Smart Antenna Systems

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Definition:

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.

Key word: smart antenna, dipole, coverage pattern, Switched Beam

Overview:

What does an antenna do in a telecommunications system? It is the port through which radio frequency (RF) energy is coupled from the transmitter to the outside world and, in reverse, to the receiver from the outside world. Antennas have been the most neglected of all the components in personal communications systems. Yet, the manner in which energy is distributed into and collected from surrounding space has a profound influence on the efficient use of spectrum, the cost of establishing new networks, and the service quality provided by those networks. The following tutorial is an introduction to the essential concepts of smart antenna systems and the important advantages of smart antenna system design over conventional omni directional approaches. The discussion also differentiates between the various and often dissimilar technologies broadly characterized today as smart antennas. These range from simple diversity antennas to fully adaptive antenna array systems.

1. A Useful Analogy for Adaptive Smart Antennas

For an intuitive grasp of how an adaptive antenna system works, close your eyes and converse with someone as they move about the room. You will notice that you can determine their location without seeing them because of the following:

- You hear the speaker's signals through your two ears, your acoustic sensors.
- The voice arrives at each ear at a different time.
- Your brain, a specialized signal processor, does a large number of calculations to correlate information and compute the location of the speaker.

Your brain also adds the strength of the signals from each ear together, so you perceive sound in one chosen direction as being twice as loud as everything else.

Adaptive antenna systems do the same thing, using antennas instead of ears. As a result, 8, 10, or 12 ears can be employed to help fine-tune and turn up signal information. Also, because antennas both listen and talk, an adaptive antenna system can send signals back in the same direction from which they came. This

means that the antenna system cannot only hear 8 or 10 or 12 times louder but talk back more loudly and directly as well.
Going a step further, if additional speakers joined in , your internal signal processor could also tune out unwanted noise (interference) and alternately focus on one conversation at a time. Thus, advanced adaptive array systems have a similar ability to differentiate between desired and undesired signals.

Smart

The concept of using multiple antennas and innovative signal processing to serve cells more intelligently has existed for many years. In fact, varying degrees of relatively costly smart antenna systems have already been applied in defense systems. Until recent years, cost barriers have prevented their use in commercial systems. The advent of powerful low-cost digital signal processors (DSPs), general-purpose processors (and ASICs), as well as innovative software-based signal-processing techniques (algorithms) have made intelligent antennas practical for cellular communications systems.
Today, when spectrally efficient solutions are increasingly a business imperative, these systems are providing greater coverage area for each cell site, higher rejection of interference, and substantial capacity improvements.

2. What Is a 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 environment. This can dramatically increase the performance characteristics (such as capacity) of a wireless system.

How Many Types of Smart Antenna Systems Are There?

Terms commonly heard today that embrace various aspects of a smart antenna system technology include intelligent antennas, phased array, SDMA, spatial processing, digital beam forming, 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 regarding the choices in transmit strategy:

- switched beam_a finite number of fixed, predefined patterns or combining strategies (sectors)

- adaptive array_an infinite number of patterns (scenario-based) that are adjusted in real time

3. What Are 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. (see figure 1)

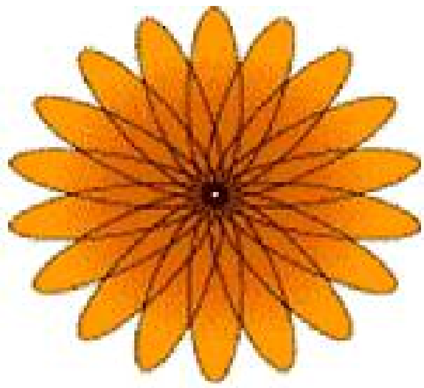

Figure 1 Switched Beam System Coverage Patterns (Sectors)

4. 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. More specifically, the features of and benefits derived from a smart antenna system include those listed in Table 1.

Feature	Benefit
signal gain—Inputs from multiple antennas are combined to optimize available power required to establish given level of coverage.	**better range/coverage**—Focusing the energy sent out into the cell increases base station range and coverage. Lower power requirements also enable a greater battery life and smaller/lighter handset size.
interference rejection—Antenna pattern can be generated toward cochannel interference sources, improving the signal-to-interference ratio of the received signals.	**increased capacity**—Precise control of signal nulls quality and mitigation of interference combine to frequency reuse reduce distance (or cluster size), improving capacity. Certain adaptive technologies (such as space division multiple access) support the reuse of frequencies within the same cell.
spatial diversity—Composite information from the array is used to minimize fading and other undesirable effects of multipath propagation.	**multipath rejection**—can reduce the effective delay spread of the channel, allowing higher bit rates to be supported without the use of an equalizer
power efficiency—combines the inputs to multiple elements to optimize available processing gain in the downlink (toward the user)	**reduced expense**—Lower amplifier costs, power consumption, and higher reliability will result

Table 1 Features and Benefits of Smart Antenna Systems

4. What Are 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.(see figure 2)

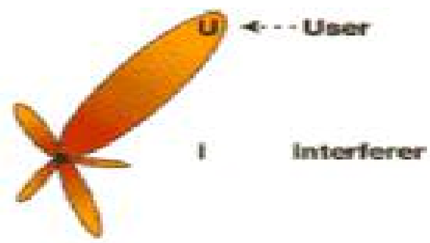

Figure 2 Adaptive Array Coverage: A Representative Depiction of a Main Lobe Extending Toward a User with a Null Directed Toward a Cochannel Interferer

What Makes Them So Smart?

A simple antenna works for a simple RF environment. Smart antenna solutions are required as the number of users, interference, and propagation complexity grow. Their smarts reside in their digital signal-processing facilities.

Like most modern advances in electronics today, the digital format for manipulating the RF data offers numerous advantages in terms of accuracy and flexibility of operation. Speech starts and ends as analog information. Along the way, however, smart antenna systems capture, convert, and modulate analog signals for transmission as digital signals and reconvert them to analog information on the other end.

In adaptive antenna systems, this fundamental signal-processing capability is augmented by advanced techniques (algorithms) that are applied to control operation in the presence of complicated combinations of operating conditions.

5. Signal Propagation: Multipath And Co channel Interference1

A Useful Analogy for Signal Propagation Envision a perfectly still pool of water into which a stone is dropped. The waves that radiate outward from that point are uniform and diminish in strength evenly. This pure omnidirectional broadcasting equates to one caller's signal—originating at the terminal and going uplink. It is interpreted as one signal everywhere it travels.

Picture now a base station at some distance from the wave origin. If the pattern remains undisturbed, it is not a challenge for a base station to interpret the waves. But as the signal's waves begin to bounce off the edges of the pool, they come back (perhaps in a combination of directions) to intersect with the original wave pattern. As they combine, they weaken each other's strength. These are multipath interference problems.

Now, picture a few more stones being dropped in different areas of the pool, equivalent to other calls starting. How could a base station at any particular point in the pool distinguish which stone's signals were being picked up and from which direction? This multiple-source problem is called co channel interference.

These are two-dimensional analogies; to fully comprehend the distinction between callers and/or signal in the earth's atmosphere, a base station must possess the intelligence to place the information it analyzes in a true spatial context.

6. The Architecture of Smart Antenna Systems

How Do Smart Antenna Systems Work?

Traditional switched beam and adaptive array systems enable a base station to customize the beams they generate for each remote user effectively by means of internal feedback control. Generally speaking, each approach forms a main lobe toward individual users and attempts to reject interference or noise from outside of the main lobe.

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.
The switched beam system selects one of several predetermined fixed-beam patterns (based on weighted combinations of antenna outputs) with the greatest output power in the remote user's channel. These choices are driven by RF or baseband DSP hardware and software. The system switches its beam in different directions throughout space by changing the phase differences of the signals used to feed the antenna elements or received from them. When the mobile user enters a particular macrosector, the switched beam system selects the microsector containing the strongest signal. Throughout the call, the system monitors signal strength and switches to other fixed microsectors as required.(see figure 3)

Figure 3 Beam forming Lobes and Nulls that Switched Beam (Red) and Adaptive Array (Blue) Systems Might Choose for Identical User Signals (Green Line) and Cochannel Interferers (Yellow Lines)

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.
Figure 4 illustrates the relative coverage area for conventional sectorized, switched beam, and adaptive antenna systems. 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.

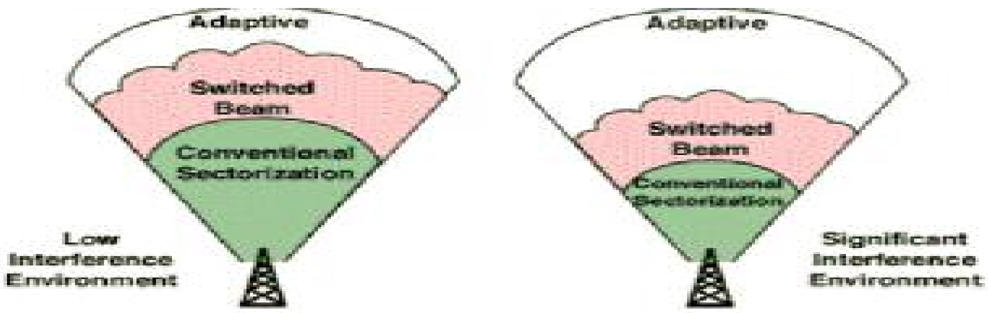

Figure 4. Coverage Patterns for Switched Beam and Adaptive Array Antennas

Relative Benefits/Tradeoffs of Switched Beam and Adaptive Array Systems

- Integration Switched beam systems are traditionally designed to retrofit widely deployed cellular systems. It has been commonly implemented as an add-on or appliqué technology that intelligently addresses the needs of mature networks. In comparison, adaptive array systems have been deployed with a more fully integrated approach that offers less hardware redundancy than switched beam systems but requires new build-out.

- Range/coverage Switched beam systems can increase base station range from 20 to 200 percent over conventional sectored cells, depending on environmental circumstances and the hardware/software used. The added coverage can save an operator substantial infrastructure costs and means lower prices for consumers. Also, the dynamic switching from beam to beam conserves capacity because the system does not send all signals in all directions. In comparison, adaptive array systems can cover a broader, more uniform area with the same power levels as a switched beam system.

- Interference suppression Switched beam antennas suppress interference arriving from directions away from the active beam's center. Because beam patterns are fixed, however, actual interference rejection is often the gain of the selected communication beam pattern in the interferer's direction. Also, they are normally used only for reception because of the system's ambiguous perception of the location of the received signal (the consequences of transmitting in the wrong beam being obvious). Also, because their beams are predetermined, sensitivity can occasionally vary as the user moves through the sector. Switched beam solutions work best in minimal to moderate cochannel interference and have difficulty in distinguishing between a desired signal and an interferer. If the interfering signal is at approximately the selected beam, the interfering signal can be enhanced far more than the desired signal. In these cases, the quality is degraded for the user. Adaptive array technology currently offers more comprehensive interference rejection. Also, because it transmits an infinite, rather than finite, number of combinations, its narrower focus creates less interference to neighboring users than a switched-beam approach.

- 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 (see figure 5)

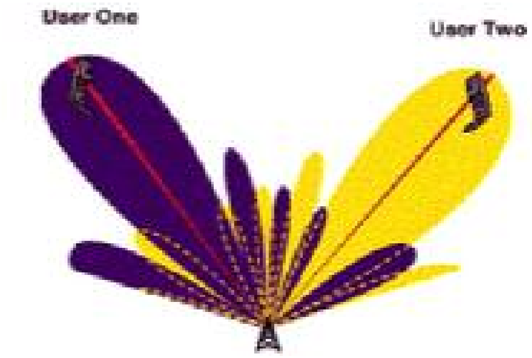

Figure 5 Fully Adaptive Spatial Processing, Supporting Two Users on the Same Conventional Channel Simultaneously in the Same Cell

Utilizing highly sophisticated algorithms and rapid processing hardware, spatial processing takes the reuse advantages that result from interference suppression to a new level. In essence, spatial processing dynamically creates a different sector for each user and conducts a frequency/channel allocation in an ongoing manner in real time.
Adaptive spatial processing integrates a higher level of measurement and analysis of the scattering aspects of the RF environment. Whereas traditional beam-forming and beam-steering techniques assume one correct direction of transmission toward a user, spatial processing maximizes the use of multiple antennas to combine signals in space in a method that transcends a one user-one beam methodology.

7. Who Can Use Smart Antenna Technology?

Smart antenna technology can significantly improve wireless system performance and economics for a range of potential users. It enables operators of PCS, cellular, and wireless local loop (WLL) networks to realize significant increases in signal quality, capacity, and coverage. Operators often require different combinations of these advantages at different times. As a result, those systems offering the most flexibility in terms of configuration and upgradeability are often the most cost-effective long-term solutions.

Added Advantages of Spatial Processing

A wide range of wireless communication systems may benefit from spatial processing, including high-mobility cellular systems, low-mobility short-range systems, wireless local loop applications, satellite communications, and wireless LAN. By employing an array of antennas, it is possible to multiplex channels in the spatial dimension just as in the frequency and time dimensions. To increase system capacity, spatially selective transmission as well as spatially selective reception must be achieved.
Improved algorithms and low-cost processors make sophisticated spatial processing practical alternatives for an increasing number of wireless system designs

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