Smart Antenna Technology for Wireless Communication System

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Abstract - *This paper offers a complete view about the smart antenna which is the vital part of wireless mobile communications. As we steadily march towards the world of wireless digital communication, smart antenna plays a key role in transmission and reception of digital data. Smart antenna significantly improves wireless system performance and economics for a range of potential users. This paper explains the architecture, evolution and how the smart antenna differs from the basic format of antenna. Smart antenna systems are rapidly emerging as one of the key technologies that can enhance overall wireless communication system performance. By making use of the spatial dimension, and dynamically generating adaptive receive and transmit antenna patterns, a smart antenna can greatly reduce interference, increase the system capacity, increase power efficiency as well as reduce overall infrastructure costs.*

***Key Words*: Adaptive antenna, switched beam antenna, beamforming, smart antenna, SDMA**

1. INTRODUCTION

A smart antenna system combines multiple antenna elements with a signal-processing capability to optimize its radiation and/or reception pattern automatically in response to the signal environment [2]

The fundamental idea behind smart antennas is to improve the performance of the wireless communication system by increasing the gain in a chosen direction. This can be achieved by pointing the main lobes of the antenna-beam patterns towards the desired users. Smart antenna system combines multiple antenna elements with a signal processing capability to automatically optimize its radiation and/or reception pattern in response to the signal environment. In addition to pointing the direction of the main lobe towards a chosen user the smart antenna system can automatically steer one or more nulls of the directivity pattern towards one or several sources of interferences. There are several benefits of using a smart antenna system for a wireless system and among these are the following: larger covering area, increased SNR and capacity, saving energy for the same performances, providing spatial diversity etc. In this paper both switched and adaptive beamforming techniques are analyzed in order to point out the advantages of using smart antenna technique in wireless communications systems.[5]

1.1 SMART ANTENNA

1.1.1 Smart Antenna System

In truth, antennas are not smart, antenna systems are smart. Generally co-located with a base station, a smart antenna system combines an antenna array with a digital signal-processing capability to transmit and receive in an adaptive, spatially sensitive manner. In other words, 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 of a wireless system.

Types of Smart Antenna Systems

Terms commonly heard today that embrace various aspects of a smart antenna system technology include intelligent antennas, phased array, SDMA, spatial processing, digital beamforming, adaptive antenna systems, and others. Smart antenna systems are customarily categorized, however, as either switched beam or adaptive array systems.

The following are distinctions between the two major categories of smart antennas:

- switched beam—a finite number of fixed, predefined patterns or combining strategies.
- adaptive array—an infinite number of patterns (scenario-based) that are adjusted real time.

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.

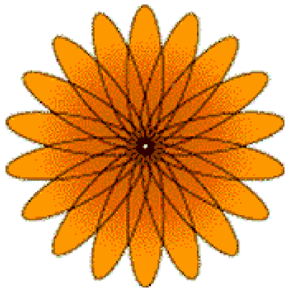

Fig.1 Switched Beam System Coverage Patterns (Sectors)

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

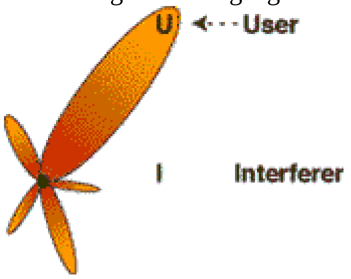

Fig 2. Adaptive Array Coverage: A Representative Depiction of a Main Lobe Extending toward a User with a Null Directed Toward a Cochannel Interferer

THE GOALS OF A SMART ANTENNA SYSTEM

The dual purpose of a smart antenna system is to augment the signal quality of the radio-based system through more focused transmission of radio signals while enhancing capacity through increased frequency reuse.

THE ARCHITECTURE OF SMART ANTENNA SYSTEMS:

Switched Beam Systems:

In terms of radiation patterns, switched beam is an extension of the current microcellular or cellular sectorization method of splitting a typical cell. The switched beam approach further subdivides macrosectors into several microsectors as a means of improving range and capacity. Each microsector contains a predetermined fixed beam pattern with the greatest sensitivity located in the center of the beam and less sensitivity elsewhere. The design of such systems involves high-gain, narrow azimuthal beamwidth antenna elements.

Smart antenna systems communicate directionally by forming specific antenna beam patterns. When a smart antenna directs its main lobe with enhanced gain in the direction of the user, it naturally forms side lobes and nulls or areas of medium and minimal gain respectively in directions away from the main lobe.

Different switched beam and adaptive smart antenna systems control the lobes and the nulls with varying degrees of accuracy and flexibility

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.

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 its transmit strategy based on changes in both the desired and interfering signal locations. The ability to track users smoothly with main lobes and interferers with nulls ensures that the link budget is constantly maximized because there are neither microsectors nor predefined patterns.

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.

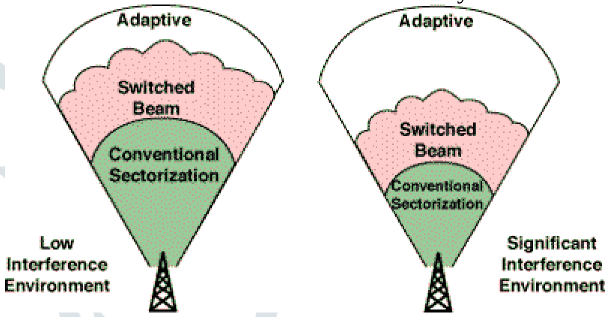

Fig 3. Coverage Patterns for Switched Beam and Adaptive Array Antennas

Spatial division multiple access (SDMA)—

Among the most sophisticated utilizations of smart antenna technology is SDMA, which employs advanced processing techniques to, in effect, locate and track fixed or mobile terminals, adaptively steering transmission signals toward users and away from interferers. This adaptive array technology achieves superior levels of interference suppression, making possible more efficient reuse of frequencies than the standard fixed hexagonal reuse patterns. In essence, the scheme can adapt the frequency allocations to where the most users are located.

General Smart Antenna Architecture

Today's smart antennas come in a variety of different forms and employ a number of different methods to achieve the benefits of using multiple antennas. Most intelligent transceiving systems employ some kind of direction of arrival estimation at the receiver to resolve the DOAs of all impinging signals on the array. The receiver then applies an adaptive algorithm to calculate complex weighting factors which multiply the analytic signal at each element of the associated array . These signals are then combined to produce a resulting signal with improved overall SINR. This signal is passed to a demodulator where BER performance is improved. Fig 4 shows the generalized smart antenna receiver architecture.

In this system a four element array consisting of omni-directional antenna elements receives the high frequency RF signal. This high frequency signal is down converted to an intermediate frequency (IF) suitable for sampling. The analog IF signals at each element of the array are then converted to digital format by high speed ADCs, these samples are then passed to the DOA estimation routine, for DOA estimation. Once estimates for the DOAs of the impinging signals have been found beamforming weights can be calculated and applied to each element of the array. It is the application of these complex weights that effectively forms the antenna pattern of the receiver that enables optimized reception of RF signals. Finally the weighted signals are summed and passed to a demodulator[1].

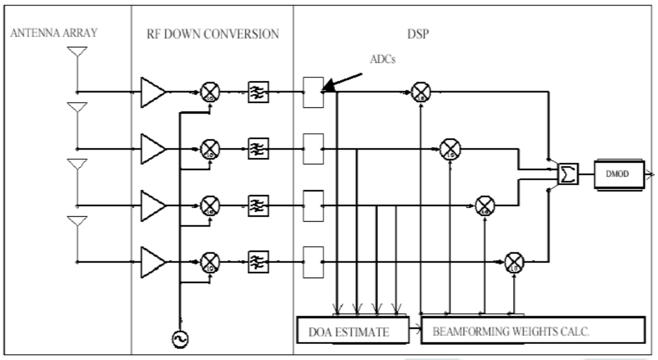

Fig. 4 General Smart Antenna Architecture

Benefits of adaptive antennas are as follows:

* **Increased range/coverage**: the *array* or *beam forming gain* is the average increase in signal power at the receiver due to a coherent combination of the signal received at all antenna elements. The adaptive antenna gain compared to a single element antenna can be increased by an amount equal to the number of array elements, e.g., an eight element array can provide a gain of eight (9 dB).

* **Increased Capacity**: One of the main reasons of the growing interest of adaptive antennas is the capacity increase. In densely populated areas, mobile systems are normally interference-limited; meaning that interference from other users is the main source of noise in the system. This means that the signal to interference ratio (SIR) is much larger than the signal to thermal noise ratio (SNR). Adaptive antennas will on average, increase the SIR. Experimental results report up to 10 dB increase in average SIR in urban areas. For UMTS networks, a fivefold capacity gain has been reported for CDMA.

* **Lowe power requirements and/or cost reduction**: Optimizing transmission toward the wanted user achieves lower power consumption and amplifier costs.

* **Improved link quality/reliability**: Diversity gain is obtained by receiving independent replicas of the signal through independently fading signal components. Based on the fact that one or more of these signal components will not be in a deep fade, the availability of multiple independent dimensions reduces the effective fluctuations of the signal.

* **Increased spectral efficiency**: Spectral efficiency is a measure of the amount of information –billable services- that carried by the wireless system per unit of spectrum. It is measured in bits/second/Hertz/cell, thus it includes the effect of multiple access methods, modulation methods, channel organization and resource reuse (e.g., code, timeslot, carrier). Spectral efficiency plays an important role since it directly affects the operator cost structure. Moreover, for a given service and QoS, it determines the required amount of spectrum, the required number of base stations, the required number of sites –and associated site maintenance-, and ultimately, consumer pricing and affordability.

* **Security**: It is more difficult to tap a connation, since the intruder has to be position himself in the same direction of arrival as the user.

* **Reduction of handoff**: there is no need for splitting the cells for the sake of capacity increase, and in consequence less amount of handoff.

* **Spatial information**: the spatial information about the user would be available at any given time, which enables the introduction of Location Based Services.

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