Abstract

An antenna array consists of antenna elements whose outputs are added in such a way that the parameters of communication system are optimized. As smart antenna is an array system aided by some intelligent algorithm designed to adapt to changes in signal environments. Smart antennas offer low co-channel interference and large antenna gain to the desired signal. Smart antenna catered for this purpose is called beam forming smart antenna. Since beam forming is performed in software, forming several beams with the same array is possible by simply reusing the array output. In this context the smart antenna is called as Space Division Multiple Axis (SDMA) smart antenna. The signal received at each antenna element is multiplied by an optimum weight and these products are added to get desired output signal. The weight vector can be calculated using one of the many adaptive algorithms such as Least Mean Square algorithm (LMS), Sample Matrix Inversion algorithm (SMI), Recursive Least Square algorithm (RLS) and their variants. This paper studies how weight vector and beam pattern of the smart antenna system are changing for different angles of arrival of desired signal and different number of antenna elements in an antenna.

Keywords:

1. Introduction

Least Mean Square algorithm (LMS) was proposed by Widrow et al. in the perspective of adaptive antennas. The method of steepest descent algorithm can be approximated by a method called Least Mean Square algorithm (LMS) as advocated by Widrow et al. Variable weights of a signal processor can be automatically adjusted by a simple adaptive technique based on the Least Mean Squares algorithm (LMS) as shown in. In R. T. Lacoss (1971) has presented many examples of spectra obtained by the maximum likelihood method and by the maximum entropy method and has shown that these newer techniques are in general superior to the more conventional spectral analysis methods. The fundamentals of adaptive arrays is well-explained in. Adaptive beam forming techniques for smart antennas based upon Least Mean Squares (LMS), Sample Matrix Inversion (SMI), Recursive Least Squares (RLS) and Conjugate Gradient Method (CGM) are discussed and analyzed in.

Smart antennas have the property of spatial filtering, which makes it possible to receive energy from a particular direction while simultaneously blocking it from another direction. This property makes smart antennas a very effective tool in detecting and locating an underwater source of sound such as a submarine without using active sonar in. Smart antennas generally encompass both switched beam and beam formed adaptive systems. Switched beam systems have several available fixed beam patterns as explained in systematically reviews the techniques, challenges, and tradeoffs of DSP software radio design. Coverage includes constructing RF front-ends; using digital processing to overcome RF design problems. The use of smart antennas in mobile ad hoc and mesh networks is discussed in. The performance of Bessel beam former based on spatial filtering criteria is discussed in. Enhanced Sample Matrix Inversion for better beamformer for a Smart Antenna System is discussed in. Two types of smart antennas adaptive and switched beam are given in. Study and Simulation of Smart antenna using SMI
A Study of Sample Matrix Inversion Algorithm for Smart Antenna Applications

and CGM Algorithm is given in13. The phase shifting and array weighing can be performed on digital data rather than in hardware is the major advantage of digital beam former. In the sample matrix algorithm a time average estimate of the array correlation matrix is calculated. If the random process is ergodic in the correlation, the time average matrix will be equal to the actual correlation matrix which is based on ensemble average.

The main goal of wireless communications research is enhancing user capacity data rates, channel and channel reliability. User capacity refers to the number of users that can be simultaneously serviced by a wireless system. Increase in data rates helps subscribers enjoy services such as multimedia and broadband Internet. Improving symbol error rates can be reduced by improving channel reliability gets affected by frequency selective channel fading, noise and interference.

Smart antennas are used for increasing the quality of a wireless communication systems. A smart antenna is an antenna with intelligence. Smart Antennas are classified as switched beam systems are fully adaptive arrays. Switched beam systems are simple in nature switched beam systems have long been popular in wireless radio systems. Fully adaptive antennas are smarter than switched beam systems both architectures can be used to achieve diversity and interference rejection. Once an architecture is chosen for a smart antenna system, an algorithm must be chosen. A lot of algorithms have been developed for both switched beam and fully adaptive arrays. Judicious decision must be made on selecting an adaptive algorithm for a particular signal environment.

2. Beam Forming

As discussed in section I there two beam forming approaches for smart antenna systems. In switched beam array a set of fixed beams from which a beam that is suitable to particular signal environment will be selected. In fully adaptive array the antenna pattern is dynamically adjusted to the signal environment.

Through the concept of the beam forming, smart antennas offer low co-channel interference and large antenna gain to the desired signal. When beam forming is implemented in software the beams change dynamically without any mechanical movement. Also because of software implementation several beams with a single array is possible by simply re-using the array output. For the same transmit power, smart antennas offer increased coverage and range, improved signal quality and increased data rates relative to other antenna systems.

Figure 1(a)&1(b), describes lobes and 9 nulls of Adaptive array and switched beam antennas for same user signals and interferers.

This figure conveys that smart antennas that used beam forming concepts can reject co-channel interference more effectively than switched beam antennas, since the gain is lower for the Direction Of Arrival (DOA) for the interference compared to the desired signal.

3. Adaptive Beamforming Algorithms

Figure 2 shows an adaptive array system with M number of antenna elements in the array, x(t) refers to in the system received signal at antenna, the received signal at each antenna is multiplied by a complex weight and all the products are some doubt to get a new signal y(t). w1, w2, … wM, are complex weights, d(t) is taken as reference signal which is basically a training signal. e(t) is the error between received weighted signals sum and the desired signal.

Figure 1. (a) Adaptive array pattern (b) Switched beam pattern
The weight vector can be calculated by using one of the many adaptive algorithms.

Smart antenna patterns are controlled via algorithms based upon certain criteria. Signal-to-Interference Ratio (SIR), maximizing the variance, minimizing the Mean Square Error (MSE), are same important criteria based on which smart antenna patterns are created.

The adaptive beamforming algorithms include Least Mean Square algorithm (LMS), Sample Matrix Inversion algorithm (SMI), Recursive Least Squares algorithm (RLS), the constant modulus algorithm (CMA) and their variants.

4. SMI Algorithm

One of the drawbacks of the LMS algorithm is the rate of convergence of weights is slow since it must go through many iterations before satisfactory convergence is achieved. So we have another algorithm called SMI algorithm. The sample matrix is a time average estimate of the array correlation matrix using K-time samples. If the random process is ergodic in the correlation, the time average estimate will equal the actual correlation matrix. The SMI algorithm has a faster convergence rate since it employs direct inversion of the correlation matrix $R_{xx}$,

$$R_{xx}^{-1} = \frac{1}{K} \sum_{k=1}^{K} \bar{r}(k)\bar{x}^H(k)$$  \hspace{1cm} [4]

where $\bar{r} = E[d * \bar{x}]$  \hspace{1cm} [2]

The optimum weight vector is given by

$$\bar{w}_{opt} = R_{xx}^{-1} \bar{r}$$  \hspace{1cm} [3]

$\bar{w}_{opt}$ = it is the Wieners solution.

We can estimate the correlation matrix by calculating the time average such that

$$R_{xx}^{-1} = \frac{1}{K} \sum_{k=1}^{K} \bar{r}(k)\bar{x}^H(k)$$  \hspace{1cm} [4]

$X_k$ is the array correlation matrix given by

$$R_k = \frac{1}{K} \sum_{k=1}^{K} d(k)\bar{x}^H(k)$$

where $d(k)$ represents the desired signal.

Since we use a K-length block of data, this method is called a block-adaptive approach. We are thus adapting the weights block-by-block. It is easy in MATLAB to calculate the array correlation matrix and the correlation vector by the following procedure. Define the matrix $X_k(k)$ as the kth block of $\bar{x}$ vectors ranging over K-data snapshots.

$$\bar{X}_k(k) = \begin{bmatrix} x_1(1+kK) & x_1(2+kK) & \cdots & x_1(K+kK) \\ x_2(1+kK) & x_2(2+kK) & \cdots & \\ \vdots & \vdots & \ddots & \vdots \\ x_M(1+kK) & \cdots & x_M(K+kK) \end{bmatrix}$$

Here where $k$ is the block number and $K$ is the block length.

Thus, the estimate of the array correlation matrix is given by

$$R_{xx}(k) = \frac{1}{K} \bar{X}_k(k)\bar{X}_k^H(k)$$

the desired signal vector can be define by

$$d(k)=[d(1+kK) \ d(2+kK) \ \cdots \ d(K+kK)]$$

the estimate of the correlation vector is given by

$$f(k) = \frac{1}{K} d^H(k)\bar{X}_k(k)$$

for the kth block of length K The SMI weights can then be calculated as

Figure 2. Narrowband Adaptive Array.
\[ \vec{w}_{SMI}^{(k)} = \vec{R}_{xx}^{-1}(k)\vec{r}(k) = [\vec{X}_K(k)\vec{X}_K^H(k)]^{-1}d^*(k)\vec{X}_K(k) \]

5. Simulation Results and Discussions

The SMI algorithm was simulated using Matlab Software. Let us take:

Case 1: An array of antennas with 8 elements, N = 8. Let the spacing between each antenna in the array be d = 0.25. Suppose that the desired signal is arriving at an angle \( \theta_0 = 25^\circ \) and an interferer is arriving at an angle \( \theta_1 = -65^\circ \).

Case 2: An array of antennas with 30 elements, N = 30, d = 0.25. The desired signal is arriving at an angle \( \theta_0 = 25^\circ \) and an interferer is arriving at an angle \( \theta_1 = -65^\circ \).

Case 3: An array of antennas with 30 elements, N = 30, d = 0.15, then the desired signal is arriving at an angle \( \theta_0 = 25^\circ \) and an interferer is arriving at an angle \( \theta_1 = -65^\circ \).

Case 4: An array of antennas with 30 elements, N = 30, d = 0.15, then the desired signal is arriving at an angle \( \theta_0 = 45^\circ \) and an interferer is arriving at an angle \( \theta_1 = -65^\circ \).

Case 5: An array of antennas with 30 elements, N = 30, d = 0.15, the desired signal is arriving at an angle \( \theta_0 = 45^\circ \) and an interferer is arriving at an angle \( \theta_1 = -85^\circ \).

Now calculate the beam strength at those angles by applying optimum weights to received signals and also observe the beam patterns at different angles in a Cartesian plot.

(a)

(b)

(c)

(d)
From figure 3(a, b, c, d, e), we can observe that the main lobe is directed towards the desired signal at 25°, 45°, and null is pointed towards the interferer at –65°, –85°. From this, we can observe that the directivity of the main lobe towards the desired user depends on the number of elements present in the array. That is, the directivity of the main lobe towards the desired signal at 25° is more when \( N = 30 \) than when \( N = 8 \).

6. Conclusion

In this work, SMI algorithms are used for interference rejection by an adaptive antenna array with various numbers of elements. The effect of the number of elements in the array of antenna on the interference rejection is observed. As expected from antenna theory, the main lobe and other lobes widths are reduced. The simulation results show that SMI is capable of nullifying the interference sources and its convergence is faster than LMS algorithm. The null depth performance of the SMI algorithm is better than that of the LMS algorithm.

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