SMART ANTENNA TECHNOLOGY

INTRODUCTION

1. A smart antenna consists of several antenna elements, whose signal is processed adaptively in order to exploit the spatial domain of the mobile radio channel. The smart antenna technology can significantly improve wireless system performance and economics for a range of potential users. It enables operators of PC's cellular and wireless local loop networks to realize significant increase in signal quality, network capacity and coverage.

2. In actual, 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.

3. This is a new and promising technology in the field of wireless and mobile communications in which capacity and performance are usually limited by two major impairments multipath and co-channel interference. Multipath is a condition that arises when a transmitted signal undergoes reflection from various obstacles in the environment. This gives rise to multiple signals arriving from different directions at the receiver. Smart antennas (also known as adaptive array antennas and multiple antennas) are antenna arrays with smart signal processing algorithms to identify spatial signal signature such as the Direction of arrival (DOA) of the signal and use it to calculate beam forming vectors, to track and locate the antenna beam on the mobile targets. The antenna could optionally be any sensor. Smart antenna techniques are used notably in acoustic signal processing, track and scan Radar, Radio astronomy and Radio Telescopes and mostly in Cellular Systems like W-CDMA and UMTS.

4. A smart antenna is a digital wireless communications antenna system that takes advantage of diversity effect at the source (transmitter), the destination (receiver) or both. Diversity effect involves the transmission and/or reception of multiple radio frequency (RF) waves to increase data speed and reduce the error rate. The result is bad signal quality at the receiver due to phase mismatch. Co-channel interference is interference between two signals that operate at the same frequency. A smart antenna enables a higher capacity in wireless networks by effectively reducing multipath and co-channel interference. This is achieved by focusing the radiation only in the desired direction and adjusting itself to changing traffic conditions or signal environments. Smart antennas employ a set of radiating elements arranged in the form of an array.

TYPES OF SMART ANTENNA SYSTEMS

5. Two of the main types of smart antennas include switched beam smart antennas and adaptive array smart antennas. Switched beam systems have several available fixed beam patterns. A decision is made as to which beam to access, at any given point of time, based upon the requirements of the system. Adaptive arrays allow the antenna to steer the beam to any direction of interest while simultaneously nullifying interfering
signals. Beam direction can be estimated using the so-called Direction-of-Arrival (DOA) estimation methods.

6. **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, switched beam systems combine the outputs of multiple antennas in such a way as to form finely directional beams with more spatial selectivity than can be achieved with conventional, single-element approaches.

7. **Adaptive Array Antennas.** Adaptive antenna technology represents the most advanced smart antenna approach as on 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.

**COMPARISON BETWEEN SWITCHED BEAM AND ADAPTIVE ARRAY SYSTEMS**

8. **Switched Beam System.**

(a) It uses multiple fixed directional beams with narrow beam widths.

(b) The required phase shifts are provided by simple fixed phase shifting networks like the butler matrix.

(c) They do not require complex algorithms; simple algorithms are used for beam selection.

(d) It requires only moderate interaction between mobile unit and base station as compared to adaptive array system.

(e) Since low technology is used, it has lesser cost and complexity.

(f) Integration into existing cellular system is easy and cheap.

(g) It provides significant increase in coverage and capacity compared to conventional antenna based systems.

(h) Since, multiple narrow beams are used, frequent intra-cell hand-offs between beams have to be handled as mobile moves from one beam to another.

(j) It cannot distinguish between direct signal and interfering and/or multipath signals, this leads to undesired enhancement of the interfering signal more than the desired signal.

(k) Since, there is no null steering involved, switched beam systems offer limited co-channel interference suppression as compared to the adaptive array systems.
9. **Adaptive Array System.**

(a) A complete adaptive system; steers the beam towards desired signal of interest and places nulls at the interfering signal directions.

(b) It requires implementation of DSP technology.

(c) It requires complicated adaptive algorithms to steer the beam and the nulls.

(d) It has better interference rejection capability compared to Switched beam systems.

(e) It is not easy to implement in existing systems i.e. up-gradation is difficult and expensive.

(f) Since, continuous steering of the beam is required as the mobile moves; high interaction between mobile unit and base station is required.

(g) Since, the beam continuously follows the user; intra-cell hand-offs are less.

(h) It provides better coverage and increased capacity because of improved interference rejection as compared to the Switched beam systems.

(j) It can either reject multipath components or add them by correcting the delays to enhance.

**THE ARCHITECTURE OF SMART ANTENNA SYSTEMS**

10. **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.

11. **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 omni-directional 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 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.

12. **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 use 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 to transmit and receive the signal (e.g. GSM). 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.

13. **Direction of arrival (DOA) Estimation.** The smart antenna system estimates the direction of arrival of the signal, using techniques such as Multiple Signal Classification (MUSIC), estimation of signal parameters via rotational invariance techniques (ESPRIT) algorithms, Matrix Pencil method or one of their derivatives. They involve findings of a spatial spectrum of the antenna/sensor array and calculating the DOA from the peaks of this spectrum. These calculations are computationally intensive. Matrix Pencil is very efficient in case of real time systems and under the correlated sources.

14. **Beamforming.** It is the method used to create the radiation pattern of the antenna array by adding constructively the phases of the signals in the direction of the targets/mobiles desired and nullifying the pattern of the targets/mobiles which are undesired/interfering targets. This can be done with a simple FIR tapped delay line filter. The weights of the FIR filter may also be changed adaptively and used to provide optimal beam forming and actual beam pattern formed. Typical algorithms are the steepest descent and LMS algorithms. There is an ever-increasing demand on mobile wireless operators to provide voice and high-speed data services. At the same time, these operators want to support more users per base station to reduce overall network costs and make the services affordable to subscribers. As a result, wireless systems that enable higher data rates and higher capacities are a pressing need.

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**Fig 1. Smart Antenna System – Beam forming**
15. **Interference Limited Systems.** Unfortunately, because the available broadcast spectrum is limited, attempts to increase traffic within a fixed bandwidth create more interference in the system and degrade the signal quality. In particular, when omni-directional antennas are used at the base station, the transmission/reception of each user’s signal becomes a source of interference to other users located in the same cell, making the overall system interference limited. An effective way to reduce this type of interference is to split up the cell into multiple sectors and use directional antennas as illustrated in Figure 2 below.

![Diagram](image)

**Fig 2 : Non-Smart Antennas System**

16. **Ultra Adaptive Beam forming Implementation.** The high-performance digital signal processing (DSP) blocks, embedded processors and Logic Elements (LEs) make them ideal for adaptive beam forming applications. In addition, the inclusion of the dual-core processor with the NEON acceleration unit can be used for beam forming adaptations. As illustrated in Figure 3 below, the signal from each receive antenna is first down converted to baseband, processed by the matched filter-multipath estimator and accordingly assigned to different rake fingers. The beam forming unit on each rake finger then calculates the corresponding beam former weights and channel estimate using the pilot symbols that have been transmitted through the Dedicated Physical Data Channel (DPDCH). The QRD-based Recursive Least squares (RLS) algorithm is selected as the weight update algorithm for its fast convergence and good numerical properties. The updated beam former weights are then used for multiplication with the data that has been transmitted through the DPDCH. Maximal Ratio Combining (MRC) of the signals from all fingers is then performed to yield the final soft estimate of the DPDCH data.
**Notes:**

1. DDC: digital down converter.
2. MRC: maximal ratio combining.
3. CORDIC: coordinate rotation digital computer.
4. QRD: QR decomposition.

17. **Advantage of Beam Forming.** There are following advantages of Beam forming:

   (a) **Processing Speed.** Smart Antenna technology requires high processing bandwidth with computational speeds approaching several billion **Multiply and Accumulate (MAC)** operations per second. Such computationally demanding applications quickly exhaust the processing capabilities of digital signal processors. Enhanced DSP blocks and Tri-Matrix memory provide throughputs in excess of 50 GMACs, offering a high-performance platform for beam forming applications.

   (b) **Flexibility.** There are a number of beam forming architectures and adaptive algorithms that provide good performance under different scenarios such as transmit-receive adaptive beam forming and transmit-receive switched beam forming. With embedded processors and easy-to-use development tools such as DSP Builder. It offers a high degree of flexibility in implementing various adaptive signal processing algorithms.
(c) **Lower Risk.** The standards for next-generation networks are continuously evolving and this creates an element of risk for beam forming implementation. Transmit beam forming for example, utilizes the feedback from the mobile terminals. The number of bits provided for feedback in the standards can determine the beam forming algorithm that is used at the base station. Moreover, future base stations are likely to support transmit diversity including space-time coding and **Multiple-Input Multiple-Output (MIMO)** technology. They reduce the risk involved with designing for evolving industry standards while providing the option for the gradual deployment of additional transmit diversity schemes.

(d) **Cost Reduction Path.** Mobile wireless service providers would likely deploy smart antennas technology initially at certain "hot spots" such as densely populated urban areas where there is more demand for high-speed wireless data services. The high NRE costs and long development cycles associated with ASICs cannot be justified for such low volume requirements. It offers a seamless migration process that supports the high-density FPGAs and can offer up to 70 percent cost reduction for relatively low Minimum Order Quantities (MOQs).

**BASIC WORKING MECHANISM**

18. A smart antenna system can perform the following functions:–

(a) First, the direction of arrival of all the incoming signals including the interfering signals and the multipath signals are estimated using the Direction of Arrival algorithms.

(b) Secondly, the desired user signal is identified and separated from the rest of the unwanted incoming signals.

(c) Lastly, a beam is steered in the direction of the desired signal and the user is tracked as he moves while placing nulls at interfering signal directions by constantly updating the complex weights.

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**Fig 4: Block diagram of Adaptive array systems**

ADC = Analog to digital converter  
D/C = Down Converter  
W's = Complex weights
19. As discussed previously, it is quite evident that the direction of radiation of the main beam in an array depends upon the phase difference between the elements of the array. Therefore, it is possible to continuously steer the main beam in any direction by adjusting the progressive phase difference between the elements. The same concept forms the basis in adaptive array systems in which the phase is adjusted to achieve maximum radiation in the desired direction.

20. In a beam forming network, typically the signals incident at the individual elements are combined intelligently to form a single desired beam formed output. Before the incoming signals are weighted, they are brought down to baseband or intermediate frequencies. The receivers provided at the output of each element perform the necessary frequency down conversion. Adaptive antenna array systems use digital signal processors (DSP’s) to weight the incoming signal. Therefore, it is required that the down-converted signal be converted into digital format before they are processed by the DSP. Analog-to-digital converters (ADC’s) are provided for this purpose.

21. For accurate performance, they are required to provide accurate translation of the RF signal from the analog to the digital domain. The digital signal processor forms the heart of the system which accepts the IF signal in digital format and the processing of the digital data is driven by software. The processor interprets the incoming data information which determines the complex weights (amplification and phase information) and multiplies the weights to each element output to optimize the array pattern. The optimization is based on a particular criteria which minimizes the contribution from noise and interference while producing maximum beam gain at the desired direction. There are several algorithms based on different criteria for updating and computing the optimum weights.

**BENEFITS OF SMART ANTENNA TECHNOLOGY**

22. There are large number of benefits of Smart Antennas, some of them are enumerated below as:

(a) **Reduction in Co-Channel Interference.** Smart antennas have a property of spatial filtering to focus radiated energy in the form of narrow beams only in the direction of the desired mobile user and no other direction. In addition, they also have nulls in their radiation pattern in the direction of other mobile users in the vicinity. Therefore, there is often negligible co-channel interference.

(b) **Range Improvement.** Since, smart antennas employs collection of individual elements in the form of an array they give rise to narrow beam with increased gain when compared to conventional antennas using the same power. The increase in gain leads to increase in range and the coverage of the system. Therefore, fewer base stations are required to cover a given area.

(c) **Increase in Capacity.** Smart antennas enable reduction in co-channel interference which leads to increase in the frequency reuse factor means smart antennas allow more users to use the same frequency spectrum at the same time bringing about tremendous increase in capacity.

(d) **Reduction in Transmitted Power.** Ordinary antennas radiate energy in all directions leading to a waste of power. Comparatively, smart antennas
radiate energy only in the desired direction. Therefore, less power is required for radiation at the base station. Reduction in transmitted power also implies reduction in interference towards other users.

(e) **Reduction in Handoff.** To improve the capacity in a crowded cellular network, congested cells are further broken into micro cells to enable increase in the frequency reuse factor. This results in frequent handoffs as the cell size is smaller. Using smart antennas at the base station, there is no need to split the cells as the capacity is increased by using independent spot beams.

**CONCLUSION**

23. Smart Antennas have been tested in a variety of field locations with promising results. The new antenna has demonstrated a considerable advantage over various indoor antennas with no amplification and the set-top UHF loop/VHF rod antenna combination with built-in amplification. In a few locations, Smart Antennas may be unable to automatically optimize the signal. A simple antenna works for a simple RF environment. Smart antenna solutions are required as the number of users, interference and propagation complexity grows. Their smartness resides 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.

24. 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 technology of smart or adaptive antennas for mobile communications has received enormous interest worldwide in recent years. In the Smart antenna, different levels of intelligence are introduced, ranging from simple switching between predefined beams to optimum beam forming. The principle reason for evolution of Smart Antennas is the possibility for a large increase in capacity, an increase of three times for TDMA systems and five times for CDMA systems has been reported. Other advantages include increased range and the potential to introduce new services. Major drawbacks and cost factors include increased transceiver complexity and more complex radio resource management. In the Smart antenna, special attention is given to the critical factors and technological challenges, including achieving equal performance on uplink and downlink as well as real-time calibration of the receiver and transmitter chains.

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