International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Impact Factor (2012): 3.358

Digital Beamforming Algorithms for Smart Antennas

Ramakrishna[1], **Anuradha S**[2]

[1]PG Student, Department of ECE, Guru Nanak Dev Engineering College (VTU), Bidar, India

[2]Professor, Dept. of ECE, Guru Nanak Dev Engineering College (VTU), Bidar, India

Abstract: ***Smart antennas have been gaining popularity in the recent times, as a means to enhance data rate. The reason behind this development is the availability of high-end processors to handle the complex computations involved. The major advantage of digital beam former is that phase shifting and array weighing can be performed on digital data rather than in hardware. Digital beam forming (DBF) is a bridge between antenna technology and digital technology. An antenna can be considered to be a device that converts spatiotemporal signals into strictly temporal signals, thereby making them available to a wide variety of signal processing techniques. In this way all of the desired information that is being carried by these signals can be extracted. The weights for the antenna elements are carefully chosen to give the desired peaks and nulls in the radiation pattern of the antenna array. Digital beam forming is the process of altering the complex weights to maximize the quality of the communications channel. A digital beam former is able to automatically optimize the array pattern by adjusting the elemental control weights until a prescribed objective function is satisfied. This project analyses the performance of three adaptive algorithms –Least Mean Square (LMS), Recursive Least Square algorithm (RLS) and Conjugate gradient method (CGMETHOD) algorithm for computing the array weights. The weights obtained by the above algorithms are then used to steer the antenna array beam in the direction of interest, and forming the nulls thereby in the direction of interferer enhancing SNR. One of the major requirements for Long Term Evolution (LTE), high data rate, can hence be achieved by smart antennas.***

Keywords: Beamforming, Smart Antennas, Uniform Linear Arrays, DOA.

1. Introduction

Conventional base station antennas in existing operational systems are either Omni directional 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 through 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 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, multipath 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. 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 and gives customers less probability 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 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 it’s transmit strategy based on changes in both the desired and interfering signal locations. Digital Beam forming 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.

Smart antennas have recently received increasing interest for improving the performance of wireless radio systems. These systems of antennas include a large number of techniques that attempt to enhance the received signal, suppress all interfering signals, and increase capacity, in general. The main purpose of the article is to provide an overview of the current state of research in the area of smart antennas, and to describe how they can be used in wireless systems. Thus, this article provides a basic model for determining the angle of arrival for incoming signals, the appropriate antenna beam forming, and the adaptive algorithms that are currently used for array processing. Moreover, it is shown how smart antennas, with spatial processing, can provide substantial additional improvement when used with TDMA and CDMA digital-communication systems. A smart antenna consists of an antenna array, combined with signal processing in both space and time, spatial processing leads to more degrees of freedom in the system design, which can help improve the overall performance of the system. The concept of using antenna arrays and innovative signal processing is not new to radar aerospace technology until recent years, cost effectiveness has prevented their use in commercial systems.

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), and outage probability. Delay spread occurs in multipath propagation environments when a desired signal, arriving from different directions, becomes delayed clue to different travel distances. Delay spread and multipath fading can be reduced with an antenna array that is capable of forming beams in certain directions and nulls in others, thereby cancelling some of delay arrivals. Usually, in the transmitting mode, the array focuses energy in the required direction, which helps to reduce multipath reflections and the delay spread in the receiving mode, however, the array provides compensation in multipath fading by adding the signals emanating from other clusters after compensating for delays, as well as by cancelling delayed signals emanating from directions other than that of the desired signal. System complexity and cost is decreased by the use of a smaller number of base stations.

2. Theoretical Analysis

2.1 Smart Antennas

The term “smart antenna” generally refers to any antenna array, terminated in a sophisticated signal processor, which can adjust or adapt its own beam pattern in order to emphasize signals of interest and to minimize interfering signals. Today, several terms are used to refer to the various aspects of smart-antenna system technology, including intelligent antennas, phased arrays, SDMA, spatial processing, digital beam forming, adaptive antenna systems, and others.Smart-antenna systems, however, are usually categorized as two types namely

1) Switched Beam
2) Adaptive Array Systems

2.1.1 Switched Beam Smart Antennas

The traditional switched-beam method is considered as an extension of the current cellular sectorization scheme, in which atypical sectorized cell site is composed of three120-degrcc macro sectors. The switched-beam approach further subdivides the macro-sectors into several micro-sectors. Each micro-sector contains predetermined fixed beam pattern, with the greatest gain placed in the center of the beam typically, the switched-beam system establishes certain choices of beam patterns before deployment, and selects one of several choices during operation. When a mobile user is in the vicinity of a macro-sector, the switched-beam system selects the micro-sector containing the strongest signal. During the call, the system monitors the signal strength, and switches to other fixed micro-sectors, if required. All switched-beam systems offer similar benefits, even though the different systems utilize different hardware and software designs. Compared to conventional sectored cells, switched-beam systems can increase the range of a base station from 20% to 200%, depending on the circumstances of operation.

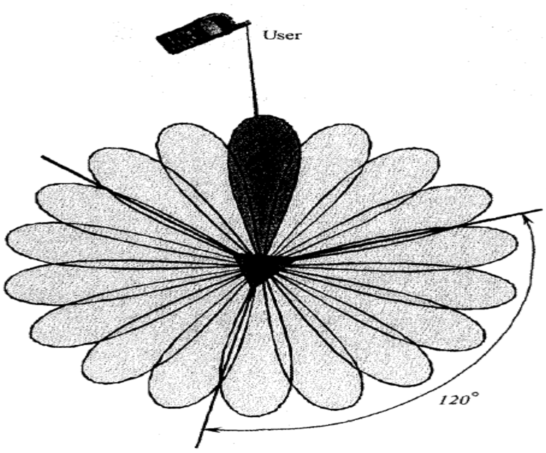

Figure 2.1: Switched beam antenna

The additional coverage means that an operator can achieve a substantial reduction in infrastructure costs. There are, however, limitations to switched-beam systems. Since the beams are predetermined, the signal strength varies as the user moves through the sector. As a mobile unit approaches the far azimuth edges of a beam, the signal strength degrades rapidly before the user is switched to another micro-sector. Moreover, a switched-beam system does not distinguish between a desired signal and interfering signals. If the intending signal is around the center of the selected beam and the user is away from the center, the quality of the signal is degraded from the mobile user.

2.1.2 Adaptive Array Systems

Adaptive antennas take a very different approach. By adjusting to an RF environmental as it changes, adaptive-antenna technology can dynamically alter the signal patterns to optimize the performance of the wireless system The adaptive antenna utilizes sophisticated signal-processing algorithms to continuously distinguish among desired signals, multipath, and interfering signals, as well as to calculate their directions of arrival. The adaptive approach continuously updates its beam pattern, based on changes in both the desired and interfering signal locations. The ability to smoothly track users with main lobes, and interferers with nulls, insures that the link budget is constantly maximized.

This effect is similar to a person’s hearing. When one person listens to another, the brain of the listener collects the sound in both ears, combines it to hear better, and determines the direction from which the speaker is talking.

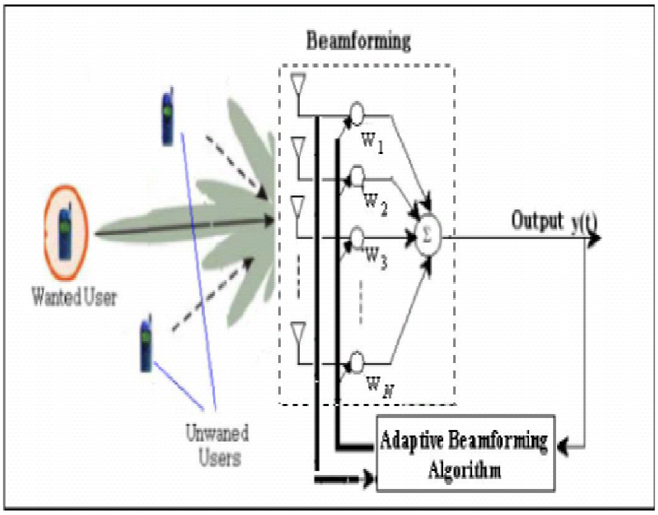

Figure 2.2: Adaptive array antenna

If the speaker is moving, the listener, even if his eyes are closed, can continue to update the angular position, based solely on what he hears. The listener also has the ability to tune out unwanted noise and interference, and to focus on the conversation at hand.

Smart antenna involves many fields. The general subject of smart antennas is the necessary union between such related topics as electromagnetic, antennas, propagation, communications, random processes, adaptive theory, spectral estimation, and array signal processing. Figure 2.3 demonstrates the important relationship between each discipline.

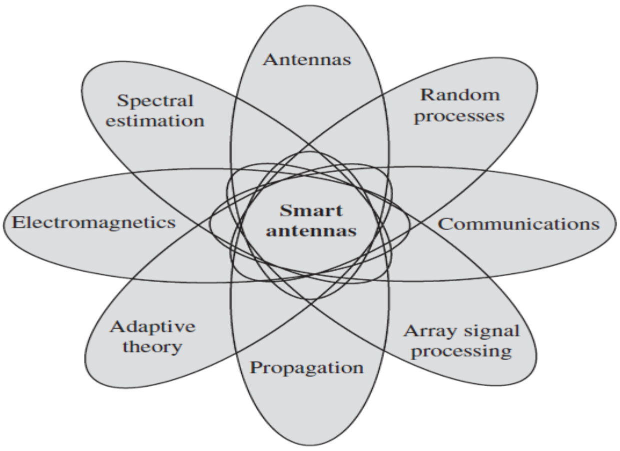

Figure 2.3: Venn diagram relating various disciplines to smart antennas

3. Digital Beamforming Algorithms

3.1 LMS Digital Beamforming Algorithm

The LMS algorithm is a member of a family of stochastic gradient algorithms since the instantaneous estimate of the gradient vector is a random vector that depends on the input data vector x (k) . The LMS algorithm requires 2M+1complex multiplications and 2M complex additions per iteration, where M is the number of weights (elements) used in the adaptive array. If the step-size is too small, the convergence is slow and we will have the over damped case. If the convergence is slower than the changing angles of arrival, it is possible that the adaptive array cannot acquire the signal of interest fast enough to track the changing signal. If the step-size is too large, the LMS algorithm will overshoot the optimum weights of Interest. This is called the under damped case. If attempted convergence is too fast, the weights will oscillate about the optimum weights but will not accurately track the solution desired.

It is therefore imperative to choose a step-size in arrange that insures convergence. It can be shown that stability is insured provided that the following condition is met.

$$0 \leq \mu \leq 1/2\ \lambda max$$

Where λ max is the largest Eigen value of Rxx so the condition for the stability can be written as,

$0 \leq \mu \leq 1/2$ trace [Rxx]

The response of the LMS algorithm is determined by three principal factors:
The step-size parameter, the number of weights, and the Eigen-value of the correlation matrix of the input data vector.

Algorithm flow:

- Step1: Initialize the weight vector to zeros (N, 1)
- Step2: Find the Rxx (the autocorrelation of input signal)
- Step3: select the step size
- Step4: calculate the output y = W*X
- Step5: find the error e =d – y
- Step6: update the weight equation =W (k + 1) = W (k) +μ X (k) e * (k)
- Step7: repeat the steps (4-6) until the error is minimized
- Step8: end of the simulation
- Step9: Plot the result

3.2 RLS Beamforming Algorithm

Algorithm Flow:

- Step1: Initialize the weight vector to zeros (N, K)
- Step2: calculate the Rxx-1
- Step3: now find the Rxx-1 for given block length by implementing the forgetting factor alpha.
- Step4: calculate the gain factor g(k)=Rxx-1* X
- Step5: update the weight equation w(k) = (k-1) +g (k) [d*(k)- XH(k)(k-1)]
- Step6: Repeat the steps 3-5 until the error is minimized ie e(k) = d*(k)- XH(k)w(k-1)
- Step7: end of simulation
- Step8: plot the result

3.2.1 CG Method

The problem with the steepest descent method has been the sensitivity of the convergence rates to the Eigen value spread of the correlation matrix. Greater spreads result in slower convergences. The convergence rate can be accelerated by use of the conjugate gradient method (CGM).The goal of CGM is to iteratively search for the optimum solution by choosing conjugate (perpendicular) paths for each new iteration. Conjugate this context is intended to mean orthogonal. The method of CGM produces orthogonal search directions resulting in the fastest convergence.

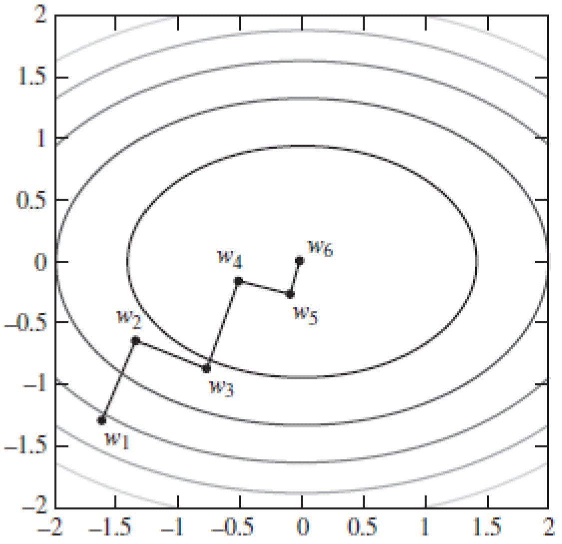

Figure 3.1: Convergence using conjugate directions

Algorithm Flow:

- Step1: Initialize the weight vector to zeros (N, K)
- Step2: calculate the residual vector as r (1) =d-A*w (1)
- Step3: Next choose the direction vector D which gives new conjugate direction to iterate towards optimum weight i.e. D(1) = A*r(1)
- Step4: calculate the mu
- Step5: calculate the general weight update as w(k+1) = w(k)- mu (k)*D(k)
- Step6: now update the residual ras r(k+1) = r(k)+mu *A*D(k)
- Step7: update the direction vector as D(k+1) = AH r(k+1)-alpha *D(k)
- Step8: repeat the steps 3-7 until the error ie rH*r is minimized
- Step9: End of Simulation
- Step10: plot the result

3.3 Simulation Results

We have used MATLAB 7.12.0 (R2011a) to perform simulations of the Digital beam forming algorithms discussed previously.

For the purpose of testing the algorithms we make the following assumptions:

1) The uniform linear array has 6 elements with spacing of λ/2.

2) There is no effect of mutual coupling between array elements.

3) All incidents fields can be decomposed into a discrete number of plane waves. That is there are finite numbers of signals.

4) The desired signal in the algorithm and the desired received signal have high correlation

5) The angle of arrival of the desired signal is 30º and the interferer is at 10º.

3.4 LMS Algorithm

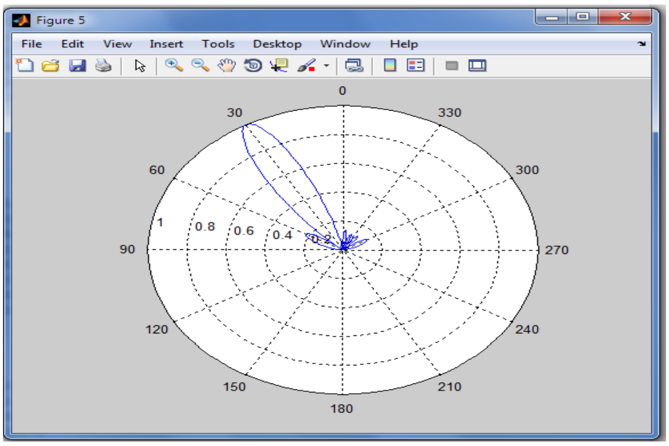

Figure 4.1: Polar plot of the LMS beam forming with AOA at 30^0 and AOI at 10^0

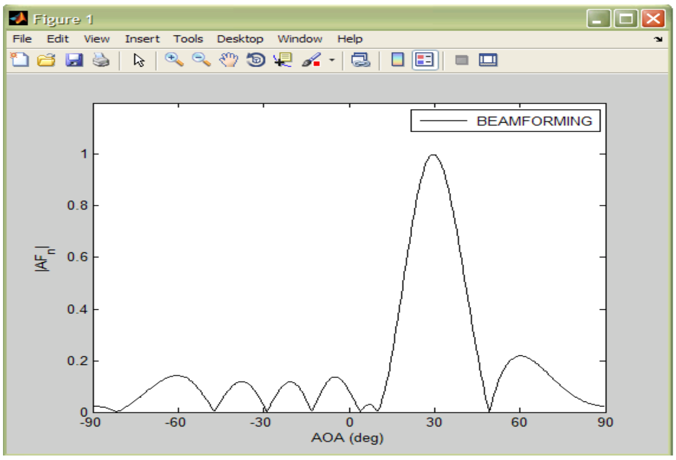

Figure 4.2: Amplitude plot of LMS beam forming with AOA at 30^0 and AOI at 10^0.

3.5 RLS Algorithm:

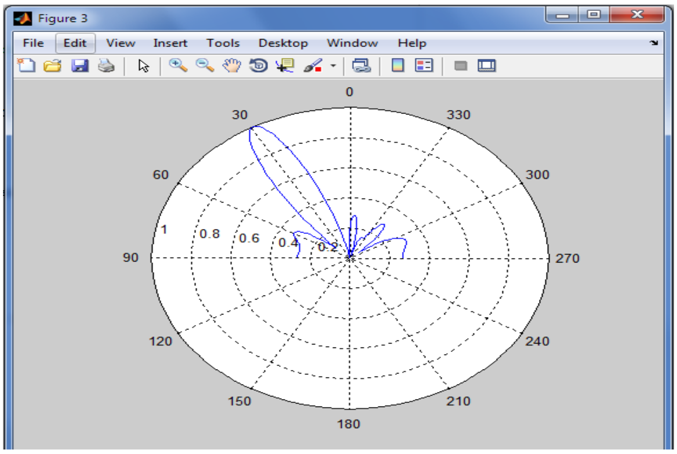

Figure 4.3: polar plot of the RLS beam forming with AOA at 30^0 and AOI at 10^0.

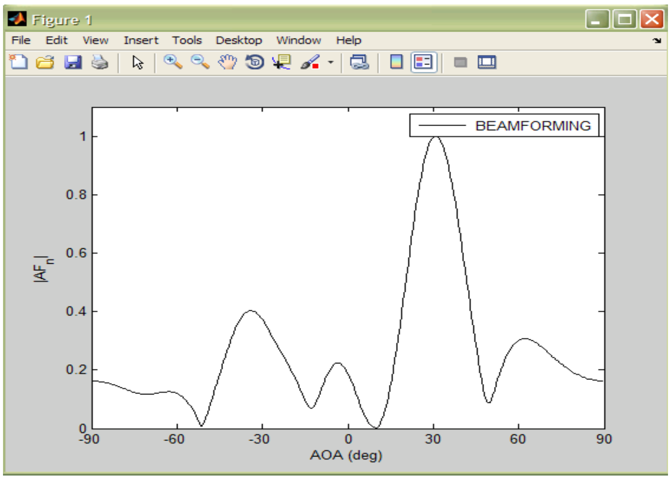

Figure 4.4: Amplitude plot of LMS beam forming with AOA at 30^0 and AOI at 10^0.

3.6 CGM Algorithm

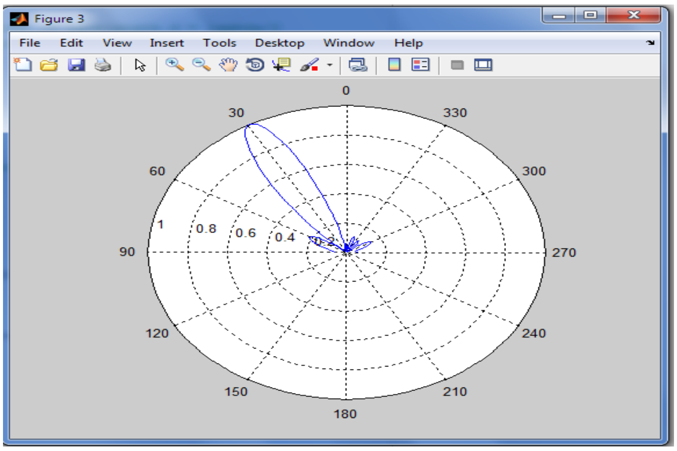

Figure 4.5: Polar plot of the RLS beam forming with AOA at 30^0 and AOI at 10^0.

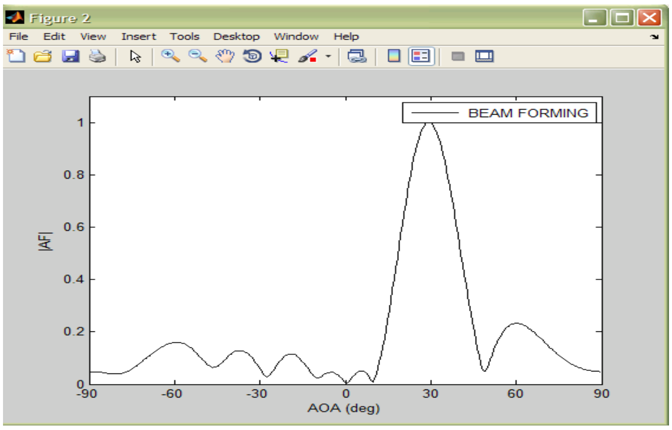

Figure 4.6: Amplitude plot of CGM METHOD beam forming with AOA at 30^0 and AOI at 10^0.

4. Applications

The accurate estimation of AOA is especially beneficial in radar systems for imaging objects or accurately tracking moving objects. Smart antenna DF capabilities also enhance geo-location services enabling a wireless system to better determine the location of a particular mobile user. Additionally, smart antennas can direct the array main beam toward signals of interest even when no reference signal or training sequence is available. This capability is called blind adaptive beamforming. Smart antennas also play a role in MIMO communications systems and in waveform diverse MIMO radar systems. Since diverse waveforms are transmitted from each element in the transmit array and are combined at the receive array, smart antennas will play a role in modifying radiation patterns in order to best capitalize on the presence of multipath. With MIMO radar, the smart antenna can exploit the independence between the various signals at each array element in order to use target scintillation for improved performance, to increase array resolution, and to mitigate clutter. In summary, let us list some of the numerous potential benefits of smart antennas.

- Improved system capacities
- Higher permissible signal bandwidths
- Space division multiple access (SDMA)
- Higher signal-to-interference ratios
- Increased frequency reuse
- Side lobe canceling or null steering
- Multipath mitigation
- Constant modulus restoration to phase modulated signals
- Blind adaptation
- Improved angle-of-arrival estimation and direction finding
- Instantaneous tracking of moving sources
- Reduced speckle in radar imaging

5. Conclusion and Future Work

5.1 Conclusion

The LMS algorithm gives the best beam forming pattern. However, conventionally, the LMS adaptive algorithm has been used to update the combining weights of adaptive antenna array. But, its slow convergence presents an acquisition and tracking problem for cellular. If the signal characteristics are rapidly changing LMS algorithm cannot achieve satisfactory convergence. The RLS algorithm shows high rate of convergence, but the side lobes are not completely cancelled. The recursive equations used in the RLS algorithm allow faster update of array weights. The convergence and accuracy of the LMS and the RLS algorithms depend on the Eigen spread of the signal correlation matrix.

The CGM algorithm calculates the array weights by orthogonal search at every iteration. It shows good beam forming pattern and a high convergence rate. The CGMethod algorithm shows better performance in terms of speed, accuracy and robustness. The choice of the adaptive algorithm decides the efficiency of the smart antennas to a great extent. The smart antennas using the CGMethod algorithm can provide increased system capacity by forming narrower beams in the desired direction and hence mitigate the interference.

5.2 Future Work

The proposed beam forming algorithms for smart antennas can be extended to Hexagonal arrays, cylindrical arrays, spherical arrays and circular arrays. These algorithms can be further implemented in FPGA’S.

6. Acknowledgment

We wish to thank Professor S.M.Joshi, Dept. of ECE, Guru Nanak Dev Engineering College, Bidar, India and Professor Ravindra Eklarker, Dept. of ECE, Guru Nanak Dev Engineering College, Bidar, India for the encouragement and support on our project.

References

[1] Susmita Das, “Smart Antenna Design for Wireless Communication using Adaptive Beam-forming Approach”, *TENCON 2008, IEEE Region 10 Conference*, Nov 2008

[2] Lal C.Godara, “Applications of Antenna Arrays to Mobile Communications, Part I: Performance Improvement, Feasibility, and System Considerations”, *Proceedings of the IEEE*, Vol. 85, No. 7, pp. 1031–1060, Jul1997.

[3] Lal C.Godara, “Application of Antenna Arrays to Mobile Communications, Part II: Beam-Forming and Direction-of-Arrival Considerations”, *Proceedings of the IEEE*, Vol. 85, No. 8, pp. 1195–1245, Aug 1997.

[4] SelvalakshmiR“Analysis of adaptive beam forming algorithms for smart antennas’’IEEE 2011.

[5] Simon Haykin, “Adaptive filter theory”, Fourth edition, Pearson Education, Asia, 2002.

[6] BernardWidrow, Samu D, Stearns, “Adaptive Signal Processing” Pearson Education Asia, Second Indian Reprint, 2002.

[7] Smart antennas by frank gross.Mc Graw hill 2005.

[8] Farhang Boroujrny “Adaptive filters theory & applications’’, Third edition, Wiley publications, USA, 2003.

[9] Barton, P., “Digital Beam forming for Radar,” IEE Proceedings on Pt. F, Vol. 127,pp. 266–277, Aug. 1980.

[10] Brookner, E., “Trends in Array Radars for the 1980s and Beyond,” IEEE AntennaAnd Propagation Society Newsletter, April 1984.

[11] Steyskal, H., “Digital Beam forming Antennas—An Introduction,” Microwave Journal,pp. 107–124, January 1987.

[12] Skolnik, M., “System Aspects of Digital Beam Forming Ubiquitous Radar,” NavalResearch Lab, Report No. NRL/MR/5007—02-8625, June 28, 2002.

[13] Skolnik, M., Introduction to Radar Systems, 3d ed. McGraw-Hill, New York,2001.

[14] Curtis, T., “Digital Beam forming for Sonar Systems,” IEE Proceedings on Pt. F,

[15] Vol. 127, pp. 257–265, Aug. 1980.

[16] Litva, J., and T. Kowk-Yeung Lo, Digital Beam forming in Wireless Communications, Artech House, 1996.

[17] Liberti, J., and T. Rappaport, Smart Antennas for Wireless Communications: IS-95 and Third Generation CDMA Applications, Prentice Hall, New York, 1999.