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# Smart antenna for wi-max radio system

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## ABSTRACT

In simple words, smart antenna is such that it can sense its environment and can adjust its gain in different directions accordingly. They provide a smart solution to the problem of communication traffic overload i.e. they increase the traffic capacity. They also improve the QOS. RF spectrum is a limited resource and is becoming crowded day by day due to the advent of new technologies. The sources of interference are increasing as well and hence interference is becoming the limiting factor for wireless communication. Smart Antenna adapts its radiation pattern in such a way that it steers its main beam in the DOA (direction of arrival) of the desired user signal and places null along the interference. It refers to a system of antenna arrays with smart signal processing algorithms. Array processing involves manipulation of signals induced on various antenna elements. Its capabilities of steering nulls to reduce cochannel interferences and pointing independent beams toward various mobiles, as well as its ability to provide estimates of directions of radiating sources, make it attractive to mobile communications system designer. Array processing is expected to play an important role in fulfilling the increased demands of various mobile communications services. This paper provides a comprehensive and detailed treatment beam-forming,adaptive algorithms to adjust the required weighting on antennas, direction-of-arrival estimation methods.

## 1.INTRODUCTION

Mobile communication systems are one of the emerging technologies in recent years. There are now more than 2.2 billion mobile phone subscribers worldwide (ITU 2006), over one over third of the human population. This rapid growth of demand of mobile communications, force the service providers to improve their capacity by employing new technologies on their systems. Mobile communication systems are cellular systems that employ base stations to serve its subscribers. Each base station serves a certain region called the cell. Omni directional antennas are employed in base stations since the early days of the mobile systems. Base stations equipped with an omni directional antenna are located at the centre of each cell and the transmitter radiates to every point inside the cell at a specified frequency. Omni directional antennas are more prone to capacity leakage of the cell and hence to reduce these leakage directional antennas, also called as Sectored antennas, are used. More than one directional antenna can be placed on a base station, each pointing to a different direction so that it is possible to sectorize the cell and use different frequencies in each sector for capacity improvement.[3]

The next generation wireless communication system faces a challenge of offering higher data rates in the range of hundreds of megabits per second which gives rise to the demand of wider frequency bands, but as of now there is a limitation on the spectrum usage, which can be overcome by the use of smart antennas. The demand for the use of smart antennas for mobile communications is increased recently and the main purpose for applying smart antennas is feasibility for increasing in capacity and efficiency. The Smart antennas, when used appropriately, help in improving the system performance by increasing channel capacity and spectrum efficiency, extending range coverage, steering multiple beams to track many mobiles, and compensating electronically for aperture distortion. They also reduce delay spread, multipath fading, co-channel interference, system complexity, bit error rate (BER). [3]

Although some the principles of smart antennas have been around for about forty years, new and improved wireless applications (in our case it is the WiMAX technology) demanding the smart antenna technology are growing exponentially. In order to be extremely effective in the present dynamic and dispersive multipath environment, the adaptive array algorithms, which control the operation of the smart antenna and which form the basis of this emerging technology, have to be quite smart enough. In this project, WiMAX technology is used which is quite new and has various advantages over the wireless technologies used now days like the Wi-Fi technology. WiMAX serves greater number of users and offers higher security and greater quality of service. WiMAX technology is designed to allow mobile users to move through the network seamlessly, although, the data rates keep on changing when a user moves far away from the WiMAX tower but the adjacent tower will automatically connect with the user and will ensure the signal is uninterrupted and clear. The smart antenna technology will add on to the features of WiMAX as the users will be able to enjoy the services even if two or three users are sharing the same frequency because the smart antennas will form beam only in the direction of the desired user thus nulling out other users and interferences. [4]

## 2. LITERATURE REVIEW

Amongst the most interesting topics of array processing techniques are beamforming and the estimation of the direction of arrival (DOA) of signals, which are widely used in areas that include radar, sonar, acoustics, astronomy, seismology, and communications[11]. Here, we focus on their developments in communications, more specifically,

wireless communications, for attenuating interference, improving estimation accuracy, and locating the positions of the sources. To simplify the discussion, we concentrate on uniform linear array (ULA), which composes of a number of identical elements arranged in a single line with uniform spacing. The extension of this material to other array configurations is fairly straightforward in most cases [8].

A detailed treatment of various methods of estimating the DOA's has been provided by including the description,limitation, and capability of each method and their performance comparison as well as their sensitivity to parameter perturbations.[5]

I focus on the development of the array processing algorithms for the applications of beamforming and DOA estimation

## 3.SMART ANTENNA

### 3.1NEED OF SMART ANTENNAS:

Wireless communication systems, as opposed to their wire line counterparts, pose some unique challenges:

- ƒ the limited allocated spectrum results in a limit on capacity
- ƒ the radio propagation environment and the mobility of users give rise to signal fading and spreading in time, space and frequency
- ƒ the limited battery life at the mobile device poses power constraints

In addition, cellular wireless communication systems have to cope with interference due to frequency reuse. Among these methods are multiple access schemes, channel coding and equalization and smart antenna employment. Fig below summarizes the wireless communication systems impairments that smart antennas are challenged to combat.[3]

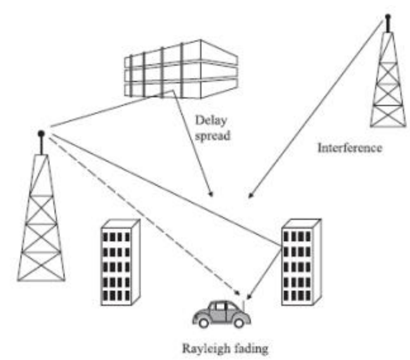



Fig 3.1 Wireless communication impairments that smart antennas have to combat

An antenna in a telecommunications system is the port through which radio frequency (RF) energy is coupled from the transmitter to the outside world for transmission purposes, and in reverse, to the receiver from the outside world for reception purposes. To date, antennas have been the most neglected of all the components in personal communications systems. Yet, the manner in which radio frequency energy is distributed into and collected from space has a profound influence upon the efficient use of spectrum, the cost of establishing new personal communications networks and the service quality provided by those networks. The commercial adoption of smart antenna techniques is a great promise to the solution of the aforementioned wireless communications' impairments.

### 3.2 BASIC IDEA OF SMART ANTENNA:

The basic idea on which smart antenna systems were developed is most often introduced with a simple intuitive example that correlates their operation with that of the human auditory system. A person is able to determine the Direction of Arrival (DoA) of a sound by utilizing a three-stage process.[1]

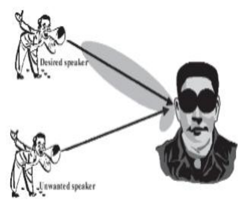



Fig 3.2 Person's ear act as acoustic sensors which determine the desired user similar to a smart antenna

- One's ears act as acoustic sensors and receive the signal.
- Because of the separation between the ears, each ear receives the signal with a different time delay.
- The human brain, a specialized signal processor, does a large number of calculations to correlate information and compute the location of the received sound.

To better provide an insight of how a smart antenna system works, let us imagine two persons carrying on a conversation inside an isolated room as illustrated in Fig. above

The listener among the two persons is capable of determining the location of the speaker as he moves about the room because the voice of the speaker arrives at each acoustic sensor, the ear, at a different time. The human "signal processor," the brain, computes the direction of the speaker from the time differences or delays received by the two ears.[1]

### 3.3SMART ANTENNA TYPES:

There are basically two types of smart antenna configurations which dynamically change their antenna pattern to mitigate interference and multipath effects while increasing coverage and range. They are;

1. Switched Beam
2. Adaptive Arrays

### 3.3(a)SWITCHEDBEAM SMARTANTENNA

It is the simplest implementation of a smart antenna, in which a single transceiver is connected to the RF beamforming unit. The RF beamforming unit, switches to one of the predefined set of beams, according to the received signal power or minimum bit error ratio. It forms multiple fixed beams with heightened sensitivity in particular directions. Such an antenna system detects signal strength, chooses from one of several predetermined fixed beams, and switches from one beam to another as the cellular phone moves throughout the sector as shown in the figure below where we can see that the antenna subdivides the sector into many narrow beams. Each beam can be treated as an individual sector serving an individual user or a group of users. The cellular area is divided into three sectors with 120 degrees angular width, with each sector served by six directional narrow beams. The spatially separated directional beam leads to increase in the possible reuse of a frequency channel by reducing potential interference and also increases the range. These antennas do not have a uniform gain in all directions but when compared to a conventional antenna system they have increased gain in preferred directions. [1]

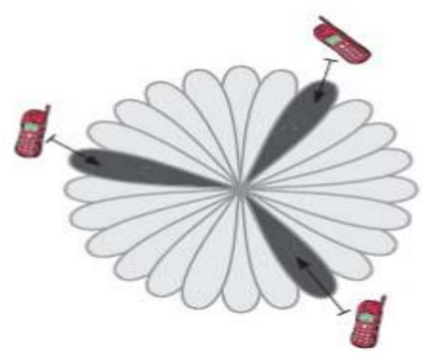


Fig .3.3 Working of Switched beam arrays

The basic working mechanism that the switched beam antenna follows is that the antenna selects the beam from the received signal that gives the strongest received signal. By changing the phase differences of the signals used to feed the antenna elements or received from them, the main beam can be driven in different directions throughout space. Instead of shaping the directional antenna pattern, the switched-beam systems combine the outputs of multiple antennas in such a way as to form narrow sectorized (directional) beams with more spatial selectivity that can be achieved with conventional, single-element approaches.

### 3.3(b) ADAPTIVE ARRAY SYSTEMS

From the previous discussion it was quite apparent that switched beam systems offer limited performance enhancement when compared to conventional antenna systems in wireless communication. However, greater performance improvements can be achieved by implementing advanced signal processing techniques to process the information obtained by the antenna arrays. Unlike switched beam systems, the adaptive array systems are really smart because they are able to dynamically react to the changing RF environment. They have a multitude of radiation patterns compared to fixed finite patterns in switched beam systems to adapt to the ever changing RF environment. An Adaptive array, like a switched beam system uses antenna arrays but it is controlled by signal processing. This signal processing steers the radiation beam towards a desired mobile user, follows the user as he moves, and at the same time minimizes interference arising from other users by introducing nulls in their directions. This is illustrated in a simple diagram shown below in figure below:

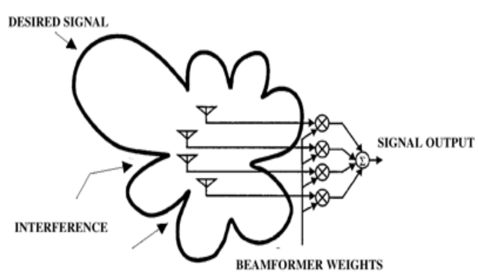



Fig 3.4 Adaptive beamforming

`The adaptive array antenna comes under phased arrays, where the term phased array means that the direction of radiation of the main beam in an array depends upon the phase difference between the elements of the array. Therefore it is possible to continuously steer the main beam in any direction by adjusting the progressive phase difference β between the elements. The same concept forms the basis in adaptive array systems in which the phase is adjusted to achieve maximum radiation in the desired direction. An adaptive array smart antenna system can perform the following functions: first the direction of arrival of all the incoming signals including the interfering signals and the multipath signals are estimated using the Direction of Arrival algorithms. Secondly, the desired user signal is identified and separated from the rest of the unwanted incoming signals. Lastly a beam is steered in the direction of the desired signal and the user is tracked as he moves while placing nulls at interfering signal directions by constantly updating the complex weights. [1]

### 4.MUSIC ALGORITHAM

MUSIC is an acronym which stands for MUltiple SIgnal Classification. This algorithm was first proposed by Schmidt and is a relatively simple and efficient eigenstructure method of DOA estimation. It has many variations and is perhaps the most studied method in its class. MUSIC provides unbiased estimate of the number of incoming signals, their angle of arrival and the strength of the waveforms. MUSIC makes the assumption that the noise in each channel is uncorrelated making the noise correlation matrix diagonal. The incident signals may be somewhat correlated creating a non-diagonal signal correlation matrix.

In MUSIC algorithm it is required that the number of incoming signals must be known or one must find out the eigenvalues which in turn are used to determine the number of incoming signal. If the number of signals is *D*, the number of signal eigenvalues and eigenvectors is *D*, and the number of noise eigenvalues and eigenvectors is $M - D$ (*M* is the number of array elements). This method estimates the noise subspace from the available samples. This can be done by either eigenvalue decomposition of the estimated array correlation matrix or singular value decomposition of the data matrix, with its columns being the K snapshots or the array signal vectors. Because MUSIC exploits the noise eigenvector subspace, it is sometimes referred to as a *subspace method*.[5]

The array correlation matrix is assuming uncorrelated noise with equal variances.

$$\bar{R}_{xx} = \bar{A}\bar{R}_{ss}\bar{A}^H + \sigma^2 I$$

We next find the eigenvalues and eigenvectors for $\bar{R}_{xx}$. We choose the eigenvectors associated with the smallest eigenvalues. For uncorrelated signals, the smallest eigenvalues are

equal to the variance of the noise. We can then construct the
$M\times(M-D)$ dimensional subspace spanned by the noise eigenvectors such that

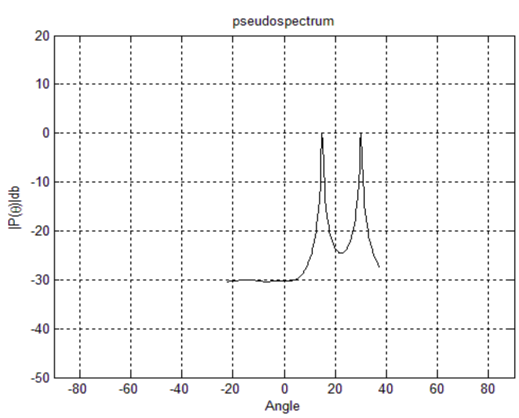
$$\bar{E}_N = [\bar{e}_1 \ \bar{e}_2 \ \dots\dots\dots \ \bar{e}_{M-D}]$$

The noise subspace eigenvectors which we found are orthogonal to the array steering vectors for the different angle of arrival ($\theta_1$, $\theta_2$, $\theta_3$,...., $\theta_D$) which are contained in the signal subspace. This orthogonality function can be used in the Euclidean distance which is given as;

$$d^2 = \bar{a}(\theta)^H \bar{E}_N \bar{E}_N^H \bar{a}(\theta)$$

As explained above the noise eigenvectors and the array steering vectors are orthogonal to each other the Euclidean distance will take the value zero for each of the angle of arrival and if this distance expression is placed in the denominator it creates peaks at the angle of arrival. This expression is called the MUSIC pseudospectrum and is given as.

$$P_{MU}(\theta) = \frac{1}{\bar{a}(\theta)^H \bar{E}_N \bar{E}_N^H \bar{a}(\theta)}$$



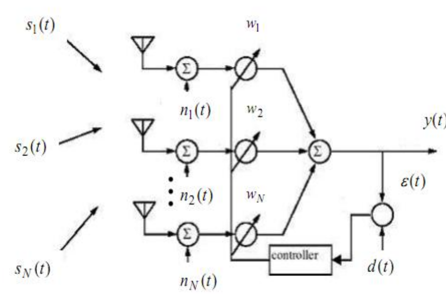

4.1MUSIC Pseudospectrum

## 4.ADAPTIVE BEAM FORMING

There are two types of beamforming approaches; one is fixed beamforming approach which was used if the angles of arrivals don't change with time i.e. the user emitting the desired signals is fixed and not moving. As explained in the previous chapters, this type of adaptive technique actually does not steer or scan the beam in the direction of the desired signal. Switched beam employs an antenna array which radiates several overlapping fixed beams covering a designated angular area. The fixed beamforming techniques used are the maximum signal to interference ratio (MSIR), the Maximum likelihood method (ML) and the Minimum Variance method (MV). If the arrival angles are such that they don't change with time, the optimum array weights won't need to be adjusted.

However, if the desired arrival angles change with time, it is necessary to devise an optimization scheme that operates dynamically according to the changing environment so as to keep recalculating the optimum array weights. The receiver signal processing algorithm then must allow for the continuous adaptation to an ever-changing electromagnetic environment. Thus, if the user emitting the desired signal is continuously moving due to which the angle of arrival is changing, this user can be tracked and a continuous beam can be formed towards it by using one of the adaptive beamforming techniques. 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. In adaptive beamforming the optimum weights are iteratively computed using complex algorithms based upon different criteria.

### 4.1 Least mean square Algorithm-




4.2An Adaptive array system

Assuming this adaptive beamforming problem setup where the array input x(t) and the desired signal d(t) are assumed to be real valued, zero mean random processes. The filter tap weights $w_0$, $w_1$, ...., $w_N$ are also assumed to be real valued. We recall that the performance function $\xi$ is a quadratic function of the filter tap weight vector w and it has a single minimum which can be obtained using the Weiner-Hopf equation given as;

$$W_{opt} = R^{-1}p$$

Instead of solving the equation directly, we can use the iterative approach to find $w_{opt}$ starting with an initial guess for $w_{opt}$ say w(0)
, then the following recursive equation may be used to update the weight vector w(k) can be given as

$$w(k+1) = w(k) - \mu.\ \nabla_k \xi$$

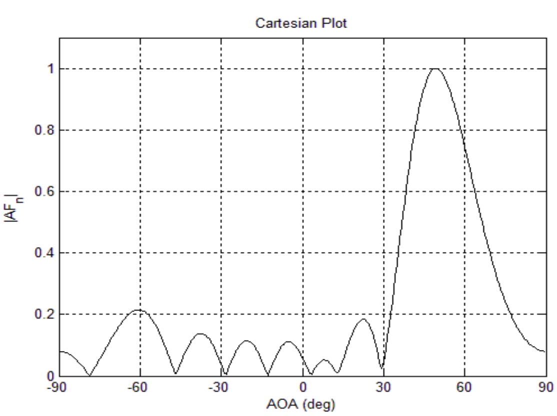
where, μ is the step size;
and $\nabla_k \xi$ is the gradient vector ∇ξ at point w = w(k);

The LMS algorithm is a stochastic implementation of the Steepest Descent algorithm. It simply replaces the performance function $\xi = E[e^2(n)]$ by its instantaneous course estimate $\xi(n) = e^2(n)$. Thus substituting it in the above equation and replacing the iteration k by time index n for real time case.

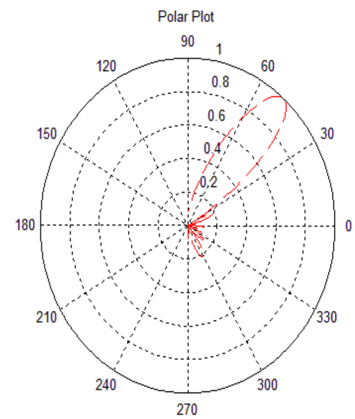
$$w(n+1) = w(n) - \mu.\ \nabla e^2(n)$$
where, $\nabla e^2(n) = -2e(n).x(n)$

Therefore, $w(n+1) = w(n) + 2\mu.e(n)x(n)$

This equation is referred to as the LMS recursion. It gives a simple method for recursive adaptation of the filter coefficients after arrival of every input sequence x(n) and its desired output sample d(n). Once the weights are adapted and they reach the optimum solution, a beam is formed in that particular direction which is the desire user signal while a null is formed in the direction of the interferers. As shown in the simulated results (Cartesian and Polar plot) below the desired signal is at 50 degrees in the direction of which the beam is formed.




4.3 Cartesian Plot of LMS algorithm




4.4 polar Plot of LMS algorithm

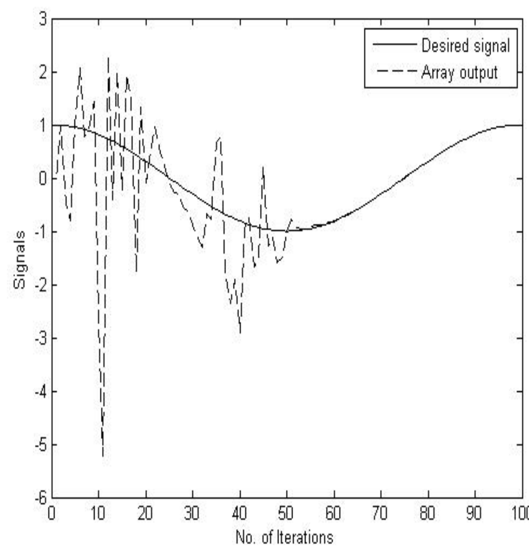



Fig 4.5 Convergence of LMS algorithm

The eminent feature of the LMS algorithm which makes it popular is its simplicity. It requires 2N + 1multiplications i.e. N multiplications for calculating the output y(n), one to obtain (2μ)×e(n) and N multiplications for scalar by vector (2μ.e(n)×x(n)) and 2N additions. Another good feature of LMS algorithm is its robustness and stable performance against different signal conditions. LMS algorithm takes to reach the optimum solution i.e. the desired user signal. As shown in the figure, the algorithm takes 70 iterations to match with the reference signal which is equal to half the period of the reference signal

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