PERFORMANCE ANALYSIS OF SAGE ALGORITHM WITH DIFFERENT PARAMETERS OF INCOMING WAVEFRONTS

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ABSTRACT

*The problem of detection, tracking and localization of multiple wide band (antenna) sources are a major concern in modern wireless communication system. Existing system lack the ability to detect, resolve and track multiple, closely spaced sources in tight formation and cause destructive interference or generate Harmonics, in addition to clutter and wind noise for indoor environments. In this paper the performance analysis of SAGE (**S**pace **A**lternating **G**eneralized **E**xpectation maximization) with respect to MUSIC (**Mu**ltiple **SI**gnal **C**lassification), algorithm using Smart Antenna which will help to enhance wireless technologies have been analyzed. The result is postulated with the help of Matlab Simulation. Simulation is for identifying the source signal incident on the Sensor Array and for directing the Main beam towards the desired source signals and also generate deep Nulls in directions of interfering signals.*

Keywords: Antenna, DOA, MUSIC, SAGE, Smart Antenna.

I INTRODUCTION

In recent years a substantial increase in the development of broadband wireless access technologies for evolving wireless Internet services and improved cellular systems has been observed. Because of them, it is widely foreseen that in near future an enormous rise in traffic will be experienced for mobile and personal communications systems. This is due to both an increased number of users and introduction of new high bit rate data services. The rise in traffic will compel demand on both manufacturers and operators to provide sufficient capacity in the networks. This becomes a major challenging problem for the service providers to solve, more of all, certain negative factors in the radiation environment contribute to the limitation in capacity.

A major limitation in capacity is co-channel interference caused by the increasing number of users. The other impairments contributing to the reduction of system performance and capacity are multipath fading and delay spread caused by signals being reflected from structures (e.g., buildings and mountains) and users traveling on vehicles. To aggravate further the capacity problem, the Internet gave the people the tool to get data on-demand (e.g., stock quotes, news, weather reports, e-mails, etc.) and share information in real-time. This resulted in an increase in airtime usage and in the number of subscribers, thus saturating the system capacity.

The deployment of smart antennas (SAs) for wireless communications has emerged as one of the leading technologies for achieving high efficiency networks that maximize capacity, improve quality and coverage. Smart Antenna systems can increase system capacity (very important in urban and densely populated areas) by dynamically tuning out interference while focusing on the intended user along with impressive advances in the field of digital signal processing.

1.1 DOA Fundamentals

The DOA estimation algorithms are directly associated with the received signals. Data from array of sensors are collected, and the objective is to locate point sources assumed to be radiating energy that is detectable by the sensors. Mathematically, such problems are modeled using Green's functions for the particular differential operator that describes the physics of radiation propagation from the sources to the sensors. The most known high speed direction finding (DF) algorithm is SAGE, which can work on blank data or voids.

The direction of the incoming signals known or estimated, the next step is to use spatial processing techniques to improve the reception performance of the receiving antenna array based on this information. Some of these spatial processing techniques are referred to as beam forming because they can form the array beam pattern to meet the requirements dictated by the wireless system.

The main objective of this spatial signal pattern shaping is to simultaneously place a beam maximum toward the signal-of-interest (SOI) and ideally nulls toward directions of interfering signals or signals-not-of-interest (SNOIs). This process continuously changes to accommodate the incoming SOIs and SNOIs.

II DOA ESTIMATION PROBLEM

There is a one-to-one relationship between the direction of a signal and the associated received steering vector. It should be possible to invert the relationship and estimate the direction of a signal from the received signals. An antenna array therefore should be able to provide for direction of arrival estimation. We have also seen that there is a Fourier relationship between the beam pattern and the excitation at the array. This allows the direction of arrival (DOA) estimation problem to be treated as equivalent to spectral estimation.

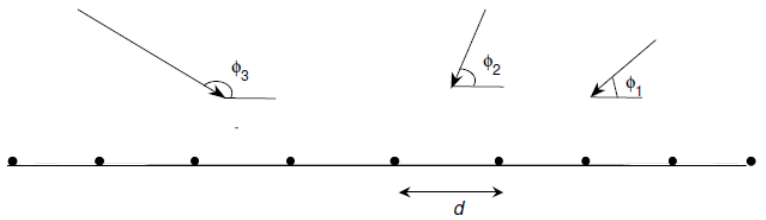

Figure 1: The DOA Estimation Problem.

The setup is shown in Fig. 1. Several (M) signals impinge on a linear, equispaced, array with N elements, each with direction φi. The goal of DOA estimation is to use the data received at the array to estimate φi, i = 1, . . .M. It is generally assumed that $M < N$, though there exist approaches (such as maximum likelihood estimation) that do not place this constraint.[1]

The problem of determining the DOAs of impinging wavefronts, given the set of signals received at an antenna array from multiple emitters, arises also in a number of applications such as radar, sonar, electronic surveillance, and seismic exploration [2]. The DOA estimation algorithms which are directly associated with the received signals. Data from an array of sensors are collected and the objective is to locate point sources assumed to be radiating energy that is detectable by the sensors. Mathematically, such problems are modeled using Green's functions for the particular differential operator that describes the physics of radiation propagation from the sources to the sensors. Although most of the so-called high resolution direction finding (DF) algorithms have been presented in the context of estimating a single angle per emitter (e.g., azimuth only), generalizations to the azimuth/elevation case are relatively straightforward.

Parameters, such as frequency, polarization angle, and range can also be incorporated, provided that the response of the array is known as a function of these parameters.

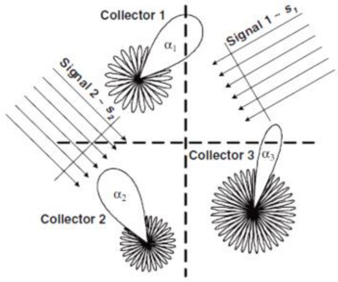

Figure 2: Illustration of a Simple Source Location Estimation Problem.

The DOA is the parameter for estimation is depicted in Fig. 2, where signals from two sources impinge on an array of three coplanar receivers. The patterns associated with each receiver indicate their relative directional sensitivity. For the intended application, a few reasonable assumptions can be invoked to make the problem analytically tractable. The transmission medium is assumed to be isotropic and non-dispersive and the sources are located in the far-field of the array so that the radiation impinging on the array is in the form of sum of plane waves. For closely located sources (in the near-field of the array) the wavefronts would possess the analogous curvature.

III SAGE ALGORITHM

The SAGE algorithm is in principle a twofold extension of the well-known Expectation Maximization (EM) algorithm which computes the maximum-likelihood (ML) estimators of the unknown parameters in a sequential way. In other words, it replaces the computationally prohibitive high-dimensional non-linear optimization process by several low-dimensional maximization procedures[4,5]. In each SAGE iteration, only a subset of the parameters is updated, while keeping the estimators of the remaining parameters fixed. The derivation of the algorithm still relies on the key notions of *complete* (unobservable) and *incomplete* (observable) data [6,7,8,9].

The scheme was initially applied to the problem of multipath parameter estimation in [3, 4] and since then has undergone a plethora of extensions to account for additional selectivity domains (polarization and elevation).[8,10] Generally with the SAGE algorithm, consider the tractable case of uniformly distributed white noise which significantly simplifies the derivations included throughout the execution of the algorithm.

During the measurements the transmitter antenna, which emulates the mobile station antenna and move at a variable pace. From the recorded CIRs on each of the array elements, the desired channel characteristics (complex amplitude, azimuth angle of incidence and relative delay) associated with each multipath component was estimated, using ***Space-Alternating Generalized Expectation maximization***(SAGE) algorithm [12,14]. The SAGE algorithm is based on the expectation-maximization (EM) algorithm to compute the maximum likelihood (ML) estimate of the desired set of parameters.[15]

The spatial resolution has been the object of many studies based on incident direction of arrival (DOA) algorithms, where the different users are located by distance and angle[3]. We propose a technique derived from the maximum likelihood (ML) principle, which allows for high-resolution determination of propagation delay, azimuth and elevation incidence angle and amplitude of the complex signal. The expectation maximization (EM) algorithm [7] updates all parameters simultaneously, which might imply a slow convergence and a complicate maximization [1,5,7,11].

This algorithm updates the parameters sequentially by replacing the high-dimensional optimization process, necessary to compute the estimates of the parameters, by several separate, low-dimensional maximization procedures, which are performed sequentially. These separate maximization procedures are linked up in the SAGE algorithm [2,4,5]. We have studied the resolution of the algorithm, the convergence speed and the bit error rate (BER) as a function of the signal to noise ratio (SNR) in the general three-dimensional case. As the two-dimensional case was explained [9, 10].

The ambiguity of detecting different users in a three-dimensional case with a two-dimensional antenna configuration can be resolved by using, two parallel planes with a quarter of a wavelength distance. This solution suffers from the spatially limited radiation pattern of the array elements.

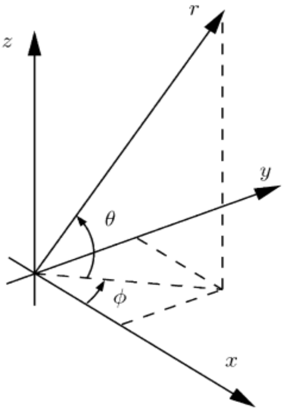

FIG. 3: The Axial Conventions

The parameters to be estimated are the relative delay τ_l, the azimuth and elevation angle φ_l and θ_l of the incident wave, and the complex amplitude γ_l. Axial convention for the azimuth and elevation angle.

All these parameters are placed together in a vector ζ_l. The different incident waves form L different ζ_l, because the number of paths is L.These vectors are all stacked together in the matrix ζ.Each step of the SAGE algorithm is an estimate of a subset of the components of ζ, while keeping the estimates of the other components fixed. We define one iteration cycle of the SAGE algorithm as L consecutive iteration steps for updating the parameters of all waves at one time.

The correlation function $z\left(\hat{\tau},\widehat{\varphi},\hat{\theta},\widehat{x}_l(t;\hat{\zeta})\right)$ between the calculated and the received signalis the cost function that has to be minimized as follows

$$\hat{\tau}_l' = argmax\left(\left|z\left(\tau,\widehat{\varphi},\hat{\theta},\widehat{x}_l(t;\hat{\zeta})\right)\right|^2\right) \quad \text{(eq.7)}$$

$$\widehat{\varphi}_l' = argmax\left(\left|z\left(\hat{\tau},\varphi,\hat{\theta},\widehat{x}_l(t;\hat{\zeta})\right)\right|^2\right) \quad \text{(eq.8)}$$

$$\hat{\theta}_l' = argmax\left(\left|z\left(\hat{\tau},\widehat{\varphi},\theta,\widehat{x}_l(t;\hat{\zeta})\right)\right|^2\right) \quad \text{(eq.9)}$$

$$\hat{\gamma}_l' = \frac{1}{N_a T_a}\left(\left|z\left(\hat{\tau},\widehat{\varphi},\hat{\theta},\widehat{x}_l(t;\hat{\zeta})\right)\right|^2\right) \quad \text{(eq.10)}$$

Where, the prime variables denote the new values after the iteration. After each step the estimation vector $\hat{\zeta}$is updated with the last calculation. Please notify that N_a stands for the number of omnidirectional antennas, and T_a stands for the measured time interval.

The correlation function $Z\left(\hat{\tau},\hat{\varphi},\hat{\theta},\hat{x}_l(t;\hat{\zeta})\right)$ is defined as follows:

$$Z(\hat{\tau},\hat{\varphi},\hat{\theta},\hat{x}_l) = \left[c(\hat{\theta}\hat{\varphi})\right]^H \int u^*(\acute{t}-\hat{\tau})\hat{x}_l(\acute{t};\hat{\tau})d\acute{t} \qquad \text{(eq.11)}$$

with $u^*(t)$ the complex conjugate of the desired signal u(t), which is based on the training sequence and corrected with an estimate of the relative delay $\hat{\tau}$. The ^{H} stands for the Hermitian operator, which is the complex conjugate transpose of that vector. The received signal $x_l(t)$ for one user is calculated based on the received global signal y(t) and on the estimates of the signals s(t;$\hat{\zeta}_l$) of the other interfering sources (which might be due to the channel itself, for interintersymbol interference (ISI)):

$$x_l(t;\zeta) = y(t) - \sum_{\substack{\acute{l}=1 \\ l\neq\acute{l}}}^{L} s(t;\zeta_{\acute{l}}) \qquad \text{(eq.12)}$$

$$s(t;\zeta_l) = \zeta_l c(\varphi_l,\theta_l)u(t-\tau_l) \qquad \text{(eq.13)}$$

The direction vector e(φ;θ) and the steering vector c(φ;θ) are defined as follows (with r the location of the different elements of the antenna array, λ the wave length, θ_l the elevation and φ_l the azimuth angle of the l^{th} path

$$c(\emptyset_l,\theta_l) = \begin{bmatrix} \cos(\emptyset_l) & \cos(\theta_l) \\ \sin(\emptyset_l) & \cos(\theta_l) \\ \multicolumn{2}{c}{\sin(\theta_l)} \end{bmatrix} \qquad \text{(eq.14)}$$

$$c(\emptyset_l,\theta_l) \triangleq e^{i\frac{2\pi}{\lambda}<e(\varphi_l,\theta_l),r>} \qquad \text{(eq.15)}$$

In the previous formula, the $< e(\varphi_l,\theta_l), r >$, indicates the inner product (Scalar) of the two vectors.

IV METHODOLOGY

Smart antenna with 4 antenna elements are used in which A/D conversion and Signal Acquisition for Phase using PLL is done using hardware and Maximum likelihood Estimation is done using SAGE algorithm. Simulation is done using MATLAB.

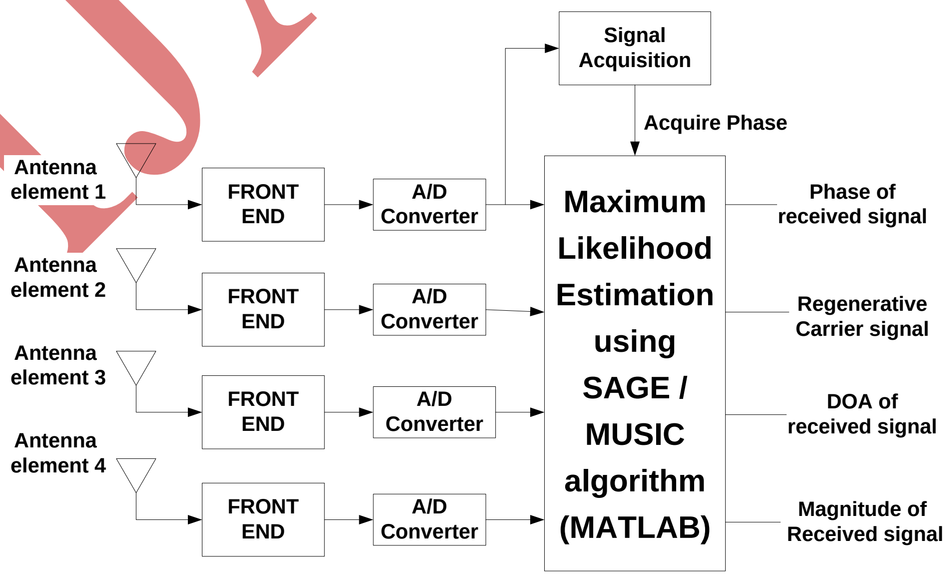

Figure 4: Experimental Setup for Simulation of Transmitter

In the figure 4 an Experimental setup, where a Smart antenna with four elements is used. Further the signal is amplified using low noise amplifier followed by a programmable gain amplifier. The received signal is further fed to analog to digital converter. Further the received signal is our desired input for the analysis of SAGE algorithm and similarly MUSIC algorithm.

Inputs for MATLAB Simulation are self-generated by engraving it in the MATLAB code. Desired phase of Input signal is an Input which will be provided in real time by Phase Lock Loop circuitry in Physical hardware design.

The output of SAGE algorithm and MUSIC algorithm are desired Phase of the received signal, the regenerative carrier to be used in IF stage and Direction of Arrival where maxima is expected. Magnitude of the signal is obtained for different channel coding techniques.

In case of the MATLAB Simulation the output will be in the form of electric field in dB such that the received signal and its Harmonics will be observed. The Other part will determine the Block of received data as generated by randomizer.

4.1 Implementing Algorithms in Smart Antenna Systems.

4.1.1 Signal Creation

In actual hardware implementation where RF end is designed actual signals are received from the environment and further processing is done on them. But we have not implemented the RF end and therefore instead of actual signals we have created dummy signals which imitate the actual signals. We must know the effect of the impinging signals on the antenna. So simply when a signal impinges on the antenna array, it induces some phase in its elements. We suppose that the phase induced in the first element is α z given by

$$a_z = kdcos\theta \quad \text{(eq.16)}$$

Where k is the wave no. and is given by

$$k = \frac{2\pi}{\lambda} \quad \text{(eq.17)}$$

d is the inter-element spacing and θ is the direction of the incoming signal. It is important to note that our algorithm does not know about this direction but phase is physically induced on its elements.

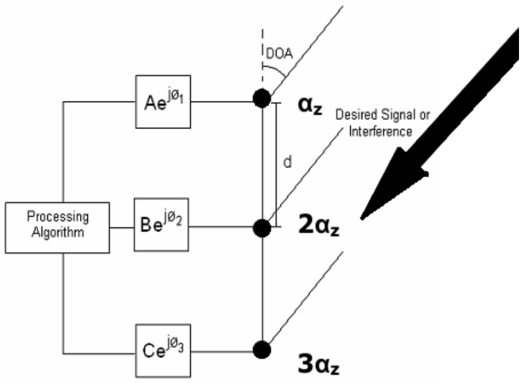

FIG. 5: Experimental Setup for Simulation of Transmitter

The phases that are induced on the next elements are the integral multiple of phase induced on the 1st element, as shown in figure 5. So what we have done is we have catered for these phases that correspond to the incoming signals.

4.1.2 Multi-user Environment

Each incoming signal induces its own phase. Now the received current will be the addition of currents due to all the phases induced by the incoming signals. When the received current is processed by Genetic Algorithm to find the DOA, it will converge randomly to any one of the directions of arrival. After that we intentionally subtract the current due to that direction of arrival

$$\textbf{Received current} = \textbf{Received current} - e^{jDOA} \quad \text{(eq.18)}$$

This changed received current is again fed to the processor and it randomly finds some other direction of arrival. This process is repeated cumulatively until directions of arrivals of all the users are calculated.

V RESULTS

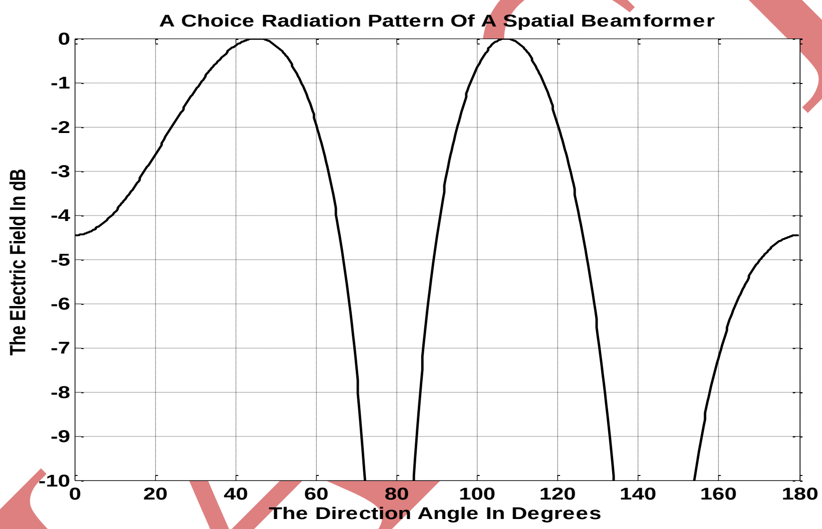

FIG: 6 Radiation Pattern for User 1 Using SAGE Algorithm

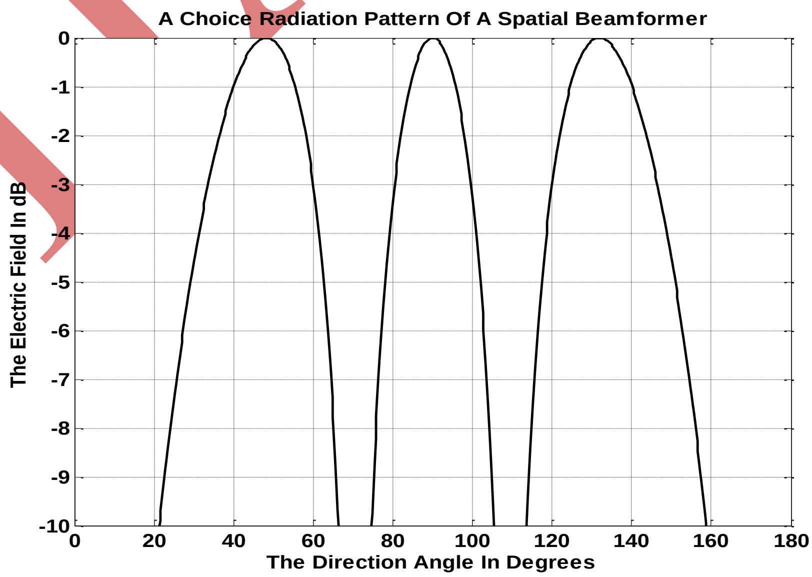

FIG: 7 Radiation Pattern for User 1 Using MUSIC Algorithm

TABLE 1. COMPARISON OF SAGE AND MUSIC ALGORITHM FOR SPATIAL BEAMFORMER FOR USER1

ANGLE(°)	SAGE ALGORITHM (dB)	MUSIC ALGORITHM (dB)
0	-4.454219	Not Defined
10	-3.923964	Not Defined
20	-2.620331	-11.071182
30	-1.161579	-4.568659
40	-0.157809	-0.975038
50	-0.173156	-0.043888
60	-1.978207	-3.089608
70	-7.457065	Not Defined
80	Not defined	-3.382786
90	-4.483817	-0.00124
100	-0.657853	-3.269402
110	-0.092987	Not Defined
120	-1.938962	-3.009535
130	-6.750406	-0.053589
140	Not defined	-0.99937
150	Not defined	-4.607278
160	-9.361555	-11.092154
170	-5.017609	Not Defined
180	-4.454722	Not Defined

The table1 is replica of existing graphs in Figure 6 and 7 for DOA angle in degrees with respect to electric field intensity of User 1 for SAGE and MUSIC algorithms under identical conditions. The convergence of SAGE Outputs is more prominent as number of maxima's are less as compared to Music with less abrupt changes and Nulls are much dynamic than that of MUSIC.

VI CONCLUSION

From the figure 6 and 7 we have observed that the channel is converging adaptively to SAGE algorithm with respect to MUSIC algorithm. The hidden data spaces allow us to adaptively analyze the incoming signal and hence determine the weights of the input coming to the user. The observation is evident with respect music algorithm.

Hence we can conclude from the above results that convergence of SAGE algorithm is better than MUSIC algorithm.

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