Commission for
Communications Regulation

Briefing Note Series

Smart Antenna Technology

Document No:	**04/52**
Date:	**14th May 2004**

An Coimisiún um Rialáil Cumarsáide
Commission for Communications Regulation
Abbey Court Irish Life Centre Lower Abbey Street Dublin 1 Ireland
Telephone +353 1 804 9600 *Fax* +353 1 804 9680 *Email* info@comreg.ie *Web* www.comreg.ie

Contents

1 Comments on this Briefing Note

We welcome any comments or views on this Briefing Note and these should be sent to:

Jonathan Evans
Market Development
Commission for Communications Regulation
Irish Life Centre
Abbey Street
Dublin 1
Ireland

Tel: +353 1 8049709 Fax: +353 1 8049680
E-mail: jonathan.evans@comreg.ie

to arrive on or before Friday 25th June, 2004.

Comments will be reviewed by ComReg when carrying any out further work on issues covered in this Briefing Note. In submitting comments, respondents are requested to reference the relevant section of this document. Responses will be available for inspection by the public on request. Where elements of any response are deemed confidential, these should be clearly identified and placed in a separate annex to the main document.

Disclaimer
This document does not constitute legal, commercial or technical advice. The Commission for Communication Regulation is not bound by it. This document is issued without prejudice to the legal position of the Commission for Communications Regulation or its rights and duties under relevant legislation and does not form part of any formal tender process.

This document is for information purposes only and is not intended to give any indication of ComReg policies, current or future, relating to any of the issues raised, or to any alternative technologies not included here.

2 Executive Summary

This Briefing Note is issued as part of ComReg's Forward-looking Programme to help raise awareness of smart antenna technology. This is an important new development in the area of commercial wireless communications technology, which could help telecoms operators deliver cost-effective wireless broadband and mobile services to Irish users. Readers may wish to treat this Briefing Note as a reference text that explains the technologies and issues surrounding smart antenna systems in communications networks. This document is primarily intended for non-technical readers with some background knowledge of telecommunications.

Smart antenna systems, sometimes called adaptive antennas, utilise advanced signal processing technology to make more efficient use of radio spectrum. These antenna systems are able to steer their attention to particular directions. This means that while transmitting, radio waves can be limited to the required direction (i.e. in the direction of the recipient – like a spot-light), and when receiving, the device could focus its attention only in the direction from which the desired signal is coming. This results in increased possibilities for an operator to reuse a given portion of spectrum to serve more customers, and in many cases in areas outside of the reach of conventional systems. Smart antenna technology can be applied to both fixed and mobile wireless networks to deliver greater capacities and enhanced services. The potential advantages provided by smart antenna systems are particularly important as operators seek to cost-effectively increase broadband penetration. Smart antenna systems can help make business cases more attractive for potential fixed and mobile wireless operators.

This document begins with an introduction to smart antenna technology in simple and understandable terms. Section 4 describes the main applications in which smart antennas are likely to be used. Section 5 continues by explaining the individual variants of smart antenna technology. Market development and regulatory implications of smart antenna technologies are covered in section 6. ComReg would be pleased to see innovative applications of smart antenna technology – that do not compromise the ability of existing services to function – providing a whole range of broadband wireless access services to Irish telecoms users.

3 Introduction

The widespread adoption of mobile and broadband wireless access is placing additional strain on current spectrum resources[1] in some geographical areas. This is particularly evident in areas of more dense wireless activity (e.g. urban areas) and in certain frequency bands (e.g. mobile, licence exempt, and some fixed wireless access bands). For wireless network operators improved spectrum efficiency can mean greater individual capacity for end-users, the ability to support more end-users, improved quality of service, and greater range. Traditional techniques to increase the amount an operator can get out of allocated spectrum typically involve a trade-off between attributes such as user capacity, quality of service, power, and coverage[2].

Increased efficiency is achieved by controlling the way an antenna transmits and receives radio waves (e.g. by confining the radio waves that they emit to the particular direction of the receiver only when transmitting). This basic principle has long been applied in fixed point-to-point systems where highly directive and focused antennas are used to emit a very narrow beam of radio waves between two fixed points. With this technique the same frequency can be re-used within a smaller area without causing interference between stations[3]. Smart antenna technology enables the direction of the narrow beam to be changed to transmit to different locations, or even follow a mobile user as they move. Smart antenna systems can typically support multiple simultaneous beams, which mean that multiple users can be connected to the same base-station with more efficient narrow focused beams (See Figure 1).

What makes an antenna system smart?

An antenna itself has no intelligence associated with it. It is a passive device that converts between one medium and another - i.e. electromagnetic radiation (radio waves) that carry information through the air and electrical signals that are used in our devices and handsets. An antenna's ability to do this is determined by its physical attributes such as its size shape and what it is made of. Some antennas emit signals equally in all directions[4] (e.g. a mobile handset antenna), but with less range than a more focused one. A focused antenna must be physically orientated towards the other party in the communications link (e.g. a satellite dish has to be physically pointed towards the correct satellite in the sky) because it will not operate in any direction other than where it is pointed.

By combining several antenna elements together and applying some advanced signal processing, intelligence can be introduced to the antenna system (i.e. a 'smart' antenna). The signal processors are able to determine the direction of the incoming

[1] Radio spectrum must be managed so that users can co-exist without interfering with one another. This management of the spectrum may restrict the number of users who can share a piece of spectrum in a particular area.

[2] For example, if an operator with a fixed amount of spectrum wanted to increase the data rates available to its customers the options might be to: (a) increase power levels – reducing the possibility to reuse frequencies at another location, (b) allocate each customer more bandwidth – reducing the number of customers that can be served, (c) install more base-stations – requiring additional expenditure, (d) use a higher form of modulation – reducing quality of service.

[3] This is analogous to using a telescope to focus in on a small segment of the sky, blocking out anything that could be seen in other directions.

[4] This is known as an omni-directional antenna.

radio signal and alter the direction of outgoing radio signals. Similarly, such systems can detect the direction that unwanted signals are coming from and adjust themselves to ignore signals from those directions.

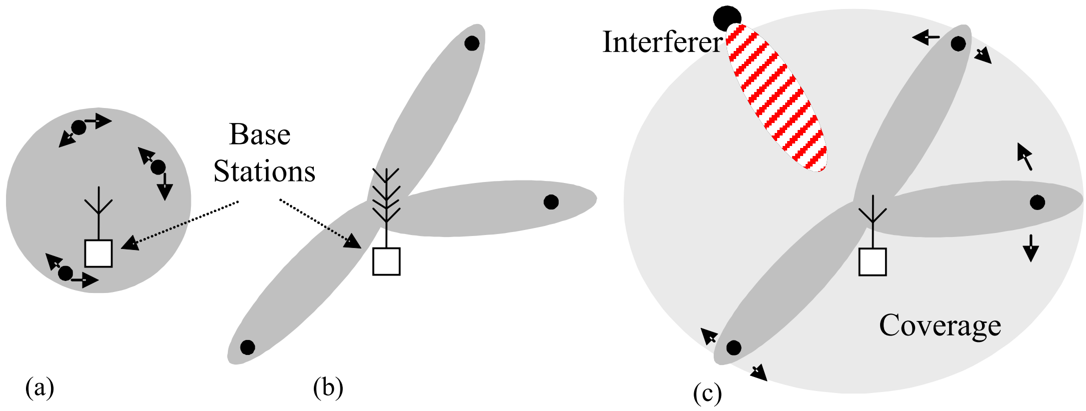

Figure 1. Basic smart antenna operation: (a) Antenna operates in all directions (omnidirectional) and users can be anywhere within the coverage area, (b) Point to multi-point antenna system connects fixed users – i.e. not mobile, (c) smart antenna system enables mobile users with greater range than in (a) and does not emit radio waves in unwanted directions. This antenna system is able to avoid the interfering signal shown.

Although smart antennas have existed in some form since at least the 1930s[5], the most significant developments have occurred since World War II (e.g. long range radar[6] for military systems, radio astronomy[7]). Until relatively recently the sophisticated signal processing needed to enable smart antenna systems was too expensive and difficult to implement for commercial use and this type of technology was therefore confined to military and specialist applications. However, the continued falling costs and increasing performance of digital signal processing technology has now made smart antenna systems a viable prospect for commercial networks. Smart antenna technology is now incorporated in commercially available advanced fixed wireless access systems and some mobile base-stations (see Section 4). In some cases smart antenna technology can be added to existing systems (e.g. wireless LANs, mobile systems) to provide capacity and coverage improvements, while in other cases this technology is emerging as an integral piece of entirely new radio systems (e.g. '4G' mobile systems[8]). This trend is likely to continue as operators seek to increase the capacity they can get from limited spectrum allocations. Furthermore, as technology advancements are made it is likely that smart antenna technology could be applied to more end-user devices, including mobile handsets (see Section 4.1).

---

[5] H.T. Friis, C.B. Feldman, "A multiple unit steerable antenna for short wave reception", *Proc. IRE,* vol. 25, no. 7, p. 841, 1937.

[6] Synthetic Aperture Radar (SAR).

[7] Long Baseline Interferometry (LBI).

[8] Although there is no formal 4G standard, several systems are being described in the technology media as 4G, based on the fact that they can deliver enhanced services compared to 3G systems, combining elements of mobile, wireless LAN and broadcasting as appropriate (e.g. Flarion, Navini, ArrayCom, IPWireless).

4 Applications

Smart antenna technology and techniques could be applied to many wireless communications systems to help increase spectrum efficiency. These techniques are particularly suitable in systems where multiple users need to share a limited amount of spectrum in a given location (e.g. mobile cellular systems).

4.1 Mobile

Smart antenna technology can be deployed to enhance existing mobile systems or as part of more advanced new mobile systems (e.g. 3G). This technology can be used to serve greater numbers of users with higher capacities and better quality of service than conventional antenna systems.

Current smart antenna technologies are generally more suitable for deployment in mobile base-stations than in actual handsets. Mobile base-station towers typically have enough room to mount several antennas. This is much more difficult to achieve on a user handset where size and form are key commercial issues. The power consumption of current smart antenna processors also makes them unsuitable for many mobile applications (i.e. battery life is important in mobile device design). Keeping end-user equipment as simple as possible is also an effective way of keeping costs down. However, as technology develops, smart antenna systems are likely to be increasingly incorporated into mobile devices. A recent study[9] showed that smart antennas in mobile devices could increase data rates by between 20 and 100%, or reduce the number of base-stations needed by up to 15%. Mobile base-stations can be supplied with ample power to operate computationally intensive smart antenna systems. Smart antenna systems can also be used to help provide more accurate positioning information on users in a mobile network (e.g. to assist with emergency services).

There are other advanced mobile systems that do employ multiple antennas in end-user devices to achieve significant enhancements in capacity. These are known as Multiple-In Multiple-Out (MIMO – see Section 5.3.3) systems and can require increased processing power and radio hardware in handsets.

Several mobile equipment manufacturers have developed and deployed base-stations incorporating smart antenna systems (e.g. Ericsson, Siemens, Motorola, Lucent, Nokia, Metawave, etc.). This trend is likely to increase as operators make progress in rolling out 3G mobile networks. Other advanced mobile systems such as those from Flarion, Navini, Arraycomm, or those using standards such as IEEE 802.20, typically rely on smart antenna technology to function.

4.2 Fixed Wireless Broadband Access

4.2.1 Non-line-of-sight (NLOS) systems

Smart antenna systems are already becoming a key part of emerging broadband fixed wireless access networks. In particular smart antenna technology can be used to enhance the operation of non-line-of-sight (NLOS) fixed wireless access systems.

[9] Ofcom in the UK published a report on the potential benefits of smart antenna technology in mobile devices in 2003 – "The Benefits of Adaptive Antennas on Mobile Antenna Systems for 3G", Multiple Access Communications Limited.

NLOS systems are important for providing alternative broadband access in urban areas where the potential number of customers is greatly increased compared to line-of-sight systems. Smart antenna systems are able to do this by capturing and combining signals coming from multiple directions that have been reflected off nearby objects (e.g. buildings) – see Figure 2 below. Some examples of NLOS fixed wireless access systems that can utilise smart antenna systems are made by Navini, Arraycomm, Flarion. Some of these technologies enable portable and even mobile use in addition to standard fixed wireless access scenarios.

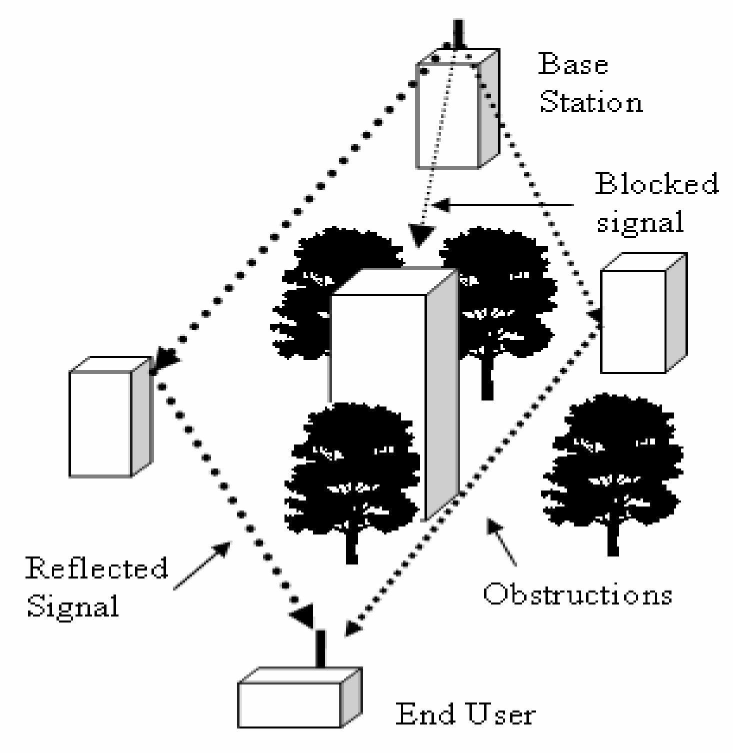

Figure 2. NLOS fixed wireless access system using smart antenna technology.

4.2.2 Re-configurable networks

Smart antenna systems can be used to help cost effectively deploy a wireless network which may need to be re-configured from time to time to accommodate new users. For example if a network operator using traditional wireless technology wishes to move some of its customers to a new base-station to re-balance network traffic, they would typically need to send out an engineer to re-point antennas on base-stations and individual end-users' sites. With smart antenna technology these types of network upgrades can be carried out remotely by changing the direction of the antenna beams. The end-users' antenna systems can be re-configured to point at the new base-station via instructions given over the air.

Some advanced mesh networking technologies are emerging that include the use of smart antenna technology to achieve more efficient spectrum and traffic management (see ad-hoc and mesh networking Briefing Note[10]) e.g. Arraycomm[11].

[10] http://www.comreg.ie/_fileupload/publications/ComReg03110.pdf

[11] http://www.arraycom.com

4.2.3 Wi-Fi & Wi-Max (IEEE 802)

In some cases smart antenna technology can be added onto existing standard products (e.g. Wi-Fi/IEEE 802.11) being used for portable wireless access. Smart antenna systems are also being developed for emerging wireless standards such as Wi-Max (IEEE 802.16) and IEEE 802.20. Advanced smart antenna technologies such as MIMO may also be incorporated into developing standards such as IEEE 802.11n[12] (Intel are developing technology for 802.11n) (See Section 5.3.3).

Fixed wireless access systems operating in unlicensed bands may find particular benefit from smart antenna systems that can adaptively blank out interfering signals from certain directions.

4.2.4 Military Communications

Military users were among the earliest to develop smart antenna systems. The added value that this technology could bring them was greater than the additional cost associated with the complex systems needed before the technology became more developed. The ability of smart antenna systems to blank out interfering signals is very valuable in military systems as it can mitigate 'jamming'[13], enabling users to maintain communications in hostile military environments. Smart antennas also enable military users to form ad-hoc networks in battlefield situations where erecting fixed communications infrastructure would be impractical.

[12] Developing standard that is expected to deliver 100Mbit/s in the 5GHz band

[13] Jamming is a process where communications systems can be rendered inoperable by malicious users broadcasting noise over the same frequencies as the wanted communications.

5 Smart Antenna Technology

In general, and for the purposes of this document, smart antenna technology refers to a group of technologies that utilise a combination of multiple antennas and signal processing to increase spectrum efficiency. These smart antenna technologies, which vary in complexity from simple diversity combining systems to advanced Multiple-In Multiple-Out (MIMO) systems, are described in this section.

5.1 How Smart Antennas Work

By combining multiple antennas (e.g. side by side) and adding some signal processing, the way in which the antenna receives and transmits signals can be controlled. It is the signal processing that makes the antenna systems smart. Using complex algorithms the processors are able to distinguish between different signals coming from different users by determining which directions the signals are coming from. The signal processors are also able to adjust the signals that they send to the array of antennas so that they can be transmitted in narrow beams in the most appropriate directions. An adjustable hose or shower head is in some ways analogous to a smart antenna system in that by adjusting the nozzle (i.e. the signal processing and control) the water coming from the hose (i.e. the radio waves) can come out in a light but wide ranging spray, or a strong and narrow jet. A smart antenna system may physically take up more space than a conventional antenna because the structure must contain multiple antenna elements.

5.2 Smart Antenna System Enhancements

Generally speaking smart antenna technology can provide enhancements to radio systems, when transmitting or receiving, in the following main ways:

- Combine signal strength from multiple antennas (Array gain).
- Use the signals received at different antennas to compensate for the effects caused by signals taking different routes between the transmitter and receiver known as multi-path (Diversity gain).
- Combine antennas to form a steerable beam that can focus in on users in a particular location (Adaptive Beam-Forming).
- Combine antennas to steer blind spots (known as nulls) in the direction of an interfering signal (Interference suppression gain).
- Deploy multiple antennas at both the transmitter and receiver to enable multiple data streams to be transmitted separately over the same frequency (Spatial multiplexing).

In some cases these enhancements can be combined in a system, but they are typically mutually exclusive[14].

[14] Khurram Sheikh, et al. "Smart Antennas for Broadband Wireless Access Networks", IEEE Communications Magazine, November 1999.

5.3 Types of Smart Antenna System

The main types of smart antenna systems are described below:

5.3.1 Diversity

Diversity systems use more than one antenna to achieve better reception than using a single antenna. This is typically applied in mobile environments to help mitigate multi-path effects[15]. The most commonly used type of diversity in mobile systems is known as spatial diversity where antennas are physically separated from one another on the same tower, and used to receive the same signal (our ears could be considered as a spatial diversity system allowing us to combine sounds heard in both ears to form a better perception of the direction of arrival of actual sounds).

There are two main types of diversity system commonly in use: switched diversity and diversity combining. In a switched diversity system, only one antenna is in use at a time. In this case the radio receiver equipment will select the antenna with the strongest signal. In a diversity combining system the signals from both antennas are combined to form a stronger overall signal[16].

5.3.2 Smart antenna arrays

Smart antenna arrays are an enhancement of the systems described above, where signal processing is used to configure an antenna system in the optimal way. There are two main categories of smart antenna: switched beam and adaptive array.

- **Switched beam** – These would typically have a number of main beams that focus in on individual end-users. Such systems would typically detect signal strengths in particular directions and then adjust their patterns accordingly. Switched beam systems have a fixed number of predefined antenna patterns that can be selected.

- **Adaptive Array** – These are more complex than switched beam systems. Adaptive array systems can provide an infinite number of different instantaneous beam patterns (although the number of beams will be limited), and they can be varied in real-time to track or follow multiple individual end-users. Such antenna systems can also adapt their radiation patterns to help reject interfering signals from certain directions. The use of adaptive arrays is also known as optimum combining.

[15] Multi-path fading is the effect of reflected signals arriving at the receiver at slightly different times and cancelling each other out.

[16] The signals must be lined up relative to one another (i.e. put in phase) to account for slight differences in their arrival due to the different physical positions of the antennas and different paths that they may have taken to get there.

Company	Description
Vivato[17]	Steerable beams for Wi-Fi applications (indoor and outdoor)
Lumera[18]	Beam steering for Wi-Fi & Wi-Max
E-tenna[19]	Low cost beam steering technology for legacy systems
Paratek[20]	Indoor Wi-Fi applications, GSM, GPRS, EDGE - DRWiN[21]
Navini[22]	Non-line-of-sight broadband wireless access
Wavion	Spatial division multiplexing
Nortel[23]	Adaptive Antenna Beam System (AABS) – for 3G
Motia[24]	Smart antenna chips for Wi-Fi systems

Table 1. Some examples of currently available smart antenna systems

5.3.3 Multiple Input Multiple Output (MIMO)

In these systems there is more than one antenna at both the transmitter and the receiver. Different signals are transmitted over the same frequency using the different transmitter antennas. In a conventional radio system these signals would interfere with one another. At the MIMO receiver, the signal processing can distinguish between the different signals by analysing the data received on each of the multiple antennas[25]. This technique actually makes use of multi-path effects in the real transmission environment as the more the signals spread across multiple paths, the more easily each one will be distinguishable from another. Similarly this technique can be applied to cancel out interferers using the same frequency as the wanted signal. This technique is known as adaptive interference cancellation.

MIMO systems can involve receiver processing only, transmitter processing only or processing at both the receiver and transmitter. For mobile or fixed wireless access systems it might be advantageous to carry out power consuming processing at the base-station. This would also help keep the cost of customer equipment down. An example of this is Lucent's Blast technology that has been developed for 3G applications (tests have achieved over 19Mbit/s)[26].

With MIMO systems the increase in capacity over conventional systems is proportional to the number of antennas used. Lucent's V-BLAST system can achieve up to 40 bits/Hz[27] compared to approximately 1- 5 bits/Hz for a traditional mobile system. There is a potential cost increase with such systems as each antenna requires separate receiver functionality.

[17] http://www.vivato.net

[18] http://www.lumera.com

[19] http://www.etenna.com

[20] http://www.paratek.com

[21] Dynamically Reconfigurable Wireless Networks

[22] http://www.navini.com

[23] http://www.nortelnetworks.com/solutions/wrlsmesh/architecture.html

[24] http://www.motia.com

[25] Some of the techniques for MIMO are known as maximum likelihood detection (MLD), Vertical Bell Laboratories Layered Space-Time (V-BLAST), and Singular Value Decomposition (SVD) also known as space time coding.

[26] http://www.lucent.com/livelink/090094038000e509_Presentation.pdf

[27] i.e. 1.2Mbit/s in a 30kHz channel.

MIMO systems are being developed for several IEEE standards. IEEE 802.11n is likely to make use of MIMO technology in the 5GHz licence exempt band in order to improve efficiency. The emerging Mobile Broadband Wireless Access (MBWA) standard IEEE 802.20 also includes MIMO technology[28]. Flarion's technology which is in line with the IEEE 802.20[29] standard is being trialled in the US and Korea[30].

Companies such as Airgo[31] and Agere[32] have developed MIMO systems. Intel has also identified MIMO technology as a key component of future wireless systems that they develop.

Smart Antenna Type	Advantages	Disadvantages
Diversity	Simple to implement	Limited improvement
Switched Beam	Simple to implement	Limited configuration possibilities
Adaptive Array	Efficient use of spectrum	Increased equipment complexity and cost.
MIMO	Increased capacity	Increased equipment complexity and cost. Developing technology.

Table 2. Comparison of smart antenna technologies.

5.4 Technology Development

Until relatively recently smart antenna technology has been mostly confined to military users due to the high cost of the complex signal processors needed. The falling cost of digital signal processors (DSPs) has made integrated smart antenna systems economically viable for commercial applications. Furthermore, developments in the implementation of algorithms to process signals being sent to and from antenna arrays are helping to reduce the computational requirements of smart antenna systems.

In many cases smart antenna technology is being introduced in conjunction with other sophisticated wireless techniques such as adaptive modulation and mesh network architectures (e.g. ArrayComm). In such cases smart antenna technology is just one part of an overall solution.

Plasma antenna technology is an emerging area of research and development that could potentially benefit smart antenna systems. This technology uses plasma tubes to radiate in place of traditional metal elements[33].

[28] http://grouper.ieee.org/groups/802/20/

[29] IEEE 802.20 is being backed by Flarion and ArrayComm and is felt to be in competition with supporters of the IEEE 802.16e standard backed by the Wi-Max forum.

[30] Flarion is being trialled by Nextel in the US, and by SK Telecom, Korea Telecom and Hanaro Telecom in Korea. Vodafone recently announced that it will trial Flarion technology in Japan.

[31] http://www.airgonetworks.com

[32] http://www.agere.com

[33] e.g. Markland Technologies – http://www.marklandtech.com

6 Market Development and Regulatory Issues

Smart antenna technology can help deliver enhanced services to both broadband fixed wireless access and mobile users, as described in Section 4. This technology is particularly useful in situations where radio spectrum is limited.

6.1 Market Development

6.1.1 *Efficient and effective use of spectrum*

For wireless network operators smart antenna systems can help achieve increased spectral efficiency, enabling them to serve more customers with better services for a given number of base-stations (e.g. up to 15% fewer base-stations when using smart antennas in a mobile device alone[34]). Smart antennas are reported to provide spectrum efficiencies three or four times greater than conventional systems (i.e. can support three or four times as many customers). This means that business cases for new wireless networks are likely to be more viable for operators than they have been in the past, creating the potential for a more competitive challenge to traditional wireless and fixed line operators for broadband access provision. Strategy Analytics estimates that the global market for residential fixed wireless access could be between 15 and 20 million households[35] providing significant opportunities for efficient smart antenna systems. This increased efficiency is also important for 3G network operators in the process of rolling out networks with limited funding available. According to analysts the number of smart antenna systems deployed globally is expected to increase from 100,000 in 2001 to over one million by 2006 (Allied Business Intelligence);[36] and up to ten percent of base-stations deployed globally are implemented with smart antenna technology (Visant Strategies)[37]. In Ireland there are currently approximately 4000 mobile base-stations, and the total number of base-stations is likely to increase as more 3G and fixed wireless access networks are deployed[38]. MIMO technology in particular holds the potential to provide high capacity wireless broadband access services (see Section 5.3.3). Smart antenna and MIMO technology can be applied in both fixed and mobile environments.

6.1.2 *Remote network management*

Smart antenna technology offers other benefits to wireless network operators beyond increased network capacity. Many smart antenna systems can be reconfigured remotely to allow different customers to be served, without the need for a network engineer to manually re-point antennas (see Section 4.2.2); therefore greatly

---

[34] Multiple Access Communications Limited. "The Benefits of Adaptive Antennas on Mobile Antenna Systems for 3G", Ofcom, 2003.

[35] Strategy Analytics, "Residential Fixed Wireless Access – Is It Still Just a Niche Market?", November 2003.

[36] Allied Business Intelligence, "Smart Antenna Markets: Strategies, Technologies and Trends for Next Generation Wireless Systems", September 2001.

[37] Visant Strategies, "Smart Antennas: Wading Into The Mainstream 2003", September 2003.

[38] It is worth noting that base-station sites are often shared by more than one operator, and are used to provide more than one type of service (e.g. GSM900, GSM1800, 3G). See http://www.comreg.ie/_fileupload/publications/ComReg0328.pdf for more information on site sharing in Ireland.

reducing installation and network upgrade costs for the operator. This allows a network operator greater flexibility while rolling out a network to better manage extra traffic and the addition of new customers. In this way smart antenna technology is more scalable therefore reducing the initial capital costs incurred by a wireless operator, which have put fixed wireless operators under excessive strain in the past. Smart antenna systems can therefore help lower barriers to entry to the fixed wireless access market for new operators by enabling them to begin operating with a more modest network which can be expanded as business grows.

6.1.3 Non-line-of-sight (NLOS)

Another important application of smart antenna technology is to enhance the operation of NLOS broadband wireless access systems. Line of sight technologies can be limited in the number of customers that they can serve due to buildings, trees and terrain obstructing the direct path needed between base-stations and end-users (see Section 4.2.1). NLOS systems potentially offer a far more economical prospect for wireless network operators, making them more competitive with respect to fixed line operators. NLOS systems are able to reach customers in scenarios that would require an entirely new base-station in a line-of-sight fixed wireless access system, thus reducing capital and installation costs.

A significant advantage of some NLOS systems is that the antennas do not need to be mounted externally and can therefore be installed by the end-user (i.e. ‘plug and play’). The effect of self-installable systems has already been seen to help accelerate consumer take-up of DSL services and is likely to apply similarly in fixed wireless access networks. Eliminating the need for engineers to install equipment for individual end-users can greatly reduce the cost and provisioning time of broadband services. According to Maravedis Inc; IP Wireless, Navini, and NextNet Wireless are market leaders in the NLOS, plug and play fixed wireless access market[39].

6.1.4 Fixed and mobile convergence

Some advanced fixed wireless access systems deploying smart antenna technology are being developed to provide mobility (e.g. Flarion, Navini, Arraycomm, 802.20, 802.16e). This represents an important step in the convergence between the mobile and fixed wireless markets which could eventually create competition between such services. In some cases these technologies are also likely to develop in ways that complement one another. This could enable mobile operators to deliver broadband mobile services in some areas and fixed wireless access providers to deliver mobile services to their customers. Dual purpose mobile and portable/fixed devices would then be able to deliver customers the highest data rates at any particular location, or while moving.

6.1.5 Falling equipment costs

The high cost of the sophisticated technology needed to implement smart antenna systems has been a significant barrier to the use of this technology in commercial networks in the past. However, technology advancements have now reached the point where this technology is affordable and the extra value to be gained from them outweighs any additional equipment costs. Costs for base-stations with smart

[39] Maravedis Inc. “WiMax, NLOS and Broadband Wireless Access (Sub 11GHz) Worldwide Market Analysis 2004-2008”, February 2004.

antenna technology can still be 30% + greater than conventional base-stations[40]. However, overall network and installations costs have also been estimated to be up to 50% lower than DSL or cable networks, and up to 70% lower than some conventional fixed wireless systems[41]. End-user devices employing smart antenna or MIMO systems can also be more costly than conventional equipment as they can require a separate internal radio receiver (and/or transmitter) for each antenna on the device (e.g. typically three or four). See Section 5.3 for details of some key smart antenna systems developers.

6.2 Regulatory Issues

As with conventional wireless systems smart antenna technology must conform to any appropriate national and international spectrum management regulations. It is recognised however that smart antenna technology is in many cases being developed along with other innovative wireless technologies such as MIMO which are substantially different from conventional wireless systems. In some cases it may not be entirely appropriate to apply the same rules to smart antenna systems as conventional systems, or they may need to be interpreted in different ways. In such cases different limitations of use and methods of managing radio spectrum are needed.

6.2.1 Licensed Radio Spectrum

In the case of licensed wireless systems such as 2G and 3G mobile networks and fixed wireless access networks, smart antenna systems can be deployed by operators so as not to interfere with other wireless systems (i.e. they must conform with the relevant ETSI standards e.g. UMTS standards). In Ireland, fixed wireless access systems are typically assessed on a case by case basis by ComReg, which enables the properties of particular smart antenna systems to be assessed individually.

6.2.2 Harmonised Un-licensed Spectrum

In Europe many of the frequency bands of interest to developers of smart antenna technologies are harmonised un-licensed bands with regulations based on ETSI standards. ETSI has made reference to the fact that such standards may need to be changed to benefit from smart antenna technology (ETSI EN300 328 – 'multi-radio systems'[42]). A key benefit of smart antenna systems in unlicensed frequency bands is their ability to operate in a harsh radio interference environment where conventional radio systems may struggle.

In the US the FCC went to consultation on the use of smart antenna systems in certain frequency bands (e.g. the 2.4GHz ISM band) in September 2003. This FCC consultation includes issues such as adaptive antennas in the 2.4GHz band, reduction of restrictions on replacement antennas for Part 15 (low power, unlicensed) devices, and more flexible authorisation procedures for modular radio systems. The FCC

[40] Source – Wireless Web, "Smart Antennas are Gaining in Popularity", September 2003, http://wireless.iop.org/articles/news/4/9/4/1

[41] Source: Daily Wireless, "Navini Unwires Douglas County", http://www.dailywireless.org/modules.php?name=News&file=print&sid=1209

[42] ETSI EN 300 328, Introduction - "It is intended to include requirements for multi-radio equipment in the present document, but at this time the technical considerations are still ongoing. Upon completion of this work, the present document will be revised to include these requirements."

makes the point that current rules apply to omni-directional or point-to-point (including point-to-multi-point) antenna systems, and are not geared towards sectorised or smart antenna systems[43]. These proposed regulations do not specifically accommodate MIMO systems.

[43] They have defined a smart antenna as having at least two discrete beams but with a total simultaneous beamwidth (i.e. the angle over which the signals are emitted) not exceeding 120 degrees. Furthermore they propose that each discrete beam is limited to the power of a beam allowed in a point to point system. The aggregate power on all beams transmitting simultaneously must be limited to 8dB above the strongest individual beam.

7 Conclusion

Smart antenna and MIMO technologies can make more efficient use of radio spectrum, enabling operators to roll-out services to a larger number of users with higher capacity and better quality of service than current simple antenna technologies. A number of new systems are emerging that rely on the enhancements provided by smart antenna technology to operate. In other cases smart antenna technology can be added to existing systems to improve capacity and performance. Although smart antenna technology itself will be transparent to the end-user, they will be able to experience the increase levels of broadband wireless access that the technology enables.

This technology can be used to help make the provision of fixed broadband wireless access more economical by reducing the number of base-stations needed to provide a certain level of service and by allowing operators to reconfigure their networks remotely as they expand (i.e. reducing the cost of sending out engineers). Smart antenna technologies can be particularly useful in NLOS wireless access systems where end-users can install their own systems (i.e. ‘plug and play’). Considering these advantages smart antenna technology could potentially make a significant difference to the business cases for many Irish fixed wireless access operators. Advanced smart antenna and MIMO technology is also being applied in mobile systems, and in some cases helping to add a level of mobility to fixed systems. Another major area where smart antenna technology can help increase the levels of service is in wireless LAN networks (i.e. internal corporate networks and public hotspots). In such cases these antennas can potentially increase the capacity of existing systems and reduce the effect of interference.

As smart antenna technology makes more efficient use of radio spectrum than conventional antenna systems it may therefore not be appropriate to apply existing radio standards and limits to these systems. In some cases the standards that spectrum management regulations are based on may need to be reinterpreted and revised to accommodate these new technologies, and to take advantage of the efficiencies that they can bring without allowing them to compromise existing users.

8 Annex 1 - Glossary

3G	Third generation mobile
3GPP	Third generation partnership project
EDGE	Enhanced Data rates for GSM
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
GPRS	General Packet Radio Service
GSM	Global System for Mobile
IEEE	Institute of electrical and electronic engineers
LAN	Local area network
MIMO	Multiple input multiple output
NLOS	Non line of sight
Ofcom	Office of communications
SDR	Software defined radio
Wi-Fi	Wireless local area network technology (IEEE 802.11)
WLAN	Wireless Local Area Network (Wi-Fi)