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Study on Smart Antenna Systems and Implementation in Mobile Ad Hoc Networks

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Abstract
Wireless carriers have begun to explore new ways to maximize the spectral efficiency of their networks. Research efforts investigating methods of improving wireless systems performance are currently being conducted worldwide by the deployment of smart antennas (SAs) along with impressive advances in the field of digital signal processing for achieving high efficiency networks that maximize capacity and improve quality and coverage. Selected control algorithms, with predefined criteria, provide adaptive arrays the unique ability to increase spectral efficiency.
Keywords: Adaptive arrays, Smart antenna system, Direction of arrival (DOA), MANET.

I. INTRODUCTION

Antennas are passive devices that transmit or receive electrical energy in the form of electromagnetic waves. Antennas act as a transducer in between free space and the transmitter/receiver section for converting electrical energy to the radio frequency (RF) signals and vice versa. In general, antennas of individual elements may be classified as *isotropic*, *omnidirectional* and *directional* according to their radiation characteristics. An isotropic radiator is one which radiates its energy equally in all directions. In Omnidirectional radiators the power is radiated equally in all directions in the horizontal (azimuth) plane. And, in directional radiators a directional antenna concentrates the power primarily in certain directions or angular regions. Here we will be discussing about how these directional antennas will be modified along with the Digital Signal Processing (DSP) unit to form a Smart antenna system. In section III we have discussed about, Mobile Ad hoc Networks (MANET), one of the applications where the smart antenna system will be used to increase its efficiency.

A. Antenna arrays

In many applications we need highly directive beams to focus to the desired user so that the unwanted user interference is avoided. Directivity can be increased in an effective way by forming an assembly of radiating elements in a geometrical and electrical configuration, without necessarily increasing the size of the individual elements. Such a multi element radiation device is defined as an *antenna array*. The total electromagnetic field of an array is determined by vector addition of the fields radiated by the individual elements, combined properly in both amplitude and phase. The array configurations like linear, circular, rectangular, etc patterns. The relative displacement between the elements, the amplitude and phase excitations and the individual relative patterns makes the difference in the overall beam forming pattern of the antenna.

Antenna arrays can be classified into two categories: phased array antenna and adaptive antenna.

A phased array antenna uses an array of single elements and combines the signal induced on each element to form the array output. The direction where the maximum gain occurs is usually controlled by adjusting properly the amplitude and phase between the different elements.

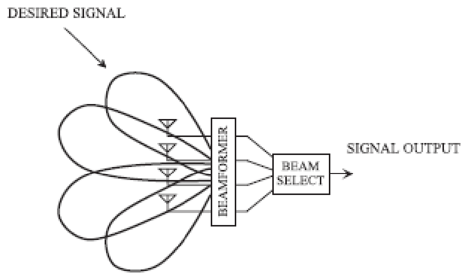

Fig. 1. Describes the phased array concept.

Whereas, an adaptive antenna array is the one that continuously adjusts its own pattern by means of feedback control. The principal purpose of an adaptive array sensor system is to enhance the detection and reception of certain desired signals. The pattern of the array can be steered toward a desired direction space by applying phase weighting across the array and can be shaped by amplitude and phase weighting the outputs of the array elements. Additionally, adaptive arrays sense the interference sources from the environment and suppress them automatically, improving the performance of a radar system, for example, without *a priori* information of the interference location. In comparison with conventional arrays, adaptive arrays are usually more versatile and reliable.

Adaptive antenna arrays are commonly equipped with signal processors which can automatically adjust by a simple adaptive technique the variable antenna weights of a signal processor so as to maximize the signal-to-noise ratio. At the receiver output, the desired signal along with interference and noise are received at the same time. The adaptive antenna scans its radiation pattern until it is fixed to the optimum direction (toward which the signal-to-noise ratio is maximized). In this direction the maximum of the pattern is ideally toward the desired signal. A major reason for the progress in adaptive arrays is their ability to automatically respond to an unknown interfering environment by steering nulls and reducing side lobe levels in the direction of the interference, while keeping desired signal beam characteristics.

Adaptive arrays based on DSP algorithms can, in principle, receive desired signals from any angle of arrival. However, the output signal-to-interference plus-noise ratio (SINR) obtained from the array, as the desired and interference signal angles of arrival and polarizations vary, depends critically on the element patterns and spacing used in the array. Such a system of arrangement that is, digital signal processing along with the adaptive array antenna forms a Smart antenna System.

II. BASIC PRINCIPLE OF SMART ANTENNA

To explain the basic principle of smart antenna system, let us consider two antennas and a digital signal processor (DSP) configuration as shown in the fig. 2. This arrangement is able to determine the Direction of Arrival (DoA) of a signal by utilizing a three-stage process:

i. Antennas act as sensors and receive the signal.
ii. Because of the separation between the antennas, each antenna receives the signal with a different time delay.
iii. The DSP unit, a specialized signal processor, does a large number of calculations to correlate information and compute the location of the received sound.

The digital signal processor makes a decision based on the time delay between the received signals at the antenna locations. Thus, based on the time delays due to the impinging signals onto the antenna elements, the digital signal processor computes the direction-of-arrival (DOA) of the signal-of-interest (SOI), and then it adjusts the excitations (gains and phases of the signals) to produce a radiation pattern that focuses on the SOI while tuning out any interferers or signals-not-of-interest (SNOI).

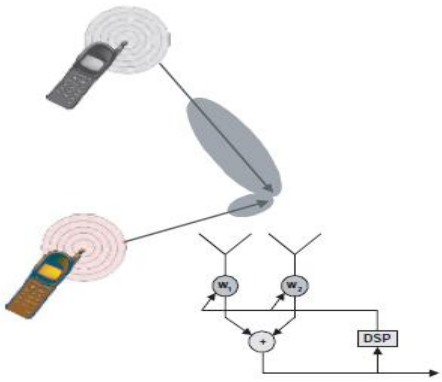

Fig. 2. A two-element electrical smart antenna.

Similarly for the mobile communication system, a digital signal processor located at the base station works in conjunction with the antenna array and is responsible for adjusting various system parameters to filter out any interferers or *signals-not-of-interest* (SNOI) while enhancing desired communication or *signals-of –interest* (SOI). Thus, the system forms the radiation pattern in an adaptive manner, responding dynamically to the signal environment and its alterations.

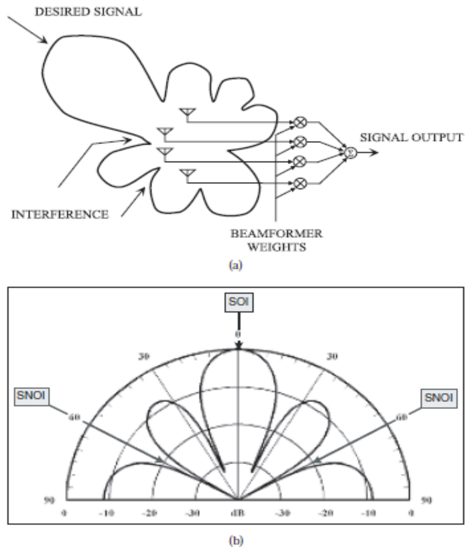

Fig. 3. Adaptation procedure: (a) Calculation of the beamformer weights and (b) Beamformed antenna amplitude pattern to enhance SOI and suppress SNOIs.

A. *SMART ANTENNA CONFIGURATIONS*

Basically, there are two major configurations of smart antennas:

1) *Switched-Beam:* A switched-beam system is the simplest smart antenna technique. 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 illustrated in Fig.

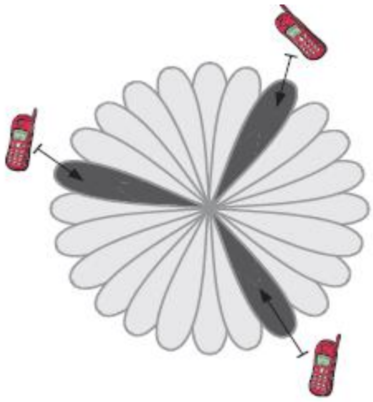

Fig. 4. Switched beam coverage pattern

2) *Adaptive Array:* The adaptive concept is far superior to the performance of a switched-beam system. Also, it shows that switched-beam system not only may not be able to place the desired signal at the maximum of the main lobe, but also it exhibits inability to fully reject the interferers. Because of the ability to control the overall radiation pattern in a greater coverage area for each cell site, as illustrated in Fig. 5, adaptive array systems can provide great increase in capacity.

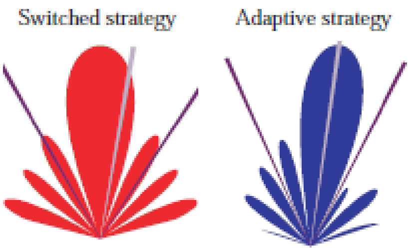

Fig. 5. Beamforming lobes and nulls that Switched-Beam (left) and Adaptive Array (right) systems might choose for identical user signals (light line) and co-channel interferers (dark lines).

Fig. 5 illustrates the beam patterns that each configuration may form to adapt to this scenario. The light lines indicate the signal of interest while the dark lines display the direction of the co-channel interfering signals. The adaptive system chooses a more accurate placement, thus providing greater signal enhancement. Similarly, the interfering signals arrive at places of lower intensity outside the main lobe, but again the adaptive system places these signals at the lowest possible gain points. The adaptive array concept ideally ensures that the main signal receives maximum enhancement while the interfering signals receive maximum suppression.

Adaptive array systems can locate and track signals (users and interferers) and dynamically adjust the antenna pattern to enhance reception while minimizing interference using signal processing algorithms. A functional block diagram of the digital signal processing part of an adaptive array antenna system is shown in Fig. 6. After the system downconverts the received signals to baseband and digitizes them, it locates the SOI using the direction-of-arrival (DOA) algorithm, and it continuously tracks the SOI and SNOIs by dynamically changing the complex weights (amplitudes and phases of the antenna elements).

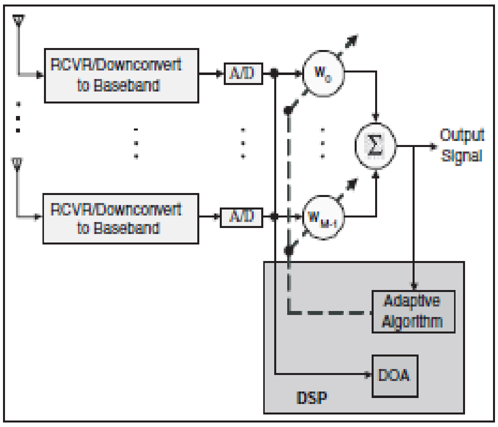

Fig. 6. Functional block diagram of an adaptive array system.

Basically, the DOA computes the direction-of-arrival of all the signals by computing the time delays between the antenna elements, and afterward, the adaptive algorithm, using a cost function, computes the appropriate weights that result in an optimum radiation pattern. Because adaptive arrays are generally more digital processing intensive and require a complete RF portion of the transceiver behind each antenna element, they tend to be more expensive than switched-beam systems.

Such network of Smart Antenna System when included in the self configurable and autonomous network it helps as an added advantage for the communication purpose. To know such an implementation, an example of implementation of Smart Antenna System in Mobile Ad hoc Network (MANET) is being illustrated in the next section.

III. MOBILE AD HOC NETWORKS

Mobile Ad-hoc NETwork (MANET) is a selfconfigurable, Infrastructure less, autonomous and selfhealing system of nodes using wireless links. MANETs fall into the category of wireless networks in which each device can act as a source, destination and a moving router and can communicates with other devices in its range.

Conventionally, MANETs have been known to use omnidirectional antennas for transmission as well as reception. The use of omnidirectional antennas may result in lower power efficiency due to interference caused by the transmission of packets in undesired directions. Use of Smart Antenna System (SAS) in MANETs is envisioned to take advantage of Space Division Multiple Accesses (SDMA) to increase network efficiency by directing the transmitted power in the desired direction. As seen before, SAS allows the energy to be transmitted or received in a particular direction as opposed to disseminating energy in all directions; this helps in achieving significant spatial re-use and thereby increasing the capacity of the network. The advantages of MANETs lie in their low costs (because no infrastructure is required) and high flexibility.

A MANET is an autonomous ad-hoc wireless networking system consisting of independent nodes that move dynamically changing network connectivity. Unlike cellular wireless networks, no static or fixed infrastructureless exists in MANET, and no centralized control can be available. The network can be formed anywhere, at any time, as long as two or more nodes are connected and communicate with one another either directly when they are in radio range of each other or via intermediate mobile nodes because of flexibility that a MANET offers. In contrast, cellular networks are managed by a centralized administration or Base Station Controller (BSC) where each node is connected to a fixed base station. Moreover, cellular networks provide single hop connectivity between a node and a fixed base station while MANETs provide multihop connectivity between Nodes A (source) and Node B (destination), as illustrated in Fig. 7.This figure shows an example of two nodes, Node A and Node B, that desire to exchange data and at some distance apart. Because they are out of radio range with each other, it is necessary for Node A to use the neighboring or intermediate nodes in forwarding its data packets to Node B.

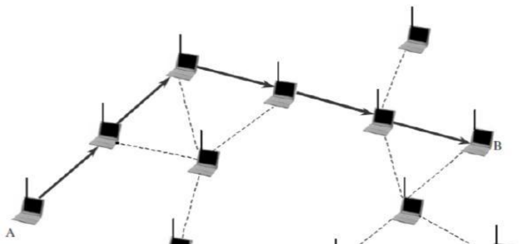

Fig. 7. Multihop Example of MANET.

The routing in MANETs is very challenging due to the frequent updates for changes in topologies, and active routes may be disconnected as mobile nodes move from one place to another. Routing protocols can be classified as follows: unicast, broadcast, multicast, and geocast. There are some other routing protocols that do not rely on any traditional routing mechanisms, instead rely on the location awareness of the participating nodes in the network.

Generally, in traditional MANETs, the nodes are addressed only with their IP addresses. But, in case of location-aware routing mechanisms, the nodes are often aware of their exact physical locations in the three-dimensional world. This capability might be introduced in the nodes using GPS or with any other geometric methods. GPS is a worldwide, satellite-based radio navigation system that consists of 24 satellites in six orbital planes. By connecting to the GPS receiver, a mobile node can know its current physical location.GRP also known as position based routing, is a well-researched approach for ad hoc routing. GRP is based on two assumptions; nodes are aware of their own geographic locations and also of its immediate neighbors and source node are aware of position of destination. The nodes update its immediate neighbor's locations periodically by beaconing. The data packets are routed through the network using the geographic location of the destination and not the network address. GRP operates without routing tables and routing to destination depends upon the information each node has about its neighbors. In the position (location)-based routing protocols, a mobile node uses a directional antenna or GPS system to estimate its (x, y) position. If GPS is used, every node knows it's (x, y) position assuming z = 0. Fig. 8, Shows two mobile nodes with their positions determined using GPS The positions of the two mobile nodes in Fig. 8, are ($x1$, $y1$) and ($x2$, $y2$) respectively. Using Fig. 8. The distance (d) between the two Mobile nodes and the angle of arrival (θ) can be calculated as in (1) and (2) respectively. This shows how the packet will be routed to the desired location by calculating the angle and the distance between the nodes.

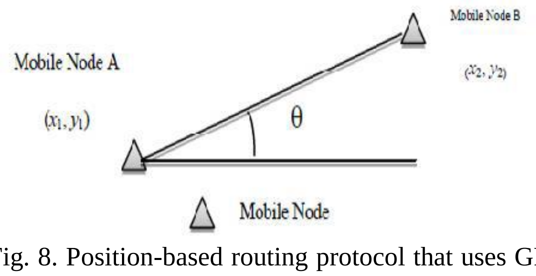

Fig. 8. Position-based routing protocol that uses GPS to determine mobile nodes (x, y) positions.

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \quad (1)$$

$$\theta = \tan^{-1}\frac{(y_2 - y_1)}{(x_2 - x_1)} \quad (2)$$

IV. CONCLUSION

As the demand for communications is constantly increasing, the need for better coverage, improved capacity and higher transmission quality rises. Thus, a more efficient use of the radio spectrum is required. Smart antenna systems are capable of efficiently utilizing the radio spectrum and, thus, are a promise for an effective solution to the present wireless systems' problems while achieving reliable and high-speed high-data-rate transmission. MANETs are one of the applications.

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