Development of Smart Antenna For Future Generation Wireless Internet Connection

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Abstract

The adoption of smart antenna techniques in future wireless systems is expected to have a significant impact on the efficient use of the spectrum, the minimization of the cost of establishing new wireless networks, the optimization of service quality, and realization of transparent operation across multi technology wireless networks. Nevertheless, its success relies on two considerations that have been often overlooked when investigating smart antenna technologies.

INTRODUCTION

Over the last few years, a wide variety of 'smart' antenna technologies have been proposed as potential techniques for improving the spectrum efficiency of cellular radio systems. 'Smart' in this context, means either using antennas with multiple radiating elements to increase the directivity of the antenna beam so as to enhance the signal at the intended receiver without causing interference to other radio users, or using multiple receive/transmit antenna channels simultaneously in order to increase reliability and hence data capacity of the link.

This part of the study has shown that there are significant advantages to installing smart antenna techniques in terms of spectrum efficiency and hence the provision of new radio services to users in the crowded cellular spectrum. However, these advantages are only likely to be realized if operators have a clear migration path from current practice and are not discouraged from investing by the spectrum regulatory environment. From our studies, it appears that the proposed low-cost semi-smart technique offers an excellent migration path for the improvements of cellular networks at minimum complexity and cost, when compared to conventional smart-antenna techniques.

Wireless networks face ever-increasing demands on their spectrum and infrastructure resources. Increased minutes of use, capacity-intensive data applications and the steady growth of worldwide wireless subscribers mean carriers will have to find effective ways to accommodate increased wireless traffic in their networks. Smart antennas have emerged as potentially a leading technology for achieving highly efficient networks which maximize capacity and improve quality and coverage.

Smart antennas can provide greater capacity and performance benefits than standard antennas because they can be used to customize and fine-tune antenna coverage patterns that match the traffic conditions in a wireless network or that are better suited to complex radio frequency (RF) environments. Furthermore, smart antennas provide maximum flexibility by enabling wireless network operators to change antenna patterns to adjust to the changing traffic or RF conditions in the network.

There is little doubt regarding the ability of smart antenna technologies to make more efficient use of spectrum in wireless systems and to enhance overall quality of service to wirele9ss users. Commercial deployments of smart antenna arrays for macro-cellular base stations have already appeared in some countries, but various issues are still hampering the wide adoption of the technology in today's systems.

Objectives and Work Packages

The main objective of the project is to demonstrate an improvement of system capacity by deploying the semi-smart antenna into cellular base stations without introducing substantial infrastructural modifications.The work was divided into three work packages (WPs), each led by one of the participating partners.**WP1** aimed to identify the key obstacles in the development of proposed smart antenna systems and to address the breakthroughs needed to overcome these obstacles. The study involved a detailed evaluation of the technical, standard and business issues raised by employing smart antenna systems and suggesting possible solutions.**WP2** involved the study of semi-smart antenna systems and traffic load balancing algorithms. The study involved development of a novel optimization algorithm and system level simulations on 3G UMTS/W-CDMA networks using real topological traffic data. The study also covered the hardware aspects of this technology and built a prototype system to demonstrate the feasibility of this technique.Finally**, WP3** studied the regulatory issues and additional benefits of deploying such systems. The study involved an extensive literature survey and discussions with UK/EC and Chinese network operators and antenna manufacturers.

Classes of smart antennas

A typical mobile radio base station uses three antennas oriented mutually at 120º in azimuth and having individual 3-dB beamwidths of around 65º. Alternative schemes have been proposed in which each 120º sector is served by an array of multiple antennas provided with a passive beamforming network able to form several separate narrow beams spread across the sector. These *switched fixed beam antennas* have been shown to provide increased total capacity in the cell, as they reject interference coming from many directions and provide more gain – at least near beam centers – than would be achieved by the standard wider-beamwidth sector antenna. Antennas of this type have been marketed in the USA and elsewhere, but have not been sufficiently successful to capture a significant share of the market and a number of products have been withdrawn from sale.

There are various methods of combining the outputs of several antennas forming a broadside array. The methods can be broadly classified as:

- ***Switched fixed beam arrays***. These arrays operate as described above. They are the simplest to understand and require minimum hardware to create and manage the multiple beams. The same beam is chosen for the uplink as the downlink. It will be appreciated that several beams will be needed to serve dispersed users. The apparent simplicity of this technique is compromised by the need to identify individual users and steer beams towards them.

• ***Direction finding arrays.*** These arrays are connected to a processor which determines the effective bearing of the incoming signals and forms a single beam in the determined direction, enhancing the signal-to-interference plus noise ratio (SINR) of a wanted signal. Information on the direction of arrival of the uplink signal is used to steer the corresponding downlink signal. Multiple beams are formed to serve multiple dispersed users.

• ***Optimum combining arrays.*** The processing for these arrays adds all the available signal power – which may be contained in a number of components dispersed in angle of arrival and with differing phase and amplitude – in such a manner as to optimize the SINR. This technique provides excellent uplink characteristics, but the downlink signal can only be pointed in the direction of the average or maximum incoming signal unless there is feedback from the mobile. Once more, serving multiple users requires a complex system.

• ***Space division multiple access*** (SDMA). In this scheme the processing creates a number of spatially separate beams within each sector (Figure 2-1). Each beam is directed at a different user who can share channel resources (such as the frequency, spreading code or burst time) with the other users. The extent to which sharing is possible depends on how narrow and well-defined the individual beams are and the amount of scattering in the radio propagation environment which limits the minimum angle of arrival possible. SDMA requires a more intelligent and dynamic version of a beam-forming array with multiple concurrent inputs/outputs.

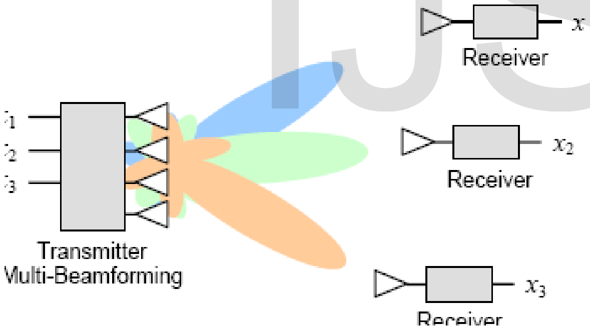


Figure 2-1: The concept of an SDMA system. The users can share spectral resources because they are served by different beams provided by the antenna

• ***Spatial filtering for interference reduction (SFIR).*** This scheme operates by using spatial (angular) separation of wanted and unwanted signals; as well as adding wanted signal components it forms nulls in the direction of interfering signals. This approach may allow closer frequency re-use than would conventionally be obtained with fixed antennas.

• ***Opportunistic beam forming*** is a cross layer technique that can be applied to a system in which a beam can be formed and randomly steered over a sector. If there is a large number of users in the sector it is probable that for some of them the beam configuration and propagation conditions are such that the signal path from the base station is optimal at the moment the beam intersects the MS. Data is then fed at the highest possible rate to the users.

• These classes provides a summary of the advantages and disadvantages of these schemes, as shown in Table 2-1.

Scheme	**Advantages**	**Disadvantages**
Switched fixed beams	Easily deployed Tracking at beam switching rate	Low gain between the beams Limited interference suppression False locking, shadowing, interference and wide angular spread
Direction finding	Tracking at angular rate of change No reference signal is required Easier downlink beamforming	Lower overall CIR gain Susceptible to signal modelling inaccuracies, needs calibration Concept is not applicable to small cell, non line-of sight environments.
Optimum combining	Optimum gain in SINR No need for accurate calibration Performs well even when the number of elements is smaller than the number of signals	Difficult downlink beamforming with FDD Needs a good reference signal for optimum performance Requires frequent updating as the target moves and signal conditions change
SDMA	No need for revised frequency planning to exploit capacity gain Single cell deployment is possible for local capacity gain	Requires discrimination between intracell SDMA users More complex radio resource management (angle and power)
SFIR	No need for major air interface changes Only minor changes to radio resource management	Relies on intelligent intracell handover Large deployments are necessary to exploit the full capacity potentials

Table 2-1: Summary of alternative smart antenna schemes

Issues in deploying smart antennas in mobile radio networks

Any smart antenna system proposed for use in existing networks must show significant advantages in terms of cost, performance and environmental acceptability relative to established current practice and the new techniques now being introduced.

There is little doubt that smart antennas would be adopted if the potential advantages claimed for them could be realized in practice with no corresponding disadvantages. The commercial and practical realities that influence the possible adoption of smart antennas in mobile radio systems relate to:

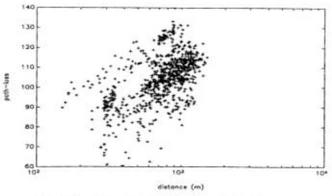
- The nature of the radio environment;
- The selection of transmission standards;
- The relative practicability and costs of other available techniques that can be adopted to increase the coverage and capacity of networks;
- Environmental considerations – size and visual profile;
- Practical concerns about complex outdoor electronics systems;
- Business and cost issues;
- Regulatory concerns.

These considerations interact with one another and it is difficult to place them in a clear order of priority.

A mobile device with which communication is established is known as a *mobile station* (MS) in GSM system and user *equipment* (UE) in UMTS terminology. A base station is known as a *base transceiver station* (BTS) in GSM and a *Node-B* in UMTS. To avoid duplication the UMTS (IMT-2000, 3G) terms will generally be used in abbreviations in the discussion below. Many of the comments relate to both systems and specific comments are made where a generally comparable situation does not exist between them.

Path loss between the mobile and the base station

In an ideal environment there would be a smooth relationship between the signal strength at any point and the distance between the point and the base station. In practice this relationship is often very chaotic. Figure 2-2 shows path loss as a function of distance as measured in an urban cell in Toronto.



Scatter plot of path length v distance in an urban cell in Toronto
(Sousa et al. 1995)

Figure 2-2: The pass loss as a function of distance (as measured in an urban cell in Toronto

Three distinct mechanisms are usually identified as being responsible for this chaotic relationship:

- Distance-dependent path loss;
- Shadowing by terrain features and buildings (seen as *slow fading* by a moving user);
- Multipath fading (seen as *fast fading* by a moving user).

Distance-dependent loss

Distance-dependent loss is sometimes called *spreading loss* and is addressed by choosing an appropriate spacing between base stations and the provision of enough RF power, receiver sensitivity and antenna gain to provide coverage of the terrain round the base station. If we include the loss that occurs beyond line-of-sight propagation, then we can reduce the transmission loss and increase the coverage of the base station by increasing the antenna height. The disadvantage is that we will probably increase the level of signals received in adjacent cells, impairing frequency re-use and reducing the spectral efficiency of the network.

The typical dependence of propagation loss on distance *d* in the mobile radio environment is usually assumed to be proportional to about *d3.8*. Even in a city built on level terrain this severely limits the distance to which coverage can be extended from a base station even by using a very directional high-gain antenna.

Shadowing

Shadowing is the obstruction of some parts of the intended coverage area by terrain features or major fixed structures. It can be reduced to some extent by careful choice of the base station location, but apart from raising the base station antenna there is little that can be done to overcome it. Severe shadowing loss may make it necessary to fill a coverage hole with an additional cell or microcell.

Multipath fading

Multipath fading is caused by the arrival at the base station of signals from a mobile which have travelled by different paths, having been reflected from a scattering objects such as buildings, cars and terrain features. The UE is typically within 2m of the ground and these scatterers are typically close to the UE, so at the base station the direct and scattered signals arrive with a small angular spread. To reduce the effect of multipath fading it has been standard practice for many years for the base station to receive two samples of the incoming signal, either at two spatially separate locations, or in two orthogonal polarizations [10]. In the case of spatial diversity the separation between the antennas at the base station effectively defines the angle within which signals will be separately resolved and can cause independent (uncorrelated) fading at the position of the antennas. In the case of polarization diversity the correlation of the signals received at the base station does not depend on the spatial separation of the scatterers, but on the different polarization characteristics of scattered signals.

The adoption of smart antenna techniques does not necessarily remove the effects of multipath fading [11]. If a smart antenna is situated in a position of temporarily low net signal it cannot produce a satisfactory output. Either the elements of the smart antenna must be sufficiently spaced to make it unlikely that fading across the array is correlated – that is to say that the width of the array must be sufficient to allow the resolution of the separate multipath components – or dual-polar operation must be adopted in accordance with present base station practice. Both techniques require additional hardware and processing and substantially increase the cost of the system.

Angular spread

In rural environments the direct and scattered signals arrive at the base station with a small angular spread – typically less than 5° – but in urban environments, especially when the mobile is close to the base station, the angular spread may be as large as 20–30°. SFB arrays or other smart antennas which effectively manipulate narrow beams may be unable to receive all the angularly-dispersed signal components and may in some circumstances provide a lower total signal power than a simple sector antenna.

Delay spread

Signals travelling between the mobile and the base station by different routes will not only arrive from different directions but will experience different propagation times. The time difference between the arrival of the first signal component and the last significant component is known as the delay spread.

Co-channel interference

In general any signal will be received together with signals from other users sharing the same frequency. In a CDMA system the other users (both singly or together) will contribute to a raised noise level determined by the spreading gain, but in other systems a single interfering signal will more directly impair the ability of the receiver to correctly demodulate the wanted signal.

Dynamic range

The power level transmitted by each mobile is dynamically controlled by the base station to ensure that signals from different mobiles arrive with almost the same signal power. It would therefore seem that there is no significant problem of a smart antenna being required to process signals with a wide dynamic range. The minimum received signal level will be that from a mobile located at the margin of the cell, having a signal level which can – by only a small margin – be decoded against thermal noise in the base station receive chain. In busy conditions a higher signal level will be needed, as the threshold will be raised by external noise and interference.

Noise

As with all receiving systems the sensitivity and throughput of the system is limited by noise. This is not just a threshold effect – the data rate that can be obtained is directly proportional to the available signal-to-noise ratio.

The uplink and downlink

In all discussions it is important to remember that the signal path between a Node-B and a UE comprises two links with important differences in their characteristics:

- The *downlink* from the Node-B to the UE. This is characterized by a high power transmitter feeding a high gain antenna at the Node-B, and a low gain antenna feeding a low-noise receiver at the UE.
- The *uplink* from the UE to the Node-B. This is characterized by a low power transmitter with a low gain antenna at the UE, and a high gain receiving antenna at the Node-B.

There is little doubt that the adoption of smart-antenna techniques can increase the utility of radio communications, providing enhanced data rates and improved coverage and spectral utilization. It is argued that the administrative and financial environment of the industry and the current technical standards adopted in the mobile radio industry may not provide the most promising environment for the adoption of these techniques. It has been shown that a wide variety of techniques for the enhancement of the reliability of coverage and increase in network capacity has been applied and will continue to be developed in both GSM and W-CDMA systems. Reference has been made to the promising experience of smart antenna techniques in TDD systems in China, but these are currently only in service in small networks and have not yet been proved in large dense networks in urban environments.

It is also suggested that the financial and environmental constraints to the adoption of enhanced techniques could be resolved to the benefit of the community at large by the adoption of a different model for the ownership and operation of services for future networks. Combined with the specific choice of technical standards that can make best use of the techniques of multiple antennas, this could lead to a significant increase in spectrum efficiency of mobile cellular services in the UK.

Having addressed smart antenna technology in general, we devote the following chapters to the smart antenna technology, which is the main body of the thesis work.

To demonstrate the practicality of the proposed semi-smart antenna, a simplified prototype base station antenna sector has been designed, constructed, measured and validated. A comparison between phase shifters, the key component in smart antennas has also been undertaken.

Experimental smart base station antenna design

The design is based on a cylindrical array consisting of twelve radiating elements whose individual excitations are controlled in order to achieve the desired radiation pattern. The elements are mounted around a cylindrical metallic surface. The four elements comprise the antenna for one base station sector; three sectors, each comprising four elements are used to provide 360° azimuth coverage (Figure 3-5-a).

In our prototype design, a single power amplifier has been assigned to each sector followed by full-power phase and amplitude controllers that are mounted at the top of the tower. However, in order to achieve better coverage capabilities, a stack of the cylindrical arrays would be used in practice to provide sufficient gain and achieve the required elevation half-power beamwidth and facilitate the adjustment of beam tilt by altering the vertical element phase (Figure 3-5-b).

The implementation of the conformal array is based on the following considerations:

Cylinder radius = 245 mm Desired frequency = 2GHz

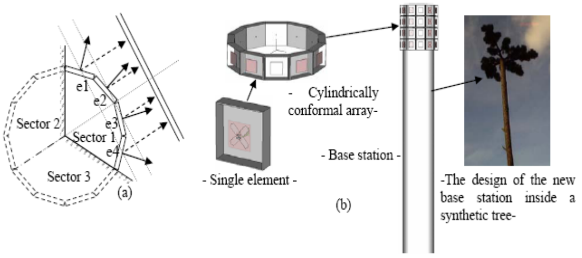


Figure 3-5: (a) A 12-element cylindrically-conformal array. (b) The structure of the proposed base station –stacks of cylindrical arrays

Design of the base station prototype

The design of the base station antenna can be divided into the following areas:

- Modeling and analysis of the antenna element radiation pattern.
- Synthesis and analysis of the array pattern to obtain the element excitations.
- Design of the feed network to obtain the desired excitations.
- Fabrication and testing of an array prototype.

A one-sector prototype consisting of four dipole antenna elements has been fabricated and tested for demonstrating the array operation (Figure 3-6-a). The elements are separated by a half-wavelength and angled at 30° from each another, forming a 120° arc. With such arrangement, the overall base station diameter can be contained within a total radius of 0.5m (Figure 3-6-b).

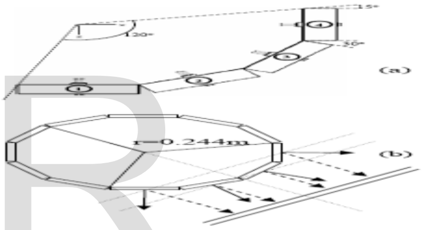


Figure 3-6: A 120° sector antenna consisting of four elements

The sector feed-network has been designed as a 4-way power splitter. Each of the output signals is connected to an independent variable phase-shifter, dynamically adjusted to satisfy the necessary coverage requirements. With this arrangement, amplitude control is regulated by introducing attenuators along each transmission line.

The excitation weight of each element is computed by synthesizing the overall array pattern that is required to be produced by the elements positioned around the cylinder. The contribution of each element to the total radiation is considered individually as the antenna elements do not point in the same azimuth direction. This means that a common element factor is considered individually for elements around the cylindrical array. An adequate synthesis technique is needed for calculating the fields radiated by the cylindrical distribution of element excitations.

In our analysis, the scenario is simplified to an equivalent linear array of unequally spaced elements with each element pattern pointing to various directions. This is achieved by projecting the contribution of each element on a plane perpendicular to the beam pointing direction. This approach has been applied here for simplicity but can be significantly improved by formulating the conformal array directly.

In order to obtain in-phase addition of the signals for the columns of elements, a feed network with appropriate phasing has been designed using phase shifters driven by computer-controlled stepper-motors.

Figure 3-7 shows the components used in building the prototype system which comprises four elements – one element of each column of a full system. The phase shifters used here are based on mechanical movement of a conducting arm around an arc to alter transmission line lengths, a design developed by Jaybeam Ltd [27]. The amplitude control was implemented using four attenuators. The amplitudes and phases of each element are computed by a software code which was developed for this purpose.

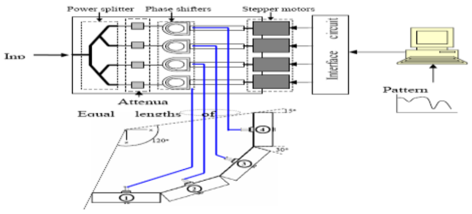


Figure 3-7: A diagram illustrating the main design of the prototype system.

Testing is performed by inputting a desired pattern into the developed software. The program performs numerical synthesis and the best element excitation weight is determined in terms of amplitude and phase. The program then automatically adjusts the phase shifters using the attached stepper motors and prompts the user to adjust the amplitude for each element (which is manually operated in the prototype). The process of altering the amplitude can become much simpler: If a stack of the cylindrical arrays is used it is possible to alter the vertical phases to control the amplitude of the signal radiated at any azimuth angle by the means of elevation pattern tilting.

Many factors influence the design and architecture of a cylindrical array antenna. In order to minimize complexity, it is important to minimize the number of controls necessary to satisfy the radiation coverage requirements.

Design verification

The initial step in the study has involved simulating the antenna element using an electromagnetic simulation code (CST Microwave Studio®)[28]. The modeled single element antenna setup was identical to that of the physical model which was measured independently (Figure 3-8). Figure 3-9 suggests a good agreement between the measured and simulated radiation patterns and the return loss of a single element.

The dipole antennas used in this project, are simple, compact and capable of satisfying the radiation and impedance requirements across a wide frequency band. They can be arranged around the surface of a metallic cylinder (See Figure 3-5-b).

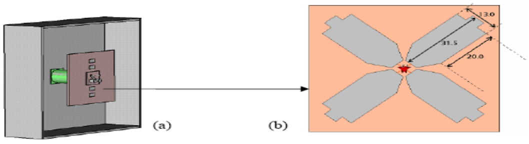


Figure 3-8: (a) A single antenna element consisting of a cross-dipole printed on a substrate and located within a metallic cavity; and (b) the printed dipole configuration.

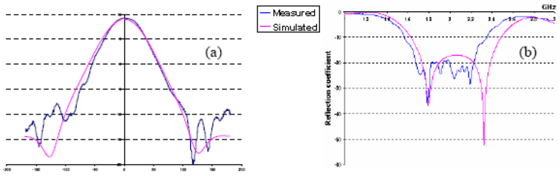


Figure 3-9: A comparison between the simulated and measured radiation patterns and the return loss of a single element.

Further electromagnetic modeling was conducted to test the performance of the 4-element conformal array sector. Figure 3-10 shows the computed radiation patterns which result from commutating the input power among each of the array elements. It can be seen that switching the radiation source from one element to another results in a main beam pointing at directions corresponding to the element azimuth angle (which is 30° in this particular case). Therefore, we can conclude that a full cylindrical array can generate a 360° azimuth scan by switching the input power around the elements pointing in each direction.

Figure 3-11 illustrates the radiation pattern produced when exciting an identical signal source at all of four elements of one sector simultaneously. In this scenario, the resulting main beam points in a direction perpendicular to the centre of the array. It is worth high lighting the fact that arranging the (square) elements around the cylindrical array has resulted in separating the element cavity edges by triangular gaps. These gaps can act as secondary sources which interfere with the overall radiation pattern. To avoid this possibility the gaps have been filled with a conducting material to minimize this effect.

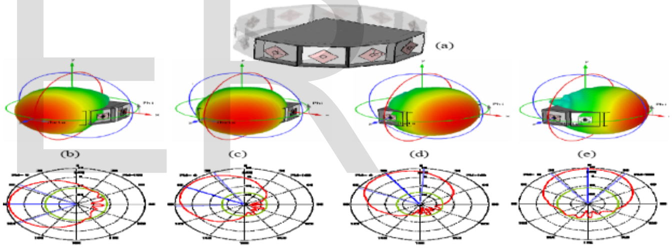


Figure 3-10: Computation of the conformal array sector; (a) illustrates the 4-element sector, and (b, c, d & e) illustrate the radiation pattern generated when switching the entire power into ports 1, 2, 3 or 4 respectively.

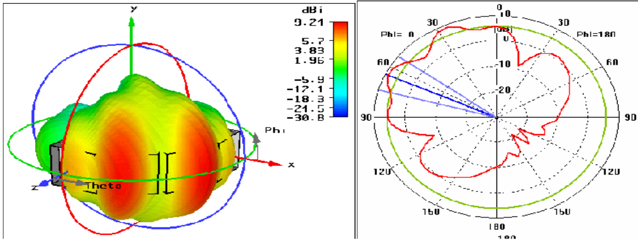


Figure 3-11: Computation of the conformal array sector; (a) a three-dimensional representation of the radiation pattern resulting from exciting all of the four-elements with identical signals, simultaneously, (b)illustrates the radiation pattern in the theta-plane

The performance of the prototype sector antenna has been further investigated by applying different excitation weights at each element. Figure 3-12 shows the radiation patterns produced when exciting the array elements with the following weights:

Element 1: Amplitude = 1.06 Phase = 32.8°
Element 2: Amplitude = 1.06 Phase = 39.6°

Element 3: Amplitude = 0.97 Phase = 0.0°

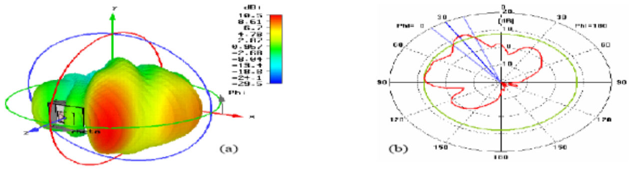


Figure 3-12: Computation of the conformal array sector; (a) a three-dimensional representation of the radiation pattern resulting from using different excitation weights at each of the four-elements, (b) illustrates the radiation pattern in the theta-plane.

The above suggests that this design provides a good means for producing various arbitrary radiation patterns if the appropriate excitation amplitude and phase weights are computed for each of the antenna elements.

Experimental verification of the antenna prototype

Experimental verification of the prototype antenna array has been carried out by performing measurements of the azimuth radiation pattern and comparing the results with electromagnetic simulations.

Several excitation scenarios have been considered, where the excitation amplitudes of each antenna was kept constant and their relative phases were altered. Initially, all of four elements of one sector were fed with identical amplitudes and phases and the azimuth radiation patterns were compared with predictions (See Figure 3-13).

Element 1:	Amplitude = 1.0	Phase = 0°
Element 2:	Amplitude = 1.0	Phase = 0°
Element 3:	Amplitude = 1.0	Phase = 0°
Element 4:	Amplitude = 1.0	Phase = 0°

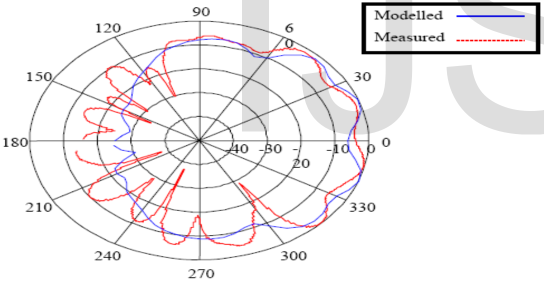


Figure 3-13: A comparison between the measured and computed radiation pattern of the prototype antenna array. In this configuration, the centre of the antenna array points in the 0 degree direction; the excitation amplitudes and phases for all elements were equal.

Figure 3-14 illustrates the radiation patterns of the antenna array when feeding all elements with similar amplitudes and phases shifted by 8 degrees respectively.

Element 1: Amplitude = 1.0	Phase = 0°
Element 2: Amplitude = 1.0	Phase = 8°
Element 3: Amplitude = 1.0	Phase = 16°
Element 4: Amplitude = 1.0	Phase = 24°

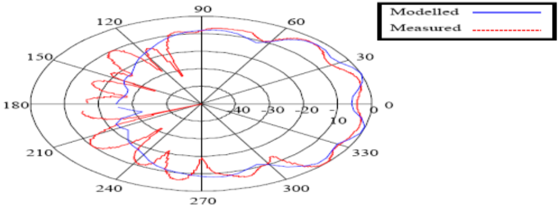


Figure 3-14: A comparison between the measured and computed radiation pattern of the prototype antenna array. In this configuration, the centre of the antenna array pointing in the 0 degree direction; the excitation amplitudes for all elements were equal, and the phases were 0, 8, 16 and 24 degrees for the elements 1, 2, 3 and 4 respectively.

Physical Design

Smart antenna systems consist of multiple antenna elements at the transmitting and/or receiving side of the communication link, whose signals are processed adaptively in order to exploit the spatial dimension of the mobile radio channel. Depending on whether the processing is performed at the transmitter, receiver, or both ends of the communication link, the smart antenna technique is defined as multiple-input single-output (MISO), single-input multiple- output (SIMO), or multiple-input multiple-output (MIMO). Exploitation of the spatial dimension can increase the capacity of the wireless network by improving link quality through the mitigation of a number of impairments of mobile communications, such as multipath fading and co-channel interference, and by increasing the data rate through the simultaneous transmission of multiple streams by different antennas.

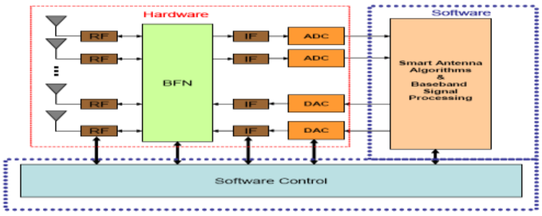


Figure 4-1: Physical Structure of Smart Antenna

In Figure 4-1 we can see that there are many logical relationship between the three fundamental blocks, they are:

- Hardware Block
- Software Block and
- Software Control Block

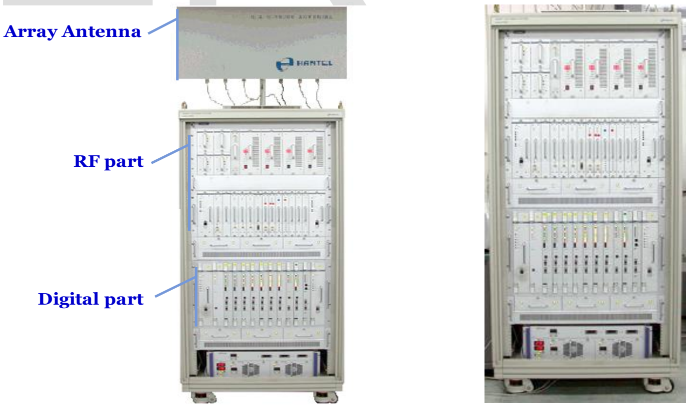


Figure 4-2: Smart Antenna BTS

Three Basic parts of Smart Antenna BTS is shown above.

- Antenna Array
- RF Part
- Digital Part

Detail Architecture of Smart Antenna

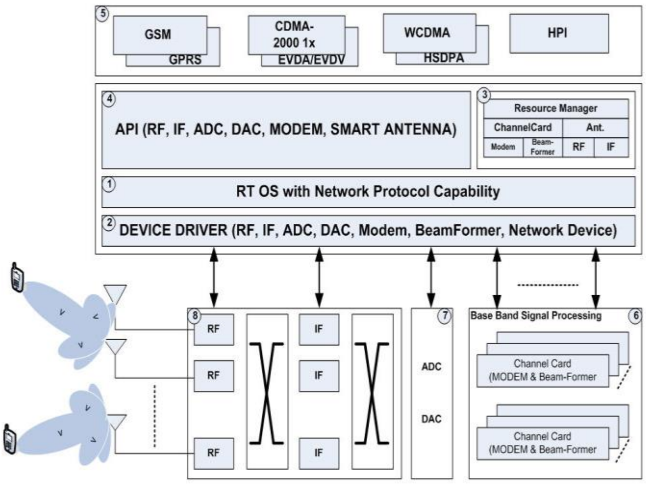


Figure 4-3: Detail architecture of Smart Antenna

Comparing the technical performance of smart antenna designs

An objective of the work in this project has been to provide clear statements about the increase in capacity and spectrum utilization that can be provided by the adoption of smart antenna techniques. However, in attempting to assess the benefits of different algorithms and physical systems and to compare the work of different authors, it is apparent that the wide range of claims made by them are based on comparisons between different parameters of antennas operating in scenarios which cannot be easily related to one another. There are unfortunately no accepted standards of comparison and no standard system models that provide any common context for the making of clear and direct comparisons. This dilutes the value of results and makes it difficult to see the value of potentially useful advances.

Table 6-1: Comparison of Four Antenna Technologies

Characteristic	Dumb	RET only	Semi-smart	Conventional smart
Gain	18dBi	18dBi	18dBi	21dBi
Polarisation	Dual	Dual	Dual	Single
Speed of response	Months	Minutes	Minutes	Milliseconds
Protocol dependence	None	None	Nome	Very dependent Sub-optimal for FDD downlink
Azimuth pattern flexibility	None	None	Medium	High
Origin of control information	n/a	n/a	RNC	BTS/Node-B
Physical size	Baseline = 1	1	4 – 8	4 – 8
Hardware	Familiar	Becoming familiar	Similar to RET	New skills needed
Cost	Low	Low	Medium	High unless protocol is chosen to suit

Advantages of the Smart Antenna

All smart antennas are intrinsically devices which operate in a closed-loop mode of control: the parameters of the antenna are changed in order to maximize some external measure of performance. The smart antenna solution investigated during the present project sets out with comparatively limited objectives, but its control input is at a very high level – it reacts to current patterns of network traffic demand. This is the same level as that required for the control of the RET antennas currently being installed. This high level of control and absence of any requirement for communication with the Node-B / BTS means that the system has many significant advantages compared with more ambitious 'smart' systems.It has many important advantages over more complex techniques:

- Complete indifference to the air interface protocol in use
- No requirement for any feedback from the base station – control is from the radio resource management system.
- No system overhead in the radio access network
- Full multi-channel duplex operation with no degradation of PIM performance
- Symmetrical uplink and downlink improvement
- Maintains polarization diversity on receive
- Maintains the current number of transmit antenna ports
- Compatible with 3GPP transmit diversity
- Can be controlled using the existing industry-standard AISG interface
- Advantage is obtained even when only some base stations are equipped with the solution
- Neighbor lists are not significantly affected by the application of the technique

- No new untried hardware designs are needed – the required phase shifters are already applied in RET antennas
- No additional feeders are needed to the antennas; each of the proposed arrays is fed by a single cable with a single TMA – large cables are not needed between columns.
- The complexity of the antenna system is not dependent on the number of connected transceivers or the number of users to be serviced.

examined the prospects for installing smart antenna technology in order to provide improved spectral efficiency at economic cost. The conclusions are:

- Significant spectrum efficiency can be achieved using smart antenna systems
- There are no agreed standards that can be used to compare cost and benefit of the various schemes that have been proposed. Existing cellular operators are unlikely to install smart antenna technology unless they can identify the best technology to install.
- The cost and effectiveness of installing smart antenna networks is strongly dependent on the selected network protocol, but one of the advantages can be that the network can be shared amongst many operators. This also has other benefits in that it is less physically obtrusive, requires less planning consent and uses lower materials and energy. If Ofcom wishes to promote this technology, it should take into account the economic analysis of Beckman & Smith of the use of neutral networks in developing future licenses. In particular, the use of the broadcast model seems appropriate for this technology.
- Existing networks have been planned to have sufficient capacity without smart antennas.
- There is great potential for smart antennas for cellular networks operated in the 3.5GHz and 5GHz bands

For the main technical focus of this study, the semi-smart approach, there may well be other factors that will be more significant than the spectrum efficiency gain. This includes the ability to handle peak traffic loads without expensive microcells, the lower network planning requirements and the greater network reliability in event of failure.

Summary

We have studied the current state-of-the-art of smart antenna technology in general. The information is derived from

published technical papers and reports, discussions with mobile radio operators worldwide and experience of the design of antenna systems for mobile radio base stations. All of this was with the aim of understanding where the technology is and where we think it may be heading. There is little doubt that the adoption of smart-antenna techniques can increase the utility of radio communications, providing enhanced data rates and improved coverage and spectral utilization. However, it is argued that the administrative and financial environment of the industry and the current technical standards adopted in the mobile radio industry may not provide the most promising environment for the adoption of these techniques. It has been shown that a wide variety of techniques for the enhancement of the reliability of coverage and increase in network capacity has been applied and will continue to be developed in both GSM and W-CDMA systems. Nevertheless, it is promising to learn that the smart antenna techniques in SCDMA systems are currently in service in small scale networks in China (mostly rural and suburban environments). The Chinese 3G standard TD-SCDMA has been engineered to enable the use of smart antennas in the network, although the implementation of the networks using this air interface continues to be delayed.

In summary, the work has further studied that the smart antenna approach has enormous advantages and potential for civilian cellular radio systems and could offer a viable migration path from the current network deployments to the full smart antenna scenario. Further work will therefore be directed to exploiting this potential by working with the industry to standardize the semi-smart concept and system interfaces further.

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