BACHELOR'S THESIS
TURKU UNIVERSITY OF APPLIED SCIENCES
Degree Programme: Information Technology
Date: 18/05/2011
Pages: 53
Instructor: Riikka Kulmala

Author: Nongjun Li

Overview of WiMax
Technical and Application Analysis

TURUN AMMATTIKORKEAKOULU
TURKU UNIVERSITY OF APPLIED SCIENCES

Abstract

WiMax stands for the Worldwide Interoperability for Microwave Access and is also known as the IEEE 802.16 wireless metropolitan area network. Along with the development of mobile communication and broadband technology, WiMax has become a hot spot for global telecom operators and manufacturers. In 1998, a working group named 802.16 was formed by the Institute of Electrical and Electronics Engineers (IEEE), and their responsibility is to develop the specifications of broadband wireless access technology.
WiMax promises to deliver the Internet throughout the globe, and connect the "last mile" of broadband wireless connectivity services.

This thesis is a technical and application analysis of Wimax, and it is understandable and useful to readers who do not want to worry about functions and technical particulars. This thesis analyzes the different historical stages of the wireless communication, from 1G in the past to the most popular 4G nowadays. Starting from the broadband wireless access technology developing rapidly, it expounds the WiMax technology and its applications, focusing on the WiMax network system, key technologies (MIMO, OFDM, OFDMA) and application solutions. Finally, by comparing WiMax with the popular WiFi, 3G and LTE (TD-LTE) in the market, it analyzes the current situation and future development trend of WiMax in terms of the differences in technology and application.

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List of Acronyms

1G	1 Generation
2G	2 Generation
3G	3 Generation
4G	4 Generation
AMPS	Advanced Mobile Telephone System
TACS	Total Access Communication System
MTS	Mobile Telephone System
FDMA	Frequency Division Multiplex Access
TDMA	Time Division Multiple Access
CDMA	Code Division Multiple Access
GSM	Global System of Mobile Communication
ADSL	Asymmetric Digital Subscriber Line
GPRS	General Packet Radio Service
WCDMA	Wideband Code Division Multiple Access
TD-SCDMA	Time Division-Synchronous Code Division Multiple Access
WiMax	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
DSL	Digital Subscriber Line
BWA-MAN	Broadband Wireless Access Metropolitan Area Network
LMDS	Local Multipoint Distribution System
MMDS	Multichannel Multipoint Distribution System
ISP	Internet Service Provider
BS	Base Station
SS	Subscribe Station
LOS	Line of Sight
NLOS	Non-Line-of-Sight
MIMO	Multiple Input Multiple Output
STC	Space Time Coding
STTD	Space-time Transmit Diversity
LTE	Long Time Evolution

Chapter 1 History of Telecommunication

The mobile communication comes into being, as it were, since the invention of radio communication. In 1897, M · G · Marconi completed his wireless communication test between a fixed station and a towage, in a distance of 18 miles.

The development of modern mobile communication technology started from the twenties in the last century, and undergone four generations.

1.1 1G

1G was a stage of flourishing development for mobile communication. In the end of 1978, American Bell Laboratory successfully developed an Advanced Mobile Telephone System (AMPS). The system capacity was largely improved by the establishment of cellular mobile communication network. In 1983, it was put into service at Chicago for the first time, and applied to Washington in December of the same year. Later, the service area expanded gradually in the USA. Till March of 1985, it expanded to 47 regions covering 100,000 users. Other industrialized countries also developed the cellular public mobile communication network successively. Japan presented a 800MHz telephone system for cars (HAMTS) in 1979, which was put into service at Tokyo and Kobe. West Germany completed C Network in 1984, with the frequency range of 450MHz. Britain developed a Total Access Communication System (TACS) in 1985, which was put into service at London firstly and then applied to the whole country, with the frequency range of 900MHz. France developed the 450 System; Canada presented 450MHz Mobile Telephone System (MTS); the four Nordic Countries including Sweden developed NMT－450 mobile communication system in 1980 and put it into service in the frequency range of 450MHz.

This stage is characterized by cellular mobile communication network as practical system, which developed rapidly all over the world. The reason for the flourishing development of mobile communication, in addition to the increasing demand of users as impetus, also came from the conditions offered by the development of other technologies. Firstly, the microelectronic technology developed tremendously during this period, making the small-size and mini-size of communication equipment possible. Various knapsack stations also came out. Secondly, a new system of mobile communication was proposed and established. Along with the increasing quantity of users, the capacity provided by large field system became saturated quickly, which necessarily requires the exploration of new system. In this respect, the most important breakthrough was the concept of cellular network proposed by Bell Laboratory in 1970s. The cellular network, i.e., a small field system, largely improved the system capacity by realising the reuse of frequencies. The concept of cellular system, as it were, actually settled the conflict between large capacity demand of public mobile communication system and the limited resource of frequency. The third was the gradually mature micro-processor and rapid development of computer technology after the development of large-scale integrated circuit. They offered technical means for management and control of large-size communication network.

This stage is called 1G, which mainly adopts simulation and frequency division multiplex access (FDMA) technology. As the limited transmission band width, long-distance roaming is impossible, and it is only a local mobile communication system.

The first generation of simulated cellular network of mobile communication, represented by AMPS and TACS, achieves a great success, but it has some problems such as limited capacity, too many and incompatible systems, poor talk quality, no data, no automatic roaming, lower utilization rate of frequency spectrum, complex mobile equipment, expensive fees and easy wire tapping, etc. The greatest problem is that the capacity cannot meet the increasing demand of mobile telephone users.

1.2 2G

It mainly adopts digital Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA), corresponding to the global GSM and CDMA systems respectively.

A competition for 2G occurred at the very beginning of its appearance, that is, the competition between two interest groups represented by USA and Europe respectively. When all goes to all, before CDMA technology of QUALCOMM became mature (1995), 2G adopted Time Division Multiple Access (TDMA) as core technology, and American standard was adopted as IS136. However, the market was in the USA basically. European TDMA standard is GSM nowadays, which is familiar to all.

GSM was put into service since 1991. Till the end of 1997, it operated in more than 100 countries, which was actual standard for Europe and Asia. The GSM digital network has good confidentiality and interference immunity, with clear timbre and steady communication. It has large capacity, high utilization rate of frequency resource, open interface and powerful functions. However, it can only provide a data transmission rate of 9.6kbit/s, equivalent to the speed of ADSL on fixed-line telephone five or six years ago. The Internet at that time only provided plain text.

Aiming at the defect of GSM communication, a new communication technology GPRS came out in 2000. It is a transition on the basis of GSM. The appearance of GPRS marks a most significant progress in the development history of GSM.

Later, the communication operators presented the EDGE technology, which is a transitional technology between 2G and 3G. So it is also called the “2.5G” technology. It effectively improves the high speed mobile data standard of GPRS channel coding efficiency, allowing a data transmission speed up to 384Kbps.

1.3 3G

The 3rd generation of mobile communication technology refers to the cellular mobile communication supporting high speed data transmission. 3G service transmits the sound and data information simultaneously in a speed of more than several hundred kbps. A present, there are four standards for 3G, CDMA2000, WCDMA, TD-SCDMA, and WiMAX.

The main difference between 3G and 2G is the improvement of speed for transmitting sound and data. 3G technology realizes wireless roaming all over the world, processes multiple media forms like picture, music, video stream and provides various information service including website browsing, conference call, E-commerce considering the good compatibility with the existing 2nd generation. To offer such service, the wireless network must support different data transmission speeds, that is to say, it at least supports 2Mbps, 384 Mbps and 144 Mbps (which vary with the network environment) transmission for indoor, outdoor and driving environment respectively.

1.4 4G

4G is 4th mobile communication and technology in short. It is a technical product integrating 3G and WLAN. It transmits high quality video and pictures, with the quality of pictures equivalent to high-resolution TV. The 4G system downloads in a speed up to 100Mbps, 2000 times faster than the ADSL, and uploads at a speed up to 20Mbps. It can meet the requirements of nearly all users on the wireless service. As the price is the most immediate concerns of users, 4G is equivalent to the fixed broadband network, with more flexible pricing system. The user can customize required services subject to this demand. Additionally, 4G can be deployed in the areas which are not covered by DSL and Cable TV Modem, and then be expanded to the whole region. Obviously, 4G has incomparable advantages.

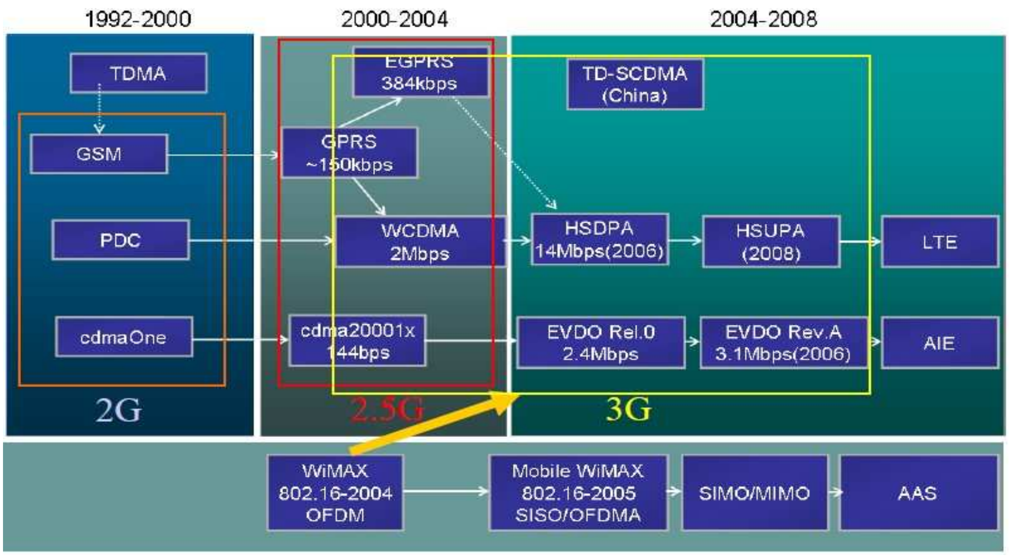


Figure 1.1 Overview of Wireless Telecommunications [3]

Chapter 2 Introduction to WiMax

2.1 What is WiMax?

With the further development of the communication network, WiMax has major realistic significance and strategic value as a standard facing to “the last kilometer” access, especially when no globally uniform standard is established for broadband wireless access. There are two main types of such standard: the IEEE 802.16d supporting air interface of fixed broadband wireless access system, and the IEEE 802.16e in the works supporting the air interface of both fixed and mobile broadband wireless access systems.

WiMax is a Broadband Wireless Access Metropolitan Area Network (BWA-MAN) technology based on the IEEE 802.16 standard, which is also called the IEEE Wireless MAN. It is a new air interface standard in connection with the frequency ranges of microwave and millimeter wave. Its main purpose is to provide a broadband wireless access approach which can be interoperated effectively in the environment of multiple manufacturers with "one-point to multi-point" in the metropolitan area network.

2.2 Background of WiMax

The broadband wireless access technology developed rapidly in 1990s. The wireless technology, represented by Local Multipoint Distribution System (LMDS) and Multichannel Multipoint Distribution Service (MMDS), found its position in the market oriented to the users of soho, medium/small companies, urban commercial centers and so on.[1] However, beyond the expectation of all, this industry did not boom and expand further. The main reason is the lack of globally uniform standard for broadband wireless access.

In 1999, IEEE organized the 802.16 workgroup to specialize in the technical specifications for broadband wireless access, aiming to establish a globally uniform standard for broadband wireless access. At present, IEEE 802.16 mainly comes down to two standards: the 802.16-2004, i.e., the 802.16d standard for fixed broadband wireless access, and the 802.16e standard supporting mobile broadband wireless access. Issued on October 1st, 2004, the IEEE 802.16d standard specifies the air interface between the user terminal and base station system in fixed access, and mainly defines the physical layer and MAC layer of air interface. The main feature of 802.16e standard is the support to mobility. This standard specifies a system supporting both fixed and mobile broadband wireless access, which works in a permitted frequency range less than 6GHz suitable for mobility and supports the user terminal moving in the speed of vehicle. Meanwhile, the user capacity of fixed wireless access specified by 802.16d will not be affected.

The IEEE 802.16 workgroup established the specification and standard specifically to the physical layer and MAC layer of the wireless MAN. To compose an operational network, IEEE 802.16 technology requires the support of other components. As a result, the WiMax Forum emerges because of demand. The WiMax Forum was established in April, 2001. At the beginning, the organization intended to offer certification service for conformity and interoperability of broadband wireless access products based on the IEEE

802.16 standard and the ETSI HiperMAN standard. The product certificated by WiMax is identified by the mark of “WiMax Certified”. Along with the development of 802.16e technology and specification, the purpose of the organization expands gradually. It not only intends to establish a whole set of certification system based on the 802.16 standard and the ETSI HiperMAN standard, but also turns to the research on broadband wireless access system, analysis of demands, exploration of application modes, expansion of market, which greatly promote the development of broadband wireless access market. It is generally agreed that the IEEE 802.16 workgroup is the constitutor of the IEEE 802.16 WiMax air interface specification, while WiMax Forum is the propellant of technology and industry chain. Nowadays, WiMax is nearly another name of IEEE 802.16 WiMax technology, with the air interface specification covering IEEE 802.16d/e standards.

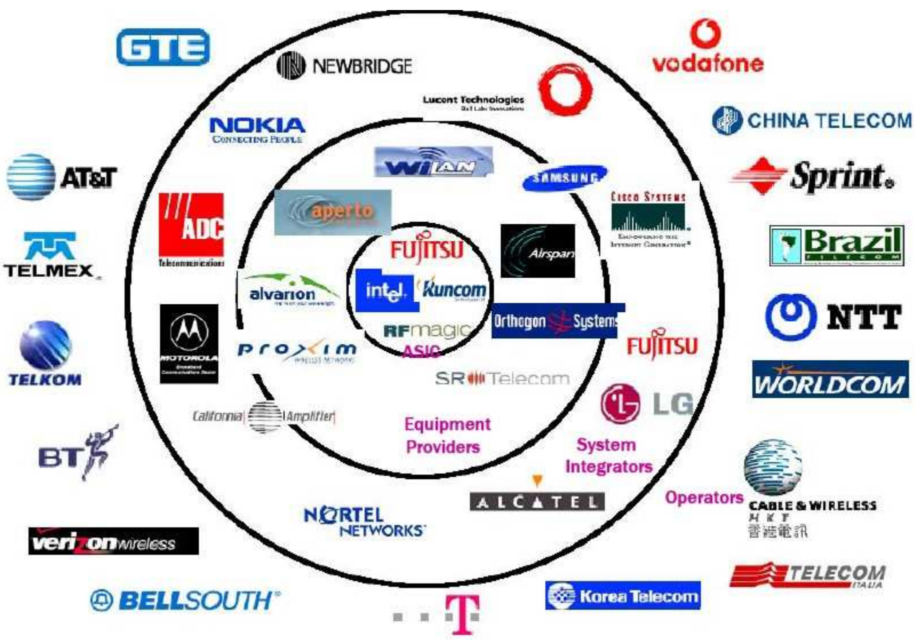


Figure 2.2 WiMax Forum’s Members [4]

2.3 Introduction of IEEE 802.16 Standards

When a user wants a network service of broadband access, he or she generally considers (or be restricted) to use DSL, T1 or Cable-modem to connect with the network. However, for the expensive infrastructure construction cost of cable network, an ISP is not likely willing to install necessary equipment, such as optical fiber and cables, in the areas sparsely populated or out of the way. As mentioned above, some broadband access technologies like LMDS or MMDS have been proposed early in the past. However, there was no uniform technical standard for LMDS and MMDS then, and the air interfaces provided by different manufacturers were incompatible, which limited the development of the whole communication industry severely. It was also the major obstacle for the development of broadband wireless access technology. To solve this problem, IEEE organized the IEEE 802.16 workgroup in 1999 to specialize in the development of broadband wireless access technology. It issued the IEEE 802.16-2001 standard formally in December 2001.

2.3.1 IEEE 802.16-2001

At the beginning of development, considering the compatibility with the existing LMDS system, the IEEE 802.16-2001 standard only regulated the frequency range of 10–66 GHz. IEEE 802.16-2001 is a wireless network specification applicable for Wireless Metropolitan Area Network (WMAN). However, IEEE 802.16-2001 is only suitable for clear areas because the microwave signals in the frequency range of 10–66 GHz have poor penetrativity, and the signals are easily affected by rain attenuation. Therefore, the LOS approach must be adopted for communication between the base station (BS) and the subscribe station (SS). It also has higher requirements on the antenna installation.

2.3.2 IEEE 802.16a

To make the IEEE 802.16 standard smoothly operate in areas with extensive buildings and structures (e.g., metropolitan areas), the IEEE 802.16 workgroup presented the IEEE 802.16a version in April, 2003. The IEEE 802.16a standard is the extension of IEEE 802.16-2001. It operates in the frequency range of 2–11GHz, including the frequency bands requiring and without requiring the license. The signal coverage reaches up to 50km (generally within radius of 10km). Compared with high frequency band, the frequency band used by IEEE 802.16a can operate in the NLOS (Non-Line-of-Sight) environment, seldom affected by rain attenuation. Therefore, the requirements on antenna installation are reduced a lot. Additionally, the support of Mesh topology is added to the IEEE 802.16a, and MAC also offers guarantee to QoS, which supports voice and video messages. All of these features make the IEEE 802.16a standard more competitive in the market. From a different perspective, this kind of WiMAX transmitted by fixed NLOS is a super WiFI base station. As the coverage of WiMAX is far beyond the WiFi, and the transmission rate is also higher than the latter, it is more attractive for ISP, and can be used to realize broader and faster Hot Spot wireless network access service.

2.3.3 IEEE 802.16-2004 (IEEE 802.16d)

The IEEE 802.16a standard is actually a mere added and revised version of IEEE 802.16-2001 (IEEE 802.16c is the supplementation of IEEE 802.16 standard, omitted here). In 2004, the IEEE 802.16 workgroup integrated the IEEE 802.16-2001 and IEEE 802.16a standards revised them again, and issued the IEEE 802.16-2004 (generally called the IEEE 802.16d) standard. IEEE 802.16-2004 defines details specifically to the physical layer and the MAC layer of the 2-66G frequency range. Compared with the old IEEE 802.16 series, IEEE 802.16-2004 is a version relatively mature and practical.

2.3.4 IEEE 802.16-2005 (IEEE 802.16e)

In its constitution, the IEEE 802.16 standard firstly emphasized the application of fixed network. However, resulting from the progress of wireless communication technology and demand of user market, only the mobility features can guarantee a broader market prospect of wireless broadband access service. To support such mobile wireless broadband access service, the IEEE 802.16 workgroup presented the IEEE 802.16e standard version based on the IEEE 802.16-2004 standard, aiming to propose a wireless broadband solution providing high-speed information transmission and supporting high-speed moving. Just because IEEE 802.16e supports the high-speed information transmission in moving, it is considered the sole wireless broadband technology of the next generation competitive to 3G. In addition to supporting mobile communication, IEEE 802.16e also defines some functions in close connection with the mobility features, including supporting Handoff, the sleep mode saving energy, call search, and improved safety. Table 2.3 is the comparison between 802.16 standards.

	802.16	**802.16a**	**802.16e**
Spectum	10-66 GHz	2-11 GHz	2-6 GHz
Channel bandwidth	20, 25, and 28 MHz	1.5 to 20 MHz	1.5 to 20 MHz with UL sub channels
Modulation	QPSK, 16QAM, 64 QAM	OFDM 256 sub carriers QPSK, 16QAM, 64 QAM	OFDM 256 sub carriers QPSK, 16QAM, 64 QAM
Bit rate	32-134 Mbps (28 MHz)	75 Mbps (20 MHz)	15 Mbps (5 MHz)
Channel conditions	LOS	Non-LOS	Non-LOS
Typical cell radius	2-5 Km	7-10 Km, max 50 Km	2-5 Km
Application	Fixed	Fixed and portable	Mobility

Table 2.3.4 802.16 standards [5]

2.4 PHY and MAC Layer of WiMax

2.4.1 Characteristics of Physical Layer

The working frequency of WiMAX ranges from 2 to 66GHz (2-11GHz for IEEE802.16 standard; 10-66GHz for IEEE802.16a standard), and the channel band width can be adjusted flexibly within the range of 1.5-20MHz, which is favorable for fully utilizing the frequency spectrum resource in the distributed channel bandwidth.

WiMAX adopts macro cells with the maximum coverage up to 50km. In the 20MHz channel band width, it supports a sharing data transmission rate as high as 70Mbit/s (the maximum coverage is 3-5km in such case). Multi-sector technology can be used to expand the system capacity, with each sector supporting more than 60 company users or hundreds of family users of E1/T1 simultaneously.

WiMAX adopts various advanced technologies to realize the NLOS and ONLOS transmission, such as OFDM, receiving-transmitting diversity, adaptive modulation, which greatly improve the efficiency of wireless transmission in cities. The physical layer supports two kinds of wireless duplex multiple access, i.e., TDD/DMTA and FDD/TDMA, to adapt to the requirements of telecommunication system in different countries or regions. It supports single carrier (SC), OFDM (256 points), and OFDMA (2048 points), which can be selected flexibly as needed. The physical layer may change subject to the performance of transmission channel. The modulation mode and parameters of physical layer (such as, modulation parameters, FEC parameter, power level, polarization method, etc.) can be adjusted dynamically to guarantee good transmission quality.

2.4.2 Characteristics of MAC Layer

The MAC layer is divided into three sub-layers: Service Specific Convergence Sub-layer (CS), Common Part Sub-layer (CPS), and Privacy Sub-layer (PS).

(1) The main function of CS is to convert and map the external network data received by SAP to the MAC SDU, and then transmit to the SAP of MAC layer. The protocol provides multiple CS specifications as interface to various external protocols.

(2) CPS is the hardcore of MAC, with the main functions of system access, band width allocation, connection establishment and connection maintenance. It receives the data

from different CS layers via MAC SAP, and classifies them into specific MAC connections. Meanwhile, it implements QoS control to the data transmitted and dispatched on the physical layer.

(3) The main function of PS is to provide authentication, key exchange and encryption/decryption processing.

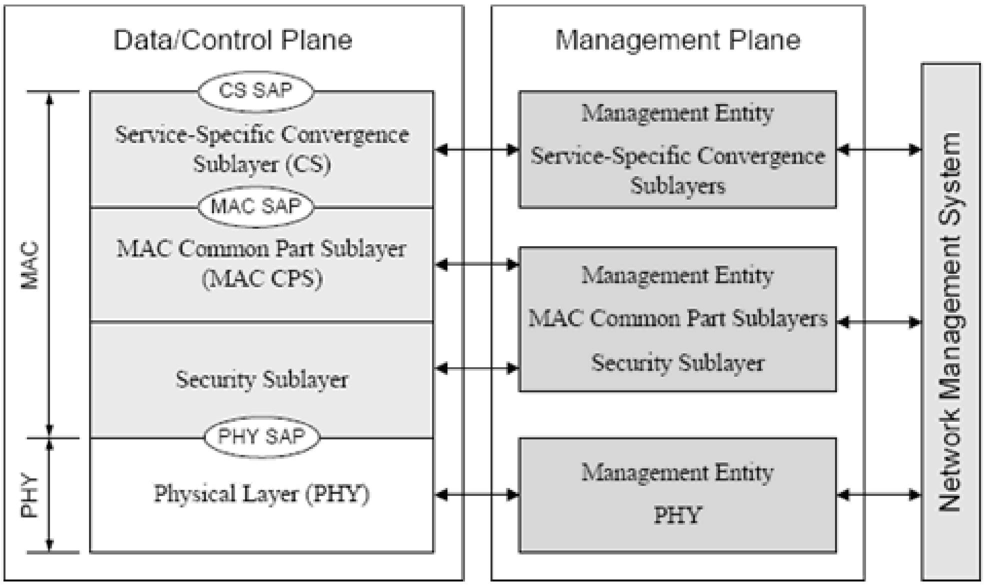


Figure 2.4 MAC Layer and PHY Layer of WiMax [1]

2.5 Structure of WiMax Network System

The WiMax network system mainly comprises of core network and access network. The core network includes the network management system, router, AAA agency or server, user database, and Intern gateway equipment. It mainly provides an IP connection to WiMax users. The access network includes base station (BS), subscriber station (SS) and mobile subscriber station (MS). It mainly provides wireless access to WiMax users. See the following figure.

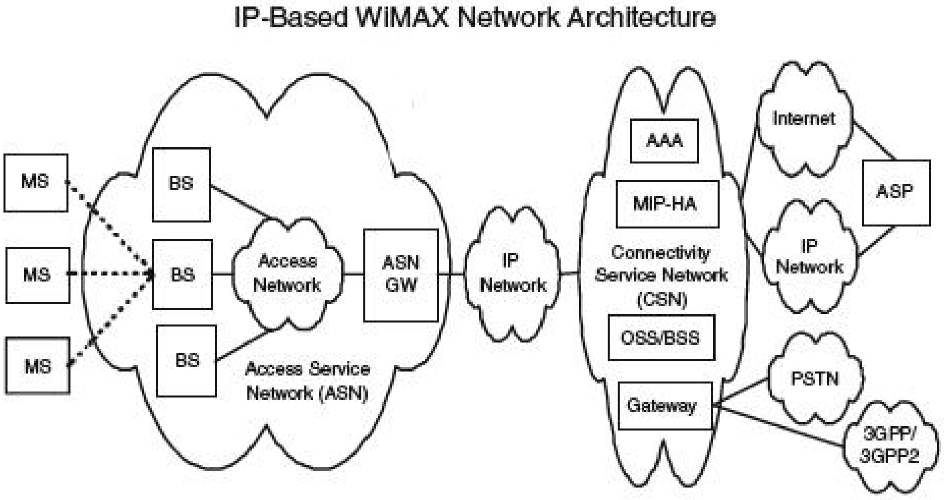


Figure 2.5 IP-Based WiMax Network Architecture [1]

2.5.1Core Network

The WiMax core network is mainly responsible for the user authentication, roaming service, network administration and providing interface to other networks. Its network administration system is used to monitor and control all base stations and subscriber stations in the network, and provide the functions of inquiry, condition monitoring, software download, and system parameters configuration. The IP network connected to the WiMax system is generally a traditional switching network or the Internet or other networks. The WiMax system provides the connection interface between the IP network and base stations. However, the WiMax system does not cover these IP networks.

2.5.2 Access Network

The base station provides a connection between the subscriber station and the core network. It generally uses a sector/beam antenna or umbrella antenna, which provides flexible arrangement and configuration of sub-channels, upgrades and expands the network based on the conditions of users. The subscriber station is a kind of base station, which provides the repeater connection between the base station and the equipment of user terminal. It generally uses a beam antenna installed on the roof. The dynamic adaptive modulation mode of the signal is used between base station and subscriber station. MS mainly refers to the mobile WiMax terminal and handheld devices responsible for realizing the wireless access for mobile WiMax users.

2.5.4 Base Station

The base station provides a connection between the subscriber station and the core network. It generally uses a sector/beam antenna or umbrella antenna, which provides flexible arrangement and configuration of sub-channels, upgrades and expands the network based on the conditions of users.

2.5.5 User Terminal Equipment

The WiMAX system defines the connection interface between the user terminal equipment and the base station, and provides the access of terminal equipment. However, the user terminal equipment does not belong to the WiMAX system.

Chapter 3 Key Technologies of WiMax

3.1 MIMO

The rapid development of wireless communication sets forth stricter requirements for the system capacity and frequency spectrum efficiency. There have been various attempts to meet these requirements, such as the expanding band width of system, optimizing modulation mode, or adopting a complex CDMA system. However, the application of these methods is restrictive. Obviously, neither the expansion of band width nor the increase of modulation order is limitless, and the channels of CDMA system are not orthogonal to each other perfectly. The MIMO (Multiple Input Multiple Output) system was born at the right moment. By using Space Time Coding (STC) technology, it realizes space division multiplexing using multi-element array, which greatly improves the frequency spectrum efficiency within the limited bandwidth. For this reason, MIMO becomes one of the necessary key technologies for WiMAX, LTE, 802.11n and nearly all "popular" wireless communication systems in the future.

MIMO means using multiple transmitting and receiving antennae at the transmitting and receiving terminals respectively. The signals are transmitted and received by multiple antennae at the transmitting and receiving terminals, and accordingly the quality of service is improved for each user. Compared with the traditional single-element system, MIMO technology greatly improves the unitization rate of frequency spectrum, which enables the system to transmit data by higher speed under limited bandwidth. The block diagram of MIMO system with N transmitting antennae and M receiving antennae is shown in Figure 3.1.

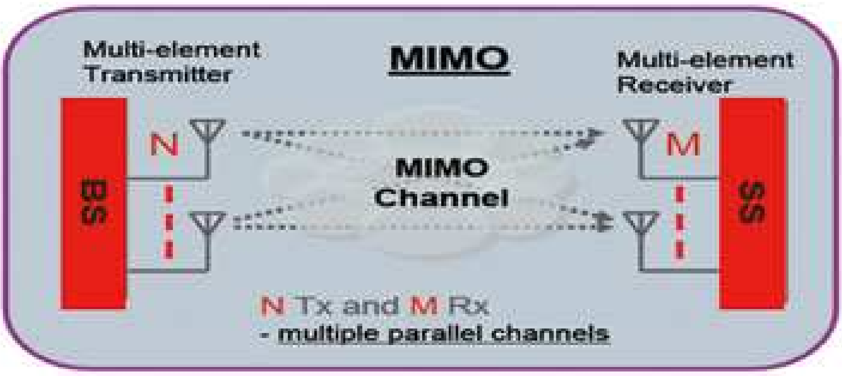


Figure 3.1 MIMO system [6]

WiMAX802.16e defines three options of MIMO. They are Space-time Transmit Diversity (STTD), Spatial Multiplexing (SM) and adaptive switching. It also defines three coding matrix: Matrix A, Matrix B and Matrix C.

In the WiMAX802.16e system, MIMO and OFDMA are combined to improve the network coverage and redouble the WiMAX system capacity. Accordingly, the costs of network construction and maintenance are reduced greatly, which promotes the development of mobile WiMAX.

3.2 OFDM

The Orthogonal Frequency Division Multiplexing (OFDM) is a multi-carrier digital modulation technology. The research on the technology is traceable to the middle of 1960s. The concept of OFDM has remained for years. However, it was recognized as a good approach for high-speed bi-directional wireless data communication until the development of media industry recently. The technology is adopted by the European Digital Television Standard (DVB-T) and Digital Audio Broadcasting (DAB) standard, and it is the core technology of WLAN (ETSI HiperLAN/2 and IEEE802.11a) and broadband wireless access (IEEE 802.16). Along with the development of DSP CMOS chips, some mature technologies adopted by Fourier Transform/Inverse Transform and high-speed Modem, such as 64/128/256QAM, Trellis Coding, soft decision, channel adaptive, inserting guard time, reducing equilibrium calculation, are gradually introduced into the field of mobile communication. People devote more and more energy to the application of OFDM in mobile communication. It is predicted that the mainstream technology for the 4th generation of mobile commutation will be the OFDM.

OFDM is a high-speed transmission technology in wireless environment. Most frequency response curves of the wireless channel are not flat. The main idea of OFDM is to divide the bonded channel into many orthogonal sub-channels in the frequency range, and use a sub-carrier on each sub-channel for modulation, in which the sub-carriers are transmitted in parallel. In this way, in spite of the non-flat channel with different frequency options, every sub-channel is flat relatively, and narrow-band transmission is completed on these sub-channels, with the band width of signal less than the corresponding band width of channel. Accordingly, the interference between signal waves will be eliminated. Because the carriers on these sub-channels in OFDM are orthogonal to each other, they have overlapped frequency spectrum, which reduces the interference between sub-carriers and improves the utilization rate of frequency spectrum. The key technologies of OFDM are guard space (cyclic prefix/postfix), simultaneous techniques, training sequence/pilot frequency and channel estimation, control of PAPR (Peak to Average Power Ratio), channel coding and interleaving and equalization technique.

FDM/FDMA(Frequency-Division Multiplexing/ Frequency-Division Multiple Access) is actually a traditional technique. It is the plainest approach to realize the broadband transmission to divide a broader frequency band into several narrower sub-bands (sub-carriers) and transmit them in parallel. However, a large space has to be reserved between neighboring sub-carriers to avoid the interference as shown in Figure 1(a), which reduces frequency spectrum efficiency. Therefore, the TDM/TDMA (Time-Division Multiplexing/ Time-Division Multiple Access) and CDM/CDMA of greater frequency spectrum efficiency turn to be the core transmission technology for wireless communication. In recent years, FDM has revolutionary changed the development of digital modulation technique FFT (Fast Frontier Transform). FFT allows the arrangement of overlapped sub-carriers in FDM, and maintains the orthogonality of sub-carriers at the same time to avoid interference between sub-carriers. As shown in the figure, the arrangement of partly overlapped sub-carriers greatly improves the frequency spectrum efficiency because more sub-carriers are contained in the same bandwidth.

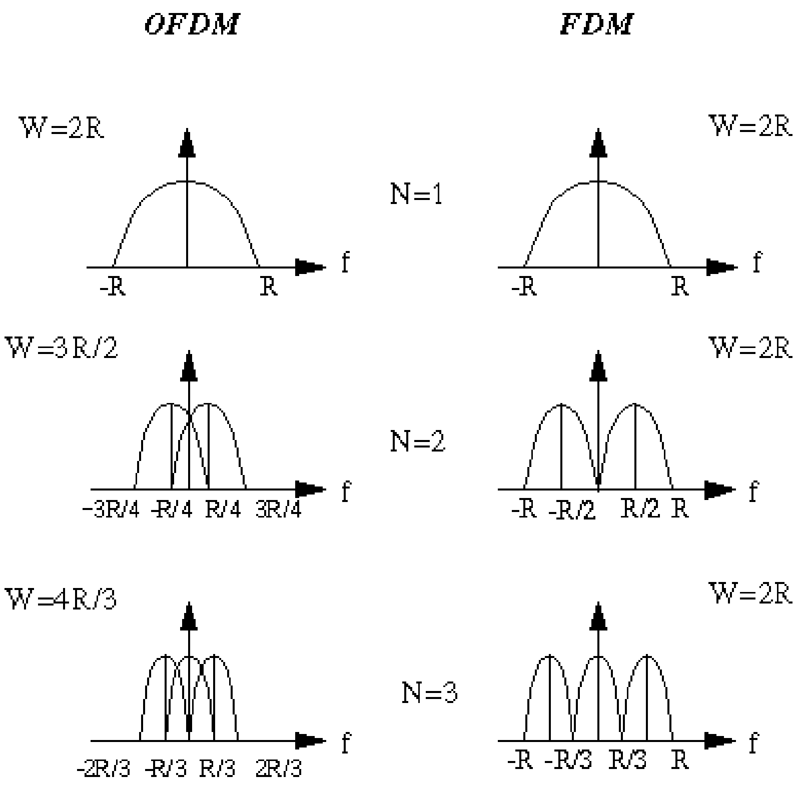


Figure 3.2 OFDM vs. FDM [6]

3.2.1 Advantages of OFDM

OFDM tends to replace CDMA to be the new generation core technology of wireless communication, mainly because of its advantages:

(1) Higher frequency spectrum efficiency

As sub-carriers partly overlap with FFT processing, they approach the Nyquist limit theoretically. The OFDM-based OFDMA (Orthogonal Frequency Division Multiple Access) realizes the orthogonality of various users in a residential area, which effectively avoids the interference between users. As a result, the OFDM system realizes a very large capacity.

(2) Good expandability of band width

As the singnal bandwidth in the OFDM system depends on the quantity of sub-carriers used, the OFDM system has good expandability of band width. It easily realizes the band widths as small as hundreds of KHz and as large as hundreds of MHz. In particular, along with the broadband service of mobile communication (increased from ≤5MHz to maximum 20MHz above), the efficient support of the OFDM system to broader band width turns to be its "decisive advantage" to single-carrier techniques such as CDMA.

(3) Anti-multipath-fading

As OFDM transforms the broadband transmission into narrowband transmission on many sub-carriers, the channel on each sub-carrier can be considered as a horizontal fading channel, which greatly reduces the complexity of the receiver equalizer. On the contrary, the complexity of the multi-path equalization of the single-carrier signal sharply increases with the increase of bandwidth, for which broader bandwidth is hard to support (such as 20MHz above).

(4) Flexibly allocation of frequency spectrum resource

By selecting suitable sub-carriers for transmission, the OFDM system realizes dynamic allocation of frequency range resource, and fully utilizes the frequency diversity and multiuser diversity to achieve optimum system performance.

(5) Simple realization of MIMO

As the channel of each OFDM sub-carrier can be considered as a horizontal fading channel, the additional complexity introduced by the MIMO system is controlled in lower level which presents a linear increase with the quantity of antenna. On the contrary, the complexity of the single-carrier MIMO system is in direct proportion to the power of product by multiplying the quantity of antennae and the quantity of multi-paths. It adversely affects the application of the MIMO technique.

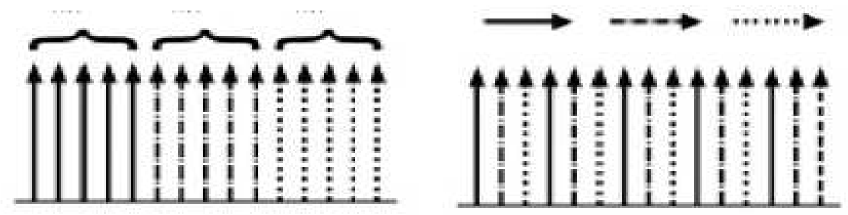
3.3 OFDMA

The OFDMA multiple-access system divides the transmission bandwidth into a series of orthogonal sub-carrier sets without overlap, and allocates these sub-carrier sets to different users to realize the multiple-access. The OFDMA system allocates the bandwidth resources available to users in demand, which realizes the optimized utilization of system resources easily. As different users occupy non-overlapped sub-carrier sets, there is no interference between users in case of ideal synchronization, i.e., no Multiple Access Interference (MAI). The figure at right gives the sketch map of The OFDMA system, where the gray, white and dark grey time-frequency trellis represent different sub-carrier sets which do not overlap on the frequency band and are allocated to different users. OFDMA solution is considered as dividing total resources (time and bandwidth) on the frequency to realize the multiuser access.

3.3.1 Sub-Channel OFDMA

The sub-channel OFDMA divides the bandwidth of the entire OFDM system into several sub-channels, and each sub-channel has several sub-carriers allocated to a user and each user may occupy more than one sub-channel.

The sub-channel is composed of two types of OFDM sub-carriers: localized and distributed, as shown in Figure 3.3.1. The localized type allocates several successive sub-carriers to a sub-channel (user). In this type, the system can select an optimum sub-channel (user) for transmission by scheduling to obtain the multiuser diversity gain (Figure a). Additionally, the localized type reduces the difficulty of channel estimation. However, the frequency diversity gain obtained by this type is small, and the average performance of users is relatively poor. The distributed type spreads the sub-carriers allocated to a sub-channel to the entire bandwidth, and the sub-carriers are arranged alternately to obtain the frequency diversity gain (Figure b). But the channel estimation is complex, scheduling is not applicable, and the anti-deviation capability is poor. The two types should be selected subject to the actual situation in design.



a. Localized **b.** Distributed

Figure 3.3.1 Sub-channels [6]

3.3.2 Frequency Hopping OFDMA

The OFDMA sub-channel allocates the sub-carriers of the sub-channel (user) fixedly, that is, a certain user occupies the allocated sub-carrier sets for quite a long time (the time depends on the cycle of scheduling). Such OFDMA system is enough to realize the multiple- access in a residential area, but it has some problems in the multiple-access among many residential areas. If these residential areas are scheduled based on the channel changes of individual, the sub-carrier resources occupied by individual residential area necessarily conflict with each other, which leads to the interference between different residential areas accordingly. In order to avoid such interference, the coordination (joint scheduling) is required between neighboring residential areas. However, the coordination may require support of signaling switching from the network layer, which affects the network architecture greatly.

Alternatively, the frequency hopping OFDMA is available. In such system, the sub-carrier resources allocated to a user change rapidly. In each timeslot, the user extracts some sub-carriers from all to occupy, and various users extract different sub-carrier sets in the same timeslot. Different from the scheduling-based sub-channel service, the selection of sub-carriers is random independent of the channel conditions. In the next timeslot, regardless of any channel change, the users hop to another sub-carrier set for transmission, but the sub-carriers they use seldom conflict with each other. Much shorter than the cycle of scheduling in sub-channel OFDMA, the cycle of frequency hopping may be the symbol length of OFDM to the minimum. Thus, the users are orthogonal to each other inside a residential area, and they can utilize the frequency diversity gain. Coordination is unnecessary between residential areas. Although the sub-carriers may conflict, the rapid frequency hopping scatters the interference in time and frequency ranges. That is to say, the interference is transformed to noise, which greatly reduces the harm of interference. With the increased load of residential areas, more and more sub-carriers may conflict with each other. The “interference noise” also accumulates to reduce the SNR accordingly. However, in those non-overloaded systems, the frequency hopping OFDMA restrains the interference between residential areas effectively and simply.

3.4 Perfect Combination of MIMO and OFDMA

In the WiMAX802.16e system, MIMO and OFDMA are combined to improve the network coverage and redouble the WiMAX system capacity. Accordingly, the costs of network construction and maintenance are reduced greatly, which promotes the development of mobile WiMAX.

MIMO is applicable for all wireless communication technologies. In the WiMAX802.16e system, the perfect combination of MIMO and OFDMA embodies the technical advantages of MIMO better.

The MIMO system has the capacity of anti-multipath fading, but it cannot do anything about the selective fading of frequency. Other communication systems generally adopt equalization technique to solve this problem in the MIMO system. The OFDMA of WiMAX conquers the selective fading of frequency successfully. The next generation of mobile communication requires technologies with higher frequency spectrum utilization rate, but the ability of OFDMA to improve the frequency spectrum utilization rate is limited after all. Combined with the MIMO, the frequency spectrum efficiency is further improved without increasing the bandwidth of system. The MIMO + OFDMA technology not only offers higher data transmission speed, but also achieves strong reliability and stability of system by diversity. Moreover, for lower code rate and additional guard interval, OFDMA has powerful capacity of anti-multipath interference. The multipath delay being less than guard interval releases the system from the intersymbol interference. In this way, single-frequency network uses the broadband OFDMA system to eliminate the shade influence relying on MIMO technology. It realizes the seamless coverage of network truly.

3.4.1 Network Coverage Ability

Because of higher frequency range, the transmission loss of WiMAX802.16e is much higher than other mobile communication systems. Expand the network coverage is a challenge to WiMAX. The application of MIMO technology in the WiMAX system greatly improves the network coverage. In the diversity mode, MIMO increases the coverage radius of residential areas by diversity gain. In the multiplexing mode, it increases the coverage radius by diversity gain obtained from increase of speed at the edges of residential area. In the adaptive switching mode, the edges of residential area work in diversity mode, and the coverage gain are identical to that of diversity mode.

3.4.2 System Capacity

The WiMAX802.16e system provides very high data throughput and mobility, which keeps the users on-line at any time. The users can experience the true broadband service even if they are moving. In the multiplexing mode, the MIMO technology multiplies the system throughput and frequency spectrum efficiency, and also multiplies the peak speed of a single user. In the diversity mode, the system throughput and the frequency spectrum efficiency are improved by increasing the proportion of High Order Modulation (HOM). In the adaptive switching mode, the center of residential area works in multiplexing mode, and the edges work in diversity mode. As a result, the improvement of the system throughput and frequency spectrum efficiency falls in between the two modes. The application of the OFDMA and MIMO technologies enables the WiMAX802.16e system to improve the frequency spectrum efficiency to the largest extent and provide high speed and broader band width necessary for high quality mobile video and televisions service.

3.4.3 Cost

In high-density urban areas and CBD areas, there are many high-end users who have higher requirements on the system throughout and peak rate. The capacity may be restrictive sometimes. By adopting the MIMO MatrixB technique, the WiMAX system capacity is improved by 55% for downstream and 33% for upstream. In case of restrictive capacity, the quantity of base stations is decreased by 25% approximately. Compared with other multi-antenna technologies (such as AAS, adaptive antenna system, also called advanced antenna system), MIMO has obvious advantages in the capacity gain for high-density urban areas, which effectively reduces the costs of network construction or capacity expansion in intensive call areas.

In case of restrictive coverage, the MIMO technology increases the coverage radius by 50% or higher, and increases the coverage area of single station by nearly 100%, which saves 40% to 60% base stations under certain coverage. The introduction of MIMO technology in suburban areas and villages realizes the maximum coverage by minimum base stations, which greatly reduces the cost of network construction.

Additionally, in respect of installation and maintenance, the AAS antenna is at least 4-beam antenna requiring large installation space. Compared with the traditional antenna, the AAS antenna requires much more feeder lines and wider chamfer of transmission tower, which greatly increases the work quantities. The AAS antenna is heavy, requiring higher installation carrying capacity. Additionally, the AAS antenna is too large to resist the wind. With higher requirements on the wind resistance, it is not suitable for areas of heavy wind or frequent typhoon. MIMO needs fewer antennae than AAS. A piece of common ±45° dual-polarized antenna is sufficient to support 2×2MIMO. With lower requirements on the installation space and carrying capacity, it is easy to arrange and maintain, which effectively saves the costs of antenna installation and maintenance.

Chapter 4 Application of WiMax Technology

4.1 Application Modes of WiMax

The technical properties and application characteristics of WiMAX decide its adaptability and different application modes under various application conditions. The following is the primary analysis and discussion on application modes of WiMax broadband wireless access.

4.1.1 PMP

As shown in Figure 4.1.1, centering on the base station, the PMP application mode uses the point-to-multipoint connection to compose a WiMax access network of star structure. The base station plays the role of service accessing point. By the dynamic allocation of band width, the base station selects the beam antenna, the omnidirectional antenna or multi-section techniques, subject to the conditions of users in the coverage, to satisfy the demand of a mass of subscriber station equipment accessing the core network. If necessary, it expands the wireless coverage by repeater stations. It also allocates the channel bandwidth flexibly based on the quantity of user groups, and thereby expands the network capacity to realize the coordination between benefits and costs.

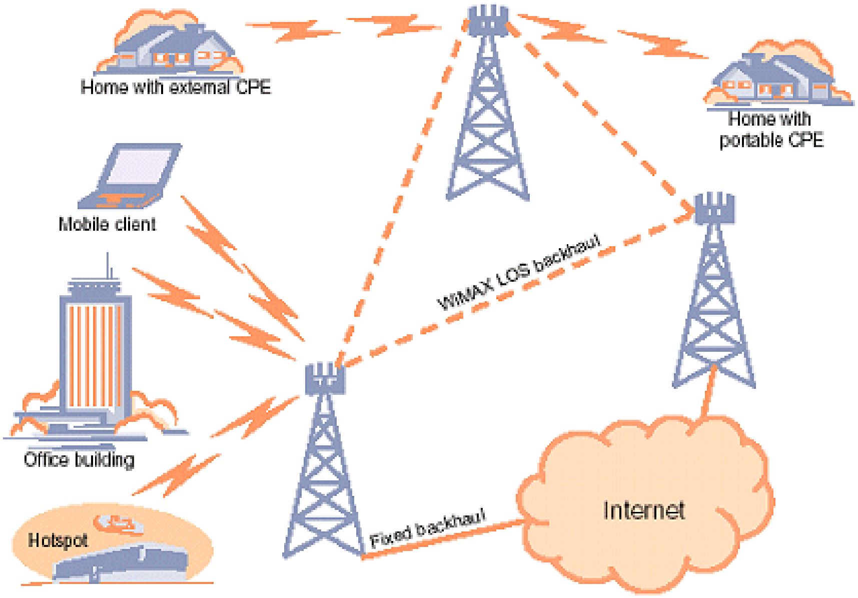


Figure 4.1.1 PMP [7]

PMP is a conventional application form of access network, characterized by the simple network architecture. The application mode is similar to the access form of cables such as xDSL. Therefore, it is an ideal option as replacement of cables.

4.1.2 Mesh

As shown in Figure 4.1.2, Mesh application mode adopts multiple base stations (BS) to expand the wireless coverage by mesh network. One of the base stations connects to the core network as a service access point (SAP), and others connects to this SAP via wireless links. Consequently, the base station as SAP is used as not only a service access point but also a junction point of accessing, and other base stations are service access points instead of simple repeater stations (RS).

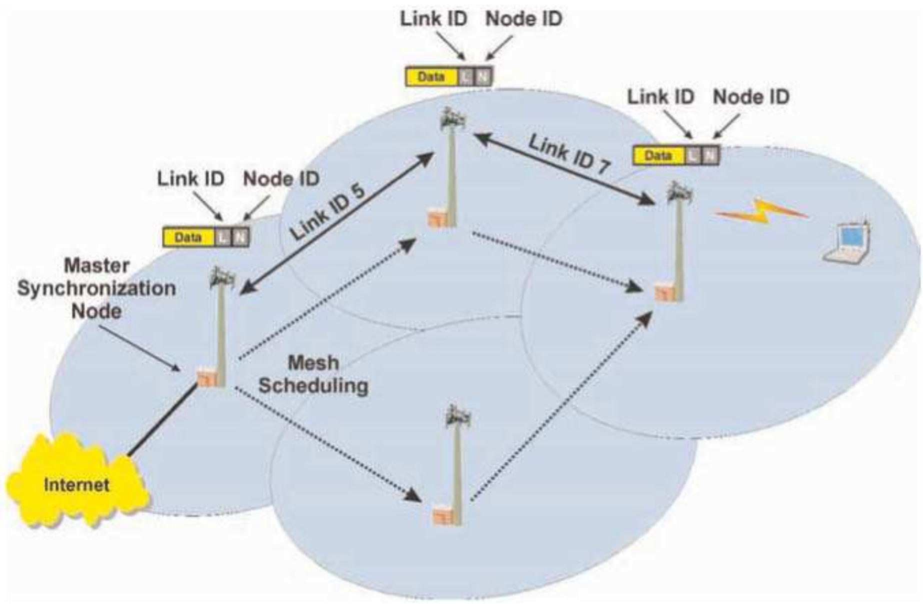


Figure 4.1.2 Mesh [7]

The Mesh application mode is characterized by the mesh network structure, which can be arranged flexibly to realize elastic extension of network in accordance with the actualsituation. For areas such as suburban areas far away from the backbone network, which is seldom covered by the cable network, this application mode can be used to expand the coverage. The scale depends on the radius of base station, the size of the covered areas, etc.

4.1.3 Hotspot Backhaul

The Hotspot Backhaul mode adopts WiMax wireless access network to haul the hotspot service of remote WiFi back to the core network. The WiMax base station still plays the role of SAP, and the WiMax subscriber station is the wireless accessing equipment at the side of hotspot, which offers standard interface to the hotspot, and then connects to the wireless terminal as the hotspot equipment of WLAN access point via IEEE802.11a/b/g wireless link.

The WiMax access network may adopt PMP or Mesh structure as the case may be. The mobile network operator can adopt the application mode to haul the service of mobile base stations in residential areas back to the mobile switching center.

The Hotspot Backhaul mode is mainly characterized by the wireless transmission for service backhaul. Compared with traditional cable backhaul, it has obvious advantages and should be the supplement or replacement of traditional mode.

4.1.4 Terminal Access

In the terminal access mode, the terminal equipment (TE) connects to the core network via the WiMax base station as SAP. If the terminal equipment intends to connect to the WiMax network directly, it must be configured with a subscriber unit (SU) conforming to the WiMax standard. The SU is generally a WiMAX wireless network card or wireless module.

For the higher access rate of WiMax and its support to mobility of terminal equipment in the metropolitan area (for IEEE 802.16e to be issued), it is particularly suitable for the terminal applications with higher requirements on the access rate and mobility.

This mode is characterized by allowing the user terminal to access the network directly in high speed and supporting the moving and roaming of mobile terminal in the metropolitan area. In respect of technology and service, only by adding the support to VoIP voice service, it turns to be worthy of the name as the next generation of mobile communication network.

4.1.5 CPN (Customer Premise Network) Access

The CPN access mode is concerned essentially with the group users, aiming to connect the CPNs such as enterprises, schools and SOHO (Small Office Home Office) to the MAN via WiMAX. Similarly to other application modes, the base station still plays the role of SAP connecting to core network to offer wireless access service. At the user terminal, the wireless access equipment of the subscriber links to the BS via wireless interface at one end, and to the CPN equipment via standard interface (such as Ethernet interface, E1, etc.) at the other end. Generally, the subscriber station (SS) adopts beam antenna and various adaptive techniques to adjust the working mode flexibly and ensure the normal access of users.

The CPN equipment may be a router, switch, hub or other network equipment, even another wireless access point such as WiFi hotspot, which is used to compose a private local area network of user. The typical examples are campus network, enterprise network, government network or SOHO widespread nowadays.

The CPN access mode is especially suitable for access among premises with inconvenient cable accessing and lower requirements of bandwidth. Compared with cable accessing, the fast arraignment of such mode is a competitive advantage.

4.1.6 Wireless Bridge

The wireless bridge mode is a point-to-point wireless link similar to the remote bridge. The purpose is to connect two geographically separated sub-networks together via WiMAX wireless link. Because of the point-to-point mode of wireless bridge, the antennae of WiMAX wireless bridge equipment at the both ends may align to each other. As a result, the transmission performance is reliable and the arrangement is simple.

Obviously, the WiMAX wireless bridge avoids the difficult works of cables pavement or expensive cable rents. Moreover, it is available to the users in a short time with long connection distance. The connection bandwidth is enough to meet the requirements of common applications. It is more competitive than the cable bridge in respect of private network construction.

4.2 Application Scenarios of WiMax

4.2.1Fixed Application Scenario

The fixed access service is the most fundamental mode of 802.16 operation network, including the services of Internet access, transmission carrying, and Wi-Fi hotspot backhaul.

4.2.2Nomadic Application Scenario

The nomadic service is the nest development stage of fixed access. The terminal connects to an operator's network via different access points. In the connection of each conversation, the user terminal only realizes the access of station type. For different network accesses, the data transmitted will not be reserved. The nomadic and all subsequent application scenarios support the roaming service and have the function of terminal power supply management.

4.2.3Portable Application Scenario

In this scenario, the user can connect to the network in walking. The connection will not be interrupted except for switching between residential areas. The portable service develops on the basis of nomadic service. Since this stage, the terminal is allowed to switch between different base stations. When the terminal holds still, the application model of portable service is the same as fixed service and nomadic service. When the terminal switches, the user experiences a momentary (maximum 2s) service interruption or delay. After the completion of switching, TCP/IP application refreshes the current IP address or re-establishes the IP address.

4.2.4Simple Moving Application Scenario

In this scenario, the user can use the broadband wireless access service in walking, driving or taking bus, etc. However, when the moving speed of terminal reaches 60～

120km/h, the data transmission speed descends. It is the first scenario allowing switching between neighboring base stations. In the process of switching, the data package losses are controlled within certain scope. In the worst case, TCP/IP conversation is not interrupted, but the service of application layer might be interrupted. After the completion of switching, QoS resets to the initial level. The simple moving and mobile networks are required to support the suspend mode, idle mode, and paging mode. The mobile data services are the main applications in mobile scenario (including simple moving and mobile), including the popular mobile E-mail, streaming media, videophone, mobile games, mobile VoIP, which occupy more wireless resources.

4.2.5Mobile Application Scenario

In this scenario, the user can use the broadband wireless access service at a moving speed of 120km/h or higher. If no network connection is available, the user terminal is in a state of low power consumption.

Chapter 5 WiMax, WiFi, 3G and LTE

5.1 WiMax vs. WiFi

As for the relation between WiMax and WiFi, they are not in the same category. WiFi is an interoperability organization related to the IEEE802.11x standard of WLAN, while WiMax is an interoperability organization related to the IEEE802.16x standard of WMAN. They are oriented to different application types.

Compared with WiFi, WiMax has a better physical layer and MAC layer technology with higher speed and QoS, and the competition follows. WiFi is mainly used in the category of WLAN, and the WiMax is used in the category of WMAN, which are complementary to each other. It can be considered that WiFi is suitable for the indoor usage, and WiMax is suitable for outdoor usage in cities.

	Wi-Fi	WiMAX
Range	Up to 300 feet (about 91.4 meters)	Up to 30 miles (about 48.3 kilometers); cell radius of 4-6 miles
Coverage	Optimized for indoor performance, short range	Outdoor Non-Line-of-Sight (NLOS) performance; support for advanced antenna technologies
Scalability	Supporting one to dozens users, one Customer Premises Equipment (CPE) per user; fixed 20MHz channel width	Effectively supporting one to hundreds pieces of CPE; unlimited subscribers within each CPE; flexible channel sizes from 1.5MHz to 20MHz
Bit rate	2.7bits/s/Hz	5bit/s/Hz, and up to 75Mbit/s in a 20MHz channel
QoS	No QoS support	Support for QoS at the MAC level, which enables differentiated services for voice and video
Security mechanism	Wired Equivalent Privacy (WEP) authentication; pre-shared key	Extensible Authentication Protocol (EAP)-based authentication; Advanced Encryption Standard (AES); Privacy Key Management (PKM)

Table 5.1 WiFi vs. WiMax [8]

5.1.1 Hybrid Network of WiMax and Wi-Fi

WiMax composes the network combining Wi-Fi to solve the problems in Wi-Fi. WiMax and Wi-Fi develop in a complementary trend. For a long time, they coexist and cooperate with each other, and also develop compatible to 3G. WiMax offers the converging access of data to realize fast and flexible WLAN. It may combine broadband data gateway or WLAN AP to provide perfect solutions for medium/small enterprises and city hotspot access, and make full use of the NLOS, high frequency spectrum efficiency and IP characteristics of WiMax. WiMax combines the WLAN to provide full-wireless solution, in which WiMax solves the “Last Kilometer”, and WLAN solves the “Last Hundred Meters”.

5.2 WiMax vs. 3G

3G is a Wide Area Network technology. 3G network is ISDN (Integrated Services Digital Network) for global mobile communication integrating various functions of mobile communication systems, such as cellular, cordless, trunking, mobile data, satellite. Compatible to the service of fixed telecommunication network, it also offers voice and data services. The goal of 3G is to realize seamless coverage in all areas (urban area and open country) to make the system services available to users anywhere. 3G also offers the voice and data services. Under present conditions, the QoS of voice service based on circuit switching is much better than the VoIP.

As the fourth standard of 3G, WiMax demonstrates its great superiority in many respects compared with other three 3G technologies. Although the speed of 3G network improves greatly than others at present, it is slower than WiMax by 30 times. Additionally, the network coverage of a 3G base station is only one tenth of WiMax.

In the past years, wireless network operators invested hundreds of billion dollars in order to acquire the 3G operation license. They still spend tens of billion dollars on the operation of 3G network now. At present, the frequency spectrum of WiMax needs no additional expenses, and the WiMax-based network requires base stations much less than 3G.

The fixed-line operators are proposed to establish a WiMax-based network of low costs firstly, and then connect the wireless network with the Internet via existing fixed telephone line. In this way, they may recapture some market shares from mobile network operators.

The core function of 3G is to provide mobile telephone service, and also to transmit data. The criterion of WiMax is the high-speed data transmission while voice quality is not the key requirement. Accordingly, they have different tasks and targets. WiMax emphasizes on the wireless service of broadband, while 3G tends to realize the broadband service of wireless network.

Specifications for 3G and WiMAX

Parameter	3G	WiMAX
Communication for stationary devices	Download 2 Mbps; Upload 0.15 Mbps	Download 10 Mbps; Upload 2-3 Mbps
Communication for mobile devices	Low speed 0.14 Mbps High latency (>100 ms)	High speed 2 Mbps Low latency (<100 ms)
Bandwidth	Theoretical maximum 2.4 Mbps	Theoretical maximum 70 Mbps
Security	High	High
QoS	High	High: latency as low as <10ms

Table 5.2 3G vs. WiMax [9]

5.3 WiMax vs. LTE

Both the Long Term Evolution (LTE) and WiMax adopt advanced methods such as OFDMA and MIMO, and both of them are completely based on IP (Internet Protocol). With high speed data function, they realize many senior applications such as fast internet access and video.

The two systems seem to compete severely, but there must be a sole winner finally. It may not be so actually. Competition of data services might exist in some areas, but it is not everything. The two standards are developed under different historical backgrounds, and they have different abilities. Obviously, LET is the successor of cellular technology such as UMTS/WCDMA/HSPA and CDMA2000 3G, while WiMax is mainly used for the broadband wireless access and backhaul links.

5.3.1 LTE

As the evolution of 3G, LTE improves and strengthens the air access technique of 3G. It adopts OFDM and MIMO as unique standards for the evolution of wireless network. It offers a peak rate of 100Mbit/s down and 50Mbit/s up under the 20MHz frequency spectrum bandwidth. It improves the performance of users at the edges of residential area, increases the capacity of residential area, and reduces the system delay.

LET has the following technical characteristics:

(1) The communication speed is improved to a peak rate of 100Mbps down and 50Mbps up.

(2) The frequency spectrum efficiency is improved to 5(bit/s)/Hz for downlink (3 ~ 4 times of R6HSDPA) and 2.5(bit/s)/Hz for uplink (2~3 times of R6HSU-PA).

(3) With the PS domain as its main purpose, the overall architecture of system is based on the packet switching.

(4) With system design and strict QoS mechanism, QoS guarantees the quality of real-time service (such as VoIP).

(5)The system is arranged flexibly to support various system bandwidths from 1.25MHz to 20MHz, and support the “paired” and “unpaired” frequency spectrum allocation. It guarantees the flexibility of system arrangement in the future.

(6) It reduces the wireless network delay. The subframe length, 0.5ms and 0.675ms, solves the problem of down compatibility and reduces the network delay to <5ms for U-plan and <100ms for C-plan.

(7) The bit rate at the boundaries of residential area is increased without changing the location of existing base stations. For example, MBMS (Multimedia Broadcast/Multicast Service) offers a data rate of 1bit/s/Hz at the boundaries of residential area.

(8) It emphasizes the down compatibility, supporting the cooperative operation of existing 3G system and non-3GPP standard systems.

Compared with 3G, LTE has great technical superiority, embodied by the high data rate, package transport, reduced delay, wider coverage and down compatibility.

Figure 5.3.1 shows the comparison between LTE and WiMax under different terminal equipment and hotspot devices.

Hotspot device	Network Technology	Test device	Average Down (Mbps)	Average Up (Mbps)	Latency (ms)	# of tests
ThunderBolt	LTE	Apple iPad 2	7.37	4.30	202	129
ThunderBolt	LTE	Toshiba Laptop	9.28	4.64	79	125
Average In-Building			***8.31***	***4.47***	***141***	***254***
EVO	WiMAX	Apple iPad 2	0.65	0.43	334	125
EVO	WiMAX	Toshiba Laptop	1.73	0.36	161	128
Average In-Building			***1.19***	***0.39***	***246***	***253***
ThunderBolt	LTE	Apple iPad 2	8.35	7.11	210	125
ThunderBolt	LTE	Toshiba Laptop	11.35	5.10	80	130
Average Near Window			***9.88***	***6.08***	***144***	***255***
EVO	WiMAX	Apple iPad 2	0.91	0.88	619	131
EVO	WiMAX	Toshiba Laptop	1.41	0.95	134	128
Average Near Window			***1.16***	***0.91***	***379***	***259***
ThunderBolt	LTE	Apple iPad 2	7.85	5.68	206	254
ThunderBolt	LTE	Toshiba Laptop	10.34	4.88	79	255
Average Both Locations			***9.10***	***5.28***	***143***	***509***
EVO	WiMAX	Apple iPad 2	0.78	0.66	480	256
EVO	WiMAX	Toshiba Laptop	1.57	0.65	147	256
Average Both Locations			***1.17***	***0.66***	***314***	***512***

Table 5.3.1 LTE vs. WiMax

5.3.2 Competitive Relation between WiMax and LTE

LTE and WiMax have commonality to a large extent. More and more chip manufactures, equipment suppliers, and operators of WiMax are turning to or intend to turn to the LTE. Although it is too early to say WiMax is a loser, the success of TD-LTE with unpaired frequency spectrum will strike a deadly blow to WiMax. When USA Verizon and Japan DoCoMo present services widely in the end of the year, 2011 will be a year of great progress for LTE. The first-mover advantage of WiMax is likely to be eroded.

Recently, IHS iSuppli publicized a research report (Figure 5.3.2) to reveal the competition between the two standards in the 4th generation of mobile communication technology. It predicts that the battle between LTE and WiMax will end soon, and LTE will win a landslide victory.

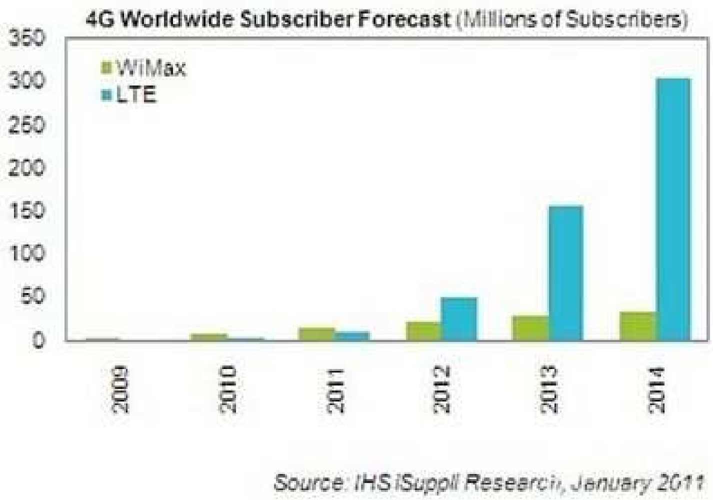


Table 5.3.2 4G Worldwide Subscriber Forecast

Although WiMAX develops steadily and mature at present, LTE will excel it in certain time of the next year. The subscribers of LTE are forecasted more than 300,000,000 in 2014.

5.3.2.1 TD-LTE and WiMAX

Recently, the topic about either “amalgamation” or “competition” between TD-LTE and WiMax causes tempests in global communication industry. Most people support or encourage the amalgamation, while some worriers or objectors also argue from the difficulties in the development stage or amalgamation technology. By observations on the causes and forecasting of results, the writer thinks that, the amalgamation of TD-LTE and WiMax depends on the strategic interests brought by their respective strategic orientations.

In October 2009, ITU collected six proposals for 4G technology submitted by 3GPP, IEEE, China, Japan and Korea. In the coming year, under the instruction of ITU-R WP5D workgroup, 14 independent evaluation workgroups will perform strict evaluation and system amalgamation on the six candidate proposals. The first version of globally core standard IMT.GCS for 4G was completed in October 2010, and the official 4G technology will be determined basically then. The TD-LTE Advanced proposed by China is a powerful competitor for 4G standard. After the evaluation of authoritative sources, there, it is almost a sure that China will win. Meanwhile, the candidate WiMax is another powerful competitor for 4G standard. Therefore, there may be two TDD standards for 4G in the future.

Against such background, the advocate to amalgamation between WiMAX and TD-LTE becomes stronger. Firstly, in the ITU TELECOM WORLD 2009 at Geneva and later International LTE Forum 2009 at Hong Kong, Wang Jianzhou, Chairman and CEO of China Mobile Communications Corporation, proposed the amalgamation of LTE and WiMax, and exchanged opinions with the CEOs of WiMax operators. They all believe that the amalgamation of LTE and WiMax will realize the globally unified communication standard of the next generation. Following him, Arun Sarin, the CEO of Vodafone Group, suggested the amalgamation of LTE and WiMax to ease the burden on communication industry for developing two technical standards at the same time. Moreover, international communication service suppliers also support the amalgamation. They think of WiMAX and LTE overlapped 80% ~ 90% in respect of techniques. WiMAX and LTE have an unprecedented opportunity of amalgamation and alliance. MOTOROLA even predicts a trend of standard amalgamation, that is to say, WiMAX 802.16m and TD-LTE will be integrated as a whole standard. ZTE thinks that, WiMax network today will become potential TD-LTE tomorrow, and this trend promotes the deployment of WiMax in return.

Certainly, there are some objections. For example, Intel, as the proposer of WiMax technology, believes that LTE and WiMax are absolutely different. One is developed from an IT perstective, and another is a completely traditional communication technique. At first, the two will not be amalgamated in respect of terminals. Secondly, the two adopt totally different commercial modes. Accordingly, neither amalgamation nor completion exists between LTE and WiMax. Especially, the down compatibility must be considered. For example, China needs to consider the dual-mode compatibility of TD-LTE and TD-SCDMA, North America needs more to consider the multi-mode compatibility of EV-DO, FDD LTE and WiMAX. As a result, the amalgamation of WiMax and TD-LTE will not be smooth. In fact, neither WiMax Forum nor GSMA calling for TD-LTE expansion propose a definite strategy of evolution. Instead, they accelerate the creation of perfect ecosystem in their respective fields and expand the user bases. As a result, the competition between the two is in progress till now. It is difficult to make a judgment of “washing out” or “amalgamation” in the future.

5.4 Global Deployment of WiMax & LTE

5.4.1 Global Deployment of WiMax

On October 19th, 2007, International Telecommunications Union (ITU) announced the approval for WiMAX as the 4th global 3G standard following CDMA2000, WCDMA and TD-SCDMA(Time Division-Synchronization Code Division Multiple Access).

Since the advent of WiMax, the standing members of WiMax Forum are up to 291 covering COMS chips companies, equipment manufacturers and telecommunication corporations such as Chinese Huawei, ZTE, Alcatel, Nortel Networks, Motorola, Cisco, and one of the initiators, Nokia, as well as some service suppliers and operators, such as British Telecom, French Telecom, Qwest Communication, Reliance Telecom. Now the service suppliers and operators occupy nearly one third of the seats in the Forum.

5.4.1.1 Europe

British Telecom is a typical case. The British government requires the operators offering broadband access service to resident everywhere in the whole country. Therefore, WiMax attracts British Telecom because it satisfies the market demand of rural areas. British Telecom has started on the technical testing related to WiMax, hoping for high quality and high speed wireless broadband access to rural areas far from ADSL and cable TV broadcasting networks. By using WiMax, British Telecom may compete with mobile communication operators by means of virtual operation. Following the British Telecom on April 28th, 2004, French Telecom, Qwest, Reliance and XO joined the WiMax Forum successively.

5.4.1.2 USA

As the practice cost of WiMax decreases gradually, the operators of America Telecom convert the WiMax technology into a practicable commercial mode, which makes WiMax an important alternative in addition to traditional copper cable and IP telephone. Federal Communications Commission (FCC) forecasts that, along with the long-distance telephone operators quitting the market, the competition in American voice market will develop among various communication approaches, which is centered on the competition between cable and wireless communication operators as well as between DSL and cable TV broadband network operators. WiMax turns to be a good choice for non-mainstream telecommunication operators to challenge the local mainstream telephone service operators in the field of voice service.

5.4.1.3 Korea

In April 2005, WiMax Forum announced that the Korean Wireless Group would support and promote the products certified by WiMax Forum, and had signed an agreement with European Telecommunication Standards Institute (ETSI) to guarantee unique global standard for WMAN technology. This implies that WiMax unifies other two technical standards of WMAN WiBro and HiperMAN.

In June 2005, Korean Telecom established the largest commercial WbFi network in the world. WiBro is the mobile internet technique developed by Korea specifically for existing communication system to improve the insufficiencies of mobile internet service. The mobile broadband service WiBro (see Table 1-6 for the main technical indexes) is compatible to 802.16 standard. At present, Korea has issued the WiBro License to operators KT and SKT respectively, and put it into commercial service formally in June 2006.

5.4.1.4Japan

Airspan signed a contract of 17 million dollars with the Japanese Telecom operator, Yozan. They agreed to deploy WiMax network in Tokyo together, for which the commercialized products were presented in December 2005, and the base stations were delivered before March 2006. The project adopted the Airspan radio technology with upgradable software, supporting 802.16-2004 at the beginning and then the 802.16e after upgraded. Till the end of 2006, Japan had issued 3 licenses of 802.16e.

5.4.2 Global Deployment of LTE

5.4.2.1 Sweden

On May 25th, 2010, Ericsson and the Swedish operator TeliaSonera initiated the first commercial station of LTE in the world, marking a significant progress to realization of mobile digital highway.

As a main operator of Sweden, TeliaSonera is dedicated in upgrading the network in these years. Its mission is to offer service by higher speed and richer contents to the users, and make the users to enjoy high speed and smooth network connection even in moving. For this purpose, TeliaSonera signed a Contract for LTE Commercial Network with Ericsson on January, with the Capital Stockholm covered by the network. The commercial time is 2010. According to the contract, Ericsson provides TeliaSonera the LTE system including LTE wireless base stations of brand-new RBS6000 series, evolved packet core network, and mobile backhaul link solution comprising of Redback SmartEdge1200 Router and latest EDA multiple access aggregation switch. Additionally, Ericsson is not only responsible for the network implementation and network management at initial stage, but also cooperates with TeliaSonera for a long term to promote the LTE mobile broadband to users.

Before the global economy bounces back, TeliaSonera announced to deploy the first LTE commercial station in the world. As a part of commercial network formally initiated in 2010, this station unquestionably offered a good demonstration for the worldwide development of LTE. The opening of the station indicated LTE to be a fact rather than out of reach.

5.4.2.2 Japan

On May 7th, 2009, Ministry of Internal Affairs and Communications of Japan issued 4 licenses of LTE. The largest mobile communication operators NTT Docomo, Softbank Mobile, KDDI, and e-Mobile obtained the licenses by default. Japan will adopt uniform LTE standard of the industry in the 4G era represented by wireless broadband, which is beneficial for the rapid popularization of LTE. From this point of view, the Ministry of Internal Affairs and Communications issued 4 LTE licenses. The three largest communication operators of Japan, NTT Docomo, Softbank, and KDDI as well as the newly-born e-Mobile competed fairly to obtain the frequency band for developing LTE.

NTT DoCoMo, the largest mobile communication operator of Japan, plans to invest 300 ~ 400 billion yen to build LTE base stations and backbone communication network in the coming 5 years. It will start the service in the next year at the earliest. The Softbank Mobile invests 120 billion yen on the equipment which will be put into service in 2011 or 2012. E- Mobile plans to reach a total investment of 300 billion yen on the equipment till 2013, which will be put into service in 2011. KDDI will start the service in 2012, with the investment as much as 100 billion yen.

Some experts point out that the Japanese government issued the license earlier because it intended to lead the deployment of 4G in the world. According to the plan of Japanese Government, LTE will cover more than 50% of Japanese population after 5 years.

5.4.2.3 Verizon Applies LTE to Commercial Use in USA First

This year, Verizon Wireless Corporation organized by Verizon Communications and Vodafone jointly selected Ericsson and Alcatel-Lucent to be the chief network suppliers to support the LTE network deployment in the U.S.A. Previously, Verizon has cooperated with Vodafone to carry out the advanced LTE network testing in USA and Europe. The two manufacturers will deploy network infrastructure for Verizon Wireless to help it with the commercial LTE service in USA since 2010.

Additionally, Verizon declares to select Nokia Siemens Networks and Alcatel-Lucent to be the core suppliers of IP Multimedia Subsystem (IMS). Regardless of the access technique, the system realizes abundant multimedia applications. IMS plays the role of core technology in the evolution of Verizon service architecture. Verizon plans to provide IMS-based IP fusion application and service on the wireless and fixed broadband networks. LTE turns to be one of the important wireless access networks adopting IMS technology. Verizon Wireless will expand the FiOS optical network when it constructs the LTE network and provides commercial service. It is a sustainable and complementary development strategy with a view to future development of broadband market.

Conclusion

From the analysis above we can see that, WiMax system adopts the MIMO and OFDM technique for higher frequency spectrum efficiency. Representing the development orientation of wireless communication technology, the technique becomes the recognized key technology for mobile communication system in the future. It is not only applicable for WiMax system, but also the kernel of the 4G system. For its excellent performance, WiMax rises from a high base, and used to be considered as the most powerful competitor of mainstream mobile communication standards. The appearance of WiMax offers theoretical foundation and technical support to the broadband service of wireless access, which represents the development orientation of broadband wireless technology. Its superiority in supporting capacity of data bandwidth is recognized by all.

However, many partner manufacturers and mainstream operators of WiMax camp have transfered their allegiance recently, and criticism is heard sometimes. The development of WiMax suffers a setback. Cisco quit the WiMax market; a senior executive of Alctel-Lucent openly stated his pessimism for the future development of WiMax; Nokia stopped the production of a WiMax mobile phone and turned to another system of the same type; Intel separated the WiMax business from the Group. All of the news throw doubts on the development of WiMax in the future.

Nevertheless, as above-mentioned, WiMax has a superior and predominant technical position and influence in the history of wireless communication. Similar to LTE, WiMax also adopts key techniques such as MIMO and OFDM. Therefore, in the incoming 4G era, WiMax must “amalgamate” the LTE for the purpose of survival and development in the future.

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