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# Wireless Broadband 2007: WiMAX & CO

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Top Ten Technologies Project

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# Executive Summary

There are strong expectations from the public for a convergence between broadband, wireless and mobile technologies. The only answer so far has been 3G networks. Other technologies exist but, apart from one notable exception, they have failed to gain any significant momentum. This publication made by e-business Center PwC&IESE will focus on that one exception: WiMAX.

The hype surrounding WiMAX —Wireless Microwave Access— has made it difficult to understand what hides behind that label. A lot of misleading or outdated information has contributed to the confusion. The backers of WiMAX have set up a non-profit organisation called the WiMAX Forum to promote WiMAX and help guarantee interoperability between equipment from different providers. The technical specifications behind WiMAX are summed up in IEEE 802.16-2004 and IEEE 802.16e-2005 also known as Fixed and Mobile WiMAX, respectively. WiMAX is designed to provide for a wide range of applications, from mobile and fixed broadband-network access to mobile telephony or very high bandwidth backhaul.

The extensive domain of WiMAX applications means it is competing against many established or emerging technologies, including ADSL, cable modems, 3G and Flash-OFDM. Things are not straightforward, though, as competing technologies can also complement each other, depending on the scenario. So, is the hype justified? What are the cost drivers? How will it affect telecommunications providers? What will be the role of regulators?

Unfortunately, it is still too early to cover all these questions extensively, but some trends are clear. Because it is being defined as a multipurpose tool, WiMAX will find it difficult to compete successfully against more specialised technologies. WiMAX can be considered mature and competitive for applications such as Fixed Wireless Broadband or as a backhaul data pipe, but the question mark as to its ability to provide a truly mobile and truly broadband wireless connection remains.

A detailed technical and business analysis of every single wireless technology available is beyond the scope of this publication. The purpose of this dossier is to provide some indications as to how one of them, WiMAX, is changing our lives.

# 1. Added Value

## 1.1. What is WiMAX

WiMAX, which stands for Wireless Microwave Access, is a Wireless MAN solution that offers high-speed broadband access, wireless rather than wireline access which makes it less expensive than cable or DSL and much easier to extend to suburban and rural areas and broad coverage similar to the cell-phone network as opposed to a Wi-Fi hotspot type of coverage. The main promoters of WiMAX exchange views and coordinate efforts through the WiMAX Forum.

## 1.2. The WiMAX Forum

The WiMAX Forum (1) describes itself as a non-profit association formed in June 2001 to promote the adoption of IEEE 802.16-compliant equipment by operators of broadband wireless access systems. As of August 2006, more than four hundred companies based in fifty countries were members of the Forum. The board members of the WiMAX Forum are:

- **Equipment manufacturers**
  - Airspan Networks
  - Alvarion
  - Aperto Networks
  - Fujitsu
  - Intel Corporation (2,3)
  - Motorola
  - Samsung
  - ZTE Corporation

(1) WiMAX Forum website - http://www.wimaxforum.org
(2) Intel Promotion material - http://www.intel.com/netcomms/technologies/wimax/experiences.htm
(3) Intel WiMAX website - http://www.intel.com/netcomms/technologies/wimax/index.htm

- **Operators**
  - AT&T
  - British Telecom
  - KDDI
  - KT Corp
  - Sprint Nextel

To successfully promote the adoption of WiMAX, the WiMAX Forum defines network architecture and ensures interoperability.

### Network architecture

The WiMAX Forum defines the network architecture, and describes how WiMAX devices should communicate with each other (WiMAX standalone network) or with 3G or any other type of network.

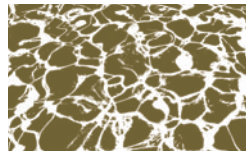
### Interoperability

By having a clear set of standards, i.e. the IEEE 802.16, and a certification program known as the WiMAX Forum Certified™ program, the WiMAX Forum aims to succeed in providing a technologically and economically sound wireless broadband infrastructure. Additionally, the WiMAX Forum maintains a database of compliant devices (4) and allows compliant devices to carry the WiMAX Forum Certified™ logo.

**Figure 1. The WiMAX Certified™ Logo**


**Source:** WiMAX Forum Webpage.
**Note:** The WiMAX Forum Certified™ logo is applicable to both fixed and mobile WiMAX devices.

(4) WiMAX Forum Certified™ Product Registry - http://www.wimaxforum.org/kshowcase/view



## 1.3. The History of Wireless Broadband

Wireless broadband was a rapidly growing business in the late 1990s, with well-financed firms such as Winstar and Teligent establishing a significant market presence and AT&T and Sprint both planning major wireless access moves. But, as shown in table 1, these initiatives did not survive the collapse of the Internet bubble.

Establishing a market presence is not enough to set up a viable business. The major reasons for the failure of these companies were common to the whole telecom bubble —unrealistic demand expectations and too much money invested in poorly tested technologies—. These conditions led to overpayment for key assets (e.g., spectrum) and the market entry of far too many competitors, even in light of the excessive demand forecasts. It is essential to avoid getting caught up in the hype and excitement of technology breakthroughs, and to focus on the business models and actual services that the technology can support.

Despite the shortcomings of this first generation, the market is more receptive now to wireless broadband than it has been for some years.

**Table 1. LMDS Bankruptcies**

| Company | Technology | Market Entry | Market Exit |
|---|---|---|---|
| Winstar | LMDS | Rolled out in 1998 | Bankruptcy 2001 |
| ART | LMDS | Rolled out in 2000 | Bankruptcy 2001 |
| Teligent | LMDS | Rolled out in 1998 | Bankruptcy 2001 |
| | | | |

**Source:** Authors, based in Financial Times. (5)

### 1.3.1. WiMAX Development Milestones

The IEEE 802.16 Working Group on Broadband Wireless Access Standards was established by the IEEE Standards Board in 1999 to prepare formal specifications for the global deployment of broadband wireless metropolitan-area networks. Table 2 lists the main milestones.

(5) "Broadband Fixed Wireless - a Proven Technology Retains Wide Appeal", Financial Times, 2002.

**Table 2. WiMAX standard milestones**

| Standard | Characteristics | Availability | Status |
|---|---|---|---|
| 802.16-2001 | - Air Interface for Fixed Broadband Wireless<br>- Access, requires Line of Sight (LoS) | 22 Oct 2002 | Superseded by 802.16-2004 |
| 802.16a | - Addresses radio spectrum issues, licensed and unlicensed<br>- Allows for Non-Line of Sight (NLoS) | 9 Oct 2003 | Superseded by 802.16-2004 |
| 802.16.2 | - Addresses inter-operability issues<br>- Adds Quality of Service (QoS) | 10 Apr 2002 | Superseded by 802.16-2004 |
| 802.16c | - Defines interoperability tests | 15 Jul 2003 | Superseded by 802.16-2004 |
| 802.16-REVd | - Aligns to aspects of the European Telecommunications Standards Institute (ETSI) HiperMAN standard | | Cancelled, rolled up in 802.16-2004 |
| 802.16-2004 | - Addresses errata<br>- Redefines conformance tests<br>- Sums up standards for Fixed Broadb and Wireless Access Systems<br>- Previous standards are withdrawn | 01 Oct 2004 | Active Amended by 802.16f Amended by 802.16e |
| 802.16e-2005 | - Adds support for mobility | 30 Aug 2006 | |
| 802.16f | - Air Interface for Fixed Broad band Wireless<br>- Access Systems<br>- Management Information Base | 01 Jun 2006 | Active |
| 802.16g | - Air interface for Fixed and Mobile Broadband Wireless Access Systems<br>- Management Plane Procedures and Services | Not yet available | In development process |
| 802.16h | - Improved Coexistence Mechanisms for License-Exempt Operation | Not yet available | Pre-draft |
| 802.16i | - Air Interface for Broadband Wireless Access Systems<br>- Mobile Management Information Base | Not yet available | Pre-draft |
| 802.16j | - Air Interface for Fixed and Mobile Broadband Wireless Access Systems<br>- Multihop Relay Specification | Not yet available | Pre-draft |
| 802.16k | - Bridging of 802.16 | Not yet available | Pre-draft |

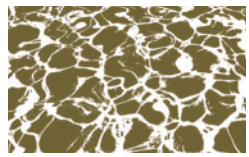
**Source:** The IEEE 802.16 Working Group on Broadband Wireless Access Standards. (6)

## 1.4. WiMAX Applications

As a technology, WiMAX provides a wireless broadband pipe that can carry data for a wide range of applications. So far, commercial applications include:

• Fixed wireless broadand for emerging markets (school network in Macedonia

(6) http://grouper.ieee.org/groups/802/16/milestones/index.html.



(7), E-MAX (8) in Peru); for rural and underserved communities in developed markets (clearwire (9) in the United States) and for high-speed enterprise connectivity for business (iberbanda in Spain).

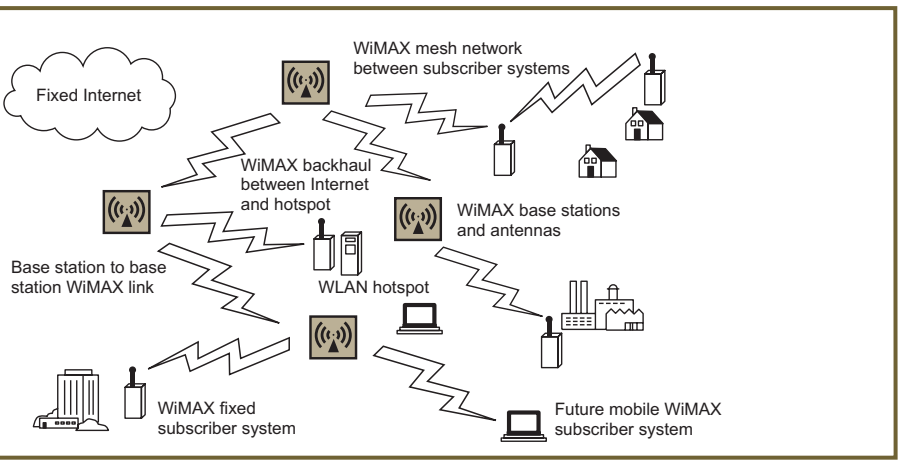
- Wi-Fi hotspots and cellular backhaul
- Mobile telephony
  - E.g. Korea Telecom WiBro (10,11).

Altough these are the most important applications, others have been successfully tested.

## 1.5. WiMAX Topology

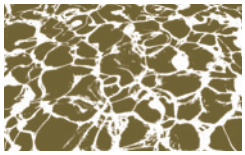
Figure 2 illustrates a sample WiMAX network:

**Figure 2. WiMAX Applications**




**Source:** Intel, (2005).

(7) Macedonia WiMAX Deployment http://www.usaid.gov/locations/europe_eurasia/press/success/student_gateway.html
(8) E-MAX website - http://www.emax.com.pe/
(9) Clearwire website – http://www.clearwire.com/
(10) "South Korea Launches WiBro Service", EEtimes, 30/06/2006. http://www.eetimes.com/news/latest/showArticle.jhtml?articleID=189800030
(11) "A Ride Around Seoul in a WiBro Equipped bus" , YouTube, July 2006. http://www.youtube.com/watch?v=Gso2WTCLC98.





## 1.6. WiMAX Description

WiMAX can be part of a fixed or a mobile telecommunications network setup. In a fixed scenario, it replaces the copper wires that connect you to your phone, Internet or television service provider. In a mobile scenario, WiMAX replaces the cellular phone network (2G, 2.5G or 3G) for voice and data communications.

A minimal WiMAX installation consists of two parts:

1. A WiMAX base station, similar in concept to a cell-phone tower or Wi-Fi access point.
2. A WiMAX receiver or Customer Premises Equipment (CPE) is the client device. It varies with the application. It can be a phone handset, a subscriber system or, in the future, a desktop or laptop computer with integrated WiMAX.

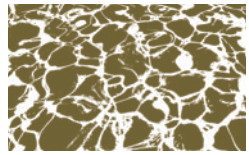
The WiMAX base station connects either directly to the Internet using a wireline connection (e.g. T3 line) or it can also connect without wires to another WiMAX tower using an LoS. This introduces the two main types of network architecture supported by WiMAX: **Point-to-Point and Point-to-Multipoint**.

### 1.6.1. Point-to-Point (PTP)

Point-to-Point is a link between one sender and one receiver, e.g. to connect a data-centre and an office. Another common application of PTP architecture is to connect a point-to-multipoint distribution node to the rest of the network, e.g. to connect a Wi-Fi hotspot to an Internet Service Provider (ISP). This application is known as backhaul. In this architecture, the highly focused radio beam allows for higher ranges and throughput compared to Point-to-Multipoint (PTM) architecture.

### 1.6.2. Point-to-Multipoint (PTM)

As mentioned earlier, Point-to-Multipoint is the architecture that performs the distribution functions. One base station serves the needs of the many users within its range. WiMAX can allocate different bandwidths and provide a range of services to different clients within a cell (telecommunication term describing the region covered by a base station). For instance, the same base station would provide the equivalent of a T1 (legacy term refereeing to a symmetric 1.544



Mbps connection) or E1 (legacy term refereeing to a symmetric 2.048 Mbps connection) connection to a company, and the equivalent of an Asynchronous Digital Subscriber Line (ADSL) to a domestic user.

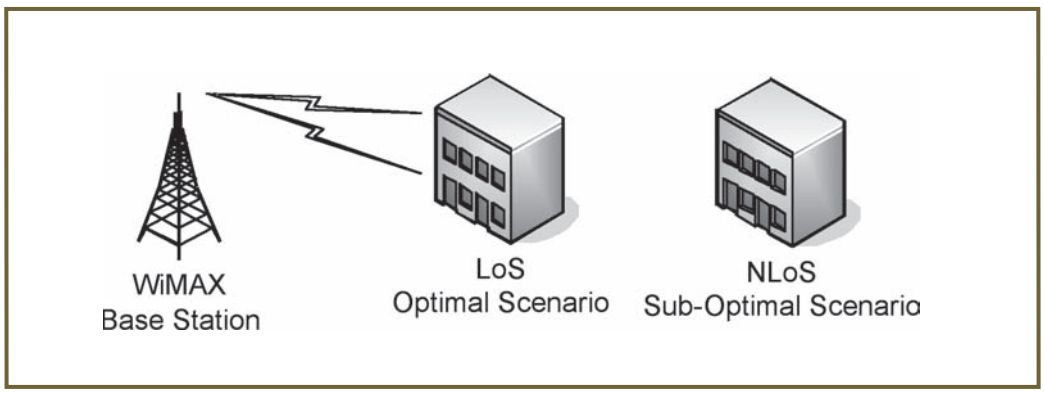
### 1.6.3. Line of Sight (LoS) and Non-Line of Sight (NLoS)

A key design requirement for WiMAX was low cost per subscriber. Since many of the potential subscribers are found in urban areas, a given WiMAX base station must be able to reach subscribers even if they are not directly in the base station's Line of Sight (LoS). In other words, even if there is another building between a subscriber and the base station, he or she should still be able to connect. This property is known as Non-Line-of-Sight (NLoS) connectivity.

NLoS connectivity is the main technical feature that differentiates Fixed WiMAX from its predecessors such as Local and Multichannel Multipoint Distribution Systems (LMDS and MMDS), which failed to become mass market phenomena. It should be understood, however, that NLoS connectivity is costly in terms of range and throughput. (12)

### 1.6.4. Fixed WiMAX IEEE 802.16-2004

**Figure 3. LoS and NLoS**




**Source:** Authors.

(12) WiMAX's technology for LOS and NLOS environments
http://www.wimaxforum.org/news/downloads/WiMAXNLOSgeneral-versionaug04.pdf

The goals that were defined for WiMAX included service coverage within a radius of 10 km from a WiMAX base station. That base station has to provide enough bandwidth to support hundreds of businesses with T1 speeds and thousands of residential customers with the equivalent of ADSL services. These goals are currently achievable only with external LoS Customer Premises Equipment (CPE). Detailed technical specifications can be found in standard IEEE 802.16-2004. (13)

### 1.6.5. Mobile WiMAX IEEE 802.16e.2005

Mobile WiMAX has the potential to replace existing cell-phones and mobile-data services. It enables streaming video to be broadcasted to a vehicle travelling at over 100 km/h. It offers superior building penetration and improved security measures over fixed WiMAX. Mobile WiMAX will be very valuable for emerging services such as mobile TV and gaming. Confusingly enough, some vendors have decided to use mobile WiMAX technology (IEEE 802.16e-2005) to offer fixed broadband access. Detailed technical specifications can be found in standard IEEE 802.16e-2005.(14)

### 1.6.6. WiMAX is not Wi-Fi

A common misconception is that WiMAX is “Wi-Fi on Steroids”. This is a very restrictive perception and a comparison that is unfair to Wi-Fi. Wi-Fi was created as a Wireless LAN solution and performs very well within the constraints for which it was developed. As a technology, Wi-Fi’s objective is to provide a wireless substitute to the Ethernet cable.

As for WiMAX, it is a Wireless MAN solution and as such provides greater range and throughput than Wi-Fi, but that’s not all. It also provides carrier-grade Quality of Service (QoS) and includes security features.

(13) IEEE Standards Association http://standards.ieee.org/getieee802/802.16.html
(14) http://standards.ieee.org/getieee802/802.16.html

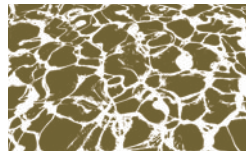


**Table 3. Wi-Fi vs. WiMAX**

| | Wi-Fi | WiMAX |
|---|---|---|
| Base Station Range | 100 m.<br>~An office floor. | 10 km.<br>~ A small city. |
| Throughput | Up to 54 Mbps. | Up to 72 Mbps. |
| Security | Limited.<br>Can be optionally implemented. | Multiple encryption. |
| QoS | Limited.<br>Can be optionally implemented. | Dynamic bandwidth allocation.<br>Allows better audio and video transmissions. |

**Source:** WiMAX Forum webpage.

## 1.7. WiMAX Hardware

### 1.7.1. Base Station

From a technical perspective, WiMAX antennas can share masts with cellular telephony antennas. The type of antenna deployed depends on the WiMAX network architecture. For Point-to-Point (PTP) links the common choice is a panel directional antenna, which transmits or receives maximum power in a specific direction, as we can see in figure 4.

**Figure 4. Panel antenna**

**Source:** Pheenet Technology Corporation Webpage. (15)

(15) http://www.pheenet.com/

For Point-to-Multipoint (PTM) connectivity the common choices are omni-directional or sector antennas (60° - 210°). Omni-directional antennas which broadcast 360° from the base station are adapted to areas with high a density of clients within the base-station coverage area. When the demand exceeds the range or the throughput of omni-directional antennas, operators replace them with two or more sector antennas. This improves the range and throughput of the WiMAX base station for a moderate additional investment.

**Figure 5. Omni-directional and sector antenna**

**Source:** Pheenet Technology Corporation Webpage. (16)

## 1.7.2. Receiver

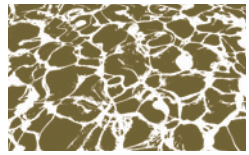
### 1.7.2.1. WiBro PDA Phones

The first devices presented to the Korean public when Korea Telecom (KT) launched its WiBro service were the Samsung SPH-M8000 and SPH-H1000.
WiBro was originally developed independently of WiMAX, but in 2004 LG Electronics agreed to include WiBro specifications in WiMAX specifications and ensure interoperability.

**Figure 6. Samsung SPH-M8000 and SPH-H1000**

**Source:** CNET Japan webpage. (17)

(16) http://www.pheenet.com
(17) http://japan.cnet.com



### 1.7.2.2. Customer Premises Equipment (CPE): Outdoor CPE or Indoor CPE

An outdoor CPE is an LoS (Line of Sight) device and as such offers better performance compared to an indoor CPE. The signal does not have to go through walls and windows to reach the receiver. The drawback is that it is more complicated to install, and more expensive because it needs to be weatherproof.

**Figure 7. Outdoor CPE - Airspan ProST**

**Source:** Airspan Webpage. (18)

**Figure 8. Indoor CPE - Airspan EasyST**

**Source:** Airspan Webpage. (19)

The big advantage of an indoor CPE is that it is pretty straightforward to install. It can be installed by the end user, thus allowing the operator to make savings on truck rolls and installation costs. The drawback is that since it is an NLoS device, the distance between the indoor CPE and the base station must be smaller.

(18) (19) http://www.airspan.com/

## 1.8. WiMAX Financial Costs

### 1.8.1. Capital Expenditures (CAPEX)

WiMAX Network capital expenditure is determined by the services offered, the clients targeted, their location and the pre-existing infrastructure. These parameters will help determine how many WiMAX base stations (BS) must be deployed, the number of BS will be driven by one the following constraints: capacity or coverage of each BS.

The items that need to be considered are:

1. Core & edge equipment.
    - Routers, switches, etc.
    - Spectrum license.
    - WiMAX can also operate in unlicensed radio spectrum.
2. The base stations.
    - WiMAX equipment.
    - Other base station equipment.
        - Antennas, cabinets, network interface cards, etc.
        - Backhaul link.
    - Base station acquisition & civil works.
3. The customer premises equipment.

The WiMAX Forum explores some scenarios in greater detail in a document titled “Business Case Models for Fixed Broadband Wireless Access based on WiMAX Technology and the 802.16 Standard”. (20)

#### 1.8.1.1. CPE Cost Development

As WiMAX adoption increases, the CPE costs are expected to halve over the next three years.

(20) Business Case Models for Fixed Broadband Wireless Access based on WiMAX Technology and the 802.16 Standard - http://www.wimaxforum.org/news/downloads/WiMAX-The_Business_Case-Rev3.pdf

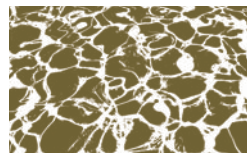
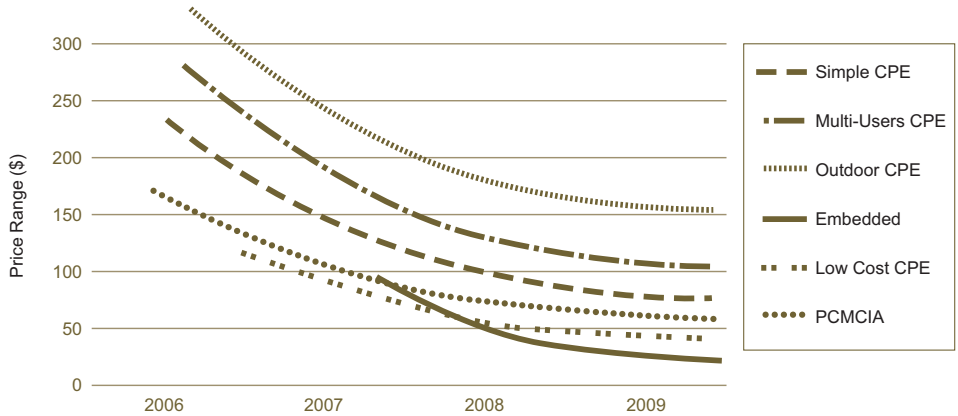


**Figure 9. WiMAX CPE Costs**




**Source:** Universal WiMAX for Fixed, Mobile, Converged and Private Operators, Alcatel, (2006).

## 1.8.2. Operating Expenditures (OPEX)

The operating-expenditure items of a WiMAX network are similar to those of other wireless telecommunication networks:

- General and administration expenses.
- Sales and marketing expenses (including customer technical support).
- Network operations.
- Equipment maintenance.
- Base station installation and commissioning (this is a one-time expense).
- CPE install and commissioning.
- Base station site lease expense.
- Customer site lease expense (not applicable for residential market segment).
- Allowance for bad debts and churn.

As for the CAPEX, some scenarios can be found in “Business Case Models for Fixed Broadband Wireless Access based on WiMAX Technology and the 802.16 Standard”.(21)

(21) Business Case Models for Fixed Broadband Wireless Access based on WiMAX Technology and the 802.16 Standard - http://www.wimaxforum.org/news/downloads/WiMAX-The_Business_Case-Rev3.pdf

# 2. WiMAX Usage Scenarios

## 2.1. Overview

Table 4 summarises the main applications of WiMAX Technology.

**Table 4. WiMAX Service Classes**

| Class Description | Real Time? | Application Type | Bandwidth |
|---|---|---|---|
| Interactive gaming | Yes | Interactive gaming | 50-85 kbps |
| VoIP, Video conference | Yes | VoIP | 4-64 kbps |
| | | Video phone | 32-384 kbps |
| Streaming media | Yes | Music/speech | 5-128 kbps |
| | | Video clips | 20-384 kbps |
| | | Movie streaming | >2Mbps |
| Information technology | No | Instant messaging | <250 byte messages |
| | | Web browsing | >500 kbps |
| | | Email (with attachment) | >500 kbps |
| Media content download (store and forward) | No | Bulk data, Movie download | >1 Mbps |
| | | Peer-to-peer | >500 kbps |

**Source:** WiMAX Forum webpage.

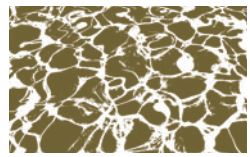
**Table 5. WiMAX Usage Scenarios**

| | Flexible Architecture | High Security | WiMAX QoS | Quick Deployment | Multi-Level Service | Interoperability | Portability | Mobility | Cost-Effective | Wider Coverage | NLOS | High Capacity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Cellular Backhaul** | | | | ● | | | | | ● | | | ● |
| **WSP Backhaul** (22) | | | | ● | | | | | ● | | | ● |
| **Banking Networks** | ● | ● | ● | | | | | | ● | | ● | |
| **Education Networks** | ● | | ● | | | | | | ● | ● | | |
| **Public Safety** | ● | ● | ● | ● | | | ● | ● | | | ● | |
| **Offshore Communications** | ● | | ● | | | | ● | ● | | ● | ● | |
| **Campus Connectivity** | ● | ● | ● | | | | | | | | | ● |
| **Temporary Construction** | | | ● | ● | | | ● | | | | ● | |
| **Theme Parks** | ● | | ● | | | | ● | ● | | | ● | |
| **WSP Access Network** | | ● | ● | | ● | ● | | | ● | | ● | ● |
| **Rural Connectivity** | | | ● | | | ● | | | ● | ● | | |
| **Military Battlefield** | ● | ● | | ● | | | ● | ● | | | | |

**Source:** WiMAX Forum webpage.

Table 5 highlights how specific properties of WiMAX come in to play in the different usage scenarios. For more details regarding the above-mentioned scenarios consult the WiMAX Forum white paper: “Can WiMAX Address Your Applications?”. (23)

(22) WSP – Wireless Service Provider
(23) For more details regarding the above-mentioned scenarios consult the WiMAX Forum white paper: Can WiMAX Address Your Applications? - http://www.wimaxforum.org/news/downloads/Can_WiMAX_Address_Your_Applications_final.pdf



## 2.2. Rival Technologies

As the usage scenarios above illustrate, WiMAX is a technology that can potentially substitute a lot of existing wireline and wireless technologies.

### 2.2.1. Wireline Broadband Technologies

The established broadband technologies are wireline. As such, they are inherently less susceptible to interferences but generally require higher investment in infrastructure. They also do not provide for any mobility. The following technologies compete mainly with the fixed incarnation of WiMAX.

#### ADSL

ADSL infrastructure is still largely tied to telephony service providers' copper wire infrastructure, it offers no mobility, and the cost per subscriber is relatively high. However, it does offer higher bandwidths and is a proven technology.

#### Cable Modem

In order for cable modems to allow broadband access, the coaxial cable networks must be bidirectional. If this is not the case they need to be upgraded. Here again, the cost per subscriber is relatively high and the system offers no mobility, but the technology is proven and offers high bandwidths.

#### Fibre to the Home (FTTH)

Once more the main issue is price. The cost of trenching and installing the fibre up to subscribers' homes is prohibitive. Fibre to the Home (FTTH) is also less proven than ADSL or cable modem technology but, where deployed, it offers extremely high bandwidths, reaching 50 Mbps and higher.

#### Broadband over Power Line (BPL)

To install Broadband over Power Line (BPL), the power company needs to intervene in each residence or business where the service is to be installed. This means

a big truck-roll expense. A power company that wants to enter the broadband market would be better off, in terms of cost per subscriber and return on investment, to deploy WiMAX using power poles to attach the WiMAX equipment and antennas, rather than attempting to roll out service to existing power subscribers using BPL. BPL is a viable option to set up an intranet, but not to access the Internet.

### 2.2.2. Wireless Broadband Technologies

Arguably these technologies are currently pitched as wireless broadband (3G), but they have not met consumer expectations.

### 3G Data Technologies

3G Data technologies such as EvDO (Evolution-Data Optimized) and UMTS (Universal Mobile Telecommunications System) are currently by far the most widely deployed mobile broadband technologies. HSDPA (High-Speed Downlink Packet Access) is an upgrade for UMTS packet data, enabling peak rates of up to 3.6 Mbps, with further steps at 14.4 Mbps planned for the near future.

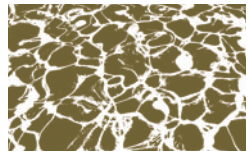
Although it is the best mobile wireless broadband solution available, its expensive infrastructure currently limits its rollout to dense urban areas and airports where it provides a positive return on investment. 3G Data technologies are not expected to be able to deliver a wireless version of triple-play services.

### Flash-OFDM

Flash-OFDM, which stands for Fast Low-latency Access with Seamless Handoff Orthogonal Frequency-Division Multiplexing, is a proprietary wireless broadband technology developed by Flarion Technologies, which was later acquired by Qualcomm (24), a major developer and patent holder of Code Division Multiple Access (CDMA) and other advanced wireless technologies.

It can operate in several licensed frequency bands, such as 450 MHz, 700 MHz, 800 MHz, 1.9 GHz, and 2.1 GHz. As it is IP-based and features low latency and

(24) Qualcomm Website - http://www.qualcomm.com/technology/flash-ofdm/index.html



enhanced QoS support, it natively supports applications such as VoIP. Flash-OFDM reaches user-data rates of 1 to 1.5 Mbps in downlink and around 300 to 500 kbps in uplink.

Compared to mobile WiMAX, Flash-OFDM has a time-to-market advantage in that its equipment is readily available on the market. Its major drawback is having only limited vendor support and not being an open technology. Flash-OFDM is also a candidate for the IEEE 802.20 standardization effort.

## Mobile Broadband Wireless Access (MBWA - IEEE 802.20)

The IEEE 802.20 Working Group (25) was established on December 11, 2002 with the aim of developing a specification for an air interface optimized for Internet Protocol (IP) based services. It is hoped that such an interface, also known as Mobile-Fi, will allow for the creation of low-cost, always-on and truly mobile broadband wireless networks for both business and residential use. It will operate in licensed bands below 3.5 GHz and provide data rates exceeding 1Mbit/s at speeds of up to 250 km/h (IEEE 2006a).

The goals of 802.20 and 802.16e-2005 (Mobile WiMAX) are similar, though mobile WiMAX is much more mature. A draft version of the specification was first approved on January 18, 2006 (IEEE 2006b). The advantage of MBWA is that it was designed from the outset to handle hand-offs between base stations gracefully. The hand-offs have created more issues than anticipated for WiMAX.

In table 6 you can find a comparison of the different wireless technologies available.

(25) IEEE 802.20 Website - http://www.ieee802.org/20/index1.html

**Table 6. Wireless Technologies Comparison**

| | Typical Range | Effective Throughput |
|---|---|---|
| **MBWA** | MAN range | >1 Mbps |
| **Flash-OFDM** | 5-20 km | 1-1.5 Mbps |
| **2.5G** | 3-8 km | 30-130 kbps |
| **3G** | 3-8 km | 300-500 kbps |
| **WiMAX** | 2-5 km NLOS<br>30-50 km LOS | <15Mbps<br><70Mbps |

**Source:** Authors.

# 3. Affected Sectors

## 3.1. Broadband Telecommunications Providers: Wireline Providers and Wirelsess Providers

### Wireline Providers

For wireline providers, broadband is part of a portfolio of services that includes voice and, increasingly, video services known as triple play. The bundling of these services helps to reduce customer churn while improving average revenue per user (ARPU). So far, broadband access is mainly provided through wired connections, either through Digital Subscriber Lines (DSL) or through cable.

Even though WiMAX is supposed to be able to handle the bandwidth requirements for such services, the telecom companies who invested heavily in their wireline infrastructure are unlikely to drop it before obtaining satisfying returns. They are currently investing further on wireline infrastructure in order to increase their penetration. At best, they might use WiMAX to complement their coverage of sparsely-populated areas that do not economically justify providing DSL or cable services.

### Wireless Providers

Wireless operators have embraced low-bandwidth data applications such as text messaging, multimedia messaging, email, games and ring-tone downloads, in an effort to increase the average revenue per user (ARPU). Despite WiMAX potential for data applications, most operators are still busy rolling out their 2.5G and 3G networks. Given that they often own the radio spectrum needed to provide a reliable WiMAX service, incumbents are best positioned to offer

wireless broadband services. At the same time, though, they are not in a hurry to cannibalise their current revenues. Internally, they will probably start using WiMAX in rural areas as a backhaul for their 2.5G or 3G base stations. For consumers, they will probably start serving some niche markets and gradually expand the broadband offer as they gain a better understanding of consumers' willingness to pay. Wireless providers also need to gain a better understanding of the actual capabilities of WiMAX in order to develop their services and set prices at a profitable yet attractive level.

# 4. Regulation and Legal Aspects

## 4.1. How Can Regulation Affect Technology Implementation?

Although the technology can operate in unlicensed spectra, it was designed and optimized to operate in licensed spectra.

### Unlicensed Spectrum

Anyone is allowed to broadcast on frequencies belonging to unlicensed spectra provided they respect the emission power limits. The advantage is that the use of these frequencies is free of charge. The downside is that they are often crowded, and if anyone interferes with your signal, as long as they are within the prescribed emission power limits there is no recourse to prevent them from doing so.

### Licensed Spectrum

In licensed spectra, the owner of the licence has exclusive access to the frequencies on the territory covered by the licence. If someone interferes with the signal, the licence owner can complain to the regulatory body that will enforce the exclusive rights.

The licence-allocation process varies from country to country. More information can be found in the following OECD report: "The Implications of WiMAX for Competition and Regulation". (26)

(26) “The Implications of WiMAX for Competition and Regulation”, OECD, (2006) Also available online in http://www.oecd.org/dataoecd/32/7/36218739.pdf

## Spectrum Allocation

Regulatory support, including radio-spectrum allocation will be a key factor in the successful growth of WiMAX and, in general, any other future radio technology.

Recurrent complaints regarding the existing bandwidth-allocation system -designed in the 1930's with unidirectional radio broadcast in mind- is that it prevents efficient bandwidth use and stymies the deployment of new applications. Usually, the owner of a licence can not change the use for which this licence was granted without undergoing lengthy administrative and regulatory screenings. As a result, declining or dead applications are allocated bandwidths they barely use (e.g. analogue mobile telephony) and emerging technologies are constrained by the limited bandwidths available to them.

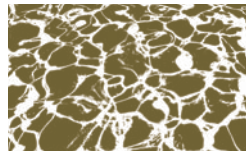
Acknowledging this issue, the European Union and other regulators are exploring a market-based approach in which industry operators can trade "exclusive usage rights" for a given radio frequency and geographical area.

**Table 7. Spectrum allocation sample**

| Frequency | Usage |
|---|---|
| 2-11GHz | IEEE 802.16-200. |
| 2.4 -2.483GHz | ISM (27), largely unlicensed and used for Wi-Fi. Interference prone. |
| 2.5GHz | Popular US WiMAX licensed spectrum choice. |
| 3.5GHz | Allocated mainly to fixed applications, an increasing number of countries are considering it for mobile applications as well. An increasing number of countries are considering it for mobile applications as well. |
| 4.9GHz | Public safety in the US: police, firemen, etc. |
| 5.72-5.85GHz | US Unlicensed. |

**Source:** Authors.

(27) ISM – Radio band originally reserved for industrial, scientific and medical applications.



## ITU - International Telecomunication Union (28)

The International Telecommunication Union (ITU) was founded as the International Telegraph Union in Paris on May 17, 1865. It is an international organization established to standardize and regulate international radio and telecommunications. Its main tasks include standardization, allocation of the radio spectrum, and organizing interconnection arrangements between different countries. It is one of the specialized agencies of the United Nations, and is headquartered in Geneva, Switzerland.

The ITU is organized into three main sectors and each sector is broken up into various technical study groups:

- ITU-R Radiocommunication Sector
- ITU-T Standardization Sector
- ITU-D Development Sector

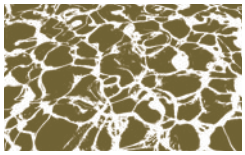
ITU guidelines are developed according to a formal process. The study groups address particular technical “questions”, which are technology areas that warrant further research. Once a topic has been sufficiently researched and a decision has been made about how to proceed, the group submits a formal “recommendation.” This recommendation is then shared with all of the external ITU partners, such as Standards Development Organizations (SDOs) and national governments.

Two groups within the ITU are relevant to WiMAX as they specifically engage in helping to define the next generation of mobile wireless systems. These two groups include:

- Working Party 8F (WP8F) in section ITU-R
- Special Study Group (SSG) “IMT 2000 and Beyond” in section ITU-T

WP8F is focused on the overall radio-system aspects of 4G, such as radio interfaces, radio-access networks (RANs), spectrum issues, service and traffic characteristics, and market estimations. The SSG “IMT-2000 and Beyond", including wireless Internet, convergence of mobile and fixed networks, mobility management, internetworking, and interoperability.

(28) ITU Website - http://www.itu.int/aboutitu/index.html





### WiSOA - WiMAX Spectrum Owners Alliance (29)

In September 2006, companies that own licenses and operate WiMAX or pre-WiMAX services formed the WiMAX Spectrum Owners Alliance (WiSOA). The objective of this alliance is to pledge roaming interoperability of next-generation commercial WiMAX networks, i.e. to enable and coordinate roaming agreements between WiMAX operators. The issue here is that the WiMAX technical specification allows operators to select their working frequency from a wide range of frequencies. This makes it more difficult to obtain a global consensus regarding which frequency to use. Intel seems to favour the 2.5 GHz spectrum band for universal WiMAX, but the majority leans towards frequencies in the 3 or 4 GHz spectrum. WiMAX without roaming would be less appealing for mobile applications.

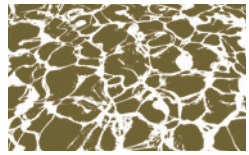
## 4.2. Intellectual Property

WiMAX Forum membership implies some obligations regarding intellectual property. Members must declare whether their intellectual property conflicts with work in progress at the WiMAX Forum. Also members must agree that they "will licence to other members, under reasonable and non-discriminatory terms (including without limitation a field of use of sufficient scope to cover at least implementation of the Specification and compliance with IEEE 802.16 standards and protocols), a non-exclusive, non-transferable (except to a successor in the interest of all or the relevant part of the business of such other Members, Affiliates or implementers), non-sublicensable worldwide license to make, have made, use, import, offer to sell, and sell and otherwise distribute implementations compliant with all relevant required portions of such Specification". (30)

## 4.3. Data Protection

Unlike Wi-Fi, data security has been taken into account from the outset of WiMAX development. Both Fixed and Mobile WiMAX incorporate encryption standards (DES and EAP or AES, respectively). However, claims from some

(29) WiSOA Website - http://www.wisoa.com/site/
(30) WiMAX Forum Intellectual Property Rights Policy - http://www.wimaxforum.org/join/Governing_Documents/WIMAXForum_IPR_2005_09_27final.PDF



vendors that the technology is foolproof should be approached with caution as advances in cryptography constantly expose previously unknown weaknesses. Nonetheless, by encrypting the link between the BS and the client, WiMAX provides subscribers with some privacy and security. WiMAX also has built-in VLAN support, which contributes to privacy by creating a virtual tunnel between a user and the data he or she is accessing.

## 4.4. Competition Law

For WiMAX-based services to be competitive, regulators must ensure that incumbent network operators do not abuse their dominant position and prevent network inter-connection or price it prohibitively. This might be an issue especially in developing countries.

# 5. Forecast

WiMAX has emerged as a serious contender when it comes to Fixed Wireless Broadband access in underserved markets. Clearstream (31), a US WiMAX operator, received more than $600M from investors, in this case Intel Capital, to expand its network. WiMAX is expected to command between 3% and 4 % of the worldwide broadband-access market by 2010 (32). But it is also contending in the mobile area. Even though 4G is not yet clearly defined, WiMAX is a prime candidate and is expected to fight for that market. Some operators have already announced their intention to deploy WiMAX gear as a 3G offer. Sprint in the US is expected to cover 100 million people with its WiMAX network by 2008. (33)

It is not clear that a single dominant wireless broadband technology will emerge. In such a case where different access technologies are used to complement each other, inter-system handovers will have to be solved.

(31) Clearstream - http://www.clearstream.com/
(32) See IDATE and Enter Mobile 2006 Report, 2006. Also available online
(33) Sprint WiMAX Press Release - http://www2.sprint.com/mr/news_dtl.do?id=12960

# 6. Conclusions

There is a strong push for wireless broadband, especially mobile wireless broadband. There are several alternative technologies for it, the most notable of which are 3G HSDPA and derivatives and mobile WiMAX. Both standards enjoy economies of scale through widespread support among leading vendors and operators, while proprietary solutions such as Flash-OFDM are more likely to end up as niche solutions.

Regulators will have their say over technology selection as successful wireless broadband deployment is currently understood to require licensed spectra. HSDPA will leverage existing 3G/GSM networks with vast subscriber bases, while WiMAX will be more popular with new entrants or operators that have a fixed broadband background.

Incumbent equipment vendors will probably have a preference for 3G or WiMAX, but most of them will play both sides of the game unless a clear winner emerges. Developing or even supporting two types of equipment seems expensive, but investing only in the wrong standard would be far worse.

The fewer access networks operators have to manage, the better off they will be. It is unlikely that a typical 3G operator would take the initiative to build a mobile WiMAX network if he can avoid it. However, other considerations such as regulations, customer density, spectrum availability and others might come into play. In the long term, mobile broadband will probably represent a sizeable share of revenue for mobile operators, and fixed wireless broadband may provide high-speed service to underserved rural areas.

Consumers will most likely not care about what technology or mix of technologies is behind their products as long as it delivers. Increased competition and lower switching costs will benefit them by fuelling both performance development and continued price erosion of wireless broadband technologies.

The challenge for WiMAX which is currently defined as a “one fits all” technology is that it will eventually compete with a range of specialised technologies. WiMAX standards give a lot of leeway to the implementer, but it still remains unlikely that any single technology will fill all wireless broadband niches. The niches that WiMAX currently dominates –Fixed Wireless Broadband– might be insufficient to sustain the hype surrounding WiMAX for more than a couple of years. Neither is the potential of backhaul applications enough. Eventually WiMAX will have to fulfil expectations regarding mobile wireless broadband.

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  http://www.wisoa.com/site/

# Appendix 1. Description of WiMAX related technologies

The following acronyms often appear in WiMAX-related literature.

## AAS

Adaptive Antenna Systems (AAS) use beam-forming technologies to focus the wireless beam between the base station and the subscriber. This reduces the possibility of interference from other broadcasters as the beam runs straight between the two points.

## DFS

A Dynamic Frequency Selection (DFS) radio explores the airwaves to determine which frequencies are interference-free and selects one of them to transmit the signal avoiding delays and loss of data.

## MIMO

Multiple In and Multiple Out (MIMO) antennas have multiple transmitters and receivers built into the antenna. When the emitted radio signals reflect off objects, they follow multiple paths which in conventional radios would be an issue. MIMO leverages these multiple paths to carry more information. The information carried through the multiple paths is recombined at the receiving end by the MIMO algorithms to restore the original signal.

## SDR

A software-defined radio (SDR) system is a radio communication system that has the instructions on how to process incoming and outgoing radio signals as

soft- coded rather than hard-coded (software rather than hardware). This makes them much more flexible and easier to maintain and upgrade.

## OFDM

Orthogonal Frequency-Division Multiplexing mitigates interference by breaking the signal into sub-streams and using separate sub-carriers to transmit them. The loss of data on a small percentage of the subdivided signal does not degrade the reception of the received signal.

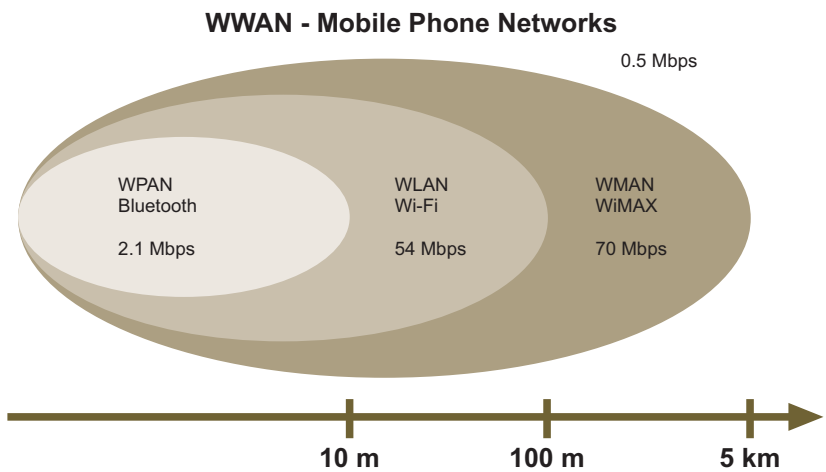
## Wireless Technologies Taxonomy

Wireless technologies are often classified in terms of effective range:

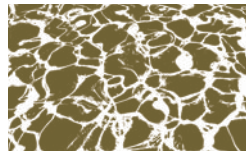
- WPAN – Wireless Personal Area Network 0 m to 10 m
- WLAN – Wireless Local Area Network 10 m to 100 m
- WMAN – Wireless Metropolitan Area Network 100 m to 5 km
- WWAN – Wireless Wide Area Network worldwide (within coverage)

The following figures provide some key indicators about some indicative technologies within the commonly accepted range categories.

**Figure 10. Wireless Technologies Taxonomy**




**Source:** Authors.



## Table 8. Wireless technologies taxonomy

| | Range | Frequency Range | Data Rate (34) | Application | Category | Logos |
|---|---|---|---|---|---|---|
| **Bluetooth** | 10 m | 2.45GHz | 2.1 Mbps | Cable replacement | WPAN | |
| **UWB** | 30 m | 3.1 - 10.6GHz | 650 Mbps | Synchronisation and transmission of video data | WPAN | |
| **Zigbee** | 300 m | 2.4 GHz (WW)<br>915 MHz (US)<br>868 MHz (EU) | 1.32 Mbps | Sensor networks | WLAN | |
| **Wi-Fi 802.11a/b/g** | 100 m | 5GHz 802.11a (US)<br>2.4GHz 802.11b (WW)<br>2.4GHz 802.11g (WW) | 54 Mbps | Intranet | WLAN | |
| **WiMAX 802.16** | NLOS<br>5 kmPTP<br>50 km | 2-11GHz | 70 Mbps | Point-to-Point and Point-to-Multipoint connectivity | WMAN | |
| **Mobile phone Networks 2.5G 3G** | Global (35) | 900 Mhz 2.5G (WW)<br>1800 MHz 2.5G (WW)<br>850 MHz 2.5G (US)<br>1900 MHz 2.5G (US)<br>1.95 GHz for 3G uplink<br>2.15 GHz for 3G downlink | 0.5 Mbps | Mobile telephony | WWAN | |

**Source:** Authors.

(34) In radio technologies effective data rates are proportional to the inverse of the distance between devices.
(35) Usually a mobile phone tower has a range of up to 8 km, but given the extent of the installed base, it can be considered a global network for most practical purposes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