed on the digitized data rather than by being implemented in hardware. On receive; the beam is formed in the data processing rather than literally being forming in space. The digital beam forming method cannot be strictly called electronic steering since no effort is made to directly shift the phase of the antenna element currents. Rather, the phase shifting is computationally performed on the digitized signal. If the parameters of operation are changed or the detection criteria are modified, the beam forming can be changed by simply changing an algorithm rather than by replacing hardware. Adaptive beamforming is generally the more useful and effective beam forming solution because the digital beam former merely consists of an algorithm which dynamically optimizes the array pattern according to the changing electromagnetic environment. Conventional array static processing systems are subject to degradation by various causes. The array SNR can be severely degraded by the presence of unwanted interfering signals, electronic countermeasures, clutter returns, reverberation returns (in acoustics), or multipath interference and fading. An adaptive array system consists of the antenna array elements terminated in an adaptive processor which is designed to specifically maximize certain criteria. As the emitters move or change, the adaptive array updates and compensates iteratively in order to track the changing environment. Many current modern radar systems still rely on older electronic scanning technologies. Recent efforts are being exerted to modify radar systems to include digital beam forming and adaptive beam forming techniques. While current modern mobile base stations tend to use older fixed beam technologies to satisfy SDMA, they also would benefit from the use of modern adaptive methods and thereby increase system capacities.The adaptation process must satisfy a specified optimization criterion.

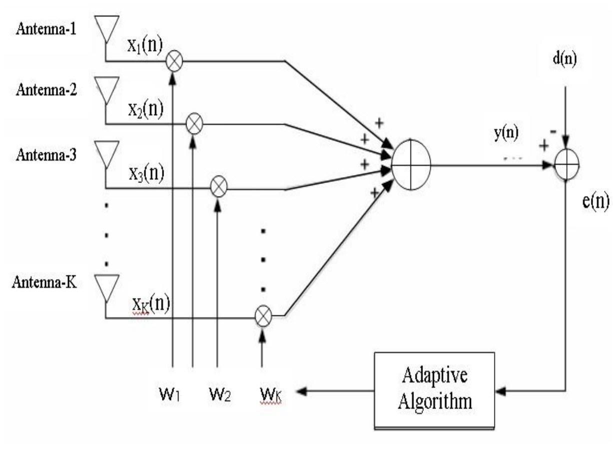


Figure.1 A generic adaptive beam forming system

II.ARRAY WEIGHTING

For a uniformly weighted linear array, the largest side lobes are down approximately 24 per cent from the peak value. The presence of side lobes means that the array is radiating energy in untended directions. Additionally, due to reciprocity, the array is receiving energy from unintended directions. In a multipath environment, the side lobes can receive the same signal from multiple angles. This is the basis for fading experienced in communications. If the direct transmission angle is known, it is best to steer the beam toward the desired direction and to shape the side lobes to suppress unwanted signals. The side lobes can be suppressed by weighting, shading, or windowingthe array elements. These terms are taken from the EM, underwater acoustics, and array signal processing communities, respectively. Array element weighting has numerous applications in areas such as digital signal processing (DSP), radio astronomy, radar, sonar, and communications

III. ADAPTIVE BEAMFORMING ALGORITHMS

A. Least Mean Squares Algorithm:

The LMS algorithm uses instantaneous gradientvector $\nabla(\xi)$ to continuously update the weight vector. If $w(n)$denotes the estimate of the weight vector at the *n*thiteration and $\xi(n)$ is the mean square error, the nextestimation of the weight vector for the$(n+1$thiteration, $wn+1$ is estimated according to thefollowing equation

$$w(n+1) = w(n) - \mu\nabla(\xi)$$

Where μ is the step size. This parameter controls the convergenceof the algorithm.

B. RLS Algorithm:

The convergence of the LMS algorithm depends upon the Eigen values of R. If R leads to a large spread, the algorithm converges slowly. This problem is solved here by replacing the step gradient size μ with a gain matrix $R^{-1}(n)$ at the nth iteration. Recursive converges fast compared to the least mean squaresAlgorithm. The algorithm initiation is done by first setting

$$R^{-1}(0) = \frac{1}{\delta} * I$$

Where δ>0 and I-Identity matrix.The weights are updated using

$$w(n+1) = w(n) - R^{-1}(n+1)x(n+1)\varepsilon$$

C. Sample Matrix Inversion Algorithm:

SMI has faster convergence as it employs directinversion of the covariance matrix R. The sample matrixis a time average estimate of the array correlation, matrixusing *K*-time samples. If the random process is ergodic in the correlation, the time average estimate will equal the actual correlation matrix. In the minimum MSE,the optimum array weights are given by the optimum Wiener solution as

$$\bar{W}_{opt} = \bar{R}_{xx}^{-1}\bar{r}$$

Where

$$\bar{r} = E[d^*\bar{x}]$$

$$\bar{R}_{xx} = E[\bar{x}\bar{x}^H]$$

As shown in the above equation, we can estimate the correlation matrix by calculating the time average such that

$$\hat{R}_{xx} = 1/k\sum_{k=1}^{k}\bar{x}(k)\bar{x}^H(k)$$

Where K is the observation interval

The correlation vector $\bar{r}$ can be estimated by

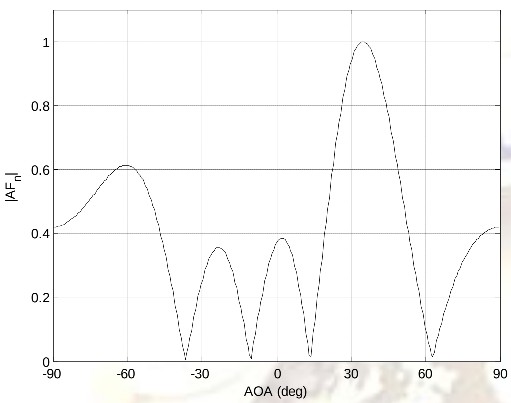
$$\hat{r} = 1/k\sum_{k=1}^{k} d^*(k)\,\bar{x}(k)$$

IV. RESULTS AND DISCUSSIONS

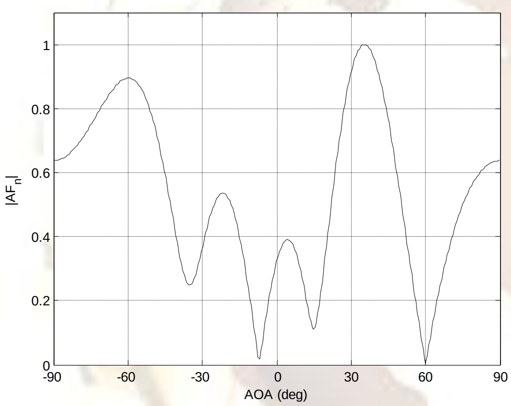
Simulation for antenna array is done using MATLAB. In simulation process, we analyse amplitude response and trace of correlation matrix for adaptive beam forming algorithms RLS, LMS and SMI. The parameters used for our simulation are:

Number of antenna elements:5
Element spacing:0.5λ
DOA of desired signal:45˚
DOA of interference signal:60˚
Forgetting factor(α)(for RLS):0.9
Number of data samples:100

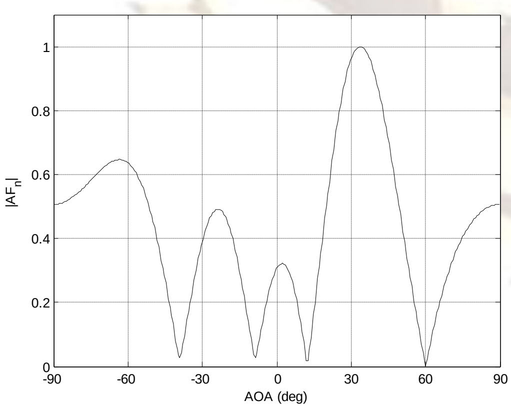
In figure2, the amplitude responses of the three algorithms from -90 degrees to +90 degrees are plotted. It is evident from the figure that in LMS algorithm the interference signal is not completely rejected at 60°.Whereas, in RLS and SMI algorithms the interference signal is completely rejected at 60°.



(2.a). LMS algorithm



(2.b). RLS algorithm



(2.c). SMI algorithm

Figure.2.Comparision of amplitude responses of LMS, RLS and SMI.

In figure 3, circles line (oooooo) represents the trace of LMS. It is evident that LMS has a very slow convergence. Continuous wave

(_______) represents trace of RLS. Although, it has high convergence for smaller number of iterations, there is a sudden drop as the number of iterations increase. Dashed line(-------) represents the trace of SMI. In case of SMI, trace output is stable. So, it is better when compared with RLS in terms of convergence.

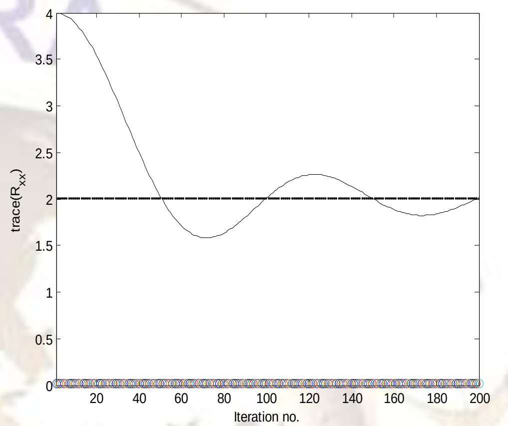


Figure.3. Comparison of convergence plots for LMS, RLS and SMI.

V. CONCLUSION

In adaptive beamforming, the radiation pattern of smartantenna is controlled through various adaptive algorithms.Adaptive algorithm dynamically optimizes the radiationpattern according to the changing electromagneticenvironment. Here we compare and analyzethree popular adaptive techniques including LMS, RLS and SMI throughsimulation of various parameters likeamplitude response and trace of correlation matrices. We can conclude that LMS is thesimplest and more suitable choice because of its simplicity and a reasonable performance. Since it is an iterative algorithm it can be used in a highly time-varying signal environment. It has a stable and robust performance against different signal conditions. However it may not have a really fast convergence speed compared other complicated algorithms like the Recursive Least Square (RLS). It converges with slow speeds when the environment yields a correlation matrix R possessing a large Eigenspread.RLS has fastest convergence at the costof high computational burden when compared to LMS. RLS is the best choice and has also its application where quick tracking of thesignal isrequired. The RLS algorithm does not require any matrix inversion computations as the inverse correlation matrix is computed directly. It requires reference signal and correlation matrix information. It is almost ten times faster compared to LMS.The SMI algorithm has a faster convergence rate since it employs direct inversion of the covariance matrixR. It provides good performance in a discontinuous traffic. However, it requires that the number of interferers and their positions remain constant during the duration of the block acquisition.Since SMI employs direct matrix inversion the convergence of this algorithm is much faster compared to the LMS algorithm. However, huge matrix inversions lead to computational complexities that cannot be easily overcome.

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