A Review of Smart Antenna System (SAS) with Array Processing Algorithms.

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Abstract- Smart Antenna System (SAS) is one the emerging technologies for the next generation of wireless communication systems. SAS lead to communication networks with higher capacity and better performance [1]. Performance is also enhanced by employing suitable adaptive algorithm to achieve high data rate and increased user base [2]. This paper introduces the need of SAS in existing and upcoming generation of wireless communication. This paper explains the working of SAS and the algorithms which makes the whole system smart. Also this paper throws light on the classification of SAS. This study demonstrates the practical requirement of SAS at the Base Station.

Keywords – SAS Smart Antenna System, Multiple Input and Multiple Output (MIMO), Adaptive Array, Algorithms: LMS NLMS MUSIC and ESPRIT.

I.INTRODUCTION

Basic mobile communication employs single transmission antenna and signal received at the base station antennas, in turn base station rebroadcasts this to the intended destination. With increasing user base, demand for faster 3G wireless internet give rise to multiple complex methods of transmission and reception. 4G systems evolved in 2011 leaps to a data rate of 100 Mbps. As mobile data rates and services are at their peak usage and are demanding for various changes in the upcoming mobile generations with a continued legacy called as MIMO.[3-5] Beyond 4G (B4G), LTE Advanced and 5G are on the way of evolution[3-5]. An ill effect of wireless channel is fading, sticking to the Rayleigh Fading in cellular situations. Diversity is the premier solution to combat fading.[11] Spatial Diversity lead to te use of multiple collocated antenna at both transmitter and receiver ends. MIMO systems exploits the use of multiple antenna in 3G, 3.5G and 3.75G.Owing to the increased data rate requirement multiple antennas alone may not be fruitful until proper control is not devised. These multiple antenna array is supported by smart processing algorithms which adapt automatically in the interference environment [1].

SAS does not only makes the system more smarter by selective signal processing but also decreases Inter symbol interference (ISI) and improves Bit error rate (BER)[2]. Traffic based channel allocation with reduced power consumption and RF pollution are some of the key advantages of SAS.[9] Typical rates of 4G systems start with 40Mbps with a wider coverage and better performance as compared to the conventional systems because of SAS. SAS employs Spectral filtering and DOA Algorithms. Direction of Arrival (DOA) is the premier feature of SAS through which it calculates Beam forming Vectors, thus the location of mobile units. Major classification of SAS includes Switched Beam and Adaptive array. More over Cheng [1] pointed out adaptive array, MB-MIMO (multiple beam MIMO), and receive diversity as the SAS classification. Algorithms widely incorporated are LMS,NLMS MUSIC and ESPRIT[6,8,10].Also implementing with different array geometries and dynamic weight adaptation lead to better results[7].

The rest of the paper is organized as follows. Smart antenna Systems and its explanation are explained in section II. SAS algorithms are presented in section III. Concluding remarks and challenges are given in section IV.

II.SMART ANTENNA SYSTEMS (SAS)

Use of Multiple antennas with array processing algorithms is the basis of SAS. Besides this return loss, bandwidth, gain and radiation pattern and operating frequencies are the key considerations for SAS [12]. Multiple antennas in handheld devices surely improve performance and maximize SNR but there are certainly some factors such as RF and power requirement which affects its implementation [12]. Where at the base station there are little issues of concern as compared with handset or subscriber unit.

III.A. HOW DOES SAS WORKS ?

In wireless cellular communication, the areas of SAS focus include Uplink transmission by Mobile unit, adaptive filtering or adaptive array beam-forming, Direction of Arrival (DOA) estimation and Selective Downlink transmission by Base station.SAS separates the desired Mobile unit (MU) signal from the interference received with the desired signal. Received signals at the array are combined with suitable weights. These weights are decided according to the required gain and bandwidth. Beam-forming and beam steering in a dynamic environment comprising of interference is done by adopting LMS and NLMS algorithms. Through this minimum square error is achieved and interfering signals are rejected or filtered out [1]. Estimation of signal from a requisite direction is necessary at the base station, MUSIC and ESPRIT are popular Direction of arrival estimation algorithms. In the downlink process, selective transmission is the major basis for differentiating between switched beam and adaptive array systems. Switched beam communicate to the user by changing between preset directional patterns and predefined multiple beams and adaptive arrays attempt to understand RF environment more selectively.

IV.B.CLASSIFICATION OF SAS

In case of Switched beam there are multiple beams with higher directivity and narrow beam width. Its required phase shift is achieved by fixed phase shifting network such as Butler Matrix. It is practically employable in the existing network as also it has low insertion loss with no complex algorithm [1]. But these systems of smart antenna cannot reduce interference which leads to signals from undesirable environment.

Another type is Adaptive array which steers the beam towards desired signal and nulls in the interfering signal directions. Algorithms for beam-forming and direction of arrival estimation are used as shown fig.1.

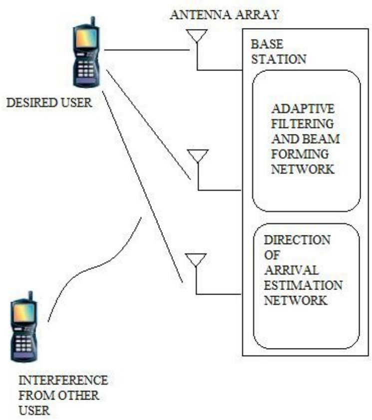

Fig. 1: Adaptive array Smart Antenna System

These systems are much more complex to retrofit in the existing system. This SAS technique is far more advanced than the switched beam technique as it reduces the interference and multipath components. With its continuous movement of beam negligible inter-cell handoff exist.

V. ALGORITHMS USED IN SAS

Previous section reveals about the algorithms in SAS. This section does the same with mathematical formulations. This section of paper revolves around the beam forming and direction of arrival algorithms namely Least Mean Square (LMS) for adaptive array beam-forming, also looking at with its normalized version called NLMS. Moreover Direction of Arrival algorithms for the probabilistic signal and noise estimation. DOA algorithms are multiple signal Classification (MUSIC), its improved version root-MUSIC and Estimation of signal parameters with rotational invariance technique (ESPRIT).

LMS algorithm is an adaptive beam-forming algorithm for tuning at the required signal and rejecting interfering signal at the antenna array[6]. LMS is an iterative procedure for weight calculation which leads to minimum square error.

Mathematically, $y(t) = \sum r_i(t)s(\Theta)' + \sum i_i(t)s(\Theta)'' + n(t)$ where i € 1 to N eq. 1

In equation 1 y(t) is antenna array output, r(t) is received signal from mobile user, s(Θ)' is steering vector for desired direction, i(t) is interference signal and s(Θ)" is steering vector for undesired interference direction. n(t) is noise signal in the channel (here its Gaussian noise with zero mean) and N is the total number of array elements.

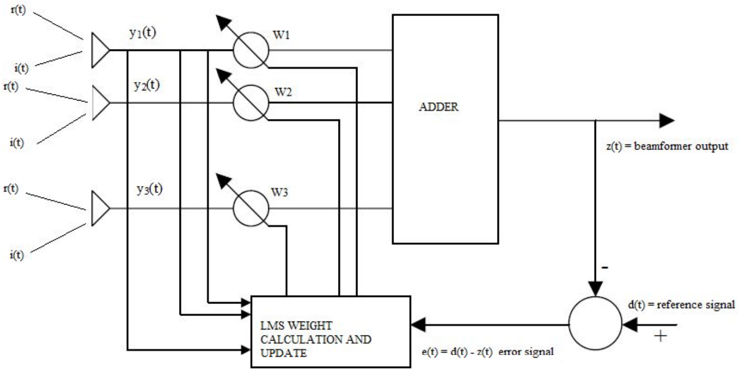

Fig.2: LMS Algorithm

Above figure clearly shows that output at each antenna array are combined and scaled accordingly and the weights (complex minimum error factors) are iteratively changed by LMS update based on Minimum Square error criteria. LMS algorithm is based on the method of steepest decent as given in equation 2.

$$W_{n+1} = W_n + 0.5\mu\, [-\nabla\{E\,(e^2\,(n)\}] \qquad \text{eq.2}$$

$$e^2\,(n) = [d(n) - w^H y(n)]^2 \qquad \text{eq.3}$$

μ in equation 2 is step size parameter with value between 0 and 1, it controls the convergence of weights. $e^2(n)$ is mean square error in the beam forming output and reference signal. n+1 is the number of iterations for weights and w^H hermitian form of complex weights. In steepest decent method ∇ gradient vector calculation is different, in real time which is simplified in LMS algorithm because LMS makes easier calculation of covariance matrix R and r and is also initiated by a non zero weight. R is covariance of received signal and its complex vector and r is covariance of received signal and desired signal. For Stability and proper convergence, $0< \mu< 1/\ (2\lambda_{max})$, λ_{max} is the largest Eigen value of covariance matrix R.

This μ step size parameter needs to varied in accordance with the run time signal conditions, whereas in Normalized Least mean Square Algorithm NLMS solves this problem. NLMS is a novel approach with variable adaptive rate. It improves convergence speed in dynamic environment. NLMS normalizes the output power. Given equation shows the NLMS weight Update as the rest of formulation will be the same.

$$w(n+1) = w(n) + [\mu e(n)y(n)] / [\alpha + y(n)\, y^H(n)] \qquad \text{eq. 4}$$

To overcome the numerical difficulties when $y(n)\, y^H(n)$ is close to zero, a constant α alpha is used. NLMS is having improved convergence as compared to LMS.

After selective filtering of interference estimation of signal and noise is performed through subspace (i.e. vector space for signal and noise) DOA algorithms. This includes MUSIC, root-MUSIC and ESPRIT algorithms. These algorithms rely on decomposition of covariance matrix into signal subspace and noise subspace [12]. MUSIC is abbreviated as Multiple Signal Classification. It has better resolution and signal parameter estimate [10]. As the noise is considered Gaussian with zero mean, thus correlation and covariance are equal.

$$y(t) = r(t)s(\Theta) + n(t) \qquad \text{eq. 5}$$

where, y(t) is the array output, r(t) is the received signal, $s(\Theta) = [s_1(\Theta)\ s_2(\Theta)\ s_3(\Theta)$____ __ __ __ $s_D(\Theta)]$ is steering vector matrix with D non zero complex steering functions, and n(t) is Gaussian noise with zero mean and σ^2 as the variance. MUSIC approaches by creating individual signal and noise space and calculation of Eigen vectors of covariance matrix by SVD method. As shown in above figure there are 3 received signals, so these signals are scaled according to the complex weights which gives array factor.

Array Factor = $[r_1 r_2 r_3]\ [w_1 w_2 w_3]^T$, this will lead to 3*3 matrix of array factor, similarly for M received signals M*M matrix components are obtained. $R_{yy} = E[y\ y^H]$ is M*M square matrix of array output covariance. e_n are the various Eigen values of R and E_n are respective Eigen vectors. E_n is divided in $\hat{E}_S$ signal subspace and $\hat{E}_N$ noise sub space with dimensions M*D and M*(M-D) respectively[10]. Thus both the sub space are orthogonal are each other. MUSIC plots pseudo spectrum with maximum power given by

$$P_{music}(\Theta) = 1/\{\|\, E_n\, s(\Theta)\ \|\}^2 \qquad \text{eq. 6}$$

As the denominator of this equation reduces it gives maximum power peak and thus reduced threshold (i.e sharper peak). root – MUSIC is a another version of MUSIC with increased resolution [12]. For Uniform linear array direction of arrival estimation can be made by finding the roots of polynomial [10]. These are the roots of denominator in equation 6 and are treated as characteristic equation. It is a model based estimation technique based on received signal. This lead to much reduced threshold than MUSIC.

ESPRIT stands for Estimation of signal parameters with rotational invariance technique, this is another method for DOA estimation based on parameter estimation, it introduces to the technique of array division into identical sub arrays and is computationally efficient and robust[12]. Steering matrix $s(\Theta) = [s_1(\Theta)\ s_2(\Theta)\ s_3(\Theta)\_\_\_\_\_\ \_\_\ \_\_\ s_D(\Theta)]$ is divided in s^1 and s^2 as $s_{ESPRIT} = [s_1\ \phi s_2]^T$ individually s_1 and s_2 are D*M matrix, $s_2 = \phi s_1$ where ϕ is diagonal matrix with individual phase shift in the array elements. $\phi = [e_1^{jkdsin\Theta}\ e_2^{jkdsin\Theta}\ e_3^{jkdsin\Theta}\ \_\_\_\ \_\ e_D^{jkdsin\Theta}]$ is a D*D diagonal matrix where k is the number of time samples in ESPRIT(more number of sample more sharper peak in the spectrum), d is the distance in array elements. Based on this ESPRIT formulation is given by

$$y(k) = [r_1(k)\ r_2(k)]^T\ [s_1(k)\ s_2(k)] + [n_1(k)\ n_2(k)]^T \qquad \text{eq.7}$$

IV.CONCLUSION

This paper reviews the Smart antenna systems and its potential characteristics of enhanced spectrum efficiency and improving Signal to noise ratio. This paper also suggests some of the array processing algorithms for Beam Forming and Direction of Arrival estimation which makes the whole system smarter. This paper also classifies the Smart antenna systems and analyses the algorithms involved. NLMS has better convergence and Esprit has better resolution among the other DOA algorithms. But future challenges are also the area of concern and require attention while designing smart antennas, these are;

- Modeling of non linear parameters of antennas,
- Analysis of Noise in other than Gaussian form,
- Design of handheld devices implementing multiple antennas so that size and cost both reduces,
- Two directional array approach for direction of arrival algorithms, and
- Reduction of power consumption and an eye over the RF pollution involved.

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