A Review Paper on Adaptive Beamforming Algorithms for Smart Antenna

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Abstract*— Evolution of wireless access technologies is about to reach its further generation. The adaptation of smart antenna in future wireless system is expected to have a significant impact on the efficient use of the spectrum. As there is tremendous growth in the number of wireless users there is a need to expand capacity and coverage of networks. To achieve these goals powerful techniques named as Smart Antennas are employed. This paper focus on the review of the various algorithms to implement the principle of smart antenna i.e. adaptive beamforming. Smart antenna using digital signal processing capability exploits the radiation pattern in the direction of desired user and rejects the interference which is nothing but the adaptive beamforming which makes use of Direction of Arrival (DOA) to achieve the target. This paper depicts the ideas of different beamforming algorithms form different thesis and papers taking into account various parameters such as array factor, Mean Square Error (MSE), Beam pattern, convergence and entities such as array spacing, step size, number of array elements etc.*

Keywords— Adaptive beamforming, Mean Square Error, Beam pattern, and Convergence etc.

I. INTRODUCTION

Smart antenna technology is used for various mobile platforms such as automobiles, cellular telephones and laptops. Most of 3G systems are arranged to operate in 3GHz frequency band and 4G gives the next stage of cellular evolution beyond 3G and offers efficient cellular services. Smart antenna in mobile communication enhances capabilities of system such as bit rate increase in range, multipath mitigation, reduction of errors due to multipath fading and in turn it proves to be more secure. The signal that smart antenna transmits or receive cannot be tracked or received by any other antenna ensuring very high security of transmitted data. This paper concentrates on the required algorithm needed for adaptive beamforming in the antenna radiation pattern. It is an array of antenna which uses digital signal processor. It makes use of array gain, diversity gain, interference suppression and improves capacity of wireless network which results in increased data rate. It enhances the scope of adding new more users to the system with same data rate per user. Multipath fading results due to reflection and scattering which is avoided by smart antennas

Smart antennas have been long predicted to provide much better performance than existing antennas in terms of power consumption, user capacity and noise suppression.

These advantages are due to antenna array We are using uniform linear array of antennas [1]. Smart antenna system combines multiple antenna elements with a signal processing capability to optimize its radiation pattern automatically in response to the signal environment. They are having ability to change the radiation pattern dynamically by adjusting noise and interference and avoids multipath effects. The difference between smart and fixed antenna is based on the radiation pattern which have adaptive and fixed lobe respectively. These antennas transmit or receive signals in adaptive or spatially sensitive manner. These antennas are having smart systems and can change directionality of its radiation pattern and they are co-located with a base station. The smart antenna system improves wireless communication system performance for number of potential users. So many operations of PC's cellular networks realize significant increase in signal quality and coverage. This is a new and promising technology in the field of wireless and mobile communication which are limited by factors such as multipath and co-channel interference.

Smart antennas are of two types namely Switched Beam Antenna and Adaptive Array Antenna. Switched beam system have several fixed beam pattern. a decision is made as to

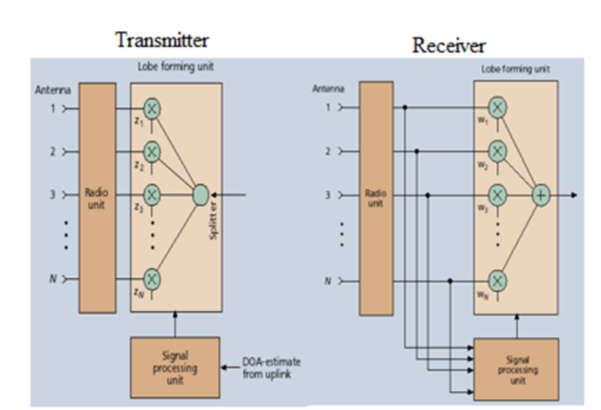

Fig. 1: Block Diagram of Smart Antenna

which beam to access, at any given point of time based on system requirement. From multiple fixed beam one beam is steered towards the target. Adaptive array antennas allow to steer the beam to any direction of interest by simultaneously nulling the interfering signals. Switched beam system form multiple antennas with heightened sensitivity in particular direction and switch from one beam to other as mobile moves throughout the sector. Adaptive array system represents most advanced smart antenna approach which uses a variety of new signal processing algorithms and takes advantage of its ability to track and locate the signals.

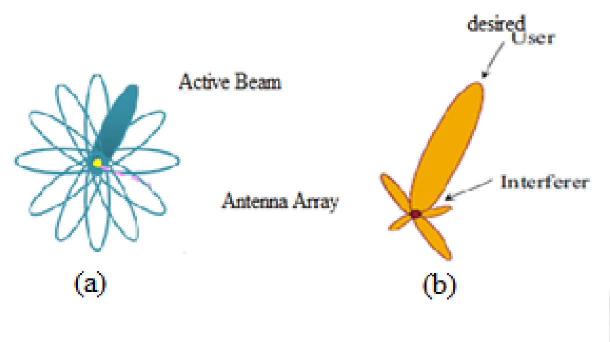

Fig. 2: Radiation Pattern (a) Switched Beam Antenna (b) Adaptive Array Antenna

II. Adaptive Beamforming

Adaptive array antennas are nothing but the smart antennas. Adaptive antenna system provides optimal gain by identifying, tracking and minimizing interfering signals. It requires implementation of digital signal processing technology. It has better interference rejection but it is expensive. High interaction between mobile and base station is required due to continuous steering. It provides better coverage and increased capacity by rejecting multipath components.

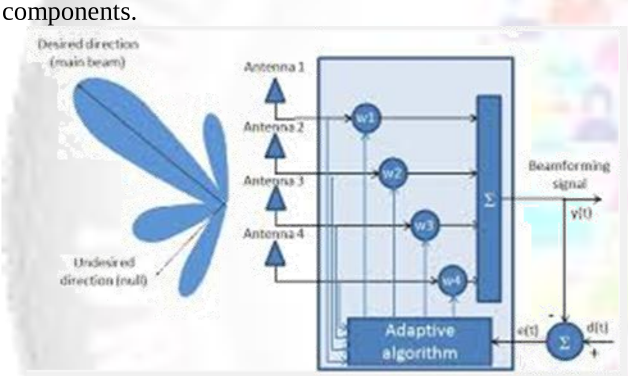

Fig. 3: Block Diagram of Adaptive Beamforming

Adaptive array antenna systems enable a base station to customize the beams they generate for each remote user effectively. Generally, each lobe forms a main lobe toward the individual users and attempts to reject interference or noise from outside of main lobe. The smart antenna performs two main functions of Direction of Arrival (DOA) estimation and Beamforming.

Smart antenna estimates DOA using various techniques such as MUSIC (Multiple Signal Classification), ESPRIT (Estimation of Signal Parameters via Rotational Invariance Technique). Direction of arrival are calculated from the peaks of the spectrum. This is computationally intensive. Beamforming is the main function on which this paper mainly concentrates. Beamforming as the name depicts provides narrow beam in desired direction as well as reduce interference .If angle of arrival of desired signal are same then fixed beamforming is used, which is very simple but if angle of arrivals change with time then optimization is employed that adjusts the weight of arriving signals iteratively which is termed as Adaptive Beamforming .It separates desired signal from interfering signal by adapting weights by increasing Signal to Noise Ratio (SNR) and array output .Adaptive algorithms are formulated depending on performance criteria. These are being implemented by a set of iterative equations to meet the criteria mostly include minimum mean square error (MMSE), maximum signal to noise interference ratio, maximum gain and variance. The two major types of adaptive algorithms are blind and non-blind algorithms. Non blind algorithms requires training sequence to detect desired signal and adjust the weight .and blind algorithm does not require to detect desired signal.

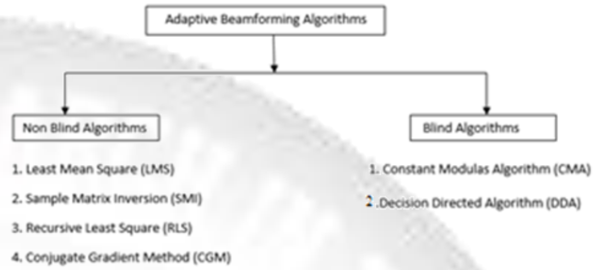

Fig. 4:

III. Literature Survey

To define the proposed work we have carried out literature survey from many of the papers .That is the work they have executed in their respective research and what work can be done in future. By considering the assets of each algorithm we have tried to design our proposed work . Literature survey gives idea about the implementation, performance and analysis of each algorithm on the basis of different parameters

Many of the adaptive algorithms can be implemented to achieve the defined target. Following study shows the literature survey of various adaptive beamforming algorithms studied so far and the future work.

A. Non Blind Adaptive Beamforming Algorithms:

1) Least Mean Square (LMS) Algorithm:

LMS algorithm is introduced by Widrow. This algorithm adjust the filter coefficients by estimating the gradient of the quadratic Mean Square Error (MSE) surface and then moving the weights in the negative direction of the gradient by small amount called step size .The equation for array weights updation is given by ,

$$w(n+1)=w(n)+\mu e^*(n)\,x(n) \qquad (1)$$

LMS algorithm is very simple and easy to implement.It has very low computational complexity. It does not involve matrix inversions and calculations. Instead it uses weight adaptation principle.LMS algorithm has very low convergence rate.This can be proved by analysing its performance on the basis of beam pattern it can be a rectangular plot or polar plot and mean square error value (MSE) LMS beamformer demonstrated its ability to direct the antenna beam in the direction of the mobile user as well as its ability to null out the jammers. This technique is significant in highly time varying signal environments and could serve as a potential solution to jammer rejection. In future we can consider distributed downlink beamforming with cooperative base stations [1] [3] [4] [6] [9] [11] [14] [15] [18].

a) Normalized Least Mean Square (NLMS)Algorithm:

NLMS algorithm is an extension of LMS algorithm and also they have same practical implementations .In NLMS algorithm step size parameter is chosen based on current input values. Thererfore step size is said to be normalized . It shows greater stability with unknown signals .Weight vector is given by equation,

$$w(n+1)=w(n) + \frac{\mu}{p+\|x\|\, n\|^2} e^*(n)\, x(n) \qquad (2)$$

Where, $\mu(n) = \frac{\mu}{p+x\|\, n\|^2}$

NLMS algorithm has improved convergence rate.It has been analyzed that ,normalized-LMS performs better than LMS algorithm.The radiation pattern is better and more directed when we implement NLMS algorithm. These are shown using linear beam pattern and polar beam pattern formats in the graphs.

These are shown using linear beam pattern and polar beam pattern formats in the graphs.NLMS algorithm provides better balance between simplicity and performance.In future the analysis is carried for different channels such as Rayleigh and Racian channels [2] [4] [7] [8] [13]

b) Block Based Normalized Least Mean Square (BBNLMS)Algorithm:

In BBNLMS algorithm, the additional computations required to compute μ(n) can be further reduced in which the input data is portioned in to blocks and maximum magnitude within each block is used to compute μ(n). Which this the weight update relation for xm ≠ 0 and p = 0 takes the following form,

$$w(n+1) = w(n) + \frac{\mu}{X_m{}^*X_m} e^*(n)\, x(n) \qquad (3)$$

Where xm is the maximum of x(n) in the block. Using such an approach the number of multiplications reduces in the computation on μ(n).Analysis reveals that when compared with LMS and NLMS algorithms BBNLMS algorithm has more increase in convergence rate in multipath and multiple signal environment which can be proved on the basis of radiation pattern and mean square error [2]

2) Sample Matrix Inversion (SMI)Algorithm:

SMI algorithm 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. If a priori information about the desired and the interfering signals is known, then the optimum weights can be calculated directly by equation,

wopt = Rxx-1 rxd (4)

This algorithm is based on an estimate of the correlation matrix and cross correlation vector of the adaptive array output samples. Estimate of weight vector is given by,

$$Rxx = \frac{1}{k} \Sigma\, x(k)\, x^H(k) \qquad (5)$$

SMI improves the convergence speed at the cost of more computational complexity and singularity problem of correlation matrix .It has been proved that. 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. Performance of SMI algorithm can be verified in multiple paths and multiple signal environment [1] [3] [6] [15].

3) Recursive Least Square (RLS) Algorithm:

The problem of slow convergence of LMS algorithm is solved with RLS algorithm by replacing gradient step size with gain matrix R -1(k) at the kth iteration ,producing weight update equation given by,

w(k)=w(k-1)- R-1(k) x(k) e*(w(k-1)) (6)

RLS algorithm overcomes the problem of SMI algorithm showing better null depth .RLS algorithm shows best main lobe formation as it has maximum signal strength in desired direction. In case of RLS we have narrowest beam width, complete rejection of interference and fastest convergence at the cost of high computational burden but has greater power in side lobes as compared to LMS. RLS is the best choice and has also its application where quick tracking of the signal is required. RLS Algorithm is found to have minimum BER and error signal magnitude, therefore it has been proved the best algorithm for implementation on Base Station Smart Antenna System As the recent developments in digital signal processor (DSP) kits and field-programmable gate arrays (FPGA) have made it possible to implement RLS algorithms in real time systems, and complexity to an extent is not a problem anymore [1] [3] [5] [10] [15] [18]

4) Conjugate Gradient Method (CGM) Algorithm:

CGM algorithm increases the rate of convergence by iteratively searching for the optimum solution by choosing conjugate (perpendicular) paths for each new iteration. Thus, the path taken for the (n+1) th iteration is perpendicular to that for the nth iteration. The weights are updated according to the following equation,

w(n+1) =w(n)- μ(n) D(n) (7)

where,μ(n) is the step size and D(n) is the direction vector.

The CGM algorithm calculates the array weights by orthogonal search at each iteration. It shows good beam forming pattern and a high convergence rate. It also has a better resolution compared to the previous algorithms because the main beam pointing towards the desired user is quite sharp with a high directivity and the side lobes are very less and have power level very low than what was achieved in the previous algorithms. CGM algorithm by replacing the gradient step size with a gain matrix, noticed that increasing the number of elements of the antenna array ensures better performance. CGM has also narrow beam width, complete rejection of interference, fast convergence as compared to LMS but has the largest power in side lobes as compared to others. It finds its application in mobile communication where it is used to eliminate multipath fading [1] [3] [5] [15] [18]

B. Blind Adaptive Algorithm:

1) Constant Modulas Algorithm (CMA):

CMA is a well known algorithm of adaptive beamforming of blind adaptation. This algorithm is derived keeping in view the constant complex envelope (amplitude) property of the signal. CMA does not require a pilot signal. These signals generally include FM, FSK, PSK,QAM and PAM. If the arriving signal has constant amplitude then this algorithm maintains and restores the amplitude of desired signal . The weights can be calculated using following equations,

$$w(n+1)=w(n) + \mu\, e^*(n)\, x(n) \qquad (8)$$

$$\text{where,} \quad e(n) = \frac{y(n)}{|y(n)|} - y(n)$$

$$\text{and} \quad y(n) = wH(n)\, x(n)$$

e(n)=error signal y(n)=output signal x(n)=input signal

CMA has widest beam width in the desired direction, suppress interference to some extent and unstable behaviour in case of convergence due to which CMA can be used in applications where complex envelope of the signal should ideally be constant CMA doesn't use any reference signal but automatically selects one or several of the multipaths as the desired signal. When array vector is updated it does not need to know the arrival timings of the incident rays. It does not need to synchronously sample the received signal with the clock timing. CMA bears maximum error but focusing on co channel interference it gives more reliable results than LMS and RLS. Results obtained from simulation assert that capability to reject the interfering signal by placing nulls in undesirable direction is really accomplished by CMA. But when angle of arrival of interference and user were quite close to each other then CMA had BER even more than single antenna element [1] [3] [9] [18] [19]

2) Decision Directed Algorithm (DDA):

For BPSK communication with low bit error rate (BER), the complex limited Constant Modulus Reference Signal y(n)/|y(n)| can be replaced by a decision directed term defined as sgn(Re (y(n))).Decision directed form uses the demodulated signal to reference the variation in the modulus of array output.

Equation is given by,

$$w(n+1) = w(n) - 1/2\, \mu\, x(n)\, e^*(n) \qquad (9)$$

$$\text{where, } e(n)=y(n)-\mathrm{sgn}(\mathrm{Re}(y(n)))$$

$$y(n)=w\text{-}H(n)\, x(n)$$

The algorithm uses symbol decisions made on initial signal estimate which generate a reference signal used to estimate minimum of mean squared error (MSE).An asymptotic analysis technique is used for this purpose. A number of simulation examples have been presented to validate the analysis and to demonstrate the advantage of decision directed approach [17]

In above explanation we have seen overview of various non-blind and blind adaptive beamforming algorithms. In this paper main focus is given on the review of implementation ,analysis and performance of all these adaptive algorithms.

IV. Conclusions

From the above literature survey it is concluded that ,there are various adaptive beamforming algorithms given for smart antennas which have ability to provide maximum gain in desired direction neglecting the interference condition .These algorithms are implemented and evaluated considering different parameterssuch as radiation pattern ,mean square error ,convergence rate under different conditions of number of user ,number of number of antenna elements and element spacing. Maximum antenna gain implies the better system performance under the interference conditions .By using multiple paths and multiple users it provides another way to make the system more compatible .The MATLAB software used is more user friendly. Same system can be simulated using Simulink software.Instead of using only smart antenna we can use smart antenna with cognitive radio and analyse respective algorithms.

In short adaptive beamforming algorithms are more convenient and simpler techniques through which we can propose a better signal reception ensuring maximum gain as it zeros out the interference.It indirectly helps to give more throughput and improved system performance.

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