ISSN: 2277-3754
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 1, Issue 2, February 2012

Adaptive Antenna System: Design and Applications for the Next Generation Mobile Devices

Sarosh K. Dastoor, Niteen B. Patel
dastur_sarosh@yahoo.com, niteen.patel@scet.ac.in

Abstract*— adaptive antenna system is a smart antenna with an array of antenna elements connected to a digital signal processor, enhancing the capacity of a wireless link. The optimization of its radiation or reception pattern automatically in response to the signal environment is the consequence. This can dramatically increase the performance characteristics (such as capacity) of a wireless system. Better range/coverage, increased capacity of signal transmission, multipath rejection, at reduced expense is some of its pros which makes it efficient. Adaptive antenna systems are applicable to FDMA, TDMA, CDMA, FDD and TDD. The Adaptive Antenna can also separate the signals from multiple users separated in space (i.e. by distance) but who use the same radio channel (i.e. center frequency, time-slot, and/or code); called space-division multiple access (SDMA). The design parameters and the simulation results of the Adaptive Antenna are presented in this Seminar Topic

Index Terms— **Adaptive Antenna, multipath rejection, Smart Antenna, radiation pattern, SDMA**.

I. INTRODUCTION

It is truly said that antennas are not smart, Antenna Systems are smart. Such a system can automatically change the directionality of its radiation patterns in response to its signal environment. This can dramatically increase the performance characteristics (such as capacity) of a wireless system. The following are distinctions between the two major categories of Adaptive antennas regarding the choices in transmit strategy:

1. **Switched Beam**—a finite number of fixed, predefined patterns or combining strategies (sectors)
2. **Adaptive Array**—an infinite number of patterns (scenario-based) that are adjusted in real time.

A. Switched Beam Antennas: Switched beam antenna systems form multiple fixed beams with heightened sensitivity in particular directions. These antenna systems detect signal strength, choose from one of several predetermined, fixed beams, and switch from one beam to another as the mobile moves throughout the sector. Instead of shaping the directional antenna pattern with the metallic properties and physical design of a single element (like a sectorized antenna), switched beam systems combine the outputs of multiple antennas in such a way as to form finely sectorized (directional) beams with more spatial selectivity than can be achieved with conventional, single-element approaches.

B. Adaptive Array Antennas: Adaptive antenna technology represents the most advanced smart antenna approach to date. Using a variety of new signal-processing algorithms, the adaptive system takes advantage of its ability to effectively locate and track various types of signals to dynamically minimize interference and maximize intended signal reception.

Both systems attempt to increase gain according to the location of the user; however, only the adaptive system provides optimal gain while simultaneously identifying, tracking, and minimizing interfering signals.

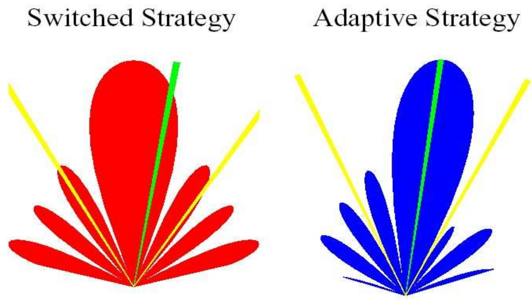

Fig. 1. Switched beam and adaptive antenna strategy for locating the target

C. Adaptive Antenna Approach: 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 (or the spatial origin of signals), adaptive antenna technology can dynamically alter the signal patterns to near infinity to optimize the performance of the wireless system. Both types of smart antenna systems provide significant gains over conventional sectored systems. The low level of interference on the left represents a new wireless system with lower penetration levels. The significant level of interference on the right represents either a wireless system with more users or one using more aggressive frequency reuse patterns. In this scenario, the interference rejection capability of the adaptive system provides significantly more coverage than either the conventional or switched beam system [2].

II. ADAPTIVE ARRAY TECHNOLOGY

The field strength representation of a normal Omni-directional antenna is shown in figure below. Figures 2 to 4 indicate that as the mobile user moves out of the coverage area the field Strength reduces substantially, as the full Signal Strength is available only in the limited area. As the user

ISSN: 2277-3754
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 1, Issue 2, February 2012

moves away the signal strength rapidly worsens and finally it yields nothing beyond the coverage [10]

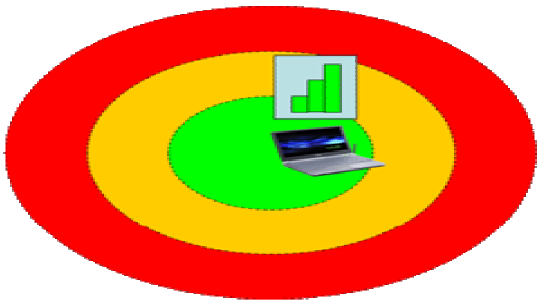

Fig. 2. Signal strength of the Omni-directional antenna

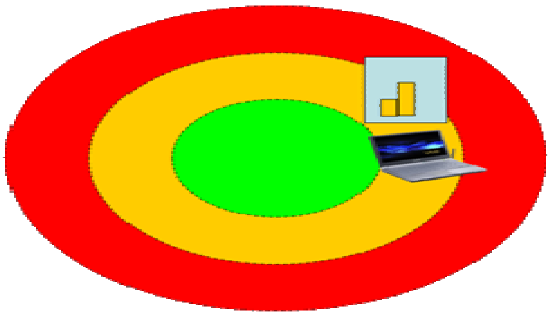

Fig. 3. Signal Strength reduces as the mobile user moves away

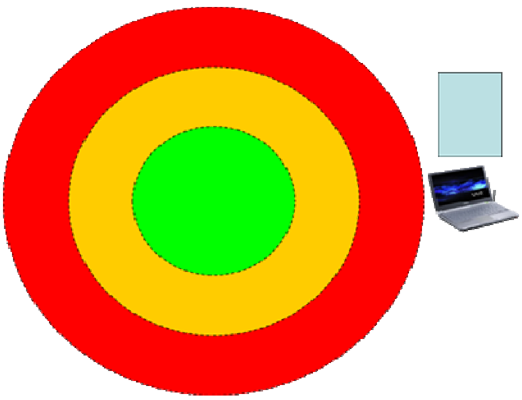

Fig. 4. Signal Strength finally becomes 0

In case of Adaptive antenna Array as shown in the figure 5, the range extended is two to four times compared to normal omni-directional antenna by focusing signal in the direction of the user. Adaptive Antennas technology can also focus the signal towards multiple users as shown in the figure 6. This is the salient feature of using the Adaptive Antenna System to focus the beam and track the multiple user using causing any interference with the multiple mobile users. It enhances the Carrier-to-Interference ratio and hence the Field Strength in the desired direction increases as compared to the conventional omni-directional antenna whose signal was deterioration exponentially when the range was increasing [10].

The figure 5 clearly indicates the advantage of using the Smart antennas for enhancing range in terms of Coverage. It concentrates the beam in the direction of desired user and hence increases the signal strength, which in turn enhances the Front-to-back ratio, overcomes the problems of interference and thus the C/I Carrier-to-Interference) ratio increases.

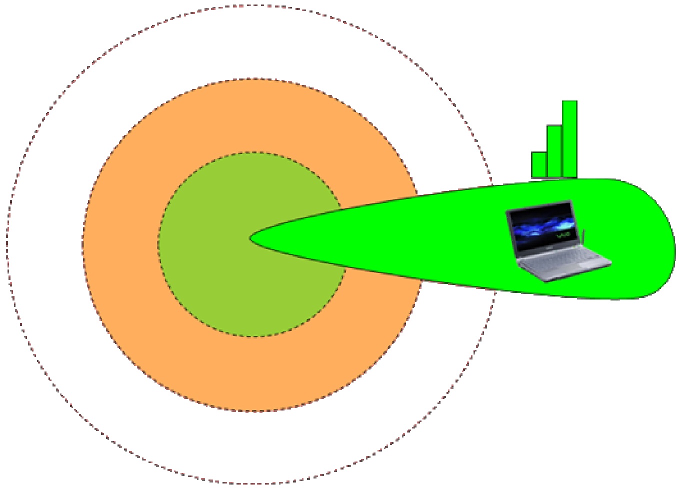

Fig. 5. Adaptive Antenna array focusing in the direction of user and hence increasing the range

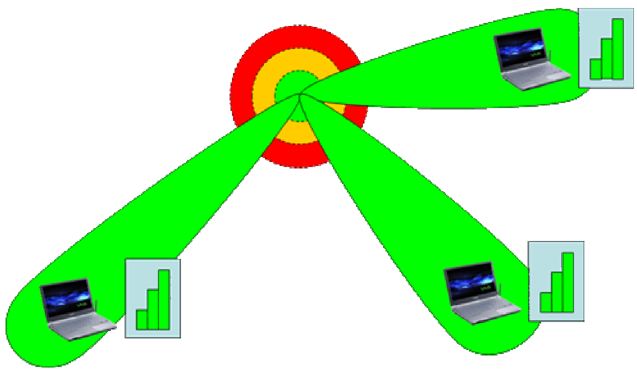

Fig.6.Adaptive Antennas technology focuses signal towards multiple users

III. ADAPTIVE ANTENNA DESIGN

Antenna elements play an important role in shaping and scanning the radiation pattern and in constraining the adaptive algorithm used by the digital signal processor. The type of antenna element considered is generally a micro strip antenna (patch antenna), since it is intended to be conformably mounted on a smooth surface or a similar device. They have very attractive radiation pattern characteristics, both as single elements and in arrays. They are inexpensive, lightweight, conformal, easy to manufacture and versatile. The most common shape is the rectangular patch, because of its attractive radiation characteristics, especially low its cross-polarization radiation.

Given any array of identical elements, the total array pattern can be represented b y the product of the electric field and the array factor. A planar-array configuration was chosen, because of its ability to scan in 3-d space. For $M \times N$

ISSN: 2277-3754
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 1, Issue 2, February 2012

identical arrays with uniform spacing, positioned symmetrically in x-y plane as shown in the figure 7, the array factor is given by [1]:

$$[AF(\theta,\varnothing)]_{M\times N} = \sum_{m=1}^{M}\sum_{n=1}^{N} W_{mn}\, e^{j[(m-1)\psi x+(n-1)\psi y]} \quad \text{----(1)}$$

$$\Psi x = kd_x(\sin\theta\cos\varnothing - \sin\theta_o\cos\varnothing_o),$$

$$\Psi y = kd_y(\sin\theta\sin\varnothing - \sin\theta_o\sin\varnothing_o)$$

Where W_{mn} represent the complex excitations of the individual, elements and $(\theta o, \varnothing o)$ represent the angle of maximum radiation. It is the W_{mn} that the adaptive-beam forming algorithms adjust to place the maximum of the main beam toward the signals of interest and nulls towards the signals of no-interest. For the narrow-beam width designs, the main beam can resolve the signals of interest more accurately, can allow the smart antenna system to reject more signals not of interest. It however increases the cost and complexity of the hardware implementation, because of large number of elements that may be needed. It has been found that a planar array of 8×8 antenna elements gives necessary throughput for the mobile communication devices.

The Micro strip array considered here is designed to operate at a frequency of 20 GHz, using a substrate material of Silicon, with a dielectric constant of 11.7 and a loss tangent of 0.04, a thickness of 0.3 mm and an input impedance of 50Ω. The physical dimensions of the final design of the rectangular patch are listed in the figure 7.From the dimensions of a single patch antenna, a planar array of 8×8 micro strip patches, with an inter-element spacing of λ/2 is designed. In this case the antenna array provides a performance improvement though spatial diversity. Once the antenna array is designed, the DOA (Direction-Of-Arrival) algorithm computes the direction of all signal based on the time delays, which for the M×N planar array shown in figure 7 is computed by [7]:

$$\tau_{mn} = \frac{md_x\sin\theta\cos\Phi + nd_y\sin\theta\sin\Phi}{V_o}$$

Where V_o = Speed of light in free space.

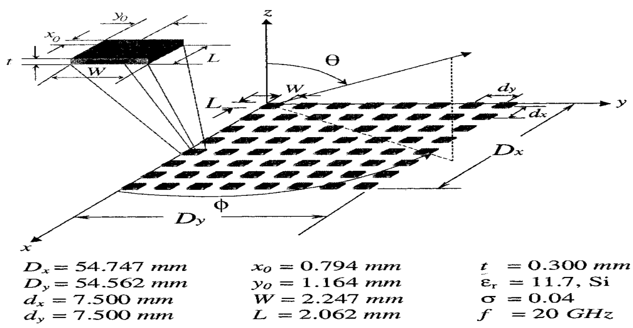

Fig. 7. A planar Array Configuration [7]

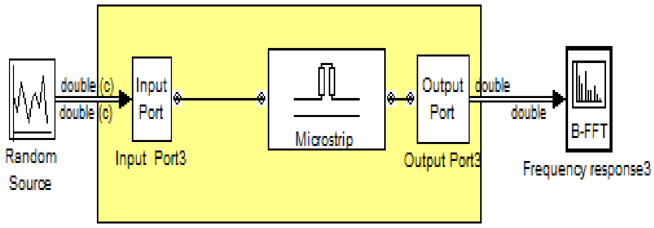

Fig.8. Modeling a Micro strip transmission line in MATLAB

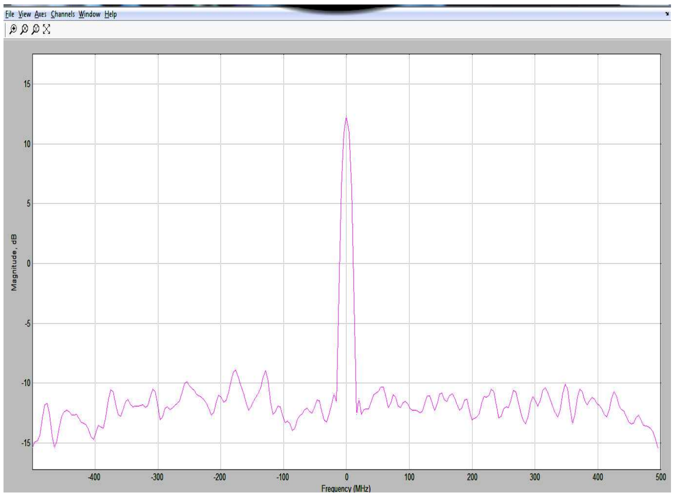

Fig .9. Frequency Response of the Microstrip transmission line obtained at FFT scope

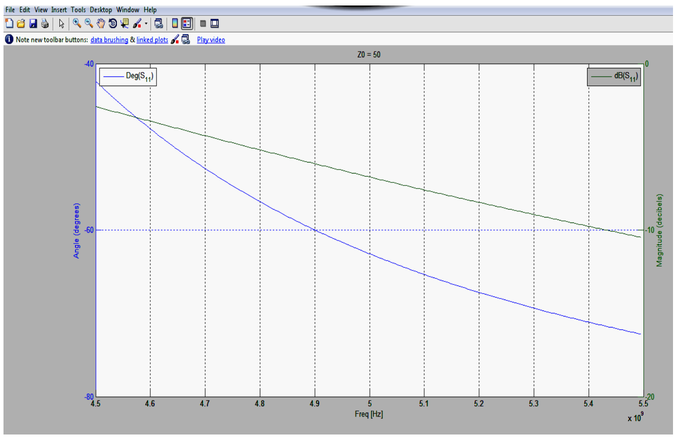

Fig. 10. Plot of S_{11} (return Loss) as a function of frequency for the above Simulink Model

The figure 8 was simulated using RF tool Box Simulink model. Various parameters of the Micro strip line used for the Simulation are shown in Table 1. The frequency Response of the Transmission Line is shown in figure 9. The centre frequency considered is 5 GHz. Figure 10 shows the Return Loss (S_{11}-Scattering Parameter) as a function of frequency. The technical specifications for the Micro strip line considered are shown in the table below:

Table 1. Micro strip line parameters used in the Simulation:

S. N	Parameter	Value
1	Strip width (m)	2.6501e-3

ISSN: 2277-3754
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 1, Issue 2, February 2012

2	Substrate height (m)	0.635e-3
3	Strip thickness (m)	0.01e-3
4	Relative Permittivity constant	9.8
5	Transmission Line Length	0.00663
6	Frequency data (Visualization)	1.5e9 : 10e6 : 5e9

IV. ADAPTIVE ANTENNA TECHNOLOGIES FOR FUTURE WIRELESS SYSTEMS

Adaptive antenna systems can improve link quality by combating the effects of multipath propagation or constructively exploiting the different paths, and increase capacity by mitigating interference and allowing transmission of different data streams from different antennas. More specifically, the benefits of smart antennas can be summarized as follows

Increased range/coverage: The array or beam- forming gain is the average increase in the signal power at the receiver due to a coherent combination of the signals received at all antenna elements. It is proportional to the number of receive antennas and also allows for lower battery life.

Lower power requirements and/or cost reduction: Optimizing transmission toward the wanted user (transmit beam-forming gain) achieves lower power consumption and amplifier costs.

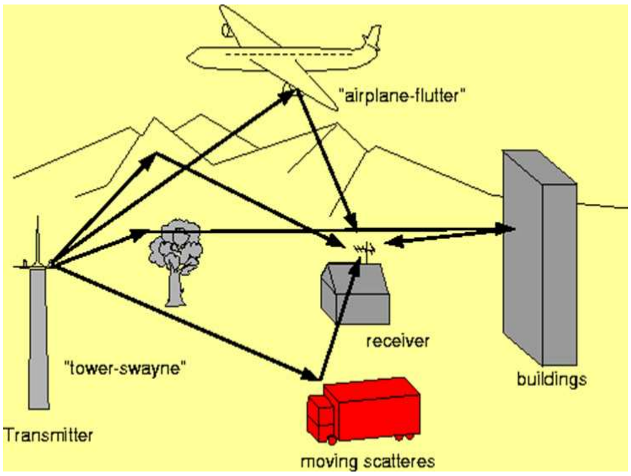

Fig. 11. Multipath propagation [4]

Increased spectral efficiency: Precise control of the transmitted and received power and exploitation of the knowledge of training sequence and/or other properties of the received signal (e.g., constant envelope, finite alphabet, cyclo stationary) allows for interference reduction/mitigation and increased numbers of users sharing the same available resources (e.g., time, frequency, codes) and/or reuse of these resources by users served by the same base station/access point. The latter introduces a new multiple access scheme that exploits the space domain, space-division multiple access (SDMA). Moreover, increased data rates -and therefore increased spectral efficiency can be achieved by exploiting the spatial multiplexing gain, that is, the possibility to simultaneously transmit multiple data streams, exploiting the multiple independent dimensions, the so called spatial signatures or MIMO channel eigen-modes. It was shown [2] that in uncorrelated Rayleigh fading the MIMO channel capacity limit grows linearly with min(M,N), where M and N denote the number of transmit and receive antennas, respectively. Traditionally, smart antenna systems have been designed focusing on maximization of one of the above-mentioned gains (beam forming, diversity, and multiplexing gains).

A. Smart Antenna Systems for Mobile Adhoc Networks (MANETs): In MANETs, as the name suggests there does not exist a fixed network infrastructure and nodes move randomly as shown in figure 12. In MANNETS, data packets are transferred in single hops and the use of directional beams for communication results n reduced interference and hence improved capacity. To facilitate the use of Adaptive Antennas in a MANET, nodes must be capable of estimating the direction of the desired node. With Adaptive Antennas it is possible to detect the incoming signals using DOA estimation techniques such as MUSIC and ESPRIT algorithms or using LMS-type beam-forming algorithms [8].

The MAX protocol proposed in this work allows nodes to exchange training packets before the data transfer. Nodes start with the isotropic mode of antennas and switch to the directional mode by the end of the training period. Data transfer takes place in the directional mode of antennas. Thus antennas should be able to operate in both isotropic directional modes.

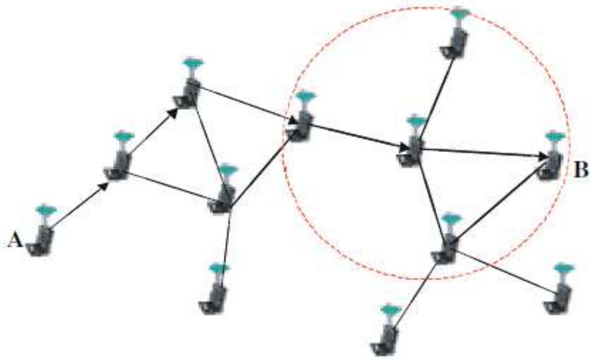

Fig. 12. A Typical MANET topology [5]

B. Adaptive Antennas for WLAN: Adaptive Antennas can significantly improve the performance of Wireless Local Area Networks (WLANs). The TDD (Time Division Duplexing) operation only need smart antenna at access point or terminal for performance improvement in both directions. It provides various advantages like:

ISSN: 2277-37
International Journal of Engineering and In
Volume 1, Issue 2, Fe

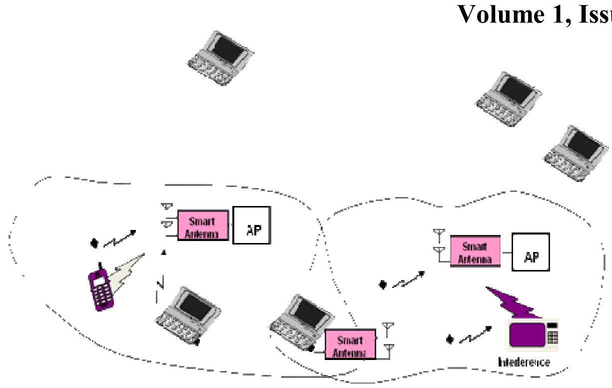

Fig. 13.Adaptive Antenna for Wireless LANs [8]

- **Higher antenna gain:** It enhances the range, increases data rate and Extend the battery life.
- **Multipath diversity gain:** Improves reliability of the Wireless System
- **Interference suppression:** Improve system capacity and throughput. It supports aggressive frequency re-use for higher spectrum efficiency, thereby provides robustness in the ISM band.

C. Lightweight Aerostat System (LAS): It consists of a small specially designed tethered blimp, called a Helikite, mounted on a trailer Carrier as shown in Figure 14. The LAS blimp can be flown up to a thousand meters altitude to provide coverage 24 hours a day for a week or more without maintenance or downtime. Operating and maintenance cost is a fraction of the cost of using aircraft or Unmanned Air Vehicles to lift the surveillance or relay payloads. LAS can elevate a communications relay payload to 1000 meters, providing extended communication coverage out to 100 or more km from its location, or a circle 200 km in diameter. Surveillance versions at 100 meters can cover a radius of 5 to 10 km. depending upon terrain. The Aerostat based Floating Base Station becomes very useful in those cases where the terrain is not suitable for establishing a Base Station. Also the transmission and reception of signals become difficult in those terrains. In these circumstances the aerostat is made floating at a particular height. It comprises an array of Adaptive antennas which provides the coverage and capacity in that terrain. It is generally used in mountainous regions or marine region where it is practically not possible to set-up a Base Station to serve the number of mobile users. [10].As shown in Figure 14, consider the case when the breeze movement has caused the Aerofloat to tilt at an angle with respect to its original position. As a result the Principal beam will also move from its reference position and there will be an offset created with the principal axis of measurement. The offset could be compensated using Adaptive set of Algorithms which modifies the weights and scales the needful.

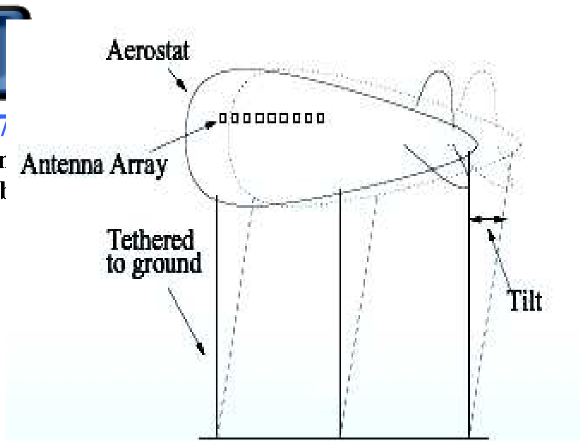

Fig 14.A Floating Base Station showing a tilt due to breeze

V. CONCLUSION AND FUTURE ENHANCEMENT

Adaptive antennas improve user experience and system capacity by reducing interference, extending range, increasing data rates, and improving quality. It can be implemented in the physical layer with little or no impact on standards. Adaptive antennas can be applied for WLANs, MANETs and many other wireless applications. With the onset of 4G and later generations of Wireless Communications, Adaptive antenna will be inevitable with its Advanced Signal Processing Capabilities.

In comparison to the conventional λ/2 dipole antenna, the pattern obtained by the Adaptive Array Antenna is unidirectional. Much amount of Field Strength is concentrated in a particular direction. The front-to-back ratio is highly improved in this case and much higher directivity is the consequence. The radiation pattern could be enhanced using Adaptive Signal Processing Algorithms like LMS (Least Mean Square), NLMS (Normalized Least Mean Square) or RLS (Recursive Least Square),considering the parameters of the Smart antenna and using adaptive filtering. The parameters include the setting of the weights and thereby taking the decision to change the direction of the beam as per the algorithm. The Adaptive processing can make the beam pattern move as per the required direction, tracking the mobile user. It is quite adaptive in changing the direction, as per the requirement.

REFERENCES

[1] J Constantine A. Balanis, Panayiotis I. Ionnides, “Introduction to Smart Antennas”, Third Edition, Morgan and Claypool Publishers.

[2] Joseph C. Liberti and Theodore S. Rappaport, “Smart Antennas for Wireless Communication IS 95 and Third Generation CDMA Applications, Prentice Hall PTR.

[3] Huang, X.; Guo, Y. J. & Bunton, J. D. (2010a). A hybrid adaptive antenna array. IEEE Transactions on Wireless Communications, vol. 9, no. 5, 2010, pp. 1770-1779.

[4] Schuttengruber, W., Molisch A.F. and Bonek E., “Smart Antennas for Mobile Communications-Tutorial”.

[5] Dyadyuk, V.; Guo, Y. J. & Bunton, J. D. (2009b). Study on High Rate Long Range Wireless Communications in the 71-76 and 81-86 GHz bands. Proceedings of the 39th European Microwave Conference (EuMC2009), Proceedings, Sep. 2009, pp.1315-1318, Rome, Italy.

[6] Abdulmonem, T.M.; Elsohby, A.; Hossam, B.; Shokry, A.; Eshrah, I.A., “Adaptive Antenna for Wi-Fi System Enhancement”, Potentials IEEE, Volume 30, Issue 1, pp 30-34, Jan-Feb 2011.

[7] Salvatore Bellofiore, Constantine A Balanis, Jeffrey Foutz, and Andreas S. Sapnias, “Smart Antenna Systems for Mobile Communication Networks, Part 1: Overview and Antenna Design”, IEEE Antenna and Propagation Magazine, Vol 44, No 3, June 2002.

ISSN: 2277-3754
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 1, Issue 2, February 2012

[8] Salvatore Bellofiore, Jeffrey Foutz, Ravi Govindarajula, Israfil Bahçeci, Constantine A. Balanis, "Smart Antenna System Analysis, Integration and Performance for Mobile Ad-Hoc Networks (MANETs)", IEEE transactions on Antennas and Propagation, Vol. 50, No. 5, May 2002.

[9] M. Benedetti, G. Oliveri, P. Rocca, and A. Massa, "A fully Adaptive Smart Antenna Prototype: Ideal model and experimental validation in Complex Interference Scenarios", Progress in Electromagnetics Research, PIER 96, 173–191, 2009.

[10] Haupt, R.L.; Flemish, J.; Aten, D. "Adaptive Nulling Using Photoconductive Attenuators", IEEE Transactions on Antennas and Propagation, Volume 59, Issue 3, pp 869-876, March 2011.

[11] Ke Dong, Narayan Prasad, Xiaodong Wang, Shihua Zhu, "Adaptive antenna selection and Tx/Rx beam forming for large-scale MIMO systems in 60 GHz channels", EURASIP Journal on Wireless Communications and Networking, August 2011.

[12] IEEE Communications Magazine, September 2004.