SMART ANTENNA FOR MOBILE COMMUNICATION

Abstract:
Smart antennas are one of the most hottest topics in mobile communication. 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. In truth it is not the antenna that is smart but the antenna system are smart. Firstly we present different types of smart antenna systems and features and benefits of smart antenna systems, next we deal with the basic problem of wireless transmission such as co-channel interference multi path propagation, fading and signal to interference ratio. The advantages of smart antennas over 'conventional antennas i.e Extension of range increasing capacity, reduced inter channel interference are also presented in this paper. Then we have presented how the smart antennas are useful for TDMA and CDMA technologies. Lastly weight determination using algorithms and future developments such as MIMO systems concludes our paper.

Definition:
A smart antenna consists of several antenna elements, whose signal are processed adaptively in order to exploit the spatial domain of the mobile radio channel. Usually the signals received at the different antenna elements are multiplied with complex weights W and then summed up the weights are chosen adaptively not the antenna itself, but the whole antenna system including the signal processing is called adaptive.

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 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 adjusting in 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 through out the sector. Switched beam systems combine the outputs of multiple antennas in such a way as to form finely sectorized (directional) beams with more spatial selectivity.

Adaptive 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 minimized interfering signals.

Adaptive array coverage

What Makes Them So Smart:
A simple antenna works for a simple RF environment. Their smarts reside in their digital signal-processing facilities. In adaptive antenna systems, this fundamental signal-processing capability is augmented by advanced techniques that are applied to control operation in the presence of complicated combinations of operating conditions.

Features and Benefits:
**Signal gain:** Inputs from multiple antennas are combined to optimize available power required 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 co-channel interference sources improving the signal to interference ratio of the received signals.

**Increased capacity:** Precise control of signals quality and mitigation of interference combined to frequency re use reduce distance, improving capacity.

**Spatial diversity:** Composite information from the array is used to minimize fading, other undesirable effects of multi path propagation.

**Multipath rejection:** It can reduce the effective delay spread of the channel allowing higher bit rates to be supported without the use of an equalizer.

**Power efficiency:** It combines the input s to multiple elements to optimize available processing gain in the downlink(toward user).

**Reduced expense:** lower amplifier costs, power consumption, and higher reliability will resul.

**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.

The Effect of Multipath on a Mobile User

Problems Associated With Multipath:
One problem resulting from having unwanted reflected signal 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 illustrates two out-of-phase signals as seen by the receiver.

Two Out-of-Phase Multipath Signals

**Fading:**
When the waves of multi path 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. Repesentation of reliegh fade effect on a user signal shown in below figure
Phase cancellation:
When waves of two multipath signals are rotated to exactly 180° out of phases, 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 blank hole, a service area in which call set-ups will occasionally fail.

Smart Antenna Systems Work:
Traditional switched beam and adaptive array systems enable a base station to customize the beams they generated 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 selectively 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 and 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 Process
The task of transmitting in a sparsely selective manner is the major basis for differentiating between switched beam and adaptive array systems. 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 frequency for transmit and receiving. In most FDD systems, the uplink and downlink fading and other propagation characteristics may be considered independent, whereas in TDD systems 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.

Range Extension:
In sparsely populated areas, extending coverage is often more important than increasing capacity. In such areas, the gain provided by adaptive antennas can extend the range of a cell to cover a larger area and more users than would be possible with omnidirectional or sector antennas. This approach is shown in figure.
exponential path loss model. In this model, the power at a receiver, \( P_r \) is given by

\[
P_r = P_t G_t G_r PL(d_0) \left( \frac{R}{d_0} \right)^\gamma
\]  

-----(2)

\( P_t \) is the transmitter power, \( G_t \) and \( G_r \) are the transmit and receive antenna gains, respectively, \( PL(d_0) \) is the free space path loss at some reference distance \( d_0 \) from the transmitter (on the order of 1 Km for a cellular system) \( R \) is the transmit receive range, in the same units as \( d_0 \) and \( \gamma \) is the path loss exponent which is typically between 3 and 4. This model assumes \( R \geq d_0 \). Rearranging yields

\[
R = d_0 \left( \frac{P_t G_t G_r PL(d_0)}{P_r} \right)^{\frac{1}{\gamma}}
\]  

-----(3)

and coverage area varies with antenna gain as

\[ A_c \propto G^\frac{2}{\gamma} \]  

-----------(4)

where \( G \) is either transmit or receive antenna gain and the gain of the other antenna is held constant. The following example shows how coverage can be increased by using a base station antenna with steerable or switched directional beams.

**Example 1:**

Assume it has been established that using an omnidirectional antenna a particular base station can cover an area of \( A_{c,omin} = 100 \text{ Km}^2 \). Further more assume the path loss for the channel has been measured and can be approximated by an exponential path loss model with \( \gamma = 3.5 \). If a smart antenna system is used which provides and additional 6 dB of gain, then based on (4) the system can cover an area given by

\[
A_{c,max} = A_{c,omin} \left( \frac{G_{max}}{G_{omin}} \right)^{\frac{2}{\gamma}}
\]  

-----(5)

or in this case, \( A_{c,max} = 100 \cdot 4 \left( \frac{1}{2} \right)^{\frac{2}{3.5}} \) or 220.8 km².

Range extension is best suited to rural areas, where the user density is low and it is desirable to cover as much area with as few base stations as possible. If the user density is high simply expanding the coverage area will result in a cell containing more users than the base station can serve with its limited number of channels. In this case range extension is only practical if it can be combined with one of the other approaches discussed in this section.

**Capacity:**

capacity is related to the spectral efficiency of a system as well as the amount of traffic offered by each user. The spectral efficiency \( E \), measured in channel as is expressed as

\[
E = \frac{B_t/B_{ch}}{B_{ch} N_c A_c}
\]  

\[ = \frac{1}{B_{ch} N_c A_c}
\]

where \( B_t \) is the total bandwidth of the system available for voice channels (transmit or receive), in MHz, \( B_{ch} \) is the bandwidth per voice channel in MHz is the number of cells per cluster and \( A_c \) is the area per cell in square kilometers [3]. The capacity of a system is measured in channel/km² and is given by

\[
C = EB_t
\]

\[ = \frac{B_t}{B_{ch} N_c A_c}
\]

\[ = \frac{N_{ch}}{N_c A_c}
\]

where \( N_{ch} = B_t/B_{ch} \) is the total number of available transmit or receive voice channels in the system. The actual number of users that can be supported can be calculated based on the traffic offered by each user and the number of channels per cell. From (7), it is evident that capacity can be increased in several ways. These include increasing the total bandwidth allocated to the system reducing the bandwidth of a channel through efficient modulation decreasing the number of cells in a cluster and reducing the area of a cell through cell splitting. If somehow more than one user can be supported per RF channel, this will also increase capacity. This paper concentrates on techniques for increasing capacity using adaptive or smart antennas.

**Interference reduction and rejection:**

In populated areas increasing capacity is of prime importance. Two related strategies for increasing capacity are interference reduction on the downlink and interference rejection on the uplink. To reduce interference directional beams are steered toward the mobiles interference to co-channel mobile occurs only if they are within the narrow beam width of the directional beam. This reduces the probability of co-channel interference compared with a system using omni directional base station antennas. Interference can be rejected using directional beams and/or by forming nulls in the base stations receive antenna pattern in the direction of interfering co-channel users. Interference reduction and rejection can allow \( N_c \) (which is dictated by co-channel
interference) to be reduced increasing the capacity of the system. Interference reduction can be implanted using an array with steered or switched beams. By using directional beams to communicate with mobiles on the downlink, a base station is less likely to interfere with nearby co-channel base stations than if it used an omni directional antenna. Theoretically the number of cells per cluster can be decreased, increasing spectral efficiency and capacity as shown in (6), (7) (3), (4). There will be a small percentage of time during which co-channel interference is strong e.g., when a mobile is within the main beam of a nearby co-channel base station. This can be overcome by handing off the mobile within its current cell to another that is not experiencing strong co-channel interference.

Interference reduction using adaptive antennas

**Use of 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 networks to realize significant increases in signal quality, capacity and coverage.

**Smart Antennas for TDMA:**

In a conventional time division multiple access (TDMA) or frequency division multiple access (FDMA) cellular system, carrier frequencies that are used in one cell cannot be reused in the neighboring cells, because the resulting co-channel interference would be too strong. Rather, those frequencies are reused at a greater distance. The distance (related to cell radius) between two base stations which use the same carrier frequency is named reuse distance D/R. The number of cells that have to use different carrier frequencies is called cluster size N or reuse factor. Typically, a signal-to-noise-and-interference ratio (SNIR) of 10Db is required for each user, resulting in a cluster size of 3 or more (N=3) for sector cells.

**Smart Antennas for TDMA (2):**

The increase in capacity can now be accomplished in different ways. One possibility is so-called spatial filtering for interference reduction (SFIR). Thereby, we can put base stations with the same carrier frequencies closer together, without violating the requirements for the signal-to-interference ratios. The increase in the capacity is then the decrease in the reuse factor. Simulations have show that even a cluster size of one (N=1) could become feasible. In practice, the achievable, gain is low, but extensive tests and simulations by equipment manufacturers and network operators have shown that a doubling of the capacity of existing networks is quite feasible, without putting up additional base stations.

**Smart Antennas for CDMA:**

In a code division multiple access system (CDMA system), the capacity gain is effected in a slightly different way. All cells use the same carrier frequency. Users are distinguished by their different codes, of which there is a large number. The number of users within one cell is limited mainly by the interference that each user generates for all other users. By pointing main beam of the adaptive antenna pattern to the desired user, smart antenna improves SNIR for one user without increasing interference for other users. For 3rd generation CDMA systems there are against contradictions to 2nd generation CDMA systems multi-rate services available these new CDMA systems allow to access the network with high data rates these high datarates services require higher transmission power. Nulling out of such high data rate interferers is a viable option to improve SNIR.

**Algorithms:**

**Spatial Referenfe (SR) Classification:**

For the first step In this procedure, namely the determination of the directions of arrival (DOAs). Plenty of methods have been developed in the last thirty years. The fourier transform usually shows too poor a resolution, so that parameter estimation methods are preferable. These methods achieve a high resolution of the DOAs. The best known algorithms are ESPRIT, SAGE,MUSIC, and Minimum Variance or Capon’s method (MVM).

**Spatial reference(SR)classification**

(methods for DOAs estimation)

**SR algorithms ( Parameter estimation)**

- Parametric
- Spectral-based

**Subspace maximum**

- maximum likelihood methods
- forming method

**ESPRIT SAGE MUSIC MVM**

**Different SR algorithms for DOA estimation**
Temporal reference:
Another approach for the weight determination is the use of a training sequence, also known as “temporal reference” algorithms. In the first step, the training sequence which is known to the receiver is transmitted, and the receiver adjusts the complex weights $W$ in such a way that the difference between the sum signal $Y(n)$ and the training sequence is minimized. Then, those weights are used for the reception of the actual data.

Blind algorithms:
An algorithm that exploits neither a training sequence nor the properties of the receiver array is called a "blind" algorithm. Essentially, it has as its input the received signals at the antenna elements sampled in time domain, i.e. the array output data matrix $X$. From this, the blind algorithm tries to extract the unknown channel impulse response $H$ and the unknown transmitted data $S$. In principle, there are many possible decompositions of $X$ the algorithm uses additional knowledge about the structure of the transmitted signal even though it doesn’t know the actual bits the receiver knows that the transmitted signal must have constant envelope and thus tries to find the decomposition of $HS$ where $S$ really exhibits a constant envelope. Currently all blind algorithms require too much computations to be applied in real-time to mobile radio. But the use of training sequences in so called semi-blind algorithms speeds up computation considerably. A recent algorithm of this class, DILFAST (decoupled iterative least squares finite alphabet space time) is real time capable.

MIMO Systems:
One of the most exciting developments of recent years is the emergence of so-called MIMO (multiple-input-multiple-output) systems. These systems have antenna arrays at transmitter and receiver. They exhibit a much higher capacity than standard smart antenna systems. If the number of antennas at transmitter and receiver is the same, the channel capacity increases linearly with the number of antennas. Capacities in the order of 50 bits per second per Hertz become possible with reasonably small arrays. Alternatively, a diversity order of $M$ times $M$ becomes possible. However note that always the smaller number of antennas at the two link ends limits the performance.

SUMMARY:
Summarizing, we have shown how smart antennas reduce fading and suppress interference. This in turn allows the increase in capacity of existing or future mobile communications networks. The used algorithms for weight determination can be divided into spatial reference, temporal reference and blind algorithms. The first use knowledge about the geometry of the antenna array, the second use a training sequence and the last employ knowledge about the structural and statistical properties of the transmitted signal. Future developments will include MIMO systems, which promise huge transmission capacities. Finally, let us note that for the design and simulation of any smart antenna system, knowledge of the spatially resolved mobile radio channel is essential.

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