Strategy White Paper

Universal Broadband Access: Going Wireless And Mobile

GSM/EDGE, UMTS/HSDPA/HSUPA, WiMAX, CDMA2000, UMTS-TDD-HCR, TD-SCDMA, WiFi, mobile broadcast! What is the best technology to select? Are there any bad technologies that we can forget? How can an operator ultimately satisfy the unmet demands of its users, while simultaneously meeting its own business, technical and strategic challenges? A variety of broadband wireless and mobile access technologies are available which are suitable for various usages and offer different performances. One will be optimum for a given geographical situation. Alcatel aims to offer the best access network available for users when and where they need it. This is not a single simplistic proposal, but a technology-agnostic strategy based on a wide choice of multi-access solutions.

ALCATEL

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UNIVERSAL BROADBAND ACCESS: GOING WIRELESS AND MOBILE

Are the emerging broadband wireless and mobile technologies a threat or an opportunity? Will they compete or complement one another?

Going broadband wireless and mobile is not a question of if, but how and when? Be it with Universal Mobile Telecommunications System / High Speed Downlink Packet Access (UMTS/HSDPA), WiMAX, Code Division Multiple Access (CDMA), Time Division Synchronous Code Division Multiple Access (TD-SCDMA), UMTS Time Division Duplex (TDD), WiFi or mobile broadcast technologies, there is a market for it!

Don't ask what the users would do with a higher bandwidth and improved Quality of Service (QoS)! Is there a need for mobile triple play? The answer is yes! Will many customers want to watch video clips on a small screen? Without doubt, yes! Users are ready to adopt and pay for services that are personalized, interactive, simple and carried over the best access.

The radio access network is a masterpiece in the transport of ad hoc services and will demonstrate its flexibility to achieve the most stringent performance-to-cost ratio objectives. It offers multi-access provisioning, the highest data rates, the lowest latency and best QoS in the nomadic and mobile environments.

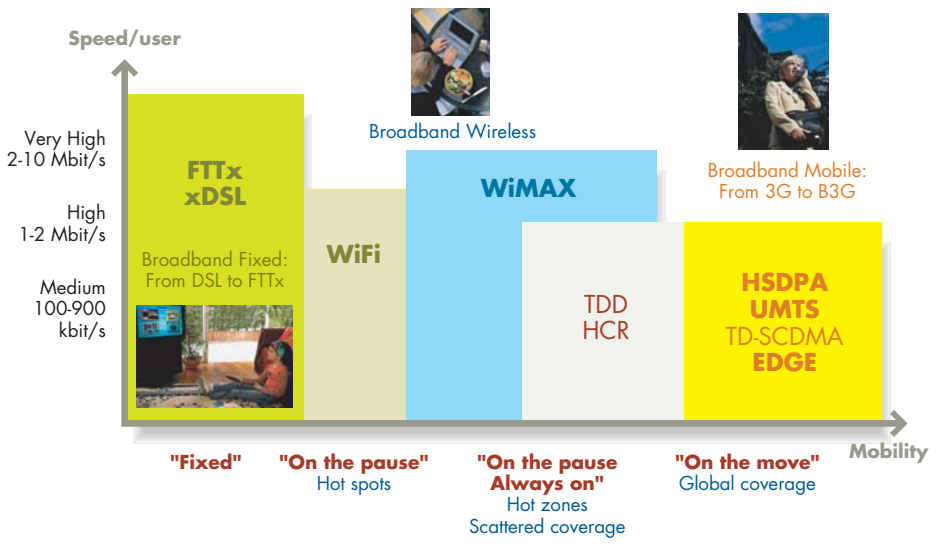
Driving Forces behind Broadband Wireless and Mobile

The value-proposition offered by mobile and wireless operators is based on numerous multimedia services delivered over fixed or mobile networks, or the Internet. Alcatel's aim is to provide these operators with all the business and technical tools they require to put the *Internet in each pocket* using the best broadband wireless technologies. A user-centric broadband world will be built using selected technologies; Alcatel's technology-agnostic approach answers the key business, technical and strategic challenges. The key technologies are shown in *Figure 1*.

The main driving forces for the success of broadband wireless and mobile are:

- All proposed services and solutions meet users' needs:
  - Broadband must be accessible anywhere, in any situation: at home, at the office, outside and inside, on the pause and on the move.
  - Access to personal broadband services should be easy, whether fixed, nomadic or mobile.
  - Users want multimedia services and the largest possible bandwidth at attractive prices.
- Several criteria are crucial when selecting the right technology:
  - Optimization of coverage, throughput per user, capacity per site and per cell, mobility and nomadicity conditions.
  - High spectral efficiency solutions that optimize radio resources management, making it possible to increase traffic throughput.
  - Reliable handover, roaming and security.
- Access must be cost-effective and maximize use of the operator's three major assets: subscriber base, base station sites and spectrum (licensed and unlicensed).

Figure 1: Benefits of the key access technologies



3G: Third Generation
B3G: Beyond Third Generation
DSL: Digital Subscriber Line
EDGE: Enhanced Data rates for GSM Evolution
HCR: High Chip Rate

The total cost of ownership at the access level must follow the general cost reduction trend, in line with devices and handsets, to ensure the widespread penetration of broadband services. To achieve this, various approaches are being used.

- High re-use of existing base station sites for rapid, low risk deployment.
- Flexible capacity growth and initial and additional investments that are closely aligned with the growth in capacity.
- Evolution to take advantage of new technologies in a future-safe way.
- Coverage and the number of existing sites that can be reused to minimize deployment costs.
- Average and peak throughput per sector to evaluate the system capacity on the air interface and dimension the terrestrial interface that feeds the radio sites.
- Average and peak throughput per user, as this affects the types of service that can be offered to subscribers.

The BWA technologies considered here are EDGE, UMTS-FDD (Frequency Division Duplex) with HSDPA, UMTS-TDD with HSDPA, WiMAX and CDMA2000 1xE-DO.

Alcatel's radio access network solutions are based on three key pillars:

1 ***Moving from multi-standard to multi-access:*** A flexible, cost-effective base station architecture allows the deployment of not only GSM/EDGE and UMTS/HSDPA, but also WiMAX, TD-SCDMA, UMTS-TDD and satellite mobile broadcasting.

2 ***Cost optimization program every nine months*** to ensure the scalability needed to allow incremental investment in the infrastructure, hardware and software flexibility, and full backward compatibility to maximize the use of earlier investment.

3 ***Rapid introduction of new technologies*** via software upgrades. EDGE is being introduced via software activation; once UMTS is deployed, it will be possible to introduce HSDPA by upgrading the software. The same is true for the smart antennas solutions being introduced in base stations.

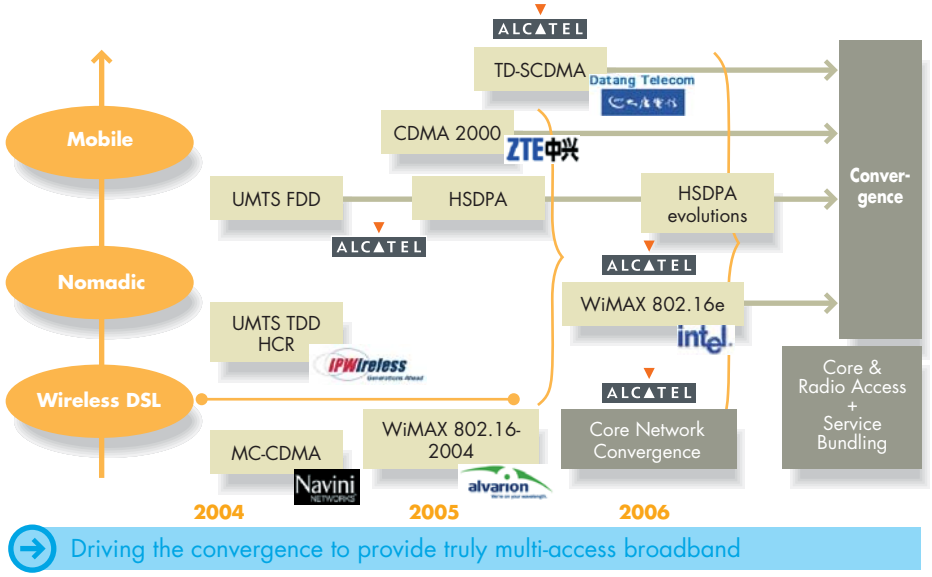
Alcatel's view is that a future radio access solution will be based on collaboration between various technologies to serve different market needs as efficiently as possible. *Figure 2* shows the portfolio of solutions Alcatel is offering broadband mobile and wireless operators to meet their short- and mid-term objectives.

Alcatel's vision is based on various radio interfaces around a common network architecture, with full flexibility in the various building blocks, as depicted in *Figure 3*.

Performance of Broadband Wireless Technologies

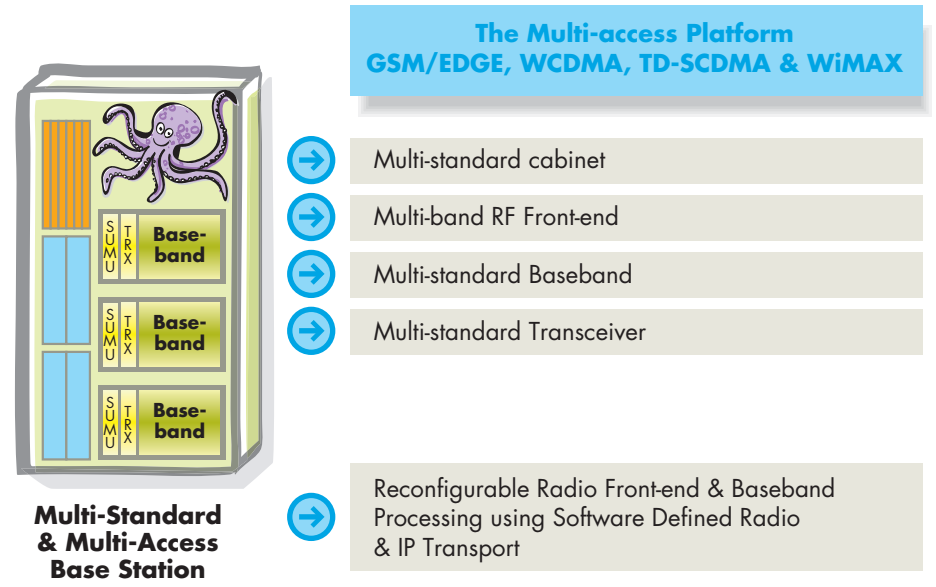
The technical characteristics of the various Broadband Wireless Access (BWA) solutions must be thoroughly assessed before one is chosen. Various radio performance indicators are needed as inputs to the economic assessment that identifies the optimum operator strategy:

Figure 2: Alcatel access technologies roadmap and evolution



MC-CDMA: Multi-Carrier CDMA

Figure 3: Towards a full multi-access platform



SUMU: Station Unit Mobile UMTS
TRX: Transmitter/Receiver

WCDMA: Wideband Code Division Multiple Access

Overview of BWA standards

Table 1 gives an overview of the parameters that influence radio performance.

The *frequency band* has a major impact on the cell radius The higher the frequency band, the lower the range (cell radius), which is why high data rate technologies have a smaller maximum reach than that offered by GSM900 systems.

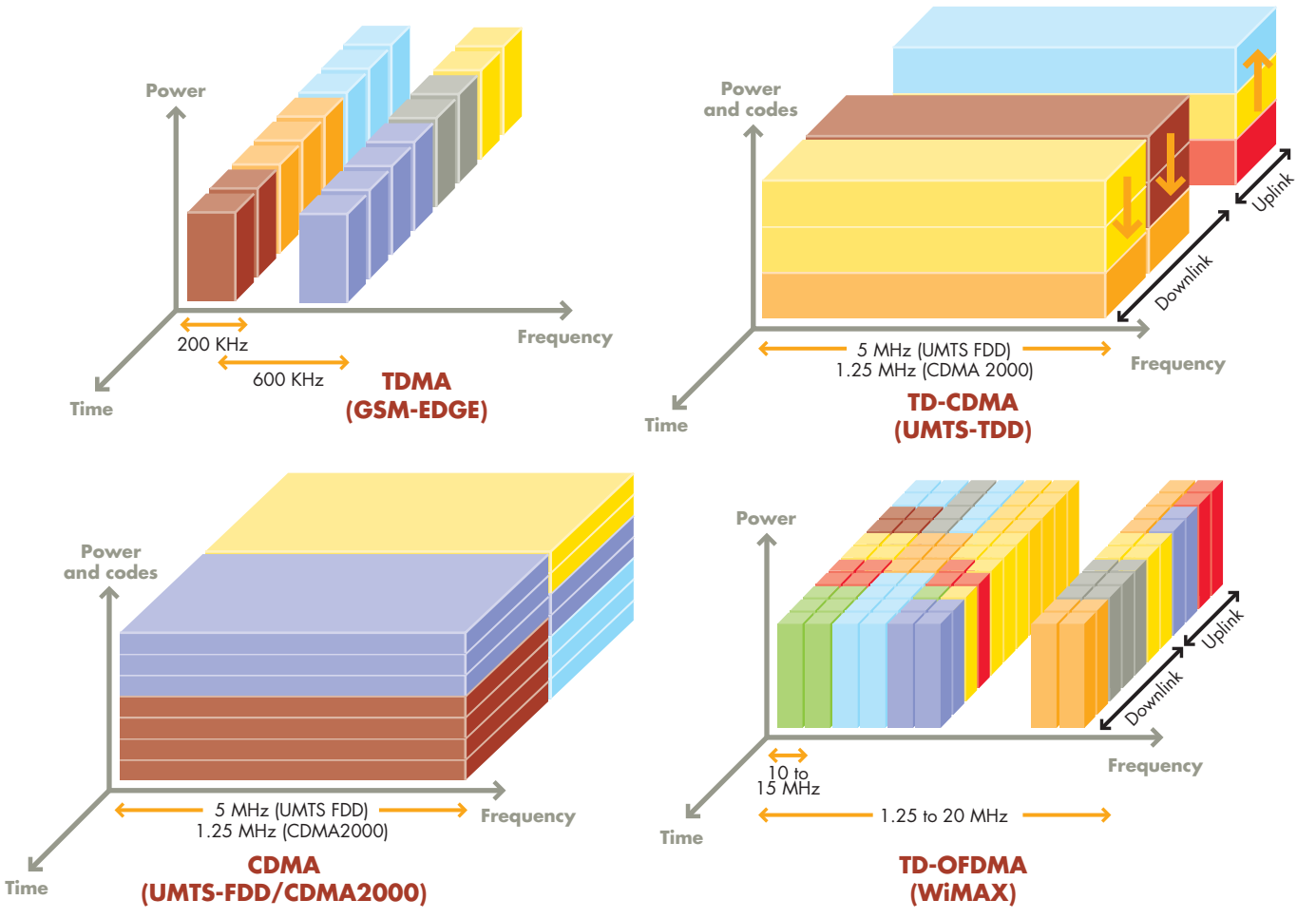
The *duplex mode* defines the way in which bandwidth is shared between the downlink (base station to terminal) and the uplink (terminal to base station). It affects the system capacity and spectrum requirements. In FDD mode, the downlink and uplink use different frequency channels and are adapted to symmetric traffic. FDD requires paired spectrum allocation. In contrast, in TDD mode the uplink and downlink share the same frequency channel in time. This mode is suitable for asym-

Table 1: Main radio parameters for selected BWA systems

	GSM-EDGE	UMTS-FDD (HSDPA)	UMTS-TDD (HSDPA)	WiMAX	CDMA 2000 (EV DO)
Frequency band	2G (850/900/ 1800/1900 MHz)	3G (2.1 GHz)	3G+BWA	BWA (2.5/3.5GHz)	2G+3G+450 MHz
Duplex mode	FDD	FDD	TDD	TDD/FDD	FDD
Channel bandwidth	200 KHz	5 MHz	5 MHz 10 MHz (BWA)	1.25 to 20 MHz	1.25 MHz
Physical layer	AMC (GMSK/8PSK)	DS+SS+AMC (QPSK/ 16QAM)	DS+SS+AMC (QPSK/ 16QAM)	QFDM+AMC (QPSK/16QAM/ 64QAM)	DS+SS+AMC (QPSK/8PSK/ 16QAM)
Access layer	TDMA	CDMA	TD-CDMA	TD-OFDMA	CDMA
Frequency reuse	9 (traffic channel), 14 beacon channel	1	1	3	1
Minimum spectrum	2x4.6 MHz	2x5 MHz	1x5 MHz	30 MHz (for 10 MHz channel)	2x1.25 MHz

AM: Amplitude Modulation
QAM: Quadrature Amplitude Modulation
GMSK: Gaussian Minimum Shift Keying
QPSK: Quaternary Phase Shift Keying
PSK: Phase Shift Keying

Figure 4: Different multiple access modes



metric traffic, since usually the ratio between uplink and downlink is adjustable. TDD can be deployed in unpaired and paired spectrum allocations.

Channel bandwidth directly affects the throughput on the air interface. The greater the channel bandwidth, the higher the data rate, which is why WiMAX systems have much higher throughputs than others.

The *physical layer* of any BWA systems is based on Adaptive Modulation and Coding (AMC) mechanisms. This enables the fluctuating propagation channel characteristics to be efficiently exploited by selecting higher level modulation schemes when possible to increase the throughput per sector. In addition, the modulation technology affects the performance. CDMA (UMTS and CDMA2000) use Direct Sequence Spread Spectrum (DSSS): narrowband signals are spread over a larger bandwidth signal, which is more robust against interference and has improved sensitivity (processing gain). GSM/EDGE and CDMA systems use single carrier modulation. In contrast, WiMAX is based on Orthogonal Frequency Division Multiplexing (OFDM), which is a multiple carrier modulation system. The high data rate information flow is transmitted in parallel on a higher number of orthogonal narrowband subcarriers (512, 1024 or 2048). OFDM offers the best performance / complexity tradeoff for transmission bandwidths larger than 5 MHz, making it one of the main building blocks for fourth generation (4G) systems.

The *multiple access* scheme (see *Figure 4*) indicates how the available bandwidth is shared between users (which impacts the throughput per user) and how the system could be deployed (frequency reuse and average throughput per sector). In the case of GSM/EDGE using Time Division Multiple Access (TDMA), the user data is divided between timeslots belonging to a given channel; the user data can be allocated to a maximum of four timeslots per TDMA frame; each timeslot can carry different user data. However, in UMTS-FDD and CDMA2000 systems, which are based on CDMA, users share the whole system bandwidth and are allocated different codes and powers. The use of codes enables CDMA systems to operate with a high level of interference. Orthogonal Frequency Division Multiple Access (OFDMA) is used in WiMAX systems.

Frequency reuse defines the minimum number of frequency blocks that are required for cellular deployments in BWA systems. Indeed, since BWA systems use AMC, the throughput per sector depends on the level of interference created by the cells transmitting at the same frequency. In CDMA systems, a frequency reuse of "1" is common (only one paired frequency block is required to deploy a CDMA system). Of course, this generates a high level of interference across the cell. In the case of GSM/EDGE, a reuse of at least nine is required; the EDGE throughput can be optimized if EDGE carriers are deployed with higher frequency reuse (thanks to the reduction in the level of interference). WiMAX has, by its nature, similar requirements to GSM/EDGE systems in terms of interference levels. However, adaptive antenna technology means that WiMAX can be deployed with a frequency reuse of just three. *Table 1* shows the spectrum required for deploying a BWA solution, based on frequency reuse, channel bandwidth and duplex mode.

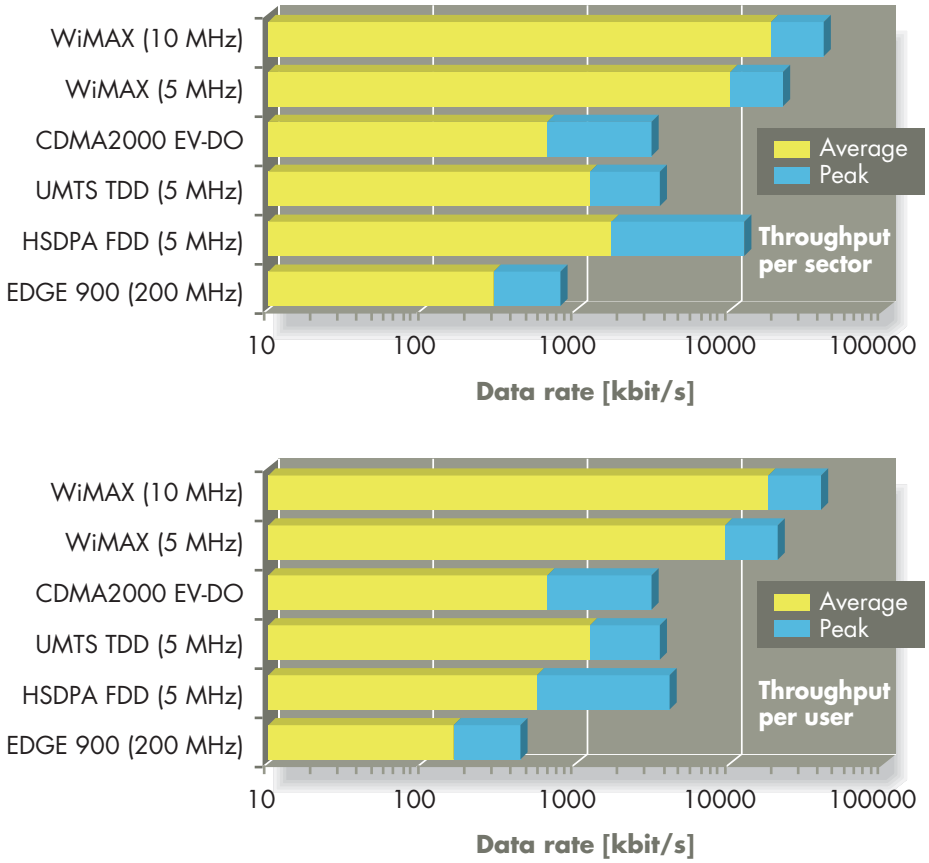
Radio throughputs of BWA technologies

The results synthesized in *Figure 5* assume that all the radio network resources are being utilized; the comparisons were made using the same assumptions about the radio environments (e.g. same propagation conditions, same antenna height, same indoor penetration requirements). The average throughputs can then be seen as the minimum achievable throughputs. In addition, a downlink / uplink ratio of 3:1 is assumed for TDD systems (UMTS-TDD and WiMAX).

In terms of throughput per sector, three performance groups can be derived:

- *300 kbit/s:* 2G technology (GSM/EDGE) can offer 320 kbit/s per carrier on average
- *700 kbit/s to 2 Mbit/s:* 3G technologies enhanced with UMTS/HSDPA or CDMA2000 1xEV-DO provide average data rates per sector of about 1 Mbit/s (from less than 1 Mbit/s for CDMA2000 1xEV-DO to around 2 Mbit/s for UMTS/HSDPA). In these systems, the ratio between the average and peak

Figure 5: Typical downlink throughputs



rates is rather low because of the high level of interference across the cell resulting from a frequency reuse of "1".
- > *10 Mbit/s:* WiMAX offers average data rates of around 15 Mbit/s, with peaks up to 22 Mbit/s.

Considering the available data rates per subscriber, the various BWA options support Asymmetric Digital Subscriber Line (ADSL) like services at the following speeds:

- Up to 128 kbit/s for GSM/EDGE.
- Up to 512 bit/s for 3G technologies (data rate at the cell edge is lower).
- Up to several Mbit/s for WiMAX.

Coverage and site reuse

Coverage determines the number of sites that are required to serve the entire service area. It is thus of the utmost importance when considering the investment needed to introduce BWA. *Figure* 6 shows the cell ranges for dense urban and rural environments with the following constraints:

- Deep indoor penetration, which is essential for BWA systems.
- Minimum uplink data rate per user at cell edge of 64 kbit/s.

> D. Renaudeau, D. Boettle, H. Steyaert: "WiMAX: From Fixed Wireless Access to Internet in the Pocket", *Alcatel Telecommunications Review,* 2nd Quarter 2005, pp 144-149 (this issue).

Two scenarios are analyzed for the WiMAX system. WiMAX PCMCIA corresponds to "Internet in the Pocket", the terminal being a PCMCIA card that can be plugged into a laptop or a Personal Digital Assistant (PDA). The WiMAX residential gateway corresponds to a deployment targeting "DSL-like" wireless with the terminal having an "ADSL modem" form factor, including a small embedded antenna, and hence capable of higher transmission powers.

Figure 6 clearly shows that the higher the frequency, the lower the range. A 900 MHz GSM/EDGE system provides the best coverage; EDGE coverage is the same as GSM coverage. For frequency bands of around 2 GHz and above, the range is at least halved compared with EDGE at 900 MHz. However, the ranges cited here are maximum ranges for GSM; in practice, GSM/EDGE ranges are limited by their capacity (typically 400 m in dense urban areas, 7 km in rural areas). Consequently, in dense urban areas, 2G sites can be used to deploy any BWA technology while providing complete coverage for BWA services. This is a key feature considering the difficulty of finding additional sites in urban areas.

Figure 6: Typical range (uplink data rate 64 kbit/s at the cell edge)

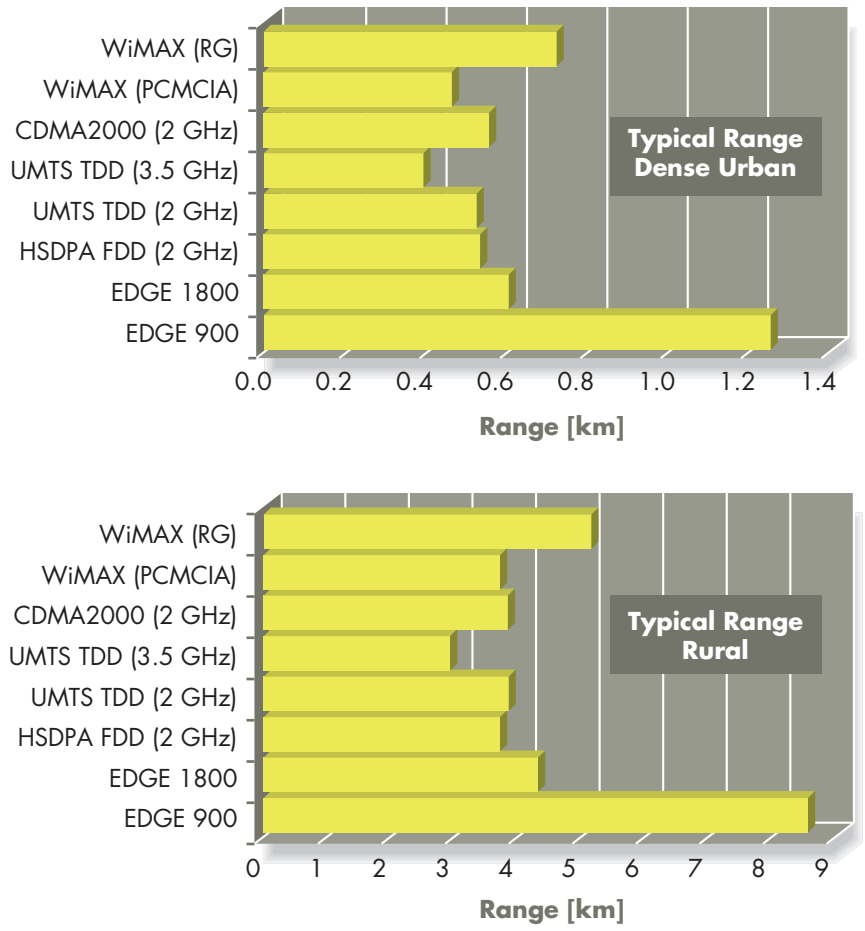
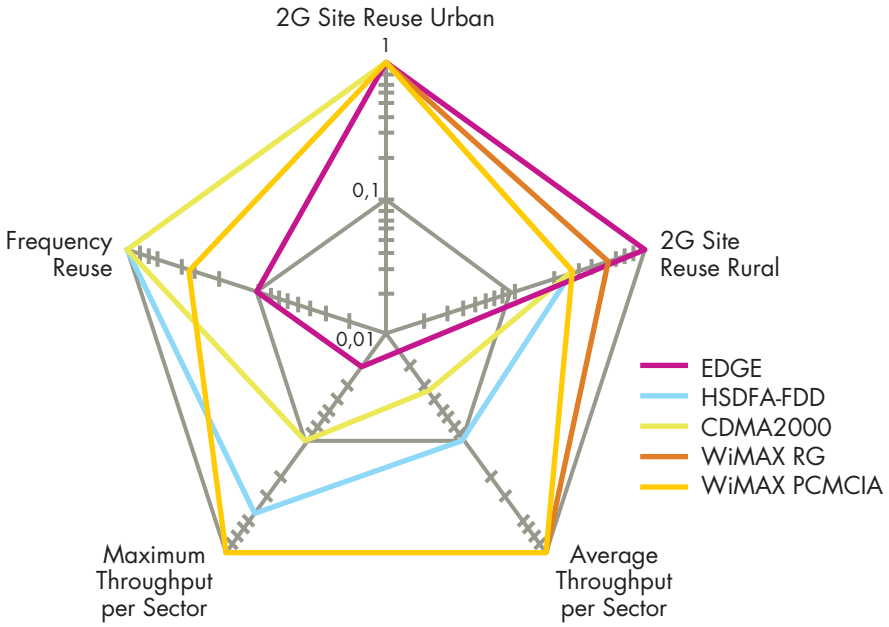


Figure 7: Performance metrics for BWA technologies



Comparative view

Figure 7 compares the performances of GSM/EDGE, UMTS-HSDPA, CDMA2000 and WiMAX; the following conclusions can be reached:

- GSM/EDGE enables BWA to be introduced smoothly at low cost: no additional sites are required, thereby optimizing capital expenditure and minimizing operating expenses. EDGE can be introduced using a simple software upgrade; Alcatel's Evolium™ hardware has been EDGE ready since 2001. Services requiring data rates of up to 128 kbit/s can be introduced.
- UMTS/HSDPA technology to support more users and higher data rates for BWA services in urban areas. Alcatel Evolium™ multi-standard base stations make optimum use of earlier 2G investments by reusing the same cabinet for both GSM and UMTS. Users receive data throughputs of up to 512 kbit/s.
- WiMAX is a real "Internet in the Pocket" BWA solution, offering high data rates per sector, and data rates in excess of 1 Mbit/s per user. Alternatively, WiMAX can be viewed as a very high capacity solution for low data rate user services, or as an overlay fixed wireless access (using WiMAX PCMCIA).

The performance results outlined here are fed into the economic models used to select the most suitable technology based on the target market, the target area and the shortest return on investment period.

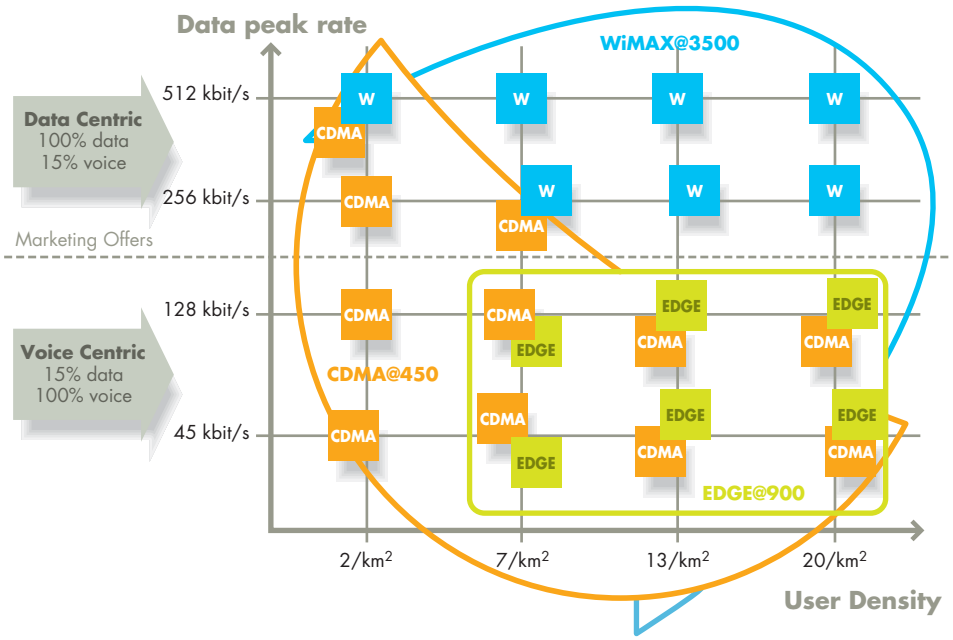
Key Broadband Wireless Technologies for Rural and Urban Environments

To help understand the positioning of the different solutions, two wireless technology groups are compared for both rural and urban areas: first a data-oriented group using WiMAX, and second a mobile-oriented group featuring EDGE, CDMA2000 1xEV-DO using 450 MHz in rural areas (CDMA450) and UMTS/HSDPA CDMA2000 1xEV-DO in urban areas. Two dimensions have been used to highlight the differences in profitability between the technologies:

- *Variations in density:* Four cases for rural fixed wireless access and three urban cases: dense urban, urban and suburban.
- Variations in data rate requirements corresponding to different marketing packages; all include both voice and data:
  - *Rural case:* Four data rates corresponding to two voice-centric marketing offers (45 and 128 kbit/s) and two data-centric offers (356 and 512 kbit/s).
  - *Urban case:* Three data rates corresponding to three well known segments: a full mobile offer up to 512 kbit/s; a nomadic / hot-zone offer up to 1 Mbit/s, and a fixed wireless offer up to 2 Mbit/s.

Note that regular design rules and classical business case rules were used to quantify the equipment needed and the profitability for each (density + data rate) case.

Figure 8: Rural area cases: What technology best meets the service requirements



The following results show that both groups of wireless technologies offer specific benefits that are needed to offer a universal wireless service in any situation (full mobile, nomadic, fixed), in any area (rural or urban), at different bitrates, and whatever the subscriber density. The overall finding is that none of these technologies can provide the optimum solution for all the scenarios, hence they should to be used to complement one another, taking the best features from each (see *Figure 8*).

WiMAX, EDGE and CDMA450A as fixed wireless access technologies for rural areas

These three wireless technologies were compared to assess how they perform economically in different density zones in a rural area while supporting the required voice + data capability. The results show that all three technologies can be used, taking full advantage of the benefits of each. However, each solution has its limitations:

- WiMAX is not yet suited to voice-oriented services, mainly for handset availability reasons. Moreover (at least in the short term), because of its mobility limitations it cannot support a full voice service.
- GSM/EDGE and CDMA hardly achieve the data capacity needed to support high-speed Internet access.

Nevertheless, each solution has its advantages:

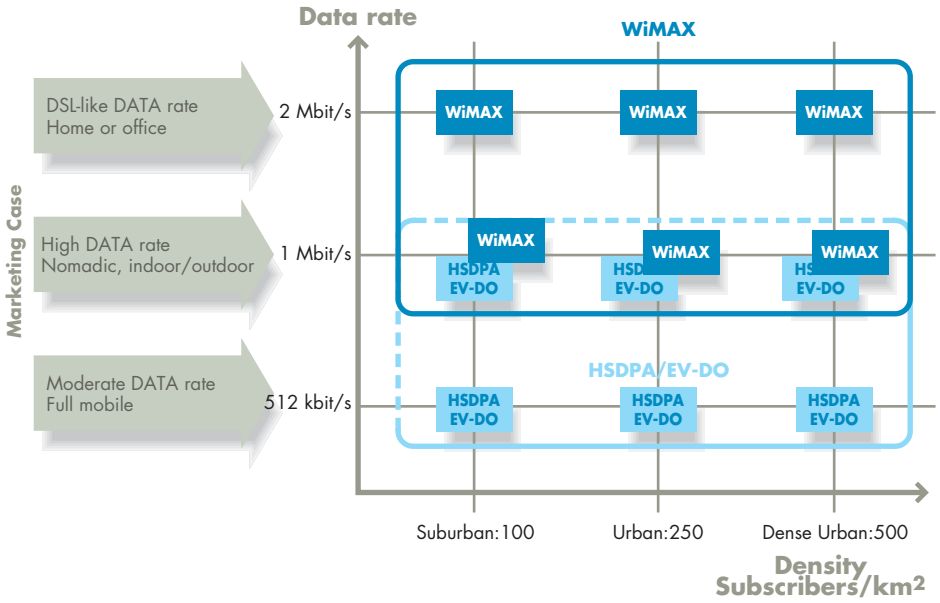
- CDMA 450 is the most economic answer in very low density rural areas thanks to its unrivalled geographical reach. It fully supports the voice service, while offering an acceptable data rate (comparable to the lowest class of fixed DSL). It could be deployed with a WiMAX implementation so that high bitrates can be offered where the user density exceeds between two and seven subscribers per square kilometer.
- EDGE and CDMA 450 are profitable in rural areas with medium to high population densities, with data rates limited to 128 kbit/s. It could be complemented by a WiMAX solution to provide higher data rates.

- WiMAX is the best answer for data rates of up to 512 Mbit/s. This is no surprise as it is a data-built-in wireless technology. It can be deployed in overlay mode on top of either EDGE or CDMA, thus offering future-safe evolution. Increased demand for voice and data services could be met either using more WiMAX + EDGE or CDMA density extension, or simply by increasing WiMAX density, using Voice over Internet Protocol (VoIP) to carry voice as soon as terminals become available.

WiMAX, UMTS/HSDPA and CDMA2000 1XEV-DO wireless technologies in urban areas

The two groups of wireless technologies were compared to assess how they perform economically in the different density zones of an urban area while supporting the required voice + broadband data capacity. The results (see *Figure 9*) show that all three technologies can be used, taking advantage of their particular benefits.

Figure 9: Urban area cases: comparing service requirements



Economically speaking, the results show that all the technologies have limitations:

- WiMAX is not yet ready for a full mobile offer, primarily because of a lack of suitable handsets.
- HSDPA and CDMA EV-DO both achieve only limited profitability when addressing nomadic hot zones. Using them to offer a combined mobile data / nomadic package could be problematic, as the larger number of sites needed would adversely affect the business case. Other drawbacks are that more equipment (and therefore investment) is needed as the data rate increases (e.g. 2 Mbit/s instead of 1 Mbit/s for nomadic use would dramatically affect the business case), and that the peak rate at the cell edges is only 128 kbit/s, compared with around 4 Mbit/s for WiMAX.

Again, each solution has specific benefits, so they can be used to complement one another:

- UMTS-HSDPA and CDMA 1xEV-DO are definitely the best fit for full mobile services, and can support a healthy throughput of 512 kbit/s on top of regular voice. They also offer greater usage flexibility, thereby enabling the existing mobile infrastructure and frequency resources to be reused when adding mobile / moderate nomadic broadband data services.
- WiMAX appears to be the best broadband data technology for any operator thanks to its DSL-like capacity, in all data-oriented cases, as already observed in the rural case. Consequently, it is the natural complement to HSDPA or EV-DO for operators that want to address all the mobile, nomadic and fixed wireless segments. WiMAX can be used for fixed wireless DSL application in areas with limited copper outside plant, as well as to provide a nomadic / hot zone wireless broadband service with HSDPA or EV-DO to meet the need for full mobility.

Conclusion

Several broadband wireless access technologies are available for different uses, providing different performances and suited to different geographies. In all cases, the aim is to offer the best access network for users when and where needed.

Alcatel can help broadband and mobile service providers to choose the best mix of these technologies as there is no *"one fits all"* solution; it is essential that the technologies should complement one another. Alcatel offers three main advantages:

- Its leading position in fixed and mobile broadband networks, applications and services, particularly its worldwide leadership in DSL.
- Its future-proof radio access network solutions which enable major new technologies, such as HSDPA, to be deployed by upgrading the UMTS software.
- Its strong commitment to optimum nomadic usage and service ubiquity combining open technology assessment, strong partnerships and network integration for the various wireless access technologies, including WiFi, WiMAX, UMTS TDD and mobile broadcast technologies.

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Abbreviations

3G Third Generation
AM Amplitude Modulation
AMC Adaptive Modulation and Coding
B3G Beyond Third Generation
BWA Broadband Wireless Access
CDMA Code Division Multiple Access
DSL Digital Subscriber Line
DSSS Direct Sequence Spread Spectrum
EDGE Enhanced Data Rate for GSM Evolution
FDD Frequency Division Duplex
GMSK Gaussian Minimum Shift Keying
HCR High Chip Rate
HSDPA High Speed Downlink Packet Access
IP Internet Protocol
MC-CDMA Multi-Carrier CDMA
OFDM Orthogonal Frequency Division Multiplexing
OFDMA Orthogonal Frequency Division Multiple Access
PDA Personal Digital Assistant
PSK Phase Shift Keying
QAM Quadrature Amplitude Modulation
QoS Quality of Service
QPSK Quaternary Phase Shift Keying
SUMU ????
TDD Time Division Duplex
TDMA Time Division Multiple Access
TD-SCDMA Time Division Synchronous Code Division Multiple Access
TROC ????
UMTS Universal Mobile Telecommunications System
VoIP Voice over Internet Protocol
WCDMA ????
WiFi Wireless Fidelity
WiMAX Wireless Microwave Access