1

Overview of End-to-End WiMAX Network Architecture

Dr Mohuya Chakraborty, Ph.D (Engg.)
Member IEEE, Head, Department of Information Technology, Institute of Engineering & Management, Salt Lake, Kolkata, India

Dr Debika Bhattacharyya, Ph.D (Engg.)
Member IEEE, Head, Department of Computer Science & Engineering, Institute of Engineering & Management, Salt Lake, Kolkata, India

1.1 Introduction

WiMAX, the *Worldwide Interoperability for Microwave Access*, is a telecommunications technology that provides for the wireless transmission of data in a variety of ways, ranging from point-to-point links to full mobile cellular-type access. The WiMAX forum describes WiMAX as a standards-based technology enabling the delivery of last mile wireless broadband access as an alternative to cable and Digital Subscriber Line (DSL).

WiMAX network operators face a big challenge to enable interoperability between vendors which brings lower costs, greater flexibility and freedom. So it is important for network operators to understand the methods of establishing interoperability and how different products, solutions and applications from different vendors can coexist in the same WiMAX network.

This chapter aims to assist readers in understanding the end-to-end WiMAX network architecture in detail including the different interface specifications and also the various interoperability issues of the WiMAX network. Section 1.1 gives an overview of different wireless communications technologies. WiMAX technology is introduced in section 1.2. Section 1.3 describes the concept of mobile WiMAX. An overview of the end-to-end WiMAX network architecture is discussed in section 1.4. Radio interface specifications

WiMAX Security and Quality of Service: An End-to-End Perspective Edited by Seok-Yee Tang, Peter Müller and Hamid Sharif

for WiMAX are discussed in section 1.5. Section 1.6 throws light upon the interoperability amongst the different WiMAX network vendors. The chapter concludes in section 1.7.

1.2 Wireless Primer

Wireless means transmitting signals using radio waves as the medium instead of wires. Wireless technologies are used for tasks as simple as switching off the television or as complex as supplying the sales force with information from an automated enterprise application while in the field. Wireless technologies can be classified in different ways depending on their range. Each wireless technology is designed to serve a specific usage segment. The requirements for each usage segment are based on a variety of variables, including bandwidth needs, distance needs and power. Some of the inherent characteristics of wireless communications systems which make it attractive for users are given below:

- *Mobility*: A wireless communications system allows users to access information beyond their desk and conduct business from anywhere without having wire connectivity.
- *Reachability*: Wireless communications systems enable people to be better connected and reachable without any limitation as to location.
- *Simplicity*: Wireless communication systems are easy and fast to deploy in comparison with cabled networks. Initial setup cost may be a bit high but other advantages overcome that high cost.
- *Maintainability*: Being a wireless system, you do no need to spend too much to maintain a wireless network setup.
- *Roaming Services*: Using a wireless network system you can provide a service any where any time including train, busses, aeroplanes, etc.
- *New Services*: Wireless communications systems provide new smart services such as the Short Message Service (SMS) and Multimedia Messaging Service (MMS).

1.2.1 Wireless Network Topologies

There are basically three ways to setup a wireless network:

- *Point-to-point bridge*: As you know a bridge is used to connect two networks. A point-to-point bridge interconnects two buildings having different networks. For example, a wireless LAN bridge can interface with an Ethernet network directly to a particular access point.
- *Point-to-multipoint bridge*: This topology is used to connect three or more LANs that may be located on different floors in a building or across buildings.
- *Mesh or ad hoc network*: This network is an independent local area network that is not connected to a wired infrastructure and in which all stations are connected directly to one another.

1.2.2 Wireless Technologies

Wireless technologies can be classified in different ways depending on their range. Each wireless technology is designed to serve a specific usage segment. The requirements for each usage segment are based on a variety of variables, including Bandwidth needs, Distance needs and Power.

- *Wireless Wide Area Network (WWAN)*: This network enables us to access the Internet via a wireless wide area network (WWAN) access card and a PDA or laptop. They provide a very fast data speed compared with the data rates of mobile telecommunications technology, and their range is also extensive. Cellular and mobile networks based on CDMA and GSM are good examples of WWAN.
- *Wireless Personal Area Network (WPAN)*: These networks are very similar to WWAN except their range is very limited.
- *Wireless Local Area Network (WLAN)*: This network enables us to access the Internet in localized hotspots via a wireless local area network (WLAN) access card and a PDA or laptop. It is a type of local area network that uses high-frequency radio waves rather than wires to communicate between nodes. They provide a very fast data speed compared with the data rates of mobile telecommunications technology, and their range is very limited. WiFi is the most widespread and popular example of WLAN technology.
- *Wireless Metropolitan Area Network (WMAN)*: This network enables us to access the Internet and multimedia streaming services via a Wireless Region Area Network (WRAN). These networks provide a very fast data speed compared with the data rates of mobile telecommunication technology as well as other wireless networks, and their range is also extensive.

1.2.3 Performance Parameters of Wireless Networks

These are the following four major performance parameters of wireless networks:

- *Quality of Service (QoS)*: One of the primary concerns about wireless data delivery is that, like the Internet over wired services, QoS is inadequate. Lost packets and atmospheric interference are recurring problems with wireless protocols.
- *Security Risk*: This has been another major issue with a data transfer over a wireless network. Basic network security mechanisms are such as the Service Set Identifier (SSID) and Wired Equivalent Privacy (WEP). These measures may be adequate for residences and small businesses but they are inadequate for entities that require stronger security.
- *Reachable Range*: Normally a wireless network offers a range of about 100 metres or less. Range is a function of antenna design and power. Nowadays the range of wireless is extended to tens of miles so this should no longer be an issue.
- *Wireless Broadband Access (WBA)*: Broadband wireless is a technology that promises high-speed connection over the air. It uses radio waves to transmit and receive data directly to and from the potential users whenever they want it. Technologies such as 3G, WiFi and WiMAX work together to meet unique customer needs. Broadband Wireless Access (BWA) is a point-to-multipoint system which is made up of base station and subscriber equipment. Instead of using the physical connection between the base station and the subscriber, the base station uses an outdoor antenna to send and receive high-speed data and voice-to-subscriber equipment. BWA offers an effective,

complementary solution to wireline broadband, which has become recognized globally by a high percentage of the population.

1.2.4 WiFi and WiMAX

Wireless Fidelity (WiFi) is based on the IEEE 802.11 family of standards and is primarily a local area networking WiMAX similar to WiFi, but on a much larger scale and at faster speeds. A nomadic version would keep WiMAX-enabled devices connected over large areas, much like today's cell phones. We can compare it with WiFi based on the following factors:

- *IEEE Standards*: WiFi is based on the IEEE 802.11 standard whereas WiMAX is based on IEEE 802.16. However both are IEEE standards.
- *Range*: WiFi typically provides local network access for around a few hundred feet with speeds of up to 54 Mbps, a single WiMAX antenna is expected to have a range of up to four miles. Ranges beyond 10 miles are certainly possible, but for scalability purposes may not be desirable for heavily loaded networks. As such, WiMAX can bring the underlying Internet connection needed to service local WiFi networks.
- *Scalability*: WiFi is intended for LAN applications, users range from one to tens with one subscriber for each Consumer Premises Equipment (CPE) device. It has fixed channel sizes (20 MHz). WiMAX is designed to support from one to hundreds of CPEs efficiently, with unlimited subscribers behind each CPE. Flexible channel sizes from 1.5 MHz to 20 MHz.
- *Bit rate*: WiFi works at 2.7 bps/Hz and can peak at up to 54 Mbps in a 20 MHz channel. WiMAX works at 5 bps/Hz and can peak up to 100 Mbps in a 20 MHz channel.
- *QoS*: WiFi does not guarantee any QoS but WiMAX will provide you with several level of QoS. As such, WiMAX can bring the underlying Internet connection needed to service local WiFi networks. WiFi does not provide ubiquitous broadband while WiMAX does. A comparative analysis of WiFi and WiMAX vis-à-vis different network parameters is given in Table 1.1.

1.3 Introduction to WiMAX Technology

WiMAX is a *metropolitan area network* service that typically uses one or more base stations that can each provide service to users within a 30-mile radius for distributing broadband wireless data over wide geographic areas. WiMAX offers a rich set of features with a great deal of flexibility in terms of deployment options and potential service offerings. It can provide two forms of wireless service:

- Non-Line-of-Sight (NLoS) service – This is a WiFi sort of service. Here a small antenna on the computer connects to the WiMAX tower. In this mode, WiMAX uses a lower frequency range ($\sim$2 GHz to 11 GHz) similar to WiFi.
- Line-of-Sight (LoS) service – Here a fixed dish antenna points straight at the WiMAX tower from a rooftop or pole. The LoS connection is stronger and more stable, so it's able to send a lot of data with fewer errors. LoS transmissions use higher frequencies, with ranges reaching a possible 66 GHz.

Table 1.1 WiFi vs WiMAX

Feature	WiMAX (802.16a)	WiFi (802.11b)
Primary Application	Broadband Wireless Access	Wireless LAN
Frequency Band	Licensed/Unlicensed 2 G to 11 GHz	2.4 GHz ISM
Channel Bandwidth	Adjustable 1.25 M to 20 MHz	25 MHz
Half/Full Duplex	Full	Half
Radio Technology	OFDM (256-channels)	Direct Sequence Spread Spectrum
Bandwidth Efficiency	<=5 bps/Hz	<=0.44 bps/Hz
Modulation	BPSK, QPSK, 16-, 64-, 256-QAM	QPSK
FEC	Convolutional Code Reed-Solomon	None
Encryption	Mandatory- 3DES Optional- AES	Optional- RC4 (AES in 802.11i)
Mobility	Mobile WiMAX (802.16e)	In development
Mesh	Yes	Vendor Proprietary
Access Protocol	Request/Grant	CSMA/CA

Source: Dr Mohuya Chakraborty and Dr Debika Bhattacharyya.

1.3.1 Operational Principles

A WiMAX system consists of two parts:

- A WiMAX Base Station (BS) – According to IEEE 802.16 the specification range of WiMAX I is a 30-mile (50-km) radius from base station.
- A WiMAX receiver – The receiver and antenna could be a small box or Personal Computer Memory Card International Association (PCMCIA) card, or they could be built into a laptop the way WiFi access is today. Figure 1.1 explains the basic block diagram of WiMAX technology.

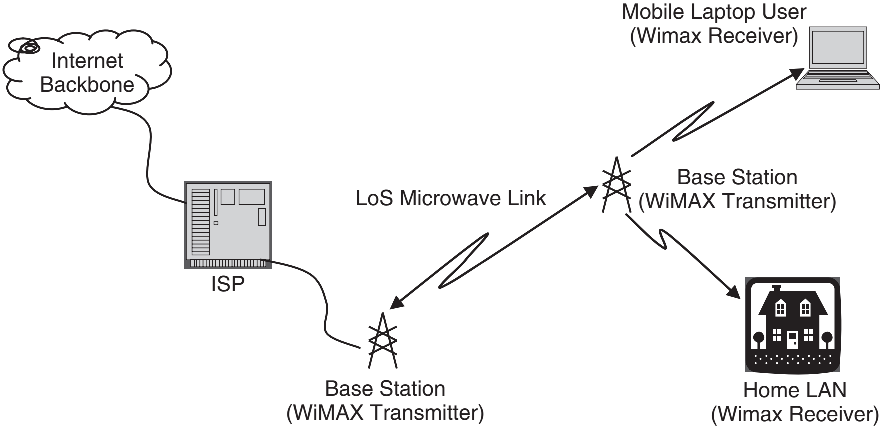

Figure 1.1 Operational principles of WiMAX technology. Source: Dr Mohuya Chakraborty and Dr Debika Bhattacharyya.

A WiMAX base station consists of indoor electronics and a WiMAX tower similar in concept to a cell-phone tower. A WiMAX base station can provide coverage to a very large area up to a radius of six miles. Any wireless device within the coverage area would be able to access the Internet. It uses the MAC layer defined in standard IEEE 802.16. This common interface that makes the networks interoperable would allocate uplink and downlink bandwidth to subscribers according to their needs, on an essentially real-time basis. Each base station provides wireless coverage over an area called a cell. Theoretically, the maximum radius of a cell is 50 km or 30 miles. However, practical considerations limit it to about 10 km or six miles. The WiMAX transmitter station can connect directly to the Internet using a high-bandwidth, wired connection (for example, a T3 line). It can also connect to another WiMAX transmitter using LoS microwave link. This connection to a second base station (often referred to as a backhaul), along with the ability of a single base station to cover up to 3000 square miles, is what allows WiMAX to provide coverage to remote rural areas. It is possible to connect several base stations to one another using high-speed backhaul microwave links. This would also allow for roaming by a WiMAX subscriber from one base station coverage area to another, similar to the roaming enabled by cell phones. A WiMAX receiver may have a separate antenna or could be a stand-alone box or a PCMCIA card sitting on user laptop or computer or any other device.

A typical WiMAX operation will comprise of WiMAX BSs to provide ubiquitous coverage over a metropolitan area. WiMAX BSs can be connected to the edge network by means of a wireless point-to-point link or, where available, a fibre link. Combining a wireless router with the WiMAX terminal will enable wireless distribution within the building premises by means of a WiFi LAN. Because of the relatively limited spectrum assignments in the lower-frequency bands, WiMAX deployments will usually have a limited capacity, requiring BS spacing on the order of two to three km. In lower density rural areas, deployments will often have a limited range, thus taking advantage of the full coverage capability of WiMAX, which can achieve NLoS coverage over an area of 75 sq km in the 3.5-GHz band.

WiMAX has been increasingly called the technology of the future. Belonging to the IEEE 802.16 series, WiMAX will support data transfer rates up to 70 Mbps over link distances up to 30 miles. Supporters of this standard promote it for a wide range of applications in fixed, portable, mobile and nomadic environments, including wireless backhaul for WiFi hot spots and cell sites, hot spots with wide area coverage, broadband data services at pedestrian and vehicular speeds, last-mile broadband access, etc. So WiMAX systems are expected to deliver broadband access services to residential and enterprise customers in an economical way.

WiMAX would operate in a similar manner to WiFi but at higher speeds, over greater distances and for a greater number of users. WiMAX has the ability to provide a service even in areas that are difficult for wired infrastructure to reach and with the ability to overcome the physical limitations of a traditional wired infrastructure.

1.3.2 WiMAX Speed and Range

WiMAX is expected to offer initially up to about 40 Mbps capacity per wireless channel for both fixed and portable applications, depending on the particular technical configuration chosen, enough to support hundreds of businesses with T-1 speed connectivity and thousands of residences with DSL speed connectivity. WiMAX can support voice and video as well as Internet data.

It is able to provide wireless broadband access to buildings, either in competition with existing wired networks or alone in currently unserved rural or thinly populated areas. It can also be used to connect WLAN hotspots to the Internet. It is also intended to provide broadband connectivity to mobile devices. Mobile devices are not as fast as fixed ones, but the expected characteristics are within the range of 15 Mbps capacity over a 3 km cell coverage area.

With WiMAX, users could really cut free from today's Internet access arrangements and be able to go online at broadband speeds, virtually wherever they like from within a Metro Zone. WiMAX could potentially be deployed in a variety of spectrum bands: 2.3 GHz, 2.5 GHz, 3.5 GHz and 5.8 GHz

1.3.3 Spectrum

There is no uniform global licensed spectrum for WiMAX, although the WiMAX Forum has published three licensed spectrum profiles: 2.3 GHz, 2.5 GHz and 3.5 GHz, in an effort to decrease cost. Economies of scale dictate that the more WiMAX embedded devices (such as mobile phones and WiMAX-embedded laptops) are produced, the lower the unit cost. (The two highest cost components of producing a mobile phone are the silicon and the extra radio needed for each band.) Similar economy of scale benefits apply to the production of Base Stations. In the unlicensed band, 5.x GHz is the approved profile. Telecom companies are unlikely to use this spectrum widely other than for backhaul, since they do not own and control the spectrum. In the USA, the biggest segment available is around 2.5 GHz, and is already assigned, primarily to Sprint Nextel and Clearwire. The most recent versions of both WiMAX standards in 802.16 cover spectrum ranges from at least the 2 GHz range through the 66 GHz range. The International standard of 3.5 GHz spectrum was the first to enjoy WiMAX products. The US license free spectrum at 5.8 GHz has a few WiMAX vendors building products. Licensed spectrum at 2.5 GHz used both domestically in the US and fairly widely abroad is the largest block in the US. Also, in the US and in Korea products are shipping for the 2.3 GHz spectrum range. Also in the US the 3.65 GHz band of frequencies now has WiMAX gear shipping to carriers. Elsewhere in the world, the most-likely bands used will be the Forum approved ones, with 2.3 GHz probably being most important in Asia. Some countries in Asia like India and Indonesia will use a mix of 2.5 GHz, 3.3 GHz and other frequencies. Pakistan's Wateen Telecom uses 3.5 GHz.

Analog TV bands (700 MHz) may become available for WiMAX usage, but await the complete roll out of digital TV, and there will be other uses suggested for that spectrum. In the US the FCC auction for this spectrum began in January 2008 and, as a result, the largest share of the spectrum went to Verizon Wireless and the next largest to AT&T. Both of these companies have stated their intention of supporting Long Term Evolution (LTE), a technology which competes directly with WiMAX. EU commissioner Viviane Reding has suggested re-allocation of 500–800 MHz spectrum for wireless communication, including WiMAX.

WiMAX profiles define channel size, Time Division Duplex (TDD)/ Frequency Division Duplex (FDD) and other necessary attributes in order to have inter-operating products. The current fixed profiles are defined for both TDD and FDD profiles. At this point, all of the mobile profiles are TDD only. The fixed profiles have channel sizes of 3.5 MHz, 5 MHz, 7 MHz and 10 MHz. The mobile profiles are 5 MHz, 8.75 MHz and 10 MHz. (Note: the 802.16 standard allows a far wider variety of channels, but only the above subsets are supported as WiMAX profiles.)

1.3.4 Limitations

A commonly-held misconception is that WiMAX will deliver 70 Mbit/s over 31 miles/50 kilometers. In reality, WiMAX can only do one or the other – operating over maximum range (31 miles/50 km) increases bit error rate and thus must use a lower bit rate. Lowering the range allows a device to operate at higher bit rates.

1.3.5 Need for WiMAX

WiMAX can satisfy a variety of access needs. Potential applications include:

- Extending broadband capabilities to bring them closer to subscribers, filling gaps in cable, DSL and T1 services, WiFi and cellular backhaul, providing last-100 meter access from fibre to the curb and giving service providers another cost-effective option for supporting broadband services.
- Supporting very high bandwidth solutions where large spectrum deployments (i.e. >10 MHz) are desired using existing infrastructure, keeping costs down while delivering the bandwidth needed to support a full range of high-value, multimedia services.
- Helping service providers meet many of the challenges they face owing to increasing consumer demand. WiMAX can help them in this regard without discarding their existing infrastructure investments because it has the ability to interoperate seamlessly across various network types.
- Providing wide area coverage and quality of service capabilities for applications ranging from real-time delay-sensitive Voice-over-Internet Protocol (VoIP) to real-time streaming video and non-real-time downloads, ensuring that subscribers obtain the performance they expect for all types of communications.
- Being an IP-based wireless broadband technology, WiMAX can be integrated into both wide-area third-generation (3G) mobile and wireless and wireline networks, allowing it to become part of a seamless anytime, anywhere broadband access solution.
- Ultimately, serving as the next step in the evolution of 3G mobile phones, via a potential combination of WiMAX and Code Division Multiple access (CDMA) standards called Fourth Generation (4G).

1.4 Mobile WiMAX

1.4.1 Overview of Mobile WiMAX

The Worldwide Interoperability for Microwave Access (WiMAX) standard, that is, the IEEE 802.16-2004 standard supports point-to-multipoint (PMP) as well as mesh mode.

In the PMP mode, multiple subscriber stations (SSs) are connected to one base station (BS) where the access channel from the BS to the SS is called the downlink (DL) channel, and the one from the SS to the BS is called the uplink (UL) channel. To support mobility, the IEEE has defined the IEEE 802.16e amendment, the mobile version of the 802.16 standard which is also known as mobile WiMAX. In mobile WiMAX battery life and handover are essential issues to support mobility between subnets in the same network domain (micromobility) and between two different network domains (macromobility).This new amendment aims at maintaining mobile clients connected to a MAN while moving around. It supports portable devices from mobile smart-phones and Personal digital assistants (PDAs) to notebook and laptop computers. IEEE 802.16e works in the 2.3 GHz and 2.5 GHz frequency bands.

During network entry a SS at first needs initial ranging to allocate CDMA codes in UL ranging opportunities. Then the SS is allowed to join the network to acquire correct transmitter parameters (timing offset and power level), a complete network entry process with a desired BS to join the network. After successful completion of initial ranging, the SS will request the BS to describe its available modulation capability, coding schemes, and duplexing methods. During this stage, the SS will acquire a downlink (DL) channel. Once the SS finds a DL channel and synchronizes with the BS at the PHY level, the MAC layer will look for downlink channel descriptor (DCD) and UCD (uplink channel descriptor) to get modulation and other parameters. The SS remains in synchronization with the BS as long as it continues to receive the DL-medium access protocol (MAP) and DCD messages. Finally, the SS will receive a set of transmission parameters from UCD as its UL channel. If no UL channel can be found after a suitable timeout period, the SS will continue scanning to find another DL channel. Once the UL parameters are obtained, the SS will perform the ranging process.

The second stage is authentication. At this stage, the BS authenticates and authorizes the SS. Then the BS performs a key exchange with the SS, such that the provided keys can enable the ciphering of transmission data. The third stage is registration. To register with the network, the SS and the BS will exchange registration request/response messages. The last stage is to establish IP connectivity. The SS gets its IP address and other parameters to establish IP connectivity. After this step, operational parameters can be transferred and connections can be set up.

1.4.2 Handover Process in Mobile WiMAX

Hard handover is definitely to be supported in mobile WiMAX networks. Hence, break-before-make operations may happen during the handover process. In other words, link disconnection may occur and throughput may degrade. Therefore, various levels of optimization are demanded to reduce association and connection establishment with the target BS. These optimization methods are not clearly defined in the IEEE 802.16e specification, so they should be supported in specific WiMAX systems and products.

On the contrary, soft handover is optional in mobile WiMAX networks. Two schemes, Macro-Diversity Handover (MDHO) and Fast Base Station Switching (FBSS) are supported. In case of MDHO, Mobile Station (MS) receives from multiple BSs simultaneously during handover, and chooses one as its target BS. As for FBSS, the MS receives from/transmits to one of several BSs (determined on a frame-by-frame basis) during

Table 1.2 LTE vs mobile WiMAX

Parameters	Mobile WiMAX	LTE
Access Technology	OFDMA(Downlink) OFDMA(Uplink)	OFDMA(Downlink) SC-FDMA(Uplink)
Frequency Band	2.3–2.4 GHz, 2.496–2.69 GHz, 3.3–3.8 GHz	Existing and New Frequency bands
Channel Bandwidth	5, 8.75, 10 MHz	1.25–20 MHz
Cell Radius	2–7 KM	5 Km
Cell Capacity	100–200 Users	More than 200 users at 5 MHz

Source: Dr Mohuya Chakraborty and Dr Debika Bhattacharyya.

handover, such that the MS can omit the decision process of selecting the target BS to shorten the latency of handover.

1.4.3 LTE vs. Mobile WiMAX

Mobile WiMAX is based on an open standard that was debated by a large community of engineers before getting ratified. The level of openness means that Mobile WiMAX equipment is standard and therefore cheaper to buy, sometimes at half the cost and sometimes even less. A parallel standardization effort is the Evolved Universal Mobile Telecommunications System (UMTS) terrestrial radio access network (E-UTRAN) also known as 3rd Generation Partnership Project (3GPP) Long Term Evolution (3GPP-LTE) launched by the 3GPP. There are certain similarities between the two technologies. First, both are 4G technologies designed to move data rather than voice. Both are IP networks based on Orthogonal Frequency Division Multiplexing (OFDM) technology – so rather than being rivals such as the Global System for Mobile Communications (GSM) and CDMA, they're more like siblings. However there are many differences between the two on various parameters such as frequency bands, access technology, channel bandwidth, cell radius and cell capacities. Table 1.2 provides a comparison of LTE and Mobile WiMAX.

1.5 Overview of End-to-End WiMAX Network Architecture

The IEEE 802.16e-2005 standard provides the air interface for WiMAX but does not define the full end-to-end WiMAX network. The WiMAX Forum's Network Working Group (NWG) is responsible for developing the end-to-end network requirements, architecture and protocols for WiMAX, using IEEE 802.16e-2005 as the air interface.

The WiMAX NWG has developed a network reference model to serve as an architecture framework for WiMAX deployments and to ensure interoperability among various WiMAX equipment and operators.

The end-to-end WiMAX Network Architecture has an extensive capability to support mobility and handovers. It will:

- Include vertical or inter-technology handovers – for example to WiFi, 3GPP, 3GPP2, DSL, or MSO – when such capability is enabled in multi-mode MS.

- Support IPv4 or IPv6 based mobility management. Within this framework, and as applicable, the architecture will accommodate MS with multiple IP addresses and simultaneous IPv4 and IPv6 connections.
- Support roaming between Network Service Provider (NSPs).
- Utilize mechanisms to support seamless handovers at up to vehicular speeds.

Some of the additional capabilities in support of mobility include the support of:

- Dynamic and static home address configurations.
- Dynamic assignment of the Home Agent in the service provider network as a form of route optimization, as well as in the home IP network as a form of load balancing.
- Dynamic assignment of the Home Agent based on policies, Scalability, Extensibility, Coverage and Operator Selection.

The network reference model envisions a unified network architecture for supporting fixed, nomadic and mobile deployments and is based on an IP service model. Figure 1.2 shows a simplified illustration of an IP-based end-to-end WiMAX network architecture [1].

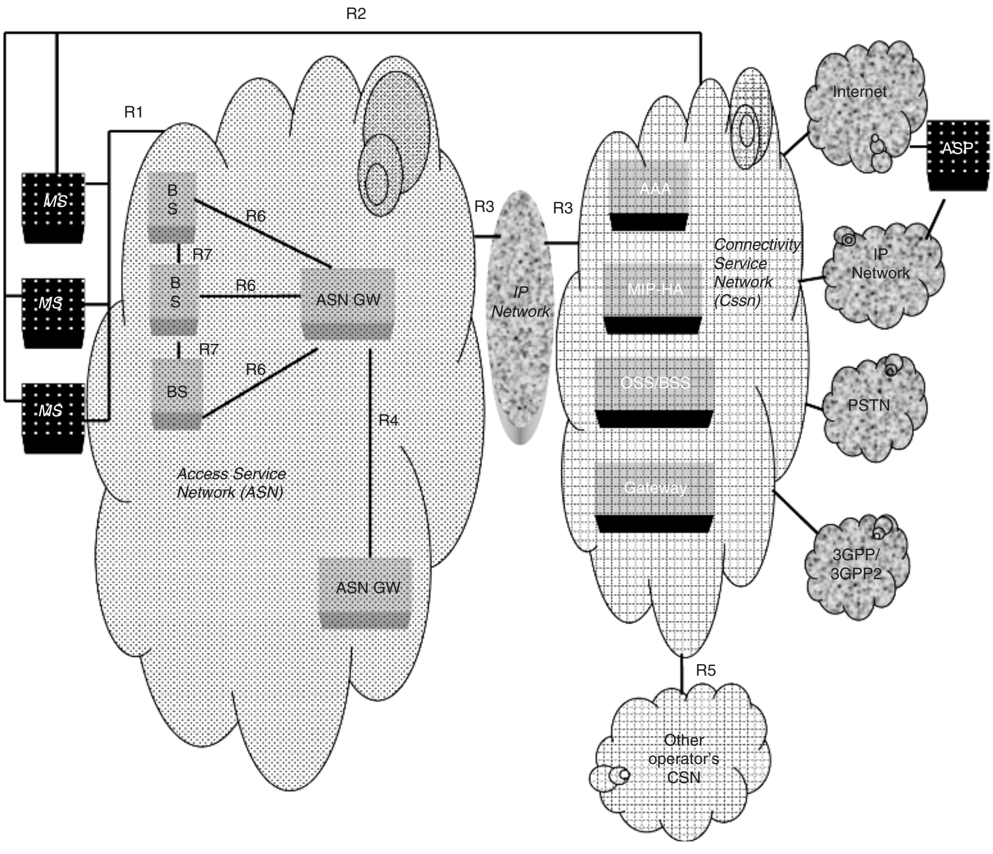

Figure 1.2 End-to-End WiMAX network architecture. Source: Dr Mohuya Chakraborty and Dr Debika Bhattacharyya.

The overall network may be divided logically into three parts:

1. MS used by the end user to access the network.
2. The Access Service Network (ASN), which comprises one or more base stations and one or more ASN gateways that form the radio access network at the edge.
3. Connectivity Service Network (CSN), which provides IP connectivity and all the IP core network functions.

The network reference model developed by the WiMAX Forum NWG defines a number of functional entities and interfaces between those entities. These entities are discussed briefly below.

- **Base Station (BS):** The BS is responsible for providing the air interface to the MS. Additional functions that may be part of the BS are micromobility management functions, such as handoff triggering and tunnel establishment, radio resource management, QoS policy enforcement, traffic classification, Dynamic Host Control Protocol (DHCP) proxy, key management, session management and multicast group management.
- **Access Service Network Gateway (ASN-GW):** The ASN gateway typically acts as a layer 2 traffic aggregation point within an ASN. Additional functions that may be part of the ASN gateway include intra-ASN location management and paging, radio resource management and admission control, caching of subscriber profiles and encryption keys, AAA client functionality, establishment and management of mobility tunnel with base stations, QoS and policy enforcement, foreign agent functionality for mobile IP and routing to the selected CSN.
- **Connectivity Service Network (CSN):** The CSN provides connectivity to the Internet, ASP, other public networks and corporate networks. The CSN is owned by the NSP and includes AAA servers that support authentication for the devices, users and specific services. The CSN also provides per user policy management of QoS and security. The CSN is also responsible for IP address management, support for roaming between different NSPs, location management between ASNs and mobility and roaming between ASNs.

The WiMAX architecture framework allows for the flexible decomposition and/or combination of functional entities when building the physical entities. The ASN interfaces the BS and the all-IP core network – the CSN. Typically the ASN includes numerous BSs with one or more ASN gateways. The ASN manages radio resources, MS access, mobility, security and QoS. It acts as a relay for the CSN for IP address allocation and AAA functions. The ASN gateway hosts the Mobile IP Home Agent.

The CSN performs core network functions, including policy and admission control, IP address allocation, billing and settlement. It hosts the Mobile IP Home Agent, the IP and Authorization, Authentication and Accounting (AAA) servers, and Public Switched Telephone Network (PSTN) and VoIP gateways. The CSN is also responsible for internetworking with non-WiMAX networks (e.g. 3G, DSL) and for roaming through links to other CSNs. Table 1.3 gives the reference network model interfaces.

In short, the ASN represents a boundary for functional interoperability with WiMAX clients, WiMAX connectivity service functions and aggregation of functions embodied

Table 1.3 Reference network model interfaces

Interface	Description
R1	Interface between the MS and the ASN. Functionality: air interface.
R2	Interface between the MS and the CSN. Functionality: AAP, IP host configuration, mobility management.
R3	Interface between the ASN and the CSN. Functionality: AAP, policy enforcement, mobility management.
R4	Interface between ASNs. Functionality: mobility management.
R5	Interface between CSNs. Functionality: internetworking, roaming.
R6	Interface between BS and ASN gateway. Functionality: IP tunnel management to establish and release MS connection.
R7	Interface between BSs. Functionality: handoffs

Source: Dr Mohuya Chakraborty and Dr Debika Bhattacharyya.

by different vendors. Mapping of functional entities to logical entities within ASNs as depicted in the NRM may be performed in different ways. The WiMAX Forum is in the process of network specifications in a manner that would allow a variety of vendor implementations that are interoperable and suited for a wide diversity of deployment requirements. A CSN providing IP connectivity services to the WiMAX subscriber(s) may comprise network elements such as routers, AAA proxy/servers, user databases and Interworking gateway devices. It may be deployed as part of a Greenfield WiMAX NSP or as part of an incumbent WiMAX NSP.

The ASN coordinates traffic across multiple BS, supports security, handoffs and QoS. The CSN manages core network operations through IP servers, AAA, VoIP and PSTN gateways, and provides an interface to legacy core networks and other operators' networks. The open IP architecture which is at the core of WiMAX marks a pivotal innovation among non-proprietary mobile technologies. It is set to decrease the complexity and cost to network operators, while increasing the flexibility in developing new services and applications and the freedom in selecting the best suited vendors. Furthermore, according to Rick Galatioto, Product Line Manager at Cisco, an ASN and IP solutions vendor, 'the adoption of an open IP architecture by network providers represents a crucial step towards empowering end users and giving them more control in choosing applications'. If network operators want to reap the full benefits that WiMAX and its all-IP architecture can deliver, they need to select carefully the ASN and CSN solutions that best suit their requirements and provide all the functionality required while avoiding unnecessary complexity in their network.

In short the end-to-end WiMAX Network Architecture has extensive support for scalable, extensible operation and flexibility in operator selection. In particular, it will:

- Enable a user to select manually or automatically from available Network Access Points (NAPs) and NSPs.
- Enable ASN and CSN system designs that easily scale upward and downward – in terms of coverage, range or capacity.
- Accommodate a variety of ASN topologies – including hub-and-spoke, hierarchical, and/or multi-hop interconnects.

- Accommodate a variety of backhaul links, both wireline and wireless with different latency and throughput characteristics.
- Support incremental infrastructure deployment.
- Support the phased introduction of IP services that in turn scale with an increasing number of active users and concurrent IP services per user.
- Support the integration of base stations of varying coverage and capacity – for example, pico, micro and macro base stations.
- Support the flexible decomposition and integration of ASN functions in ASN network deployments in order to enable use of load balancing schemes for efficient use of radio spectrum and network resources.

Additional features pertaining to manageability and performance of WiMAX Network Architecture include:

- Support a variety of online and offline client provisioning, enrollment and management schemes based on open, broadly deployable, IP-based, industry standards.
- Accommodation of Over-The-Air (OTA) services for MS terminal provisioning and software upgrades.
- Accommodation of use of header compression/suppression and/or payload compression for efficient use of the WiMAX radio resources.

It would be unfair not to mention a few WiMAX products here. The WiMAX portfolio includes:

- Aricent ASNLite – a standards-based, compact, and off-the-shelf, integrated ASN gateway software product that facilitates rapid development of WiMAX (802.16e) solutions.
- WiMAX Integrated Gateway (WING™) – A 'Network-in-a-Box' collapsed ASN and CSN solution comprising of an integrated Profile-C ASN-GW, AAA server and Home Agent. This solution serves the needs of rural, Tier 3, and enterprise deployments, and can run on any Commercial Off-The-Shelf (COTS) platform.
- eASN™ – A complete ASN gateway product supporting control plane, data plane and management plane functionalities. The product can be scaled to support up to 60 000 subscribers, and is ideal for medium to high density networks.
- sigASN™ – A control plane framework for Profile-C Macro/Micro/Enterprise ASN Gateway deployments. This framework can be used to develop ASN solutions for very high density networks.
- Base Station Framework – A Release-6 compliant control plane BS Framework for all types of Macro/Pico/Femto Profile-C Base Station deployments.

1.6 Radio Interface Specifications for WiMAX

1.6.1 Overview

The radio interface is the main building block of a WiMAX network and is responsible for most of the spectrum efficiency and cost savings that WiMAX promises. The IEEE 802.16 Working Group on Broadband Wireless Access Standards was established by the IEEE Standards Board in 1999, to develop standards for the global deployment of broadband Wireless Metropolitan Area Networks. The Workgroup is a unit of the IEEE 802 LAN/MAN Standards Committee.

Although the 802.16 family of standards is officially called WirelessMAN in IEEE, it has been commercialized under the name 'WiMAX' by an industry alliance called the WiMAX Forum. The mission of the Forum is to promote and certify compatibility and interoperability of broadband wireless products based on the IEEE 802.16 standards.

The first 802.16 standard was approved in December 2001. It delivered a standard for point to multipoint Broadband Wireless transmission in the 10–66 GHz band, with only an LOS capability. It uses a single carrier (SC) physical (PHY) standard. IEEE 802.16 standardizes the air interface and related functions associated with wireless local loop. 802.16a was an amendment to 802.16 and delivered a point to multipoint capability in the 2–11 GHz band. For this to be of use, it also required an NLOS capability, and the PHY standard was therefore extended to include OFDM and Orthogonal Frequency Division Multiple Access (OFDMA). 802.16a was ratified in January 2003 and was intended to provide 'last mile' fixed broadband access. 802.16c, a further amendment to 802.16, delivered a system profile for the 10–66 GHz 802.16 standard.

In September 2003, a revision project called 802.16d commenced aimed at aligning the standard with aspects of the European Telecommunications Standards Institute (ETSI) High Performance Radio Metropolitan Area Network (HIPERMAN) standard as well as laying down conformance and test specifications. This project concluded in 2004 with the release of 802.16-2004 which superseded the earlier 802.16 documents, including the a/b/c amendments.

An amendment to 802.16-2004, IEEE 802.16e-2005 (formerly known as IEEE 802.16e), addressing mobility, was concluded in 2005. This implements a number of improvements to 802.16-2004, including better support for QoS and the use of Scalable OFDMA. It is sometimes called 'Mobile WiMAX', after the WiMAX forum for interoperability, which is an industry-led organization formed to certify and promote broadband wireless products based upon the IEEE 802.16 standard.

1.6.2 802.16e-2005 Technology

The 802.16 standard essentially standardizes two aspects of the air interface – the physical (PHY) layer and the Media Access Control (MAC) layer. This section provides an overview of the technology employed in these two layers in the current version of the 802.16 specification (which is strictly 802.16-2004 as amended by 802.16e-2005, but which will be referred to as 802.16e for brevity).

1.6.2.1 PHY – The Physical Layer

802.16e uses Scalable OFDMA to carry data, supporting channel bandwidths of between 1.25 MHz and 20 MHz, with up to 2048 subcarriers. It supports adaptive modulation and coding, so that in conditions of good signal, a highly efficient 64 QAM coding scheme is used, whereas where the signal is poorer, a more robust BPSK coding mechanism is used. In intermediate conditions, 16 QAM and QPSK can also be employed. Other PHY features include integration of the latest technological innovations, such as 'beam forming' and

Multiple Input Multiple Output (MIMO) and Hybrid Automatic Repeat Request (HARQ) for good error correction performance.

OFDM belongs to a family of transmission schemes called multicarrier modulation, which is based on the idea of dividing a given high-bit-rate data stream into several parallel lower bit-rate streams and modulating each stream on separate carriers, often called subcarriers, or tones. Multicarrier modulation schemes eliminate or minimize InterSymbol Interference (ISI) by making the symbol time large enough so that the channel-induced delays (delay spread being a good measure of this in wireless channels) are an insignificant (typically, $<10\,\%$) fraction of the symbol duration.

Therefore, in high-data-rate systems in which the symbol duration is small, being inversely proportional to the data rate, splitting the data stream into many parallel streams increases the symbol duration of each stream such that the delay spread is only a small fraction of the symbol duration. OFDM is a spectrally efficient version of multicarrier modulation, where the subcarriers are selected such that they are all orthogonal to one another over the symbol duration, thereby avoiding the need to have non-overlapping subcarrier channels to eliminate intercarrier interference. In order to completely eliminate ISI, guard intervals are used between OFDM symbols. By making the guard interval larger than the expected multipath delay spread, ISI can be completely eliminated. Adding a guard interval, however, implies power wastage and a decrease in bandwidth efficiency.

'Beam forming' is an Advanced Antenna Technology (AAT) that ensures that radio power is concentrated where the WiMAX terminals are, adjusting the beam automatically as the terminals move around the coverage area. Beam forming enables dramatic reductions in the number of radio sites needed to provide coverage – in some instances by as much as 40 % – while reducing interference and ensuring better indoor penetration of the radio signal.

'MIMO' is an AAT that combines the radio signals transmitted and received on separate antennas. The technique takes advantage of the multiple paths and reflections of a radio signal to strengthen radio communications, particularly in densely populated areas where signals can be degraded by buildings and other physical obstacles. MIMO antennae provide good NLOS characteristics (or higher bandwidth). MIMO also helps make radio links more robust, nearly doubling the capacity delivered in dense urban environments [2, 3].

1.6.2.2 MAC – The Media Access Control Layer

The 802.16 specifications describe three MAC sublayers: the Convergence Sublayer (CS), the Common Part Sublayer (CPS) and the Security Sublayer (SeS). There are a number of convergence sublayers, which describe the manner in which wireline technologies such as Ethernet, ATM and IP are encapsulated on the air interface, and the process of data classification, etc.

The CS aims to enable 802.16 to better accommodate the higher layer protocols placed above the MAC layer. The CS receives data frames from a higher layer and classifies the frame. On the basis of this classification, the CS can perform additional processing such as payload header compression, before passing the frame to the MAC CPS. The CS also accepts data frames from the MAC CPS. If the peer CS has performed any type of processing, the receiving CS will restore the data frame before passing it to a higher layer.

The CPS is the vital part of the 802.16 MAC that defines the medium access method. It provides functions related to network entry and initialization, duplexing, framing, channel access and QoS.

The SeS provides privacy to the subscribers across the wireless network. It also provides strong protection against theft of service to the operators. It describes how secure communications are delivered, by using secure key exchange during authentication, and encryption using AES or DES (as the encryption mechanism) during data transfer.

Further features of the MAC layer include power saving mechanisms (using Sleep Mode and Idle Mode) and handover mechanisms. A key feature of 802.16 is that it is a connection oriented technology. The SS cannot transmit data until it has been allocated a channel by the BS. This allows 802.16e to provide strong support for QoS.

1.6.3 Applications

Depending on the frequency band and implementation details, an access system built in accordance with this standardized radio interface specification can support a wide range of applications, from enterprise services to residential applications in urban, suburban and rural areas, as well as cellular backhauling. The specification could easily support both generic Internet-type data and real-time data, including two-way applications such as voice and videoconferencing. The technology is known as a Wireless MAN in IEEE 802.16. The word ‘metropolitan’ refers not to the application but to the scale. The design is oriented primarily toward outdoor applications. The architecture is primarily point-to-multipoint, with a base station serving subscribers in a cell that can range up to tens of km. Terminals are fixed or, in frequencies below 11 GHz, and are therefore ideal for providing access to buildings, such as businesses, homes, Internet cafes, telephone shops (telecentres), etc. The radio interface includes support for a variety of worldwide frequency allocations in either licensed or licence-exempt bands. At higher frequencies (above 10 GHz), supported data rates range over 100 Mbit/s per 25 MHz or 28 MHz channel, with many channels available under some administrations. At the lower frequencies (below 11 GHz), data rates range up to 70 Mbit/s per 20 MHz channel.

1.6.4 WiMAX Simulation Tools

The best features of WiMAX are the accurate calculation and optimization of the Radio Frequency and Capacity, Network planning. To achieve this you have to choose the best simulation tool which works on the WiMAX system. Some of the most well-known and widely used simulation and planning tools are: OPNET tool, Planet EV, EDX (Signal-Pro), Provision Communication, Radio Mobile (Freeware), Atoll, CelPlan, ICS Telecom, Asset 3G/WiMAX, Winprop, Volcano Siradel, NS-2 (Freeware), NS-3 (Freeware), Qualnet NCTuns Network Simulator and Emulator

1.7 Interoperability Issues in WiMAX

WiMAX, as with many new technologies, is based on an open standard. While standards increasingly play an essential role in driving implementation, success is not guaranteed.

The success of a standard-based technology depends on the strong interoperability amongst the operators, vendors and solution and content providers. As a standard-based technology, WiMAX enables inter-vendor interoperability resulting in lower costs, greater flexibility and freedom and faster innovation to operators.

A strong commitment to ensuring full interoperability, both through certification and ad-hoc testing between vendors takes place within the WiMAX network. The network operators must realize the process of establishing the interoperability and the underlying principles so that they understand how different products, solutions and applications from different vendors can coexist in the same WiMAX network.

The specifications developed by the NWG within the WiMAX Forum define the role of the ASN and CSN and ensure that WiMAX networks can internetwork with other networks, using WiMAX or other wireless or wired access technologies such as cellular, WiFi, DSL, cable or fibre. In addition, the NWG specifications are designed to enable network operators to enjoy the benefits of vendor interoperability at the infrastructure level, to rely on a consistent client interface and, if they so desire, to open their network to virtual operators, akin to existing cellular Mobile Virtual Network Operators (MVNOs).

To fulfill these goals, the NWG specifications define interfaces for the Reference Network Model (RNM) between key elements of the ASN and CSN, as shown in Table 1.3. To comply with the specifications, vendors are required to leave most of these open. As such when implementing ASN-GW one should also consider ASN profiles. Multiple ASN Profiles have been specified in WiMAX as a tool to manage diversity in ASN node usage and implementation. Release 1 of NWG Specifications on WiMAX supports three ASN Profiles: Profile A (Centralized ASN Model with BS and ASN GW in separate platforms through R6 interface), Profile B (Distributed ASN with the BS and ASN-GW functionalities implemented in a single platform) and C (It is like Profile A, except for RRM being non-split and located in BS) to accommodate varying network operator requirements and the vendors' preference for different network architectures as shown in Table 1.4.

Table 1.4 ASN profiles

Profile	Key Features
A	• Hierarchical model with more intelligence located at the ASN gateway. • The ASN gateway is involved in the Radio Resource Management (RRM) and hosts the Radio Resource Controller (RRC). It also handles handoffs between BSs. • Open interfaces: R1, R3, R4, R6.
B	• Flat, distributed model, with BSs playing a more substantial role in managing traffic and mobility. • The ASN network acts as a black box, with R6 being a closed interface. • Open interfaces: R1, R3, R4.
C	• Centralized model similar to A, but BSs are responsible for all the RRM, including the RRC and Radio Resource Agent (RRA), and the handoffs between BSs. • Open interfaces: R1, R3, R4, R6.

Source: Dr Mohuya Chakraborty and Dr Debika Bhattacharyya.

As Profile C operators are not tied into one vendor for BTS and ASN Gateway equipment, they can force prices down through playing off different suppliers against each other. They can also choose the suppliers that can best support the functionality and services they want to offer over their network rather than being tied to one vendor that might not be up to the job. Despite the apparent advantages of Profile C, some ‘turnkey’ vendors are still successfully tempting operators with the two other Profiles available between the BTS and ASN Gateway: Profile A and Profile B. As both Profiles can create vendor lock-ins, they stand in the way of progress with regard to WiMAX interoperability between multiple vendors and, potentially, lower equipment prices. Profile B does not define any interface between the BTS and the ASN Gateway, so it is possible for Profile B vendors to pursue proprietary solutions and lock in their customers. Due to increased customer demand, however, many of the big WiMAX suppliers that started out by supplying profile B equipment, including Cisco (through its acquisition of Navini Networks) are now shifting to Profile C.

Profiles A and C both use a hierarchical model with a topology similar to that used in cellular networks and that is well suited to support full mobility. In profile A, the RRM resides entirely at the ASN gateway and this increases its workload. Profile C instead relies on the BS for the RRM and effectively separates the radio functionality – residing in the BS – from the network management – residing in the ASN gateway. This contrasts with profile A where both functions coexist in the ASN gateway. The separation of the radio functionality and network management facilitates intervendor interoperability as it allows network operators to select a different vendor for each function and so avoid conflicts and duplications. In addition, fixed operators may decide not to deploy an ASN gateway and instead use their existing Broadband Access Server (BRAS) and AAA server with tunneling protocols such as Point-to-Point Protocol over Ethernet (PPPoE). Profile C facilitates this approach because it does not require a separate ASN gateway for the radio management functions. To better meet the operators’ demand for flexibility, an increasing number of vendors have elected to support ASN Profile C or plans to do so and we expect it to become the dominant one.

In Profile B, more processing is required at the BS and this may increase their complexity and cost. This solution may be attractive to small network operators focusing on fixed or nomadic services. As Profile B essentially leaves the R6 interface (Table 1.3) closed, it can be implemented as a solution in which there is no ASN gateway (each BS performs the ASN gateway role) or with a proprietary ASN gateway that manages only BSs from the same vendor and acts as a black box. Network operators who want to deploy BSs from another vendor would only be able to do so by deploying another end-to-end ASN network for the new equipment. Interoperability among ASN elements (BSs and ASN gateways) is supported among all products that comply with the specifications for the same ASN profile.

1.8 Summary

WiMAX, the next-generation of wireless technology has been designed to enable pervasive, high-speed mobile Internet access to the widest array of devices including notebook PCs, handsets, smartphones and consumer electronics such as gaming devices, cameras, camcorders, music players and more. It has been observed that being 4G wireless technology, WiMAX delivers low-cost, open networks and is the first all-IP mobile Internet solution enabling efficient and scalable networks for data, video and voice.

When using WiMAX devices with directional antennae, speeds of 10 Mbit/s at 10 km distance is possible, while for WiMAX devices with omni-directional antennae only 10 Mbit/s over 2 km is possible. There is no uniform global licensed spectrum for WiMAX, although three licensed spectrum profiles are being used generally −2.3 GHz, 2.5 GHz and 3.5 GHz.

With an end-to-end WiMAX network architecture, the WiMAX system simply becomes an extension of the IP network to the mobile user. Leveraging simple IP-based backhaul connections, service providers can very readily service a myriad of WiMAX base sites (e.g. large, medium, sectorized, omni, micro, pico) for varying coverage and capacity profiles addressing outside environments, inside buildings, fixed and fully mobile connections. Service Providers will very simply grow their networks based on system usage leveraging standard IP components

The high performance of WiMAX technology paired with the cost advantages offered by a distributed WiMAX network architecture brings WiMAX solutions within reach of operators in all regions and segments. With WiMAX systems, markets, in the absence of basic voice connections, can leapfrog to VoIP, high-speed data, and video delivery – further bridging the digital divide – and markets seeking advanced, bandwidth-intensive, mobile communications can realize true personal broadband experiences.

References

[1] M. Paolini, ‘Building End-to-End WiMAX Networks’, Senza Fili Consulting, April 2007.

[2] A. Paulraj, R. Nabar and D. Gore, *Introduction to Space-Time Wireless Communications*, Cambridge University Press, Cambridge, UK, May 2003.

[3] G. G. Raleigh and J.M. Cioffi, ‘Spatio-temporal Coding for Wireless Systems’. IEEE Trans. On Communication, **4**(3): 357–66, 1996.