NORTEL

White Paper

MIMO or AAS: Key technology choice in deploying WiMAX

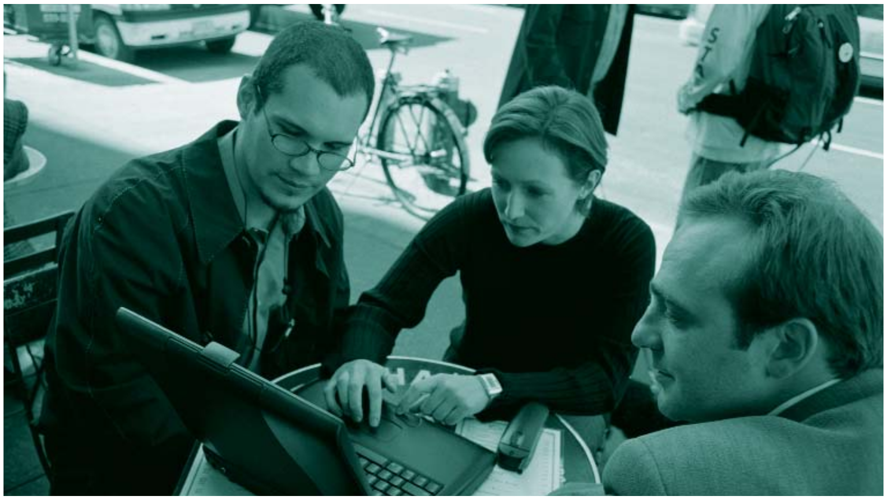
Introduction

WiMAX is an exciting new Broadband Wireless Access (BWA) technology. Running in a range of spectrum both licensed (typically 2.5 GHz and 3.5 GHz) and unlicensed (e.g. 5.8 GHz), it promises longer ranges (realistically up to 15 km) and higher bandwidths (up to 100 Mbps throughput and peak rates of up to 140 Mbps). Fitting between WLAN and cellular technologies, it is perhaps the first 4G wireless technology and offers much potential as an alternative to both wireline fixed access and 3G mobile access. As an emerging technology, it is now getting wide attention from the marketplace with serious interest in deploying for commercial use across the globe.

Key to the success of WiMAX is the commercial viability of deployment. Where ADSL is widespread, e.g. in Western Europe, the fixed market for broadband access can be highly competitive, driving down potential revenues for the WiMAX operator. The 3G cellular space continues to develop with HSDPA, HSUPA and CDMA Ev-DO all offering to boost bandwidth available to the end user, again potentially squeezing the WiMAX operators. However, both 3G cellular and wireline access have limitations. 3G has very high mobility but is still relatively expensive, less spectrally efficient and offers lower capacity than WiMAX. Wireline access (cable or xDSL) is dependent on existing deployed infrastructure and ties the user to a particular location. So there are clear opportunities for the WiMAX operator.

Key to the business case is the cost of deployment and, most notably, the cost for coverage which is dominated by the number of sites required; initially for coverage and subsequently for capacity. The key technology that drives the costs for deployment is the antenna choice. The two main contenders are MIMO (Multiple Input, Multiple Output) and AAS (Adaptive Antenna System). Nortel has been selling AAS systems for more than ten years and has been working on MIMO for more than six years. As a result, Nortel is well positioned to compare these technologies.

This paper provides an overview of Nortel's analysis and shows that MIMO is a superior technology for the WiMAX system and this is why Nortel strongly recommends that operators maximize their business case by deploying MIMO from day one.



MIMO and AAS

Both MIMO and AAS are antenna technologies that make use of multiple antennas to enhance the characteristics of the transmission. However, the approach and characteristics of each are different.

MIMO (a tri sector 2x2 mast shown in Figure 1) uses multiple antennas to send multiple parallel signals. The receiving end uses special signal processing to sort out the multiple signals. The benefit here is two-fold: firstly, use of parallel streams makes for a scalable enhancement (more antennas means more capacity) and secondly, the MIMO approach makes use of multi-path effects such as reflections off buildings, so MIMO works well in cluttered environments, e.g. urban settings. MIMO base station antennas can be standard, off-the-shelf components, which helps contain cost. Nortel has been working with MIMO technologies for many years, but it is only recently that the cost of the required signal processing has become attractive.

Figure 1. MIMO (a tri sector 2x2 mast)

AAS (a typical AAS antenna shown in Figure 2) uses a different approach. It also uses an array of close spaced antennas often enclosed in a single package. The AAS approach uses a technique known as beamforming and generates a single beam aimed at a particular user or device. This provides a stronger link to the user and hence improves reach and capacity. The solution can cope with multiple users by steering the beam

Figure 2. AAS (a typical AAS antenna)

around to different users in the coverage area. This approach is also intensive in signal processing and is based on accurately controlling the signals to each antenna, thus requiring an array of custom antennas tightly coupled to the signal processing and carefully calibrated. AAS is a proven technology that has been around for many years and Nortel has been selling AAS solutions for over 10 years.

Comparison of MIMO and AAS usage in WiMAX

Nortel has used its extensive knowledge of these two technologies and the WiMAX standards to compare these technologies in a variety of ways. The next sections will look at the characteristics of each from several viewpoints including coverage, capacity, mobility and economics.

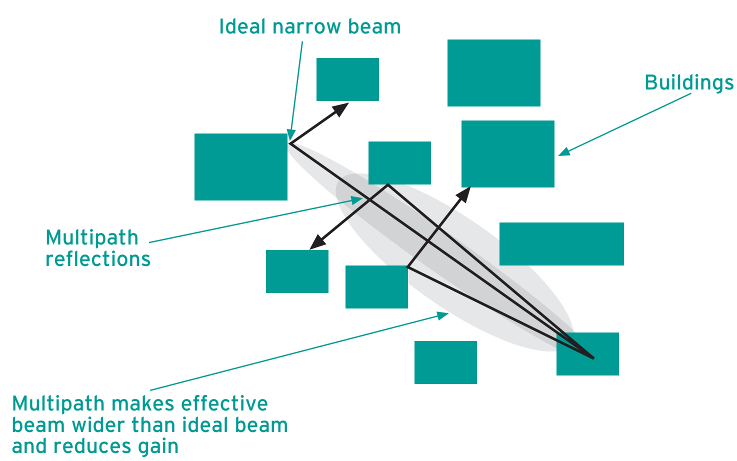
Coverage

RF Engineering is complex and there are many factors to consider in any planning exercise. It is also worth looking at the characteristics of real-world deployments rather than just theoretical and lab analysis.

In cluttered environments, such as cities, the transmitted signal may bounce off buildings, resulting in multiple paths to the receiver. With AAS beamforming, these reflections effectively make the beam wider, reducing the benefit. This effect, known as angle spread, is shown in Figure 3. The impact can be significant. For example, an AAS system using an eight-column array would have an ideal gain of 6.9dB but angle spread would reduce this to only 3.2dB in an urban environment and 4.7dB in a suburban environment. Even in the rural environment there would be some impact. There are some techniques to mitigate the effect of angle spread but these approaches are sensitive to mobility and channel estimation errors, e.g. at low signal-to-noise ratios encountered at the edge of the cell where benefit is most needed.

By contrast, MIMO is designed for multiple signal paths and benefits from multi-path. This enables it to exploit its multiple signals in different parts of the

Figure 3. Beam widening by angle spread



cell. Where the signal is strong, each signal may convey different data to the same or different users, increasing the capacity. Where the signal is weaker, nearer the edge of the cell, the same data is transmitted on all signals for that user, creating a stronger signal to the user and increasing the range. This latter approach creates its own multipath, ensuring MIMO benefits even in direct line-of-sight conditions. Studies have shown that MIMO delivers significantly increased spectral efficiency over AAS, even in suburban environments.

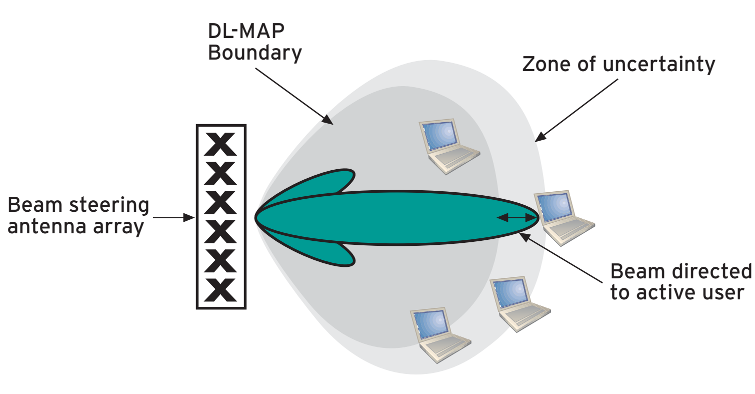
Even with angle spread, AAS could provide improved range for the signal. However, the value of this is limited in the way that WiMAX works. WiMAX supports multiple concurrent users in a sector. To achieve this, the WiMAX system transmits a MAP (Media Access Protocol) to all users in a sector indicating which parts of the signal are for which user. This information is broadcast throughout the cell and so *cannot benefit* from AAS beamforming. For data to be reliably delivered, the device must accurately receive the MAP and hence while AAS could improve the range of a cell, the MAP transmission is not reliable in the extended area (the zone of uncertainty indicated in Figure 4). So this area cannot be used for cell planning and hence there is no net benefit in terms of the number of cells required to deliver reliable coverage. There have been extensive discussions in the WiMAX forum on standardizing how to address this issue but no viable solution has been found.

Regulatory constraints may also be another practical limitation on the value of AAS beamforming. Many countries explicitly limit the transmit power levels (EIRP - Effective Isotropic Radiated Power). The MAP broadcast will be at maximum permitted power and so the AAS beam, which itself is subject to the EIRP limit, may terminate on the edge of the broadcast pattern with no gain in either range or signal strength on the sector boundary.

There is a similar pattern in the uplink budget where the AAS theoretical benefits are eroded in practice. A MIMO sector antenna has a higher gain than the column gain of an AAS antenna due to its narrower beamwidth in azimuth. This benefit can be enhanced through increased sectorization: with MIMO, a tri-sector pattern gives about 2dB benefit rising to 4.5dB for hex sector and 5.5dB for eight-sector configurations. AAS in the uplink relies on channel estimation to combine the signals received across the array. At cell edge (or areas of low signal-to-noise ratio), channel estimation becomes less accurate and degrades gain. So in practice, a tri-sector MIMO configuration achieves equivalent UL gain to four-column AAS with hex-sector equivalent to an eight-column AAS. Further improvements in the uplink can be achieved via Nortel's Tower Top Low Noise Amplifier to reduce BTS noise and thus improve uplink sensitivity. Finally, MIMO's superior capacity can be traded for uplink coverage by changing the TDD ratio. Uplink coverage will be further improved with uplink 2x2 MIMO.

Overall, while AAS can in principle deliver benefits in terms of range, the theoretical benefits are eroded in practice for both uplink and downlink, particularly in suburban and urban environments. AAS coverage benefits are further negated for cell planning purposes by the need for the MAP to be reliably transmitted throughout the cell. As a result, **AAS and MIMO offer the same coverage**.

Figure 4. MAP broadcast limits AAS effectiveness



Capacity

MIMO offers superior spectral efficiency and hence capacity. Its capacity is also more scalable by adding more antennas and/or more sectors. Nortel has been conducting MIMO field tests since 2001 which demonstrate that the theoretical benefits of MIMO are achievable in the real world.

Both MIMO and AAS use multiple antennas to enhance the signal gaining extra capacity over single antenna systems. The AAS approach is to generate a single, more powerful beam with the theoretical benefit being a slow logarithmic growth of capacity with beam gain. So a base SISO (Single Input, Single Output) WiMAX Base Transceiver Station offers around 25 Mbps, a four-column AAS might increase this by nearly 50 percent to 33 Mbps while an eight-column AAS could increase this to just 38 Mbps.

Table A. Capacity comparison across antenna type

BTS	SISO	4x1 AAS	8x1 AAS	2x2 MIMO	4x4 MIMO
Capacity	25	33	38	50	100

In contrast, MIMO uses multiple paths to achieve its benefits offering robust diversity on transmit and receive. As a result, capacity grows linearly with the number of antennas. A two-antenna MIMO BTS doubles the capacity of the base SISO BTS and a four-antenna MIMO BTS doubles that again. The results can be summarized in Table A.

MIMO offers potential for many future benefits. This is because MIMO (combined with OFDM) is the underpinning technology for all 4G technologies and is the focus of much industry investment. The WiMAX Forum will continue the evolution of higher order MIMO technology to further push the envelope. This enables a substantial link budget improvement (~7dB), translating to increased capacity and superior range. One of the objectives is to leverage MIMO cost-effectiveness in providing an alternative to xDSL and other wireline services. Nortel is leading the way in the MIMO evolution effort in the WiMAX Forum.

Overall, **MIMO offers superior capacity**, superior scalability and benefits from more industry investment.

Mobility

One key advantage of 16e over 16d is that it supports mobility at vehicular speeds (up to 125 kph). While some licenses allow full mobility, many current licenses are for fixed/nomadic use only. However, Nortel believes that such restrictions are likely to be removed in the coming years and so it is worthwhile to consider the capabilities of these antenna technologies in a mobile environment.

AAS beamforming solutions rely on accurate and rapid channel estimation to maximize the benefits. If a user is mobile, this has implications for the channel estimation since the channel conditions will vary rapidly. For example, at 30 km/h and at 3.5 GHz, channel estimation would need to occur every millisecond to maintain best performance, yet the first profile WiMAX frame length is 5 ms. As a result, AAS does not deal well with mobility at higher speeds. Hand-off can also be an issue since the interference will be rapidly changing and unpredictable as the beams steer to different directions unless rapid and complex coordination is maintained across the network. This complexity makes handover slower and less reliable, resulting in 30 percent to 40 percent dropped calls during handover at high speeds.

By contrast, MIMO deals well with mobility. In tests, Nortel has shown that MIMO can deliver the same user throughput at 120 km/h as at 3 km/h, demonstrating the excellent support for higher speed mobility inherent in the MIMO system. MIMO's passive, predictable approach also pays dividends in support for hand-off. The cell search can be used to give a very reliable indication of channel quality, eliminating the need for complex coordination between cell sites to determine the best point of hand-off. This enables the mobile device to make a rapid and accurate decision on hand-off, which is critical to good hand-off performance at high speed.

The net result is that **MIMO delivers a superior experience for the mobile user**.

TDD and FDD duplexing

The current AAS system design and implementation is based on the TDD duplexing. It relies on both the downlink and uplink channels' reciprocal property for the base station to perform beamforming. This is based on a fundamental assumption that the downlink receive and uplink transmit at the same carrier frequency. Typically, the uplink channel sounding is sent to assist the base station to generate the antenna weights to achieve downlink beamforming. For the FDD duplexing, the channel characteristics for uplink and downlink are completely different and independent and the simple uplink sounding technique fails to work for AAS. The AAS solution will require the entire transceiver systems, including the modem chip, to be redesigned for the FDD duplexing.

In contrast, MIMO does not have this limitation because the MIMO scheme does not rely on the instantaneous downlink channel information as AAS does. A simple change in the RF head of the FDD radio will enable the MIMO to operate for the FDD duplexing. So **MIMO supports both TDD and FDD**.

Economics

Independently of the relative technical merits, the economics of network rollout will be a key part of any decision. The technical characteristics of the two solutions do drive significant economic factors. As has been shown above, the coverage of the two technologies is equivalent and so the number of cell sites required to provide coverage will be the same with either technology. In the early phases of roll-out, cell site costs dominate the economics. As the number of subscribers grows, it will be necessary to increase capacity in busy, usually urban areas. Here MIMO superiority makes it a clear choice.

Looking at the individual technologies, it is possible to compare the costs. AAS uses custom antenna arrays closely coupled and carefully calibrated to the RF modules, resulting in a costly and heavy antenna to mount on the mast. These are generally heavier than currently deployed antennas, which may mean that new towers have to be built to support the extra weight and wind load of AAS antennas. MIMO uses off-the-shelf antennas which saves both cost and weight and with fewer antennas, there are fewer RF chains, all of which reduce costs. Additionally, the capacity delivered by MIMO is greater, generating a significant cost per bit advantage for MIMO. Table B shows the relative costs of the two solutions.

In particular, the cost of subsequent densification is significant. With AAS, there is a limit which would necessitate changing to MIMO. This would require a site visit and, possibly more importantly, a significant change to the visual profile of the antenna, perhaps requiring new approvals in some countries. One advantage of the use of simple off-the-shelf antennas for MIMO is that it becomes cost-effective to deploy as many antennas on initial build as may be required in the foreseeable future and simply install the extra capacity at the ground station when required. This obviates the need to work up the mast or change the visual appearance, which simplifies the operational maintenance of the solution when subscriber numbers grow.

Table B. Cost comparison across antenna type

BTS	Total Relative Cost	Capacity MB (payload)	Relative Cost/b/s
SISO	1.0	25	0.04
AAS 4x1	2.8	33	0.08
AAS 8x1	2.6	38	0.07
2 x MIMO	1.3	50	0.03
4 x MIMO	2.3	100	0.02

Overall, **MIMO is more cost-effective** both initially and as capacity requirements expand.

Conclusion

Nortel's analysis of the two technologies has resulted in a very clear view that operators should deploy MIMO antenna technology. In all aspects, MIMO is equal to or superior to AAS and, if an operator is successful, MIMO would inevitably be required to meet increasing capacity needs.

To summarize:

- MIMO delivers the same coverage as AAS: angle-spread, EIRP and map limitations eliminate AAS advantage in a WiMAX system.
- MIMO delivers higher capacity than AAS: multiple parallel streams deliver cost-effective and scalable capacity whereas AAS is limited by logarithmic growth.
- MIMO is lower in complexity and cost than AAS: simpler, passive MIMO uses cheaper and lighter components, making it attractive to plan for success.
- MIMO is more scalable than AAS: MIMO is more predictable in performance and can grow through additional sectors and/or additional antennas.
- MIMO works well in all environments (rural, suburban, urban), switching modes to deliver users the best experience.
- MIMO outperforms AAS for mobile applications: MIMO maintains performance at speed and provides a predictable environment for easier and more reliable hand-offs.
- MIMO is the basis for all 4G plans: widespread investment in developing MIMO technologies will ensure advantages are maintained.

To benefit from MIMO, the end user devices need to support MIMO. So it is important that support for basic MIMO is mandatory in WiMAX, meaning that all devices will support MIMO. With this in place, it is clear that MIMO is the right choice for the WiMAX operator.

Acronyms

AAS — Adaptive Antenna System

ARPU — Average Revenue Per User

BTS — Base Transceiver Station

BWA — Broadband Wireless Access

CDMA — Code Division Multiple Access

EIRP — Effective Isotropic Radiated Power

EUM — Extended Usage Model

EVDO — Evolution-Data Optimized

FDD — Frequency Division Duplex

HSDPA — High-Speed Downlink Packet Access

HSUPA — High-Speed Uplink Packet Access

MAP — Media Access Protocol

MIMO — Multiple Input, Multiple Output

OFDM — Orthogonal Frequency Division Multiplexing

SISO — Single Input, Single Output

TDD — Time Division Duplex

WiMAX — Worldwide Interoperability for Microwave Access

WLAN — Wireless Local Area Network also known as Wi-Fi

xDSL — (any type of) Digital Subscriber Line

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