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Evaluation of Smart Antenna for 3G Network: A Survey

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ABSTRACT
In simple words, smart antenna is such that it can sense its environment and can adjust its gain in different directions accordingly. They provide a smart solution to the problem of communication traffic overload i.e. they increase the traffic capacity. They also improve the QOS.RF spectrum is a limited resource and is becoming crowded day by day due to the advent of new technologies. The sources of interference are increasing as well and hence interference is becoming the limiting factor for wireless communication. Smart Antenna adapts its radiation pattern in such a way that it steers its main beam in the DOA (Direction Of Arrival) of the desired user signal and places null along the interference. It refers to a system of antenna arrays with smart signal processing algorithms.

Keywords: Smart Antenna, Beam forming, Switched Array, Adaptive Array, DOA.

1. INTRODUCTION
Many refer to smart antenna systems as smart antennas, but in reality antennas by themselves are not smart. It is the digital signal processing capability, along with the antennas, which make the system smart. Although it may seem that smart antenna systems are a new technology, fundamental principles upon which they are based are not new. In fact, in the 1970s and 1980s two special issues of the IEEE Transactions on Antennas and Propagation were devoted to adaptive antenna arrays and associated signal processing techniques. The use of adaptive antennas in communication systems initially attracted interest in military applications. Particularly, the techniques have been used for many years in electronic warfare (EWF) as countermeasures to electronic jamming. In military radar systems, similar techniques were already used during World War II. However, it is only because of today's advancement in powerful low-cost digital

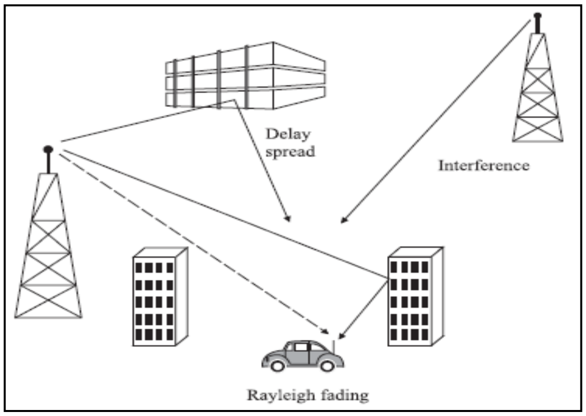

Figure 1
Wireless systems impairments

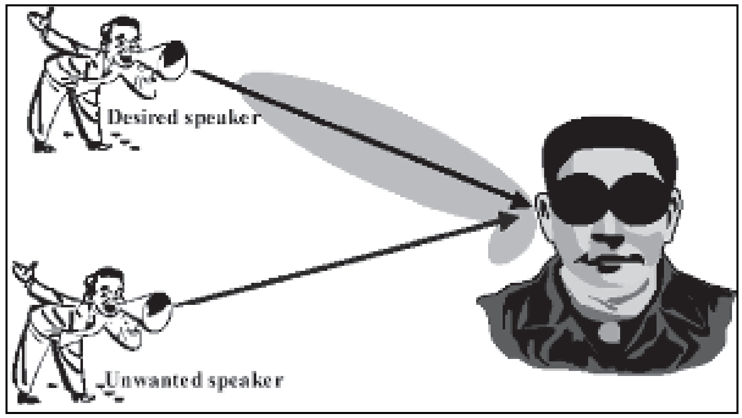

Figure 2
Human auditory function

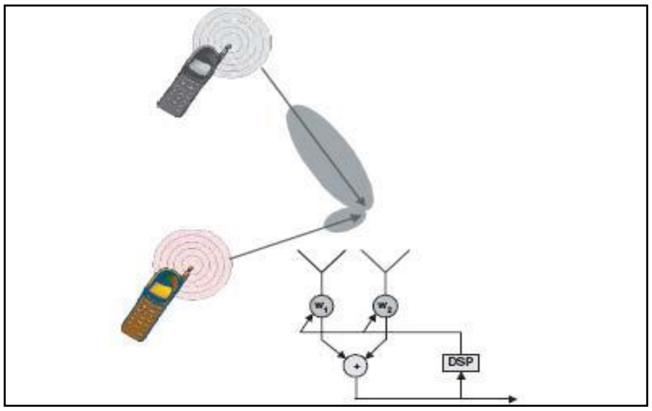

Figure 3
A two-element electrical smart antenna

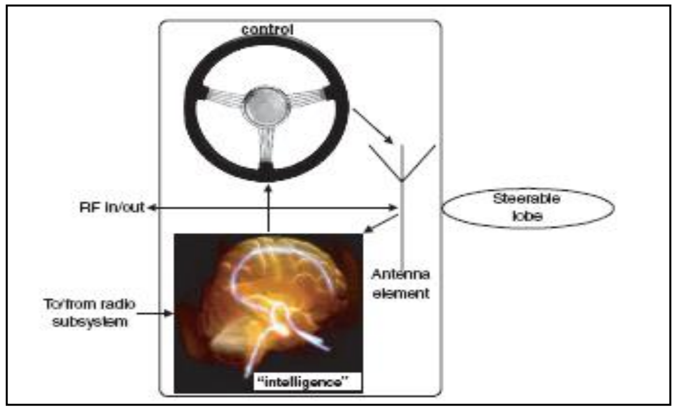

Figure 4
Principle of a smart antenna system

Signal processors, general-purpose processors and ASICs (Application Specific Integrated Circuits), as well as innovative software-based signal processing techniques (algorithms), that smart antenna systems are gradually becoming commercially available.

1.1. Need for smart antennas

Wireless communication systems, as opposed to their wire line counterparts, pose some unique challenges (Vanderveen et al., 1997):

- The limited allocated spectrum results in a limit on capacity
- The radio propagation environment and the mobility of users give rise to signal fading and spreading in time, space and frequency the limited battery life at the mobile device poses power constraints

In addition, cellular wireless communication systems have to cope with interference due to frequency reuse. Research efforts investigating effective technologies to mitigate such effects have been going on for the past twenty five years, as wireless communications are experiencing rapid growth (Vanderveen et al., 1997). Among these methods are multiple access schemes, channel coding and equalization and smart antenna employment. Figure 1 summarizes the wireless communication systems impairments that smart antennas are challenged to combat.

An antenna in a telecommunications system is the port through which radiofrequency (RF) energy is coupled from the transmitter to the outside world for transmission purposes, and in reverse, to the receiver from the outside world for reception purposes. To date, antennas have been the most neglected of all the components in personal communications systems. Yet, the manner in which radio frequency energy is distributed into and collected from space has a profound influence upon the efficient use of spectrum, the cost of establishing new personal communications networks and the service quality provided by those networks. The commercial adoption of smart antenna techniques is a great promise to the solution of the aforementioned wireless communications' impairments.

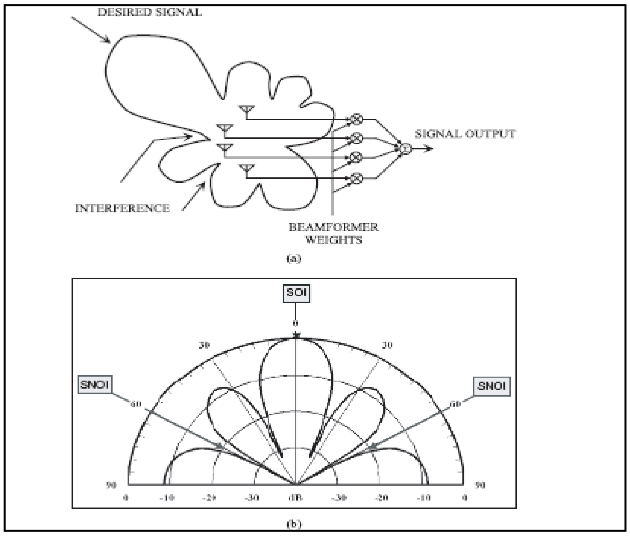

Figure 5

Adaptation procedures: (a) Calculation of the beam former weights (b) Beam formed antenna amplitude pattern to enhance SOI and suppress SNOIs

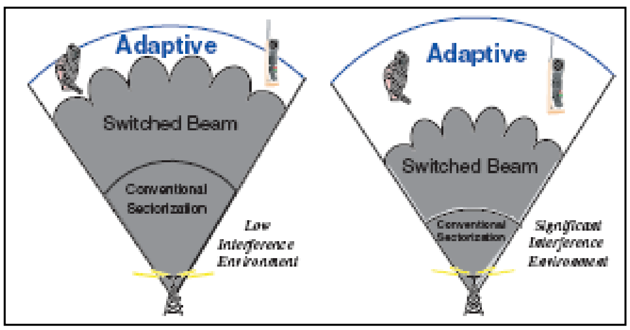

Figure 6

Coverage patterns for switched beam and adaptive array antennas

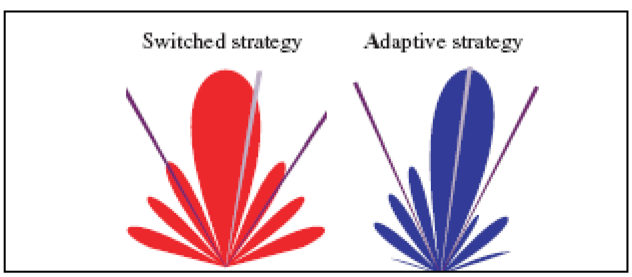

Figure 7

Beam forming lobes and nulls that Switched-Beam (left) and Adaptive Array (right) systems might choose for identical user signals (light line) and co-channel interferers (dark lines) control than adaptive arrays

1.2. Overview

The basic idea on which smart antenna systems were developed is most often introduced with a simple intuitive example that correlates their operation with that of the human auditory system. A person is able to determine the Direction of Arrival (DOA) of a sound by utilizing a three-stage process. One's ears act as acoustic sensors and receive the signal. Because of the separation between the ears, each ear receives the signal with a different time delay. The human brain, a specialized signal processor, does a large number of calculations to correlate information and compute the location of the received sound. To better provide an insight of how a smart antenna system works, let us imagine two persons carrying on a conversation inside an isolated room as illustrated in Figure 2. The listener among the two persons is capable of determining the location of the speakers he moves about the room because the voice of the speaker arrives at each acoustic sensor, the ear, at a different time. The human "signal processor," the brain, computes the direction of the speaker from the time differences or delays received by the two ears. Afterward, the brain adds the strength of the signals from each ear so as to focus on the sound of the computed direction. Utilizing a similar process, the human brain is capable of distinguishing between multiple signals that have different directions of arrival. Thus, if additional speakers join the conversation, the brain is able to enhance the received signal from the speaker of interest and tune out unwanted interferers. Therefore, the listener has the ability to distinguish one person's voice, from among many people talking simultaneously, and concentrate on one conversation at a time. In this way, any unwanted interference is attenuated. Conversely, the listener can respond back to the same direction of the desired speaker by orienting his/her transmitter, his/her mouth, toward the speaker. Electrical smart antenna systems work the same way using two antennas instead of two ears, and a digital signal processor instead of the brain as seen in Figure 3.

Thus, based on the time delays due to the impinging signals onto the antenna elements, the digital signal processor computes the direction-of-arrival (DOA) of the signal-of interest(SOI), and then it adjusts the excitations (gains and phases of the signals) to produce a radiation pattern that focuses on the SOI while tuning out any interferers or signals-not-of-interest (SNOI).Transferring the same idea to mobile communication systems, the base station plays the role of the listener, and the active cellular telephones simulate the role of the several sounds heard by human ears. The principle of a smart antenna system is illustrated in Figure 4. A digital signal processor located at the base station works in conjunction with the antenna array and is responsible for adjusting various system parameters to filter out any interferers or signals-not-of-interest (SNOI) while enhancing desired communication or signals-of-interest (SOI). Thus, the system forms the radiation pattern in an adaptive manner, responding dynamically to the signal environment and its alterations. The principle of beam forming is essentially to weight the transmit signals in such a way that the receiver obtains a constructive superposition of different signal parts. Note that some knowledge of the transmission channel at the transmitter is necessary in order for beam forming to be feasible.

2. SMART ANTENNA CONFIGURATIONS

Basically, there are two major configurations of smart antennas Switched-Beam: A finite number of fixed, predefined patterns or combining strategies (sectors). Adaptive Array: A theoretically infinite number of patterns (scenario-based) that are adjusted in real time according to the spatial changes of SOIs and SNOIs. In the presence of a low level interference, both types of smart antennas provide significant gains over the conventional satirized systems. However, when a high level interference is present, the interference rejection capability of the adaptive systems provides significantly more coverage than either the conventional or switched beam system (Shiu et al., 1998). Figure 5 below

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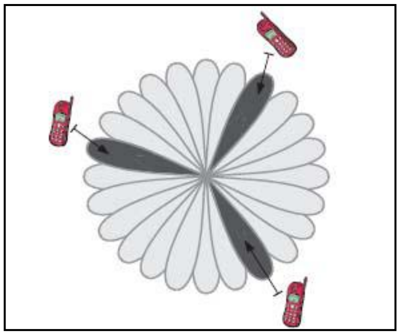

Figure 8

Switched-beam coverage patterns

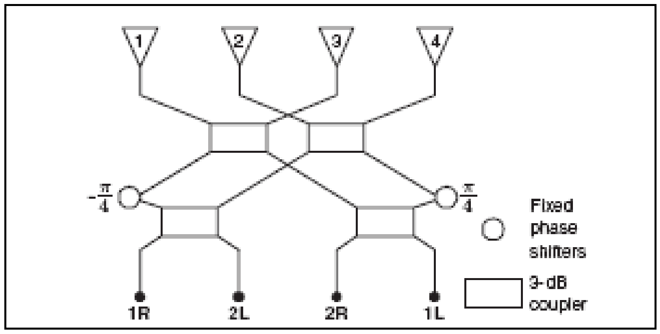

Figure 9

A schematic diagram of a 4 × 4 Butler matrix

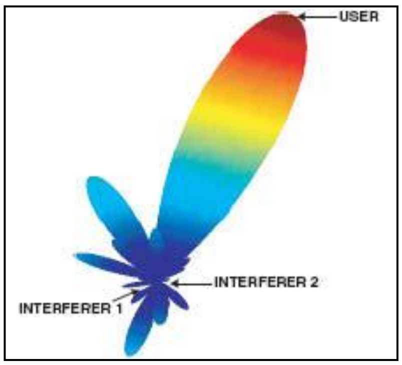

Figure 10

Adaptive array coverage: A representative depiction of a main lobe extending toward a with nulls directed toward two co-channel interferers

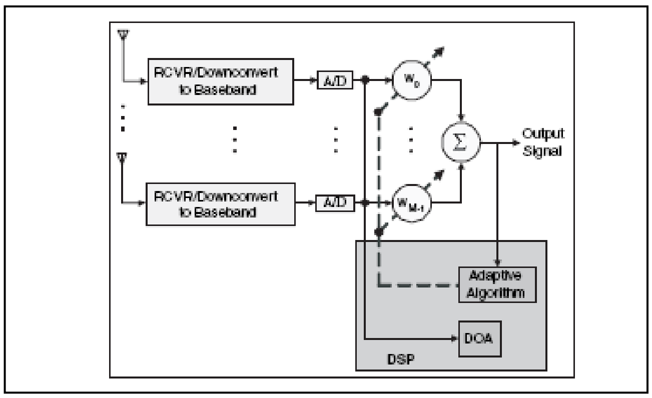

Figure 11

Functional block diagram of an adaptive array system

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 sector zed systems. The low level of Interference environment on the left represents a new wireless system with lower penetration levels. However the environment with a significant level of interference other 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 systems (Shiu et al., 1982).

Now, let us assume that a signal of interest and two co-channel interferers arrive at the base station of a communications system employing smart antennas. Figure 6 illustrates the beam patterns that each configuration may form to adapt to this scenario. The switched-beam system is shown on the left while the adaptive system is shown on the right. The light lines indicate the signal of interest while the dark lines display the direction of the co-channel interfering signals. Both systems direct the lobe with the greatest intensity in the general direction of the signal of interest. However, switched fixed beams achieve coarser pattern. The adaptive system chooses a more accurate placement, thus providing greater signal enhancement. Similarly, the interfering signals arrive at places of lower intensity outside the main lobe, but again the adaptive system places these signals at the lowest possible gain points. The adaptive array concept ideally ensures that the main signal receives maximum enhancement while the interfering signals receive maximum suppression (Figure 7).

3. SWITCHED-BEAM ANTENNAS

A switched-beam system is the simplest smart antenna technique. It forms multiple fixed beams with heightened sensitivity in particular directions. Such an antenna system detects sign strength, chooses from one of several predetermined fixed beams, and switches from one beam to another as the cellular phone moves throughout the sector, as illustrated in Figure 8. The switched-beam, which is based on a basic switching function, can select the beam that gives the strongest received signal. By changing the phase differences of the signals used to feed the antenna elements or received from them, the main beam can be driven in different directions throughout space. Instead of shaping the directional antenna pattern, the switched-beam systems combine the outputs of multiple antennas in such away as to form narrow satirized (directional) beams with more spatial selectivity that can be achieved with conventional, single-element approaches. Other sources in the literature define this concept as phased array or multi beam antenna. Such a configuration consists of either a number of fixed beams with one beam turned in toward the desired signal or a single beam (formed by phase adjustment only) that is steered toward the desired signal. A more generalized to the Switched-Lobe concept is the Dynamical Phased Array (DPA). In this concept, a direction of arrival (DOA) algorithm is embedded in the system (Shiu et al., 1982). The DOA is first estimated and then different parameters in the system are adjusted in accordance with the desired steering angle. In this way the received power is maximized but with the trade-off of more complicated antenna designs. The elements used in these arrays must be

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connected to the sources and/or receivers by feed networks. One of the most widely-known multiple beam forming networks is the Butler matrix (Butler et al., 1961; Lo et al., 1988). It is a linear, passive feeding, N × N network with beam steering capabilities for phased array antennas with N outputs connected to antenna elements and N inputs or beam ports. The Butler matrix performs a spatial fast Fourier transform and provides Orthogonal beams, where N should be an integer power of 2 (Dietrich et al., 1988). These beams are linear independent combinations of the array element patterns. A Butler matrix-fed array can cover a sector of up to 360◦ depending on element patterns and spacing. Each beam can be used by a dedicated transmitter and/or receiver and the appropriate beam can be selected using an RF switch. A Butler matrix can also be used to steer the beam of a circular array by exciting the Butler matrix beam ports with amplitude and phase weighted inputs followed by a variable uniform phase taper (Dietrich et al., 1988). The only required transmit/receive chain combines alternate rows of hybrid junctions (or directional couplers) and fixed phase shifters (Desmond et al., 2001). Figure 9 shows a schematic diagram of a 4 × 4Butler matrix.

4. ADAPTIVE ANTENNA APPROACH

The adaptive antenna systems approach communication between a user and a base station in different way by adding the dimension of space. By adjusting to the RF environment as it changes (or the spatial origin of signals), adaptive antenna technology can dynamically alter the signal patterns to optimize the performance of the wireless system. Adaptive array systems (IEEE Transaction d et al., 1976) provide more degrees of freedom since they have the ability to adapt in real time the radiation pattern to the RF signal environment; in other words, they can direct the main beam toward the pilot signal or SOI while suppressing the antenna pattern in the direction of the interferers or SNOIs. To put it simply, adaptive array systems can customize an appropriate radiation pattern for each individual user. Figure 10 illustrates the general idea of an adaptive antenna system. The adaptive concept is far superior to the performance of a switched-beam system, as it is shown in Figure 10. Also, it shows that switched-beam system not only may not be able to place the desired signal at the maximum of the main lobe, but also it exhibits inability to fully reject the interferers. Because of the ability to control the overall radiation patterning a greater coverage area for each cell site, as illustrated in Fig. above adaptive array systems can provide great increase in capacity. Adaptive array systems can locate and track signals (users and interferers) and dynamically adjust the antenna pattern to enhance reception while minimizing interference using signal processing algorithms. A functional block diagram of the digital signal processing part of an adaptive array antenna system is shown in Figure 10.

After the system down converts the received signals to base band and digitizes them, it locates the SOI using the direction-of-arrival (DOA) algorithm, and it continuously tracks the SOI and SNOIs by dynamically changing the complex weights(amplitudes and phases of the antenna elements). Basically, the DOA computes the direction-of-arrival of all the signals by computing the time delays between the antenna elements, and afterward, the adaptive algorithm, using a cost function, computes the appropriate weights that result in an optimum radiation pattern. Because adaptive arrays are generally more digital processing intensive and require a complete RF portion of the transceiver behind each antenna element, they tend to be more expensivethanswitchedbeamsystems.Adaptive arrays utilize sophisticated signal-processing algorithms to continuously distinguish between desired signals, multi path, and interfering signals, as well as calculate their Directions of Arrival (DOA). This approach updates it's transmit strategy continuously based on changes in both the desired and interfering signal locations. A number of well-documented algorithms exist for estimating the DOA; for example, MUSIC, ESPRIT, or SAGE. These algorithms, which are discussed, make use of a data matrix with the array snapshots collected within the coherence time of the channel. 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. Figure 11 illustrates the beams of a fully adaptive antenna system supporting two users.

In adaptive beam forming techniques, two main strategies are distinguished. The first one is based on the assumption that part of the desired signal is already known through the use of a training sequence. This known signal is then compared with what is received, and the weights are then adjusted to minimize the Mean Square Error (MSE) between the known and the received signals. In this way, the beam pattern can be adjusted to null the interferers. This approach optimizes the signal-to-interference ratio (SIR), and is applicable to non-line-of-sight (NLOS) environments (Do-Hong et al., 2004). Since the weights are updated according to the incoming signals, not only the interference is reduced but the multipart fading is also mitigated. In the second one, the directions of arrivals from all sources transmitting signals to the array antenna are first identified. The complex weights are then adjusted to produce a maximum toward the desired angle and null toward interfering signals. This strategy may turn out to be deficient in practical scenarios where there are too many DOAs due to multi paths, and the algorithms are more likely to fail in properly detecting them. This is more likely to occur in NLOS environments where there are many local scatters close to the users and the base station, thus resulting in a widespread of the angle of arrival (Do-Hong et al., 2004). Another significant advantage of the adaptive antenna systems is the ability to share spectrum. Because of the accurate tracking and robust interference rejection capabilities, multiple users can share the same conventional

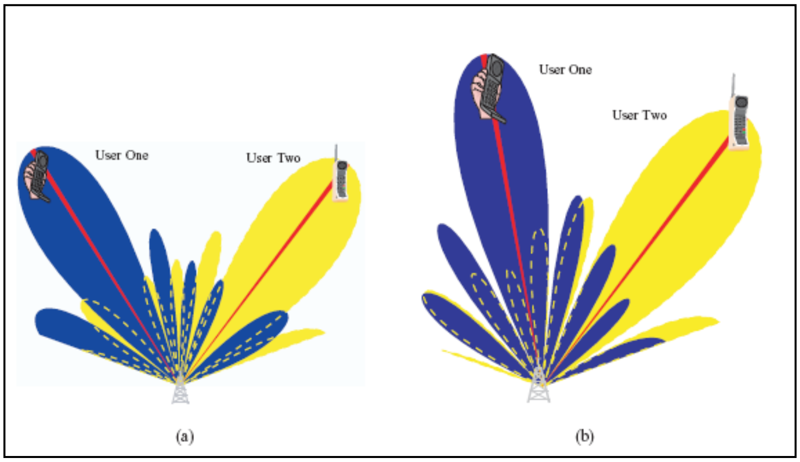

Figure 12

Fully adaptive spatial processing supporting two users on the same conventional channel simultaneously in the same cell

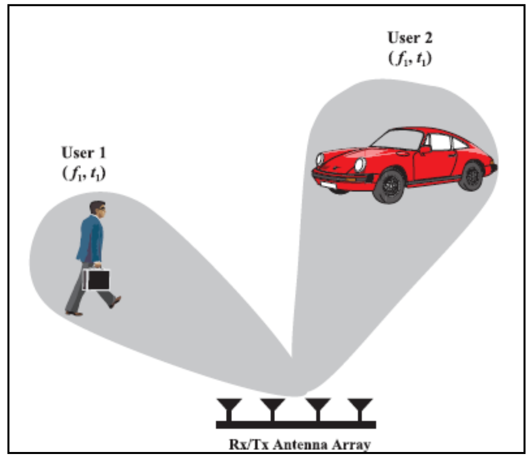

Figure 14

SDMA concept

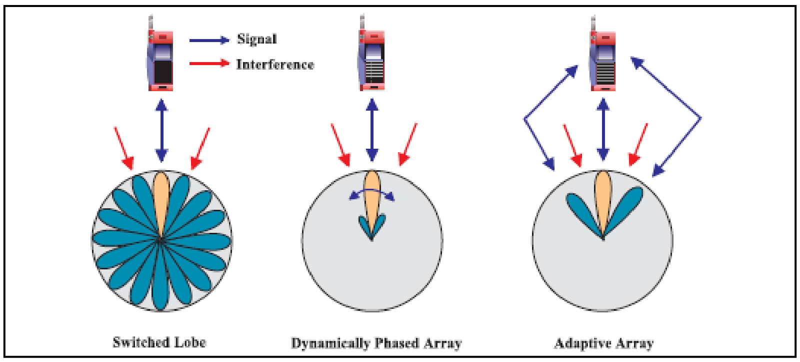

Figure 13

Different smart antenna concepts

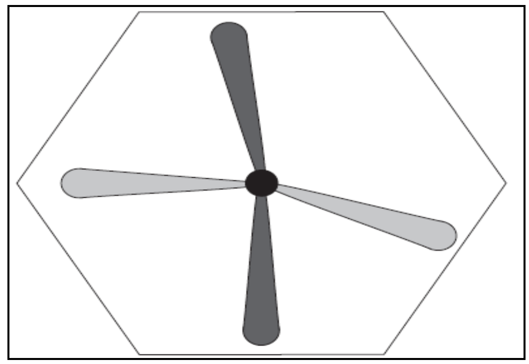

Figure15

Channel reuse via angular separation

channel within the same cell. System capacity increases through lower inter-cell frequency reuse patterns as well as intra-cell frequency reuse. Fig. above shows how adaptive antenna approach can be used to support simultaneously two users in the same cell on the same conventional channel. In each of the two plots, the pattern on the left is used to communicate with the user on the left while the pattern on the right is used to talk with the user on the right. The drawn lines delineate the actual direction of each signal. Notice that as the signals travel down the indicated line toward the base station, the signal from the right user arrives at a null of the left pattern or minimum gain point and vice versa. As the users move, beam patterns are constantly updated to insure these positions. The plot at the bottom of the figure shows how the beam patterns have dynamically changed to insure maximum signal quality as one user moves toward the other. Figure 12 summarizes the different smart antenna concepts and the functions of each one.

5. SPACE DIVISION MULTIPLE ACCESS (SDMA)

A concept completely different from the previously described multiple access schemes, is the spatial division multiple access (SDMA) scheme. SDMA systems utilize techniques by which signals are distinguished at the BS based on their origin in space. They are usually used in conjunction with FDMA, TDMA, or CDMA in order to provide the latter with the additional ability to explore the spatial properties of the signals (Thrassyvoulou et al., 2003). SDMA is among the most sophisticated utilizations of smart antenna technology; it's advanced spatial processing capability enables it to locate many users, creating different beams for each user, as shown in Figure 13 below The SDMA scheme is based upon the concept that a signal arriving from a distant source reaches different antennas in an array at different times due to their spatial distribution. This delay is utilized to differentiate one or more users in one area from those in another area. The scheme allows an effective transmission to take place in one cell without disturbing a simultaneous transmission in another cell. For example, conventional GSM/GPRS allows one user at a time to transmit or receive in

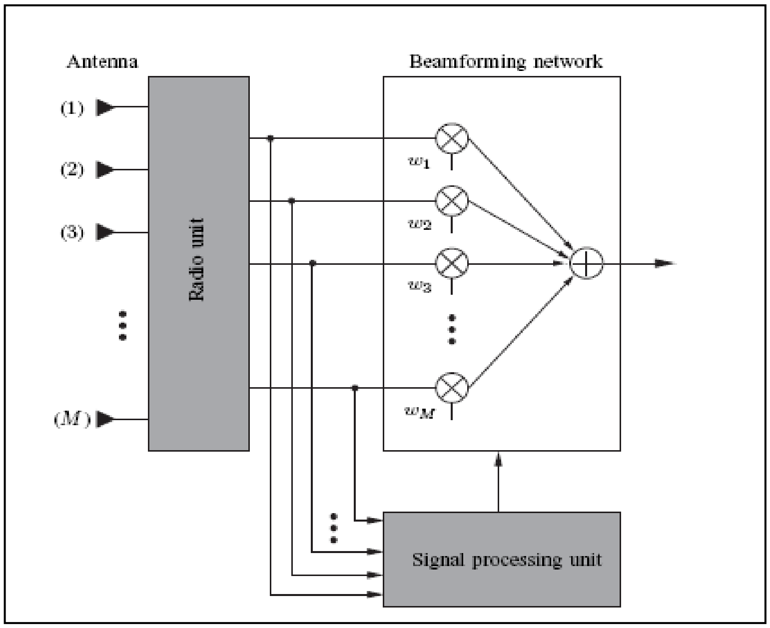

Figure 16

Reception part of a smart antenna

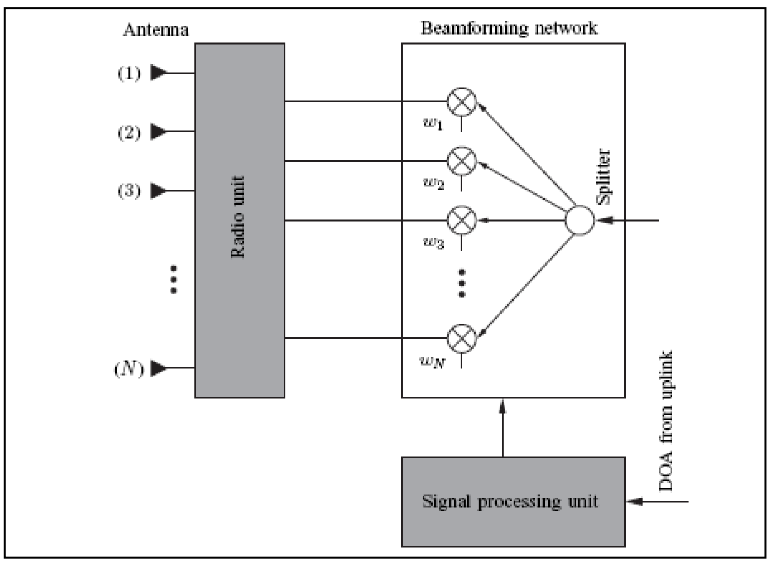

Figure 17

Transmission part of a smart antenna

a frequency band to the base station, where GSM/GPRS with SDMA allows multiple simultaneous transmissions in that same frequency band, multiplying the capacity of the system. CDMA system capacity is limited by its SIR; hence, with SDMA boosting the SIR in the system, more users will be allowed access by the network. Filtering in the space domain can separate spectrally and temporally overlapping signals from multiple mobile units and it enables multiple users within the same radio cell to be accommodated on the same frequency and time slot, as illustrated in Figure 14. This means that more than one user can be allocated to the same physical communication channel in the same cell simultaneously, with only separation in angle. This is accomplished by having N parallel beam formers at the base station operating independently, where each beam former has its own adaptive beam forming algorithm to control its own set of weights and its own direction-of arrival algorithm (DOA) to determine the time delay of each user's signal (Shad et al., 2001; Ung et al., 2001).

Each beam former creates a maximum toward its desired user while nulling or attenuating the other users. This technology dramatically improves the interference suppression capability while greatly increases frequency reuse resulting in increased capacity and reduced infrastructure cost. With SDMA, several mobiles can share the same frequency within a cell. Multiple signals arriving at the base station can be separated by the base station receiver as long as their angular separation is larger than the transmit/receive beam widths. This is shown in Figure 15. The beams that have the same shading use the same frequency band. This technique is called channel reuse via angular separation. Methods acting against fading are required for high data rate and highly reliable mobile communication systems (Ghavami et al., 2002). A SDMA system is an effective measure to cope with fading, since it distinguishes radio signals in space or angular domain by using antenna directivity or beam forming according to the direction of arrival (DOA) of signals (Litva et al., 1996).

6. ARCHITECTURE OF A SMART ANTENNA SYSTEM

Any wireless system can be separated to its reception and transmission parts. Because of the advanced functions in a smart antennas system, there is a greater need forgetter co-operation between its reception and transmission parts. Figure 16 below shows schematically the block diagram of the reception part of wireless system employing a smart antenna with M elements. In addition to the antenna itself, it contains a radio unit, a beam forming unit, and a signal processing unit (Lehne et al., 1999). The number of elements in the array should be relatively low (the minimum required), in order to avoid unnecessarily high complexity in the signal processing unit. Array antennas can be one, two, and three-dimensional, depending on the dimension of space one wants to access. The first fig shows different array geometries that can be applied in adaptive antennas implementations (Lehne et al., 1999). The first structure is used primarily for beam forming in the horizontal plane (azimuth) only. This will normally be sufficient for outdoor environments, at least in large cells. The example shows a one-dimensional linear array with uniform element spacing of x. Such a structure can perform beam forming in one plane within an angular sector. This is the most common structure due to its low complexity. The estimate of the weights can be optimized using one of the two main criteria depending on the application and complexity: Maximization of the power of the received signal from the desired user (e.g.,switched beam or phased array), or Maximization of the SIR by suppressing the signal received from the interference sources (adaptive array).In theory, with M antenna elements M− 1 sources of interference can be "nulled out", but this number will normally be lower due to the multipath propagation environment. The method for calculating the weights differs depending on the type of optimization criterion. When the switched-beam (SB) is used, the receiver will test all the predefined weight vectors corresponding to the beam set) and choose the best one giving the strongest received signal level. If the phased array approach (PA) is used, which consists of directing a maximum gain beam toward the strongest signal component, the weights are calculated after the direction-of-arrival (DOA) is first estimated.

6.1. Transmitter

Normally the adaptive process is applied to the uplink/reception only (from the mobile to the base station). In that case the mobile unit consumes less transmission power, and the operational time of the battery is extended. However, the benefits of adaptation are very limited; if no beam forming is applied in the downlink transmission (from the base station to the mobile). In principle, the methods used in the uplink can be carried over the downlink .The transmission part of a smart antenna system is schematically similar to its reception part as shown in Figure 17. The signal is split into N branches, which are weighted by the complex weights w1, w2. . . wN in the lobe forming unit. The signal-processing unit calculates suitably the weights, which form the radiation pattern in the downlink direction. The radio unit consists of D/A converters and the up-converter chains. In practice, some components, such as the antennas themselves and the DSP, will be the same as in reception. The principal difference between uplink and downlink is that since there are no smart antennas applied to the user terminals (mobile stations); there is only limited knowledge of the Channel State Information (CSI) available. Therefore, the optimum beam forming in downlink is difficult and the same performance as the uplink cannot be achieved.

Typically there exist two approaches to overcome this impairment. The first one is to devise methods that do not require any CSI, but with somewhat limited performance gain. The second one is the assumption of directional reciprocity, i.e., the direction from which the signal is arrived on the uplink is closely related to the downlink CSI. This assumption has been strengthened by recent experimental results. Physically an adaptive antenna looks very much like an ordinary antenna but has built-in electronics and control software. It cooperates with the receiver's adaptive control system in real time. It may also communicate interactively with the cellular radio network control system. Smart antenna techniques have only recently been considered for implementation in land mobile stations and vehicle installed units because of their high system complexity and large power consumption (Thompson et al. 1996). A number of smart antenna arrays for base station applications have already been proposed in. However, only limited efforts have been yet considered for developing adaptive antenna array receivers suitable for handsets (Thompson et al. 1996). In fact, there exist several practical difficulties with the implementation of such a solution at the handset level. These are: The space on the handset device is limited and does not allow the implementation of an antenna array with number of elements necessary enough for efficient spatial signal processing. In addition, two (or multiple) antennas in proximity may reduce the effectiveness of the antenna system due to coupling. The problem related to the movement of the mobile that provides an Omni directional scenario. The cost and the complexity of the implementation at every mobile is much greater than the implementation at each base radio station. Besides these difficulties, the adaptive algorithm for signal processing at the handset must be fast; however it needs only a few simple calculations, and requires a simple hardware implementation. To justify further research efforts in employing multiple antennas at handsets, the gain in performance should be large enough to offset the additional cost and power consumption. Finally, it can be stressed that the use of digital beam forming antennas, both in satellites and in land-fixed and mobile units, remains a challenge for future satellite communication systems.

7. CONCLUSION

In conclusion to this paper "Evaluation of Smart Antenna for 3 G Network: a Survey" systems are the antennas with intelligence and the radiation pattern can be varied without being mechanically changed. Smart Antenna technology has been introduced which is used for reducing interference. From a technology point of view, smart antennas can be seen as an extension of the "conventional" resource allocation schemes used in radio communications. In addition to dividing the space into cells, it will now also be possible to employ space division inside each cell. Different degrees of utilization of the spatial dimension are possible, and different steps have been described here.

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