Smart Antenna Design for Wireless Communication using Adaptive Beam-forming Approach

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Abstract – **Smart antenna is recognized as promising technologies for higher user capacity in 3G wireless networks by effectively reducing multipath and co-channel interference. Advent of powerful, low-cost, digital processing components and the development of software-based techniques has made smart antenna systems a practical reality for both base station and mobile station of a cellular communications systems in the next generation. The core of smart antenna is the selection of smart algorithms in adaptive array. Using beam forming algorithms the weight of antenna arrays can be adjusted to form certain amount of adaptive beam to track corresponding users automatically and at the same time to minimize interference arising from other users by introducing nulls in their directions. Thus interferences can be suppressed and the desired signals can be extracted. This research work provides description, comparative analysis and utility of various reference signal based algorithms as well as blind adaptive algorithms. Exhaustive simulation study of beam patterns and learning characteristics have proved the efficacies of the proposed work from application point of view.**

Index Terms* — *Antenna Arrays, Adaptive Algorithms, Beam-forming, Interference, Smart antenna, Signal Nulling

I. INTRODUCTION

Conventional base station antennas in existing operational systems are either omnidirectional or sectorised. There is a waste of resources since the vast majority of transmitted signal power radiates in directions other than toward the desired user. In addition, signal power radiated throught the cell area will be experienced as interference by any other user than the desired one. Concurrently the base station receives interference emanating from the individual users within the system Smart Antennas offer a relief by transmitting/receiving the power only to/from the desired directions. .Smart Antennas can be used to achieve different benefits. The most important is higher network capacity. It increase network capacity [1],[2] by precise control of signal nulls quality and mitigation of interference combine to frequency reuse reduce distance (or cluster size), improving capacity. It provides better range or coverage by focusing the energy sent out into the cell, multi-path rejection by minimizing fading and other undesirable effects of multi-path propagation.

The smart antenna is a new technology and has been applied to the mobile communication system such as GSM and CDMA [3] .It will be used in 3G mobile communication system or IMT 2000 also. Smart antenna can be used to achieve different benefits. By providing higher network capacity, it increases revenues of network operators anfd gives customers less propability of blocked or dropped calls. A smart antenna consists of number of elements(referred to as antenna array), whose signals are processed adaptively in order to exploit the spatial dimension of the mobile radio channel . All elements of the adaptive antenna array [4], [5] have to be combined (weighted) in order to adapt to the current channel and user characteristics . This weight adaptation is the “smart” part of the smart antenna , which should hence be called “adaptive antenna”. The adaptive antenna systems approach communication between a user and base station in a different way, in effect adding a dimension of space. By adjusting to an RF environment as it changes, adaptive antenna technology can dynamically alter the signal patterns to near infinity to optimize the performance of the wireless system. Adaptive arrays utilize sophisticated signal-processing algorithms to continuously distinguish between desired signals, multipath, and interfering signals as well as calculate their directions of arrival. This approach continuously updates its transmit strategy based on changes in both the desired and interfering signal locations.

Adaptive Beamforming [5] 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.

II. BASICS OF BEAM-FORMING

Beamforming is an advanced signal processing technique which, when employed along with an array of transmitters or receivers, is capable of controlling the 'directionality of' or 'sensitivity to' a particular radiation pattern. This method creates the radiation pattern of the antenna array by adding the phases of the signals in the desired direction and by nulling the pattern in the unwanted direction.. The phases (the interelement phase) and usually amplitudes are adjusted to optimize the received signal.

A standard tool for analyzing the performance of a beam-former as shown in Fig.1 is the response for a given N-by-1 weight vector $W(n)$ as function of θ, known as the beam response [1],[2].

This angular response is computed for all possible angle, that is $-90^{\circ} \le \theta \le 90^{\circ}$

$$R(\theta) = W^{H}(n)S(\theta) \qquad (1)$$

Where, $S(\theta)$ is an N-by-1 steering vector.

The dependence of the steering vector on θ is defined with the use of the relationship

$$S(\theta) = [1, e^{-j\theta}, e^{-2j\theta}, \ldots\ldots\ldots e^{-j(N-1)\theta}]^{T} \qquad (2)$$

Let ϕ denote the actual angle of incidence of a plane wave ,measured with respect to the normal to the linear array then

$$\theta = \frac{2\pi d}{\lambda}\sin\phi, \qquad -\pi/2 \le \theta \le \pi/2 \qquad (3)$$

Where d is the spacing between adjacent sensors of the array and λ is the wave length of the incident wave

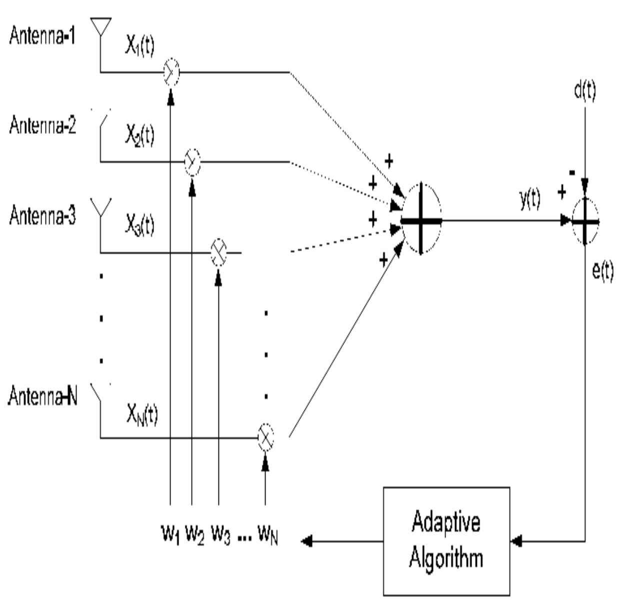

Fig.1. Adaptive beam-forming block diagram

III. ADAPTIVE BEAM-FORMING ALGORITHMS

The digital signal processor interprets the incoming data information, determines the complex weights (amplification and phase information) and multiplies the weights to each element output to optimize the array pattern. The optimization is based on a particular criterion, which minimizes the contribution from noise and interference while producing maximum beam gain at the desired direction. There are several Adaptive beam-forming [6] algorithms varying in complexity based on different criteria for updating and computing the optimum weights.

Block implementation of the adaptive beam-former uses a block of data to estimate the adaptive beam-forming weight vector and is known as “sample matrix inversion (SMI)” [7]. The sample-by-sample method updates the adaptive beam-forming weight vector with each sample. The SMI adaptive beam-former uses a block of code to get optimum weight; therefore it is not suitable for non stationary environment. Since the sample-by-sample adaptive beam-former [7] alters its weight with each new sample, it can dynamically update its response for such a changing scenario. Another important distinction between sample and block adaptive method is the inclusion of the signal of interest in each sample and thus in the correlation matrix. Therefore, for sample adaptive method, we can not use signal free version of the correlation matrix, that is, the interference plus noise correlation matrix, but rather must use the whole correlation matrix .The inclusion of the signal in the correlation matrix has profound effect on the robustness of the adaptive beam-former in the case of signal mismatch.

In this present research we have simulated sample-by-sample adaptive beam-former using least mean square (LMS) algorithm, constant modulus algorithm (CMA) ,least square CMA(LS-CMA) and recursive least square (RLS) algorithm. The weight vector W is calculated using the statistics of signal x(t) arriving from the antenna array. An adaptive processor will minimize the error e(t) between a desired signal d(t) and the array output y(t).

(a) Least Mean Square Algorithm

This algorithm uses a steepest decent method [8] and computes the weight vector recursively using the equation.

$$W(n+1) = W(n) + \mu X(n)[d^{*}(n) - X^{H}(n)W(n)] \qquad (4)$$

where μ is a gain constant and control the rate of adaptation .The least mean square algorithm(LMS) is important because of its simplicity and ease of computation , and because it does not require off-line gradient estimations or repetition of data. If adaptive system is a adaptive linear combiner and if the input vector and desired response are available at each iteration, The LMS algorithm is generally the best choice for many different applications of adaptive signal processing.

(b) *Constant Modulus Algorithm*

The configuration of CMA adaptive beamforming [7] is the same as that of the Sample Matrix Inversion system except that it requires no reference signal. It is a gradient-based algorithm that works on the theory that the existence of interference causes changes in the amplitude of the transmitted signal, which otherwise has a constant envelope (modulus). The minimum shift key (MSK) signal, for example,is a signal that has the property of a constant modulus .The weight is updated by the equation

$$\hat{W}(n+1)=\hat{W}(n)+\mu U(n)e^{*}(n) \qquad (5)$$

where μ is the step-size parameter*(n)* is the input vector, and

$$e(n)=Y(n)(R_2-|Y(n)|^2) \qquad (6)$$

where, $$R_2=E\frac{[|X(n)|^4]}{[|X(n)|^2]} \qquad (7)$$

Y(n) is the array output after the n^{th} iteration.

One severe disadvantage of the CMA is slow convergence time. The slow converges limits the usefulness of the algorithm in the dynamic environment where the signal must be captured quickly. This also limits the usefulness of CMA when channel conditions are rapidly changing. A faster algorithm was developed by Agee[10] using the method of non-linear least square and is known as least square constant modulus algorithm (LSCMA).

(c) *Recursive Least Square Algorithm*

In recursive least-square(RLS) algorithm[9], the weights are updated by the following equation.

$$\hat{W}(n)=\hat{W}(n-1)+K(n)\xi^{*}(n)\,,n=1,2,........ \qquad (8)$$

Where, *K(n)* is referred to as the gain vector and $\xi(n)$ is a priori estimation error which is given by the equation

$$\xi(n)=d(n)-\hat{W}^{H}(n-1)U(n) \qquad (9)$$

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.

IV. SIMULATION STUDY AND RESULTS

In the presence of two interfering signals and noise, both amplitude and phase comparison between desired signal and estimated output, beam patterns of the smart antennas and learning characteristics of the above mentioned algorithms are compared and analyzed. In the simulation, the smart antenna of 8-elements has been taken. The signal arrives at 10°.Two interfering signals are at -35° and 32°. The smart antenna algorithms compute the antenna weights for all eight antenna elements so that the signal-to-noise-and-interference ratio (SINR) becomes optimum.

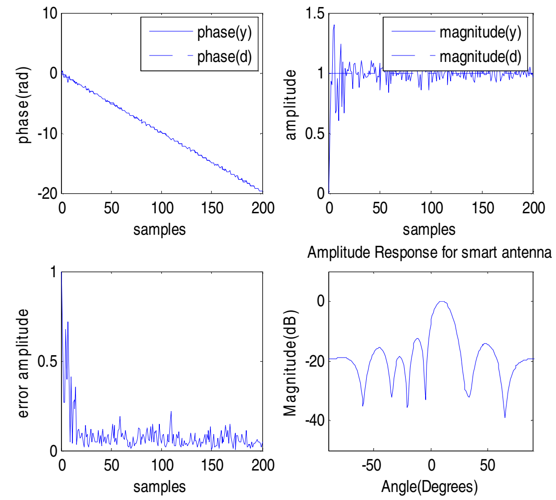

Fig. 2. The simulation result of a eight elements array using LMS algorithm for μ =0.5

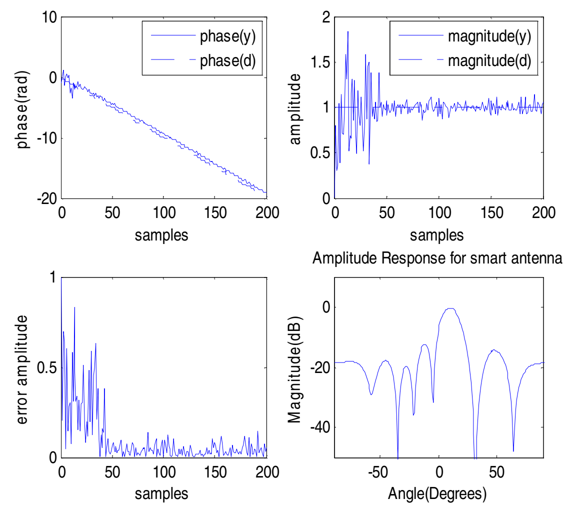

Fig. 3. The simulation result of a eight elements array using CM algorithm for μ =0.5.

The least mean square algorithm (LMS) is important because of its simplicity and ease of computation, and because it does not require off-line gradient estimations or repetition of data. If adaptive system is a adaptive linear combiner and if the input vector and desired response are available at each iteration, The LMS algorithm is generally the best choice for many different applications of adaptive signal processing. The constant modulus algorithm (CMA) converges slower then least square algorithm as shown in Fig.2 and Fig. 3. During the effort to simulate constant modulus algorithm it was clear that the algorithm is less stable than the least mean square algorithm .The constant modulus algorithm seems to be more sensitive to gradient constant μ. The chief advantage of the LS-CMA is that it can converge up to 100 times faster then the conventional CMA algorithm as observed in Fig. 5.

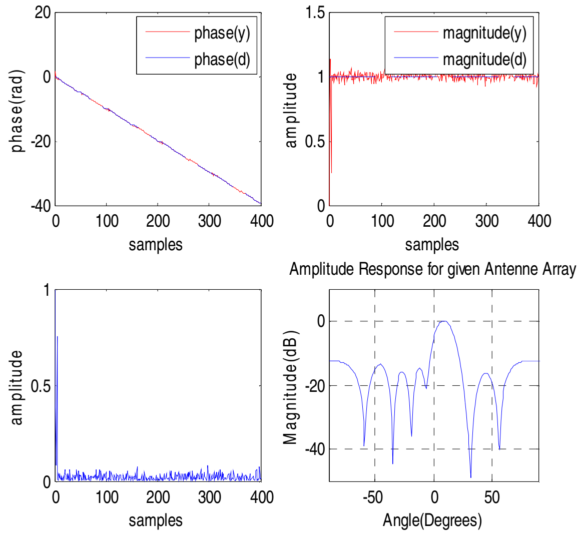

Fig.4. LS- CMA adaptive beam-forming for 8-elements ULA and μ =0.05.

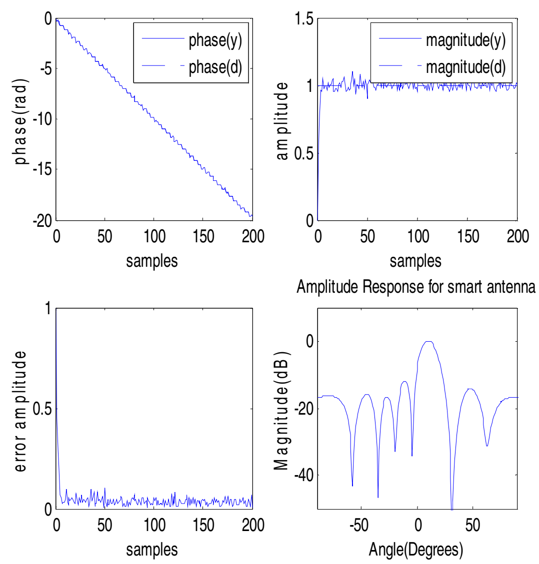

Fig. 5. The simulation result of a eight elements array using RLS algorithm for $\lambda = 1$ and $\delta = 0.004$.

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. An important feature of the recursive least square algorithm is that its rate convergence is typically an order of magnitude faster then that of the simple least square algorithm as in Fig. 4, due to fact that recursive least square algorithm whiten the input data by using the inverse correlation matrix of the data, assumed to be zero mean. This improvement however is achieved at the expense of an increase in computational complexity of the recursive least square algorithm.

V. CONCLUSION

Conventionally, the LMS adaptive algorithm has been used to update the combining weights of adaptive antenna array. However, its slow convergence presents an acquisition and tracking problem for cellular. System. The SMI algorithm has been proposed because of its fast convergence. However, it is too computationally complex. The use of a CMA adaptive array at the base station site can suppress interference and increase theuser capacity of a CDMA cellular system. Smart antennas technology suggested in this present work offers a significantly improved solution to reduce interference levels and improve the system capacity. With this novel approach, each user's signal is transmitted and received by the base station only in the direction of that particular user. This drastically reduces the overall interference in the system. Further through adaptive beam forming, the base station can form narrower beams towards the desired user and nulls towards interfering users, considerably improving the signal-to-interference-plus-noise ratio. Such smart antennas also can be used to achieve different benefits [11]. The most important is higher network capacity. It increase network capacity by precise control of signal nulls quality and mitigation of interference combine to frequency reuse reduce distance (or cluster size), improving capacity. It provides better range or coverage by focusing the energy sent out into the cell, multi-path rejection by minimizing fading and other undesirable effects of multi-path propagation. Smart antenna technologies requires high processing bandwidth, with computational speeds approaching several billion multiply and accumulate (MAC) operations per second. Such computationally demanding applications can be implemented real time with FPGAs with enhanced DSP blocks. Research into smart antenna technologies has increased tremendously to keep pace with the constantly expanding needs of the wireless communications industry. Emerging application areas such as ultra wideband (UWB), radio frequency identification (RFID), WiMax and mobile direct broadcast satellite (DBS) are expected to see extensive adoption of these technologies in the next few years.

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