Smart Antenna Systems

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.

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 omnidirectional 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.

Topics

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.

2. Antennas and Antenna Systems

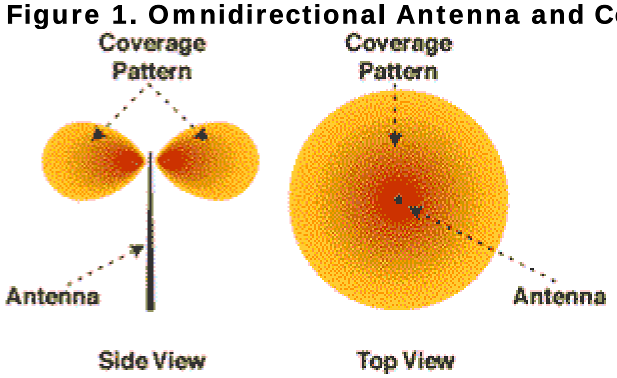
Antennas

Radio antennas couple electromagnetic energy from one medium (space) to another (e.g., wire, coaxial cable, or waveguide). Physical designs can vary greatly.

Omnidirectional Antennas

Since the early days of wireless communications, there has been the simple dipole antenna, which radiates and receives equally well in all directions. To find its users, this single-element design broadcasts omnidirectionally in a pattern resembling ripples radiating outward in a pool of water. While adequate for simple RF environments where no specific knowledge of the users' whereabouts is available, this unfocused approach scatters signals, reaching desired users with only a small percentage of the overall energy sent out into the environment.

Figure 1. Omnidirectional Antenna and Coverage Patterns



Given this limitation, omnidirectional strategies attempt to overcome environmental challenges by simply boosting the power level of the signals broadcast. In a setting of numerous users (and interferers), this makes a bad situation worse in that the signals that miss the intended user become interference for those in the same or adjoining cells.

In uplink applications (user to base station), omnidirectional antennas offer no preferential gain for the signals of served users. In other words, users have to shout over competing signal energy. Also, this single-element approach cannot selectively reject signals interfering with those of served users and has no spatial multipath mitigation or equalization capabilities.

Omnidirectional strategies directly and adversely impact spectral efficiency, limiting frequency reuse. These limitations force system designers and network planners to devise increasingly sophisticated and costly remedies. In recent years, the limitations of broadcast antenna technology on the quality, capacity, and coverage of wireless systems have prompted an evolution in the fundamental design and role of the antenna in a wireless system.

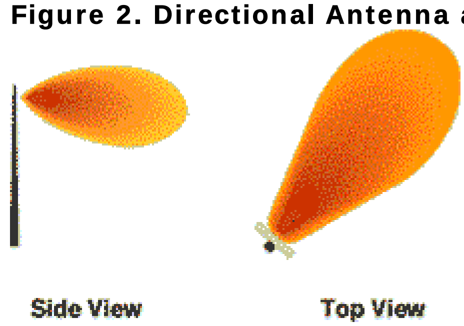
Directional Antennas

A single antenna can also be constructed to have certain fixed preferential transmission and reception directions. As an alternative to the brute force method of adding new transmitter sites, many conventional antenna towers today split, or sectorize cells. A 360° area is often split into three 120° subdivisions, each of which is covered by a slightly less broadcast method of transmission.

All else being equal, sector antennas provide increased gain over a restricted range of azimuths as compared to an omnidirectional antenna. This is commonly referred to as antenna element gain and should not be confused with the processing gains associated with smart antenna systems.

While sectorized antennas multiply the use of channels, they do not overcome the major disadvantages of standard omnidirectional antenna broadcast such as co-channel interference, which will be described more fully in *Topic 5*.

Figure 2. Directional Antenna and Coverage Pattern



Antenna Systems

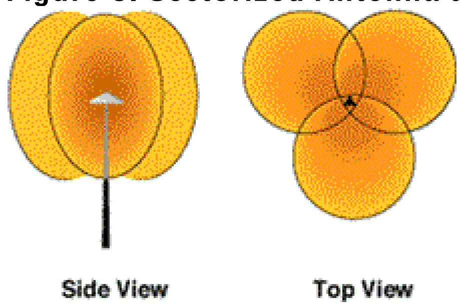
How can an antenna be made more intelligent? First, its physical design can be modified by adding more elements. Second, the antenna can become an antenna system that can be designed to shift signals before transmission at each of the successive elements so that the antenna has a composite effect. This basic hardware and software concept is known as the phased array antenna.

The following summarizes antenna developments in order of increasing benefits and intelligence.

Sectorized Systems

Sectorized antenna systems take a traditional cellular area and subdivide it into sectors that are covered using directional antennas looking out from the same base station location. Operationally, each sector is treated as a different cell, the range of which is greater than in the omnidirectional case. Sector antennas increase the possible reuse of a frequency channel in such cellular systems by reducing potential interference across the original cell, and they are widely used for this purpose. As many as six sectors per cell have been used in practical service. When combining more than one of these directional antennas, the base station can cover all directions.

Figure 3. Sectorized Antenna and Coverage Patterns



Diversity Systems

In the next step toward smart antennas, the diversity system incorporates two antenna elements at the base station, the slight physical separation (space diversity) of which has been used historically to improve reception by counteracting the negative effects of multipath (see *Topic 4*).

Diversity offers an improvement in the effective strength of the received signal by using one of the following two methods:

- **switched diversity**—Assuming that at least one antenna will be in a favorable location at a given moment, this system continually switches between antennas (connects each of the receiving channels to the best serving antenna) so as always to use the element with the largest output. While reducing the negative effects of signal fading, they do not increase gain since only one antenna is used at a time.

- **diversity combining**—This approach corrects the phase error in two multipath signals and effectively combines the power of both signals to produce gain. Other diversity systems, such as maximal ratio combining systems, combine the outputs of all the antennas to maximize the ratio of combined received signal energy to noise.

Because macrocell-type base stations historically put out far more power on the downlink (base station to user) than mobile terminals can generate on the reverse path, most diversity antenna systems have evolved only to perform in uplink (user to base station).

Figure 4. Switched Diversity Coverage with Fading and Switched Diversity

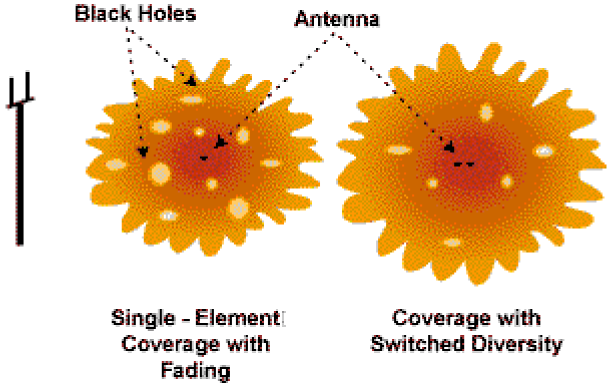
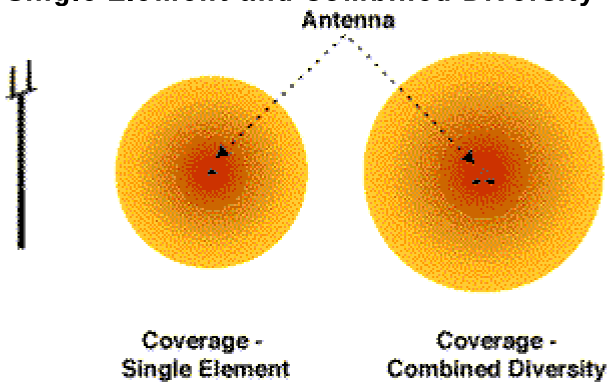


Figure 5. Combined Diversity Effective Coverage Pattern with Single Element and Combined Diversity



Diversity antennas merely switch operation from one working element to another. Although this approach mitigates severe multipath fading, its use of one element at a time offers no uplink gain improvement over any other single-element approach. In high-interference environments, the simple strategy of locking onto the strongest signal or extracting maximum signal power from the antennas is clearly inappropriate and can result in crystal-clear reception of an interferer rather than the desired signal.

The need to transmit to numerous users more efficiently without compounding the interference problem led to the next step of the evolution antenna systems that intelligently integrate the simultaneous operation of diversity antenna elements.

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.

3. 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 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.

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 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 regarding the choices in transmit strategy:

- **switched beam**—a finite number of fixed, predefined patterns or combining strategies (sectors)

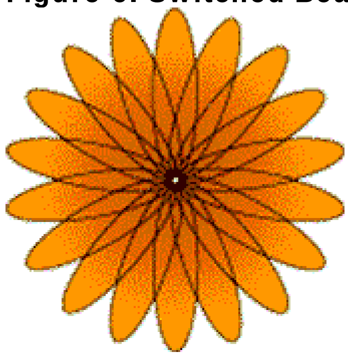
- **adaptive array**—an infinite number of patterns (scenario-based) that are adjusted in real time

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.

Figure 6. Switched Beam System Coverage Patterns (Sectors)

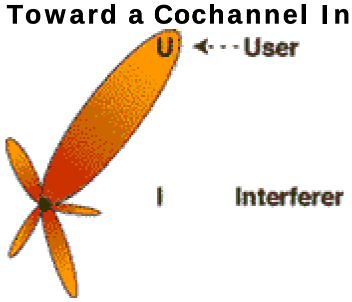


What Are Adaptive Array Antennas?

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.

Figure 7. Adaptive Array Coverage: A Representative Depiction of a Main Lobe Extending Toward a User with a Null Directed Toward a Cochannel Interferer



What Do They Look Like?

Omnidirectional antennas are obviously distinguished from their intelligent counterparts by the number of antennas (or antenna elements) employed.

Switched beam and adaptive array systems, however, share many hardware characteristics and are distinguished primarily by their adaptive intelligence.

To process information that is directionally sensitive requires an array of antenna elements (typically 4 to 12), the inputs from which are combined to control signal transmission adaptively. Antenna elements can be arranged in linear, circular, or planar configurations and are most often installed at the base station, although they may also be used in mobile phones or laptop computers.

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.

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.*

Table 1. Features and Benefits of Smart Antenna Systems

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

5. Signal Propagation: Multipath And Cochannel Interference[1]

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 cochannel 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.

Multipath

Multipath is a condition where the transmitted radio signal is reflected by physical features/structures, creating multiple signal paths between the base station and the user terminal.

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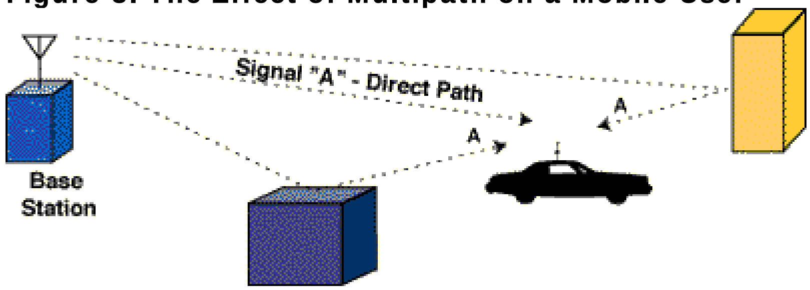
[1]Sources
Neil J. Boucher, *The Cellular Radio Handbook*, Second Edition, Mendocino, California: Quantum Publishing, Inc., 1992.
George Calhoun, *Wireless Access and the Local Telephone Network*, Norwood, Massachusetts: Artech House, Inc., 1992.

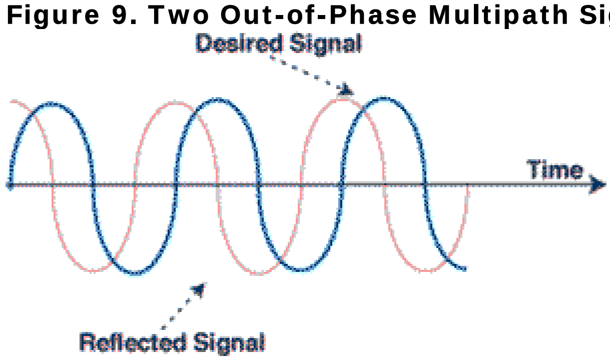
Figure 8. The Effect of Multipath on a Mobile User



Problems Associated with Multipath

One problem resulting from having unwanted reflected signals is that the phases of the waves arriving at the receiving station often do not match. The phase of a radio wave is simply an arc of a radio wave, measured in degrees, at a specific point in time. *Figure 9* illustrates two out-of-phase signals as seen by the receiver.

Figure 9. Two Out-of-Phase Multipath Signals

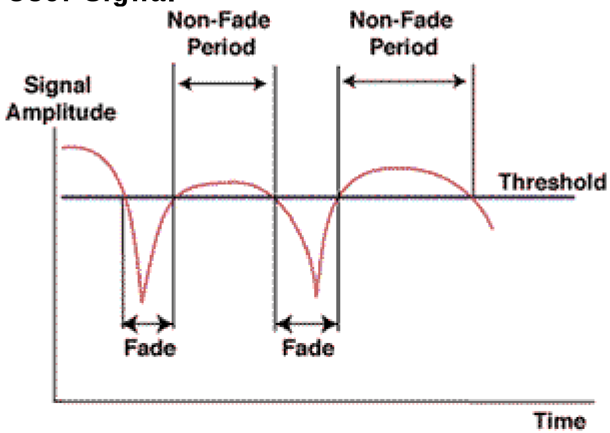


Conditions caused by multipath that are of primary concern are as follows:

- **fading**—When the waves of multipath signals are out of phase, reduction in signal strength can occur. One such type of reduction is called a fade; the phenomenon is known as "Rayleigh fading" or "fast fading."

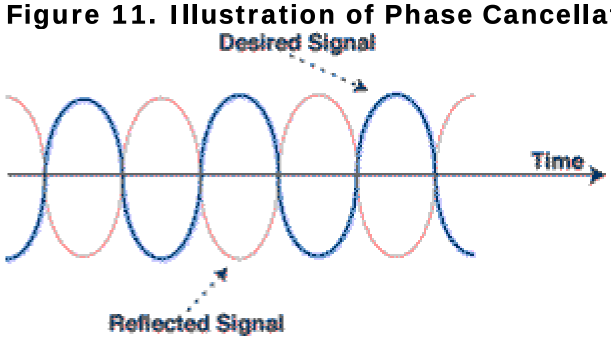
  A fade is a constantly changing, three-dimensional phenomenon. Fade zones tend to be small, multiple areas of space within a multipath environment that cause periodic attenuation of a received signal for users passing through them. In other words, the received signal strength will fluctuate downward, causing a momentary, but periodic, degradation in quality.

Figure 10. A Representation of the Rayleigh Fade Effect on a User Signal



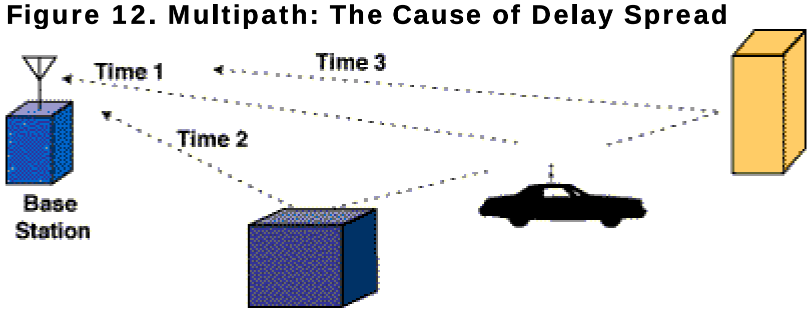
- **phase cancellation**—When waves of two multipath signals are rotated to exactly 180° out of phase, the signals will cancel each other. While this sounds severe, it is rarely sustained on any given call (and most air interface standards are quite resilient to phase cancellation). In other words, a call can be maintained for a certain period of time while there is no signal, although with very poor quality. The effect is of more concern when the control channel signal is canceled out, resulting in a black hole, a service area in which call set-ups will occasionally fail.

Figure 11. Illustration of Phase Cancellation



- **delay spread**—The effect of multipath on signal quality for a digital air interface (e.g., TDMA) can be slightly different. Here, the main concern is that multiple reflections of the same signal may arrive at the receiver at different times. This can result in intersymbol interference (or bits crashing into one another) that the receiver cannot sort out. When this occurs, the bit error rate rises and eventually causes noticeable degradation in signal quality.

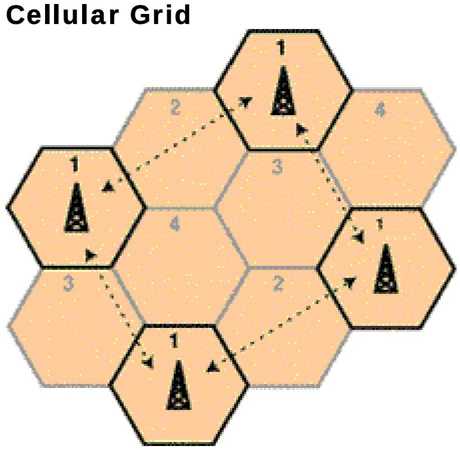
Figure 12. Multipath: The Cause of Delay Spread



While switched diversity and combining systems do improve the effective strength of the signal received, their use in the conventional macrocell propagation environment has been typically reverse-path limited due to a power imbalance between base station and mobile unit. This is because macrocell-type base stations have historically put out far more power than mobile terminals were able to generate on the reverse path.

- **cochannel interference**—One of the primary forms of man-made signal degradation associated with digital radio, cochannel interference occurs when the same carrier frequency reaches the same receiver from two separate transmitters.

Figure 13. Illustration of Cochannel Interference in a Typical Cellular Grid



As we have seen, both broadcast antennas as well as more focused antenna systems scatter signals across relatively wide areas. The signals that miss an intended user can become interference for users on the same frequency in the same or adjoining cells.

While sectorized antennas multiply the use of channels, they do not overcome the major disadvantage of standard antenna broadcast—cochannel interference. Management of cochannel interference is the number-one limiting factor in maximizing the capacity of a wireless system. To combat the effects of cochannel interference, smart antenna systems not only focus directionally on intended users, but in many cases direct nulls or intentional noninterference toward known, undesired users (see *Topic 6*).

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.

Listening to the Cell (Uplink Processing)

It is assumed here that a smart antenna is only employed at the base station and not at the handset or subscriber unit. Such remote radio terminals transmit using omnidirectional antennas, leaving it to the base station to separate the desired signals from interference selectively.

Typically, the received signal from the spatially distributed antenna elements is multiplied by a weight, a complex adjustment of an amplitude and a phase. These signals are combined to yield the array output. An adaptive algorithm controls the weights according to predefined objectives. For a switched beam system, this may be primarily maximum gain; for an adaptive array system, other factors may receive equal consideration. These dynamic calculations enable the system to change its radiation pattern for optimized signal reception.

Speaking to the Users (Downlink Processing)

The task of transmitting in a spatially selective manner is the major basis for differentiating between switched beam and adaptive array systems. As described below, switched beam systems communicate with users by changing between preset directional patterns, largely on the basis of signal strength. In comparison, adaptive arrays attempt to understand the RF environment more comprehensively and transmit more selectively.

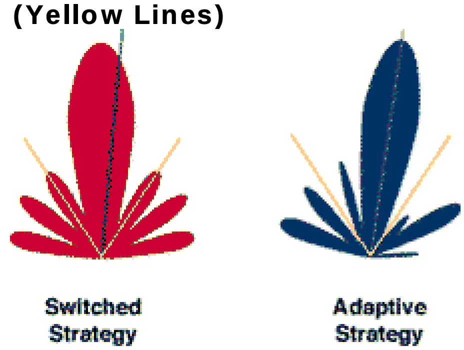
The type of downlink processing used depends on whether the communication system uses time division duplex (TDD), which transmits and receives on the same frequency (e.g., PHS and DECT) or frequency division duplex (FDD), which uses separate frequencies for transmit and receiving (e.g., GSM). In most FDD systems, the uplink and downlink fading and other propagation characteristics may be considered independent, whereas in TDD systems the uplink and downlink channels can be considered reciprocal. Hence, in TDD systems uplink channel information may be used to achieve spatially selective transmission. In FDD systems, the uplink channel information cannot be used directly and other types of downlink processing must be considered.

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.

Figure 14. Beamforming 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.

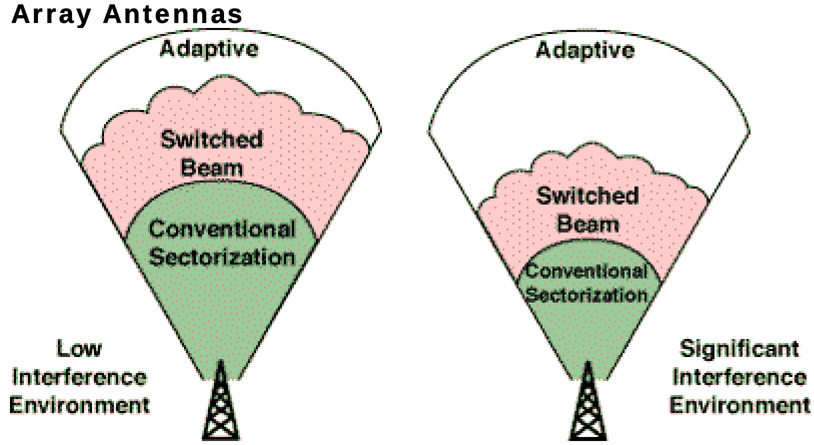
Adaptive Antenna Approach

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 15 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 15. 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.

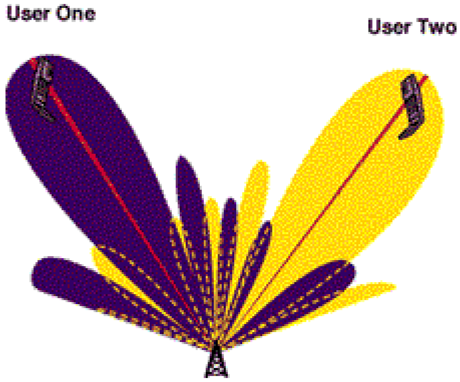
- **interference suppression**—Switched beam antennas suppress interference arriving from directions away from the active beam's center. Because beam patterns are fixed, however, actual interference rejection is often the gain of the selected communication beam pattern in the interferer's direction. 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 center of the selected beam, and the user is away from the center of 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 reuse patterns. In essence, the scheme can adapt the frequency allocations to where the most users are located.

Figure 16. 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.

Applicable Standards

Smart antenna systems are applicable, with some modifications, to all major wireless protocols and standards, including those in *Table 2*.

Table 2. Applicable Standards

access methods	**analog—**frequency division multiple access (FDMA) (e.g., AMPS, TACS, NMT)
	digital—time division multiple access (TDMA) (e.g., GSM, IS–136); code division multiple access (CDMA) (e.g., IS–95)
duplex methods	frequency division duplex (FDD); time division duplex (TDD)

Transparency to the Network

The flexibility of adaptive smart antenna technology allows for the creation of new value-added products and services that give operators a significant competitive advantage. Adaptive smart antennas are not restricted to any particular modulation format or air-interface protocol. They are compatible with all current air-interface modulation schemes.

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 manufacturers and operators. Many agree that the unique benefits of spatial processing will ultimately affect all aspects of wireless system design.

Self-Test

1. Switched beam antenna systems cover a cell area ______________.

    a. by dividing the 360°-cell into three 120°-microsectors

    b. by switching to the antenna with the best gain at the given moment

    c. with a finite number of predefined patterns or combining strategies

2. Adaptive array systems cover a cell area with _____________________.

    a. a finite number of predefined patterns or combining strategies

    b. an infinite number of patterns that are adjusted in real time

    c. dividing the 360°-cell into three 120°-microsectors

3. Which type of smart antenna system is typically employed as an appliqué or retrofit to an existing cellular system?

    a. switched beam

    b. adaptive array

    c. switched diversity

4. Which type of smart antenna system is typically implemented as an integrated approach with less hardware redundancy?

    a. adaptive array

    b. switched beam

    c. combined diversity

5. The smarts of a smart antenna system are chiefly derived from ______________.

    a. the multiple elements of the antenna array

    b. frequency reuse

    c. the digital signal-processing capability

6. The propagation condition whereby a signal arrives at a receiver both directly and by bouncing off physical structures is called ________________.

   a. multipath

   b. Rayleigh fading

   c. cochannel interference

7. A black hole in a reception area occurs when ________________.

   a. signals from the same source arrive at the antenna out of sequence

   b. the antenna system generates a null toward the user

   c. two multipath signals arrive 180° out of phase, canceling each other

8. The major disadvantage of omnidirectional antenna broadcast that smart antennas try to overcome in a cellular network is ______________.

   a. fading

   b. cochannel interference

   c. nulls

9. Switched beam antenna systems break a coverage area into microsectors in order to improve ________________.

   a. range

   b. capacity

   c. both

10. Interference suppression has a major impact on ______________.

   a. call quality

   b. capacity

   c. both

11. The type of smart antenna system technology that currently offers the most advanced capabilities for interference suppression and frequency reuse is ___________.

   a. spatial division multiple access (SDMA)

b. switched beam

c. adaptive array

12. Between uplink and downlink, which direction of wireless communication extends from the base station to the user?

    a. uplink

    b. downlink

Correct Answers

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Glossary

algorithm
an automatic signal-processing strategy that varies the way in which multiple antenna elements are employed as a function of operational scenarios

amplitude
the magnitude of the high and low points of a waveform or signal; also called wave height or signal strength

azimuth
horizontal direction expressed in degrees as the angular distance between the direction of a fixed point (as the observer's heading) and the direction of the object

backhaul
to take communications channel traffic beyond its destination and back, most often because it is cheaper to go the long way instead of going directly; tapping into a preexisting system can take advantage of established efficiencies; backhauling is often a temporary rerouting alternative to more direct connection used from moment to moment according to changing system conditions

bandwidth
the range of a channel's limits; the broader the bandwidth, the faster and more varied the data that can be sent; a wideband circuit, for example, can carry a TV

channel; the bandwidth used for one video channel is roughly equal to 1,200 voice telephone channels

base station
(cell station) a radio transceiver (transmitter/receiver) that uses processing hardware/software and an antenna array to control and relay signals between the central office (CO) and the remote handset or subscriber unit (fixed or mobile); it connects wireless users to a phone network, public or private

bits per second (bps)
the rate of data transmission pertaining to the number of pulses in one second

cochannel interference
one of the primary forms of man-made signal degradation associated with radio, co-channel interference occurs when the same carrier frequency reaches the same receiver from two separate transmitters as a result of spilling over from an adjoining cell

code division multiple access (CDMA)
a spread spectrum access technology that assigns a code to all multiple access speech bits, sends scrambled transmission of the encoded speech over the air, and reassembles the speech to its original format

cross talk
a condition of wireless communication that occurs when one user hears someone they are not talking to, commonly resulting from an inaccurately aimed or accidentally bounced signal transmission

delay spread
an effect of multipath for a digital air interface in which multiple reflections of the same signal arrive at the receiver at different times, creating a noticeable degradation in signal quality

directive transmission
directionally focused signal transmission from a base station to a remote caller made possible by certain smart antenna systems with digital signal processing capabilities; these base stations use information obtained during reception to transmit signals selectively toward certain users and away from others

diversity
Diversity antenna systems incorporate two slightly spaced antenna elements with the assumption that one or the other's location will be better at any given moment for reception of a user's signal. Switched diversity systems alternately operate with one or the other antenna to maintain communication; diversity combining systems combine signals to increase gain.

downlink
refers to the connection from the base station to the remote user site (alternately from the CO to the base station)

fading
the reduction in signal intensity of one or several of the components of a radio signal, typically caused by the reflective or refractive effects of multipath

fast fading
See Rayleigh fading.

frequency
the rate at which an electrical current alternates, expressed as the number of cycles per unit of time (from crest to crest in a sine wave pattern); frequency is typically measured in Hertz (Hz) or cycles per second.

frequency division duplex (FDD)
the simultaneous exchange of uplink and downlink information on different frequencies (see time division duplex)

modulation
the process of impressing information on a carrier wave by changing some of the wave's characteristics (such as amplitude, frequency, or phase) to reflect the changes in the information it delivers

multipath
copies of the desired signal that have arrived at the antenna after bouncing from objects between the signal source and the antenna; these signals can either cancel or reinforce each other

phase
the relationship between a signal wave and its horizontal axis; the phase between two identical signals is the ratio of the timing difference to the period of time it is measured in degrees of a 360 period

phased array
a type of antenna design that incorporates two or more elements that integrate signal information received from the spatially separate element locations and transmit in a coordinated manner (either simultaneously or alternately)

radio frequency (RF) interference
basically, undesired signals from the standpoint of any particular listener; those signals that miss their desired user become interference energy to users in the same or adjacent cells

Rayleigh fading (fast fading)
a multipath condition affecting users in motion whereby the user receives a signal both directly and reflected off structures or landscape features; the reflected signals will have traveled different distances, and the combined signals at the mobile can add and subtract out of phase, causing the signal to momentarily fade

reuse/frequency reuse
the utilization of frequency (channels) more than once in a wireless network; equated primarily with the basic cellular grid design, where each cell uses each channel once within its boundaries and is insulated from other cells using that frequency to allow for anticipated interference; due to the shortcomings of conventional transmission techniques, frequency reuse in adjacent cells has been largely implausible until the recent development of spatial processing technology, which can enable same-cell frequency reuse

selective reception
a characteristic of spatial processing that monitors incoming signals and distinguishes between desirable information and interference; by filtering out interfering signals and appropriately combining the reception from all the antennas in the array, this approach provides significant improvement in signal quality

spatial diversity
an antenna configuration of two or more elements that are physically spaced (spatially diverse) to combat signal fading and improve signal quality; the desired spacing depends on the degree of multipath angle spread

spatial division multiple access
a complement (not an alternative) to CDMA and TDMA, this technology increases the number of users that can access an existing wireless phone system by exploiting the spatial characteristics of the channel itself through highly developed implementation of an intelligent antenna system's capabilities for receiving and transmitting

subscriber unit
the fixed, typically wall-mounted equipment used by the subscriber in a wireless local-loop system to send and receive messages; a standard telephone is attached to it by wire to complete the connection to the user

time division duplex (TDD)
the method of multiplexing transmit/receive (uplink/downlink) parts of a wireless communications link together; the exchange of uplink and downlink information takes place on the same frequency, but is distinguished by time-slot characteristics (see frequency division duplex)

time division multiple access (TDMA)
a method used in wireless technology to separate multiple conversations over set frequencies and bandwidth; it is used to allocate a discrete amount of frequency bandwidth to each user; to permit many simultaneous conversations, each caller is assigned a specific time slot for transmission

uplink
refers to the return signal from the user to the base station (alternately from the base station to the CO)

wireless local loop (WLL)
in conventional wired systems, the local loop refers to the connection that runs from the subscriber's telephone set or PBX or telephone system to the telephone company's CO. As the name implies, a WLL connects potential users to the CO by substituting a wireless, base station-handset component for the local-loop connection; WLL service is the most advantageous alternative for parts of the world that can leapfrog expensive and time-consuming wire installations in establishing modern telecommunications systems