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IEEE Worldwide Interoperability for Microwave Access (WiMAX): An overview

B.Sc. Thesis

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PREFACE

Worldwide Interoperability for Microwave Access (WiMAX) is a 4G wireless communications technology defined by the IEEE 802.16 standards (Institute of Electrical and Electronics Engineers) and designed to provide peak data rates (30-40 Mbit/sec). It is also able to provide internet access to both fixed and mobile users with relatively low cost, making it the economical solution of providing last-mile broadband Internet access in remote locations. Additionally, after a few upgrades that have been accomplished in 2011, WiMAX eventually offers 1 Gbit/s speed for fixed users.

The name “WiMAX”, also known as IEEE 802.16, was created by the IEEE Forum which was founded in June 2001. The original WiMAX 802.16d standard was published in 2004 and it is called Fixed WiMAX while the 802.16e standard was published in 2005 and it is called Mobile WiMAX. The forum defines the technology as "*a standards-based technology enabling the delivery of last mile wireless broadband access as an alternative to cable and DSL”* [1]

[1] WiMAX, http://en.wikipedia.org/

The bandwidth and the range of WiMAX make it suitable for the following applications:

- Providing portable and mobile broadband connectivity in cities-countries through a variety of devices.
- Providing a wireless alternative to cable and digital subscriber line (DSL) for "last mile" broadband access.
- Providing data, telecommunications (VoIP) and IPTV services (triple play).
- Providing a source of Internet connectivity as part of a business continuity plan.
- Smart grids and metering.

The WiMAX has significant advantages over existing wireless and wired connections:

- Private companies will have the opportunity to develop independent wireless telecommunications networks and Internet services, with great ease, as no cabling installation is required at any point of the country, increasing this way the competition.
- The subscriber will use the connection from anywhere even on the move or within the city and across the whole country, which is not possible with the current ADSL connections, nor with Wi-Fi technology, due to its limited scope.
- A WiMAX network that will cover a large city can be installed in a few days, in contrast with a corresponding wired network that would take many months or even years.

Moving to another area, the subscriber will not need to enable broadband connectivity in the new area, as applied to ADSL lines. Once it is covered by the wireless signal of WiMAX service provider, can begin using the connection directly.

ΠΕΡΙΛΗΨΗ

Τα τελευταία χρόνια οι τεχνολογίες τέταρτης γενιάς (4G) όπως IEEE 802.16 (WiMAX) και LTE (Long Term Evolution) έχουν σχεδιαστεί ώστε να υποστηρίζουν τις εφαρμογές όπως πολυμέσα και διαδικτυακά παιχνίδια.

Στην πτυχιακή εργασία αρχικά θα πραγματοποιηθεί μια λεπτομερής εισαγωγή στο πρωτόκολλο IEEE 802.16 καθώς και στις ανταγωνιστικές τεχνολογίες ασύρματης δικτύωσης.

Επίσης, θα εξεταστούν οι δυνατότητες και τα τεχνικά χαρακτηριστικά του πρωτοκόλλου όπως αυτό έχει προτυποποιηθεί καθώς και οι εφαρμογές του μέχρι σήμερα.

Τέλος, θα πραγματοποιηθεί αναλυτική ανασκόπηση της ερευνητικής βιβλιογραφίας με σκοπό να παρουσιαστούν και να αναλυθούν οι ερευνητικές προκλήσεις για το πρωτόκολλο WiMAX καθώς το τι προβλέπεται να ακολουθήσει τα επόμενα χρόνια.

ABSTRACT

In recent years, the technologies of fourth generation (4G), such as IEEE 802.16 (WiMAX) and LTE (Long Term Evolution), are designed to support applications such as multimedia and online games.

In this thesis, initially there will be a detailed introduction to the protocol IEEE 802.16, as well as to competitive wireless networking technologies.

It will also examine the capabilities and the technical characteristics of the protocol as it have been standardized, as well as it's applications until today.

Finally, there will be a detailed review of the research literature with a view to present and analyze the research challenges for the protocol WiMAX and what is expected to follow the coming years.

ACKNOWLEDGEMENTS

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LIST OF ABBREVIATIONS

1G	1st Generation Wireless Technology
2G	2nd Generation Wireless Technology
3G	3rd Generation Wireless Technology
4G	4th Generation Wireless Technology
3GPP	3rd Generation Partnership Project
AAA	Accounting, Authorization, Authentication
ABR	Aggregate Bandwidth Request
ADSL	Asymmetric Digital Subscriber Line
AES	Advanced Encryption Standard
AN	Access Network
AP	Access Point
ARC	Automatic Retransmission Request
ASN	Access Service Network
ATM	Asynchronous Transfer Mode
BE	Best Effort
BS	Base Station
BSCs	Base Station Controllers
BWA	Broadband Wireless Access
CALEA	Communications Assistance Law Enforcement Act
CDMA	Code Division Multiple Access
CIDs	Connection Identifiers
CN	Core Network
CoA	Care of IP Address
CRC	Cyclic Redundancy Check
CSN	Connectivity Service Network

DHCP	Dynamic Host Configuration Protocol
DECT	Digital European Cordless Telephones
DNS	Domain Name Service
DSL	Digital Subscriber Line
DSP	Digital Signal Processing
EAP	Extensible Authentication Protocol
EDF	Earliest Deadline First
EDGE	Enhanced Data for GSM Environment
EPC	Evolved Packet Core
EPS	Evolved Packet System
ETSI	European Telecommunications Standards Institute
EVDO	Evolution Data Optimized
FA	Foreign Agent
FCH	Frame Control Header
FDD	Frequency Division Duplexing
FEC	Forward Error Correction
FIFO	First-in-First-out
FM	Frequency Modulation
FSK	Frequency Shift Keying
GPRS	General Packet Radio Service
GRE	Generic Routing Encapsulation
GSM	Global System for Mobile Communications
GTP	GPRS Tunneling Protocol
HA	Home Agent
HHO	Horizontal Handoff
HLR	Home Location Register
HoA	Home Address

HSCSD	High-Speed Circuit-Switched Data
HSDPA	High Speed Downlink Packet Access
HSPA	High Speed Packet Access
HSUPA	High Speed Uplink Packet Access
IBR	Increment Bandwidth Request
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IMS	IP Multimedia Subsystem
IMT	International Mobile Telecommunications
IS	Information Service
ISP	Internet Service Provider
ITU	International Telecommunication Union
ITU-T	International Telecommunication Union-Telecommunication Standardization Sector
LAN	Local Area Network
LLC	Logical Link Control
LMDS	Local Multipoint Distribution Services
LOS	Line of Sight
LTE	Long Term Evolution
MAC	Media Access Control
MAP	Mobile Application Part
MBS	Mobile Broadband Systems
MIMO	Multiple Input Multiple Output
MIP	Mobile IP
MMDS	Multi-channel Multi-point Distribution Services
MMS	Multimedia Messaging Service
MR	Multi-hop Relay

MS	Mobile Station
MSC	Mobile Switching Centre
MTG	Mobile Task Group
NAI	Network Access Identifier
NAP	Network Access Provider
NAV	Network Allocation Vector
NIC	Network Interface
N-LOS	Non Line of Sight
NSP	Network Service Provider
OFDMA	Orthogonal Frequency Division Multiple Access
OSI	Open System Interconnection
PACS	Personal Access Communication Systems
PDA	Personal Digital Assistant
PDG	Packet Data Gateway
PDU	Personal Digital Unit
PHS	Payload Header Suppression
PHY	Physical
PMP	Point-to-Multipoint
PoA	Point of Attachments
PPP	Point-to-Point Protocol
PSK	Pre-shared Key
QoS	Quality of Service
RAN	Radio Access Network
RAT	Radio Access Technology
RIT	Radio Interface Technology
RLC	Radio Link Control
RNG-REC	Ranging Request Message

RR	Round Robin
RRM	Radio Resource Management
rTPS	Real Time Polling Service
(n)rTPS	Non Real Time Polling Service
SAD	Service Access Point
SDMA	Spatial Division Multiple Access
SDU	Service Data Unit
SF	Service Flow
SFA	Service Flow Authorization
SFID	Service Flow Identifier
SFM	Service Flow Management
SIM	Subscriber Identity Module-cards
SLA	Service Level Agreements
SMS	Short Messaging Service
SNMP	Simple Network Management Protocol
SOFDMA	Scalable Orthogonal Frequency Division Multiple Access
SS	Subscriber Station
STC	Space Time Coding
TCP	Transmission Control Protocol
TDD	Time Division Multiplexing
TDMA	Time Division Multiple Access
TFTP	Trivial File Transfer Protocol
UDR	Usage Data Record
UGS	Unsolicited Grant Service
UMTS	Universal Mobile Telecommunication System
UTRAN	Universal Terrestrial Radio Access Network
e-UTRAN	Evolved- Universal Terrestrial Radio Access Network

VHO	Vertical Handoff
VoD	Voice on Demand
VoIP	Voice over IP
WAG	WiMAX Access Gateway
W-CDMA	Wideband Code Division Multiple Access
WECA	Wireless Ethernet Compatibility Alliance
WiFi	Wireless Fidelity
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
WPAN	Wireless Personal Area Network
WRAN	Wireless Region Area Network
WWAN	Wireless Wide Area Network

CHAPTER 1 INTRODUCTION

The start of the new millennium is promising a telecommunications world that is very different from even the recent past. The enormous explosion of wireless and broadband technologies over the last few years has captured the imagination and innovation of technologists around the world.

It has been a constant human exertion to communicate more effectively and at the same time to be free of any slavery, physical or psychological. A similar underlying trend can also be seen in the evolution of telecommunications. The need for mobility and higher speeds in an ever-changing environment has been of great importance.

It is clear that with the growing expectation and very high dynamic technologies, challenges lie ahead, led by humans and their nomadic character, as well as by the need to communicate in a featurerich environment. With the new-found power of mobility and broadband, the telecommunications industry has tapped into an explosive technology mix that can grow exponentially once creativity and innovativeness come into play.

1.1 Wireless Communication: Any Time, Any place

The main factor behind this huge growth has been the ability of the wireless medium to satisfy essentially two of the three components that constitute the ultimate goal of telecommunications: any information, any time, any place. Wireless communication systems provide anytime, anywhere communications.

The future of wireless lies in faster, more reliable methods of transferring data and, to a lesser extent, increased use of voice commands and audio improvements.

Some of the inherent characteristics of wireless communications systems which make them attractive for users, are discussed below in detail. [2]

Mobility

Wireless systems enable better communication, enhanced productivity and better customer service. A wireless communications system allows users to access information beyond their desk and conduct business from anywhere.

Reach

Wireless communications systems enable people to be better connected and reachable wherever they are.

Simplicity

Wireless communications systems are faster and easier to deploy than cabled networks. Installation can take place simply, ensuring minimum disruption.

Flexibility

Wireless communications systems provide flexibility, as a subscriber can have full control of his/her communication.

Setup Cost

The initial costs of implementing a wireless communications system compare favourably with those for a traditional wireline or cable system. Communications can reach areas where wiring is infeasible or costly, e.g. rural areas, old buildings, battlefields, vehicles.

Falling Services Cost

Wireless service pricing is rapidly approaching wireline service pricing.

Global Accessibility

Roaming makes the dream of global accessibility a reality, since today most parts of the globe are well covered by a wireless service provider. Roaming services also allow the flexibility to stay connected anywhere.

Smart

Wireless communications systems provide new smart services like SMS and MMS.

Cultural

Wireless communications systems comprise personal devices, whereas wireline is more connected to a place, e.g. the office. In today’s world wireless communication is no longer just about cell phones. Instead it is the direction in which telecommunications seem to be heading to provide all possible ways of keeping information place-independent to a greater or lesser extent (Figure 1).

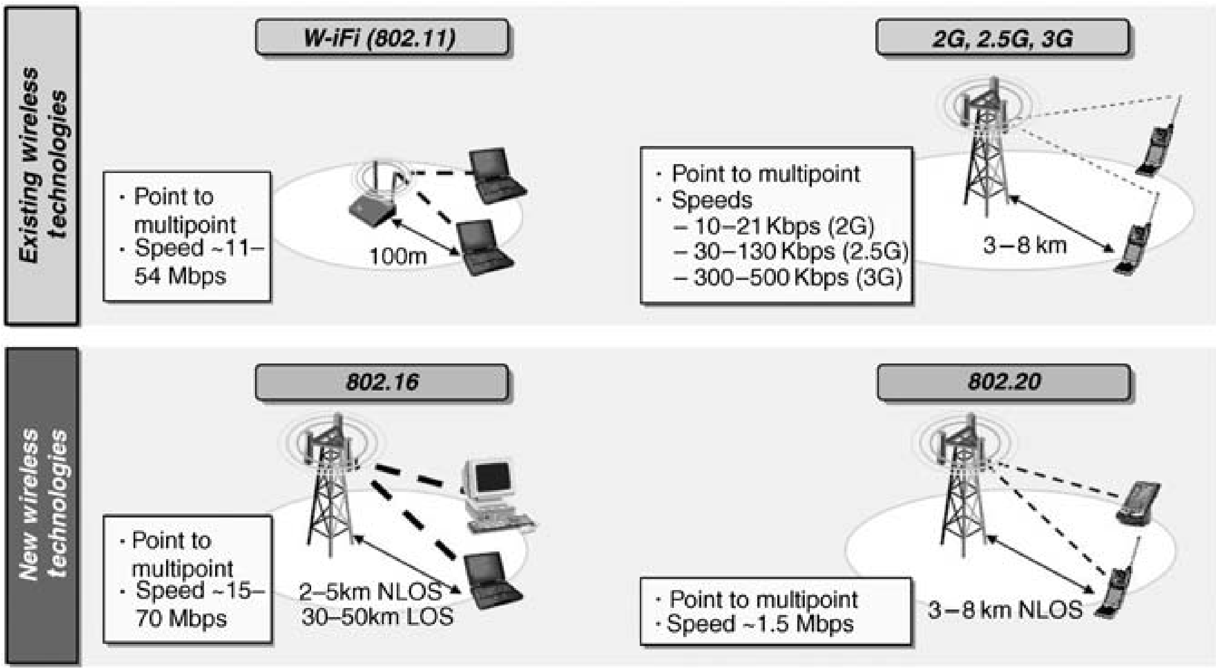

Figure 1Wireless technologies

1.2 Wireless Networks

The nature of connectivity provides its users with almost unrestricted mobility and the facility to access the network from anywhere. While in a wired network an address represents a physical location, in a wireless network the addressable unit is a station, which is the destination for a message and is not (necessarily) at a fixed location. Although wireless networks have been around for sometime, they are gaining popularity rapidly with standardization and reductions in the cost of hardware components. [2]

1.2.1 Network Topology

There are basically three ways to connect a wireless network: [2]

Point-to-point Bridge

A bridge connects two networks. A point-to-point bridge would interconnect two buildings. Access points connect a network to multiple users. For example, a wireless LAN bridge can interface with an Ethernet network directly to a particular access point. This may be necessary if you have several devices in a distant part of the facility that are interconnected using Ethernet.

Point-to-multipoint Bridge

When connecting three or more LANs that may be located on different floors in a building or across buildings, the point-to-multipoint wireless bridge is utilized. The multipoint wireless bridge configuration is similar to a point-to-point bridge in many ways. (Figure 2)

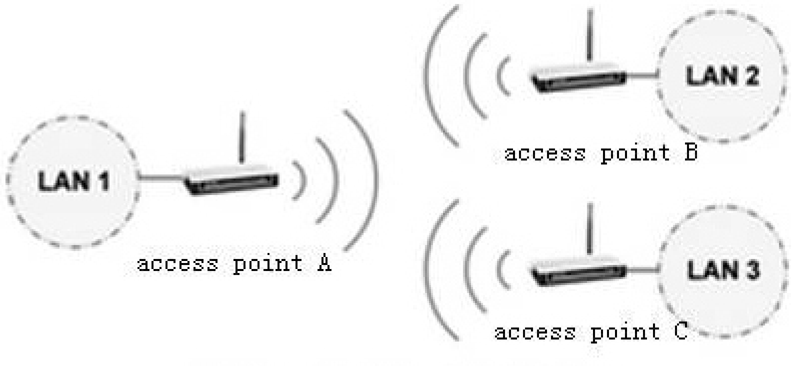

Figure 2 Point-to-multipoint bridge [2]

Mesh or ad hoc network

An ad hoc (peer-to-peer) 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 (called a mesh topology). Configuration of a WLAN in ad hoc mode is used to establish a network where wireless infrastructure does not exist or where services are not required, such as a trade show or collaboration by co-workers at a remote location (Figure 3).

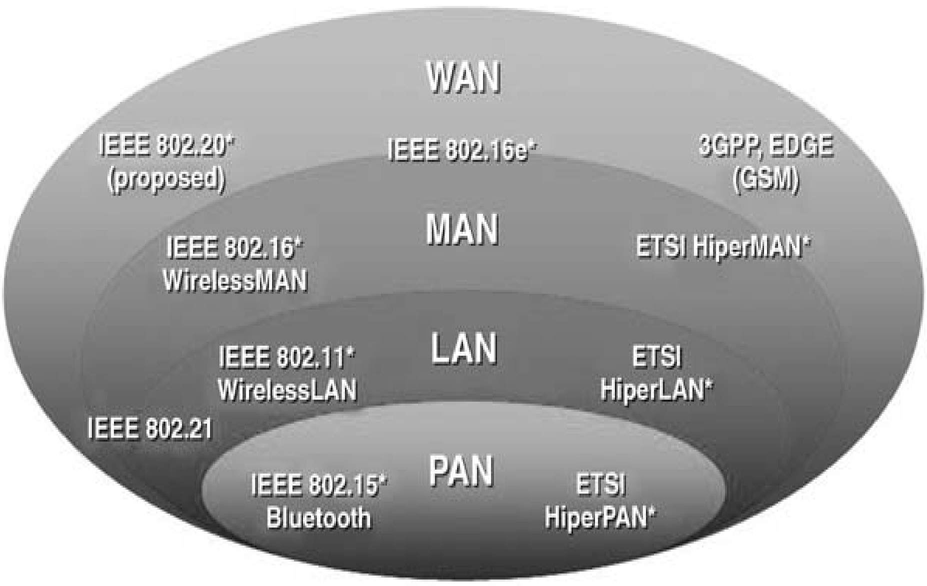

Figure 3 Wireless network standards

1.3 Wireless Technologies

Wireless networking technologies range from global voice and data networks to infrared light and radio frequency technologies optimized for short-range wireless connections. Devices commonly used for wireless networking include portable computers, desktop computers, handheld computers, PDAs, cellular phones, pen-based computers and pagers. Wireless technologies have evolved substantially over the past few years and, depending on their range, can be classified in different ways.

This network is designed to enable users to access the Internet via a wireless wide area network (WWAN) access card and a PDA or laptop. Data speeds are very fast 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. [2]

Wireless Local Area Network

This network is achieved to enable users to access the Internet in limited hotspots via a wireless local area network (WLAN) access card and a PDA or laptop. While data speeds are relatively fast related with the data rates of mobile telecommunication technology, their range is limited. Among the various WLAN solutions, Wi-Fi is the most broad and popular.

Wireless Personal Area Network

This network is designed to enable the users to access the Internet via a wireless personal area network (WPAN) access card and a PDA or laptop. While data speeds are dashing compared with the data rates of mobile telecommunications technology, their spectrum is very limited.

Wireless Region Area Network

This network is designed to enable the users to access the Internet and multimedia streaming services via a wireless region area network (WRAN). Data speeds are rapid compared with the data rates of mobile telecommunication technology, and their range is extensive, too. WRAN, which is presently in its infant stage, is the latter addition to a growing list of wireless access network acronyms characterized by coverage area.

1.4 Mobile System Generations

The last years have endorsed a remarkable growth in the wireless business, both in terms of mobile technology and its subscribers. There has been a shift from fixed to mobile cellular telephony, specifically since the turn of the century. By the end of 2010, there were over four times more mobile cellular subscriptions than fixed telephone lines. Both the mobile network operators and vendors have felt the attention of efficient networks with identically useful design.

With all the technological propositions, and the contemporary existence of the 2G, 2.5G and 3G networks, the influence of services on network efficiency have become even more analytical. Many more designing scenarios have developed with not only 2G networks but also with the evolution of 2G to 2.5G or even to 3G networks. Along with this, interworking of the networks has to be intentional.

1G introduces analog cellular technologies. It became available in the 1980s. 2G announce initial digital systems, introducing services. CDMA2000 1xRTT and GSM are the central 2G technologies, although CDMA2000 1xRTT is sometimes called a 3G technology because it meets the 144 kbps mobile throughput requirement. Despite, EDGE meets this requirement. 2G technologies became available in the 1990s. 3G requirements were specified by the ITU as part of the International Mobile Telephone 2000 (IMT-2000) project, for which digital networks had to provide 144 kbps of throughput at mobile speeds, 384 kbps at pedestrian speeds, and 2 Mbps in indoor environments. UMTS-HSPA and CDMA2000 EV-DO are the first 3G technologies, although WiMAX was also designated as an formal 3G technology. 3G technologies began to be deployed last decade.

The ITU has lately issued requirements for IMT-Advanced, which compose the official definition of 4G. Requirements include operation in up-to-40 MHz radio channels and exceptionally high spectral efficiency. The ITU proposes operation in up to100 MHz radio channels and peak spectral efficiency of 15 bps / Hz, resulting in a theoretical throughput rate of 1.5 Gbps. Before the publication of the requirements, 1 Gbps was frequently cited as a 4G goal. No achievable technology meets these requirements yet. It will require new technologies such as LTE-Advanced and IEEE 802.16m. Some people have tried to label present versions of WiMAX and LTE as “4G”. With WiMAX and HSPA extremely outperforming 3G requirements, calling these technologies 3G clearly does not give them full credit, as they are a generation beyond current technologies in capability. But calling them 4G is not appropriate. Unsuccessfully, the general labels do not properly captivate the scope of accessible technologies and have resulted in some amount of market confusion.

First-generation Mobile Systems (1G)

The first wireless generation introduced analogue systems transmitting over radio frequencies, used primarily for voice. The operation of first generation mobile phones was based on analogue radio technology. It was composed of three elements, mobile telephone, cell sites and mobile switching centre (MSC). The system was designed using two different radio channels. The first was the control channel, and the second was the voice channel.

The control channel was responsible for carrying digital messages, which allowed the phone to retrieve system control information and compete for access. It used frequency shift keying modulation (FSK) to complete this task. The responsibility of voice channels was to transmit voice data over an analogue signal using frequency modulation (FM) radio.

Second-generation Mobile Systems (2G)

In comparison with 1G system, 2G systems use digital multiple access technology, equally time division multiple access (TDMA) and code division multiple access (CDMA). The global system for mobile communications or GSM uses TDMA technology to support multiple users.

Paradigms of 2G systems are GSM, cordless telephones (CT2), personal access communications systems (PACS) and digital European cordless telephones (DECT). A new design was introduced into the mobile switching centre of 2G systems. Especially, the use of base station controllers (BSCs) lightened the load placed on the MSC found in 1G systems. This design allows the interface between the MSC and BSC to be standardized. Hence, considerable attention was devoted to interoperability and standardization in second-generation systems so that carrier could employ different manufacturers for the MSC and BSC.

Additional to enhancements in MSC design, the mobile assisted handoff mechanism was introduced. By sensing signals received from adjacent base stations (BSs), a mobile entity can trigger a handoff by performing explicit signalling with the network. 2G protocols use digital encoding and include GSM, D-AMPS (TDMA) and CDMA. The protocols behind 2G networks support voice and some limited data communications, such as fax and short messaging service (SMS), and most 2G protocols offer district levels of encryption and security. While 1G systems support firstly voice traffic, 2G systems support voice, paging, data and fax services

2.5G Mobile Systems

The move into the 2.5G world began with the idea of providing decent data connectivity without substantially changing the existing 2G infrastructure. Some of the cellular technologies capable of achieving this goal are discussed below. [2]

High-speed circuit-switched data (HSCSD)

High-speed circuit-switched data (HSCSD) were designed to allow GSM networks transfer data at rates up to four times the original network data rates.

General packet radio service (GPRS)

General Packet radio service (GPRS) is a radio technology for GSM networks that arranges packet-switching protocols, shorter setup time for ISP connections, expanded data rates as well as charging based on the amount of data transferred rather than the time spent in transferring the data. The next generation of data, heading towards third-generation and personal multimedia environments, is built on GPRS and is known as enhanced data rate for GSM evolution (EDGE).

Enhanced data GSM environment (EDGE)

EDGE allows GSM operators to use existing GSM radio bands to offer wireless multimedia IP-based services and applications at theoretical maximum speeds of 384 kbps with a bit-rate of 48 kbps per time slot and up to 69.2 kbps per time slot under good radio conditions. Furthermore, EDGE allows operators to operate without a 3G licence and competes with 3G networks offering equal data services and challenging 3G data rates (in some cases).

Implementing EDGE is comparably painless and requires small changes to network hardware and software as it uses the same TDMA frame structure, logic channel and 200 kHz carrier bandwidth as GSM networks. Designed to interwork with GSM networks and 3G WCDMA (Figure 4), EDGE offers data rates equivalent to ATM-like speeds of up to 2 Mbps.

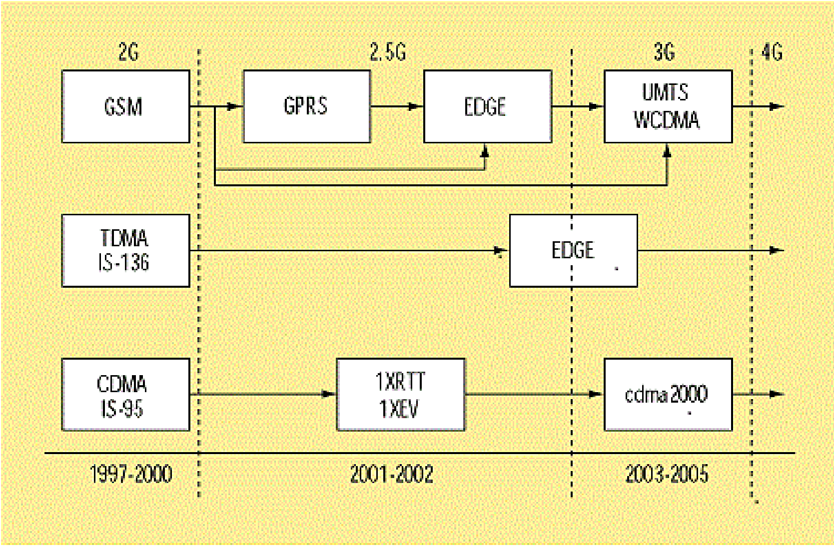

Figure 4 Migration path from 2G to beyond 3G [2]

Third-generation Mobile Systems (3G)

Third-generation mobile systems are faced with several challenging technical issues, such as the provision of seamless services across both wired and wireless networks. In Europe, there are two evolving networks under investigation: UMTS (Universal Mobile Telecommunications Systems) and MBS (Mobile Broadband Systems).

UMTS

The Universal Mobile Telecommunications System (UMTS) is a third generation mobile cellular system for networks based on the GSM standard. Developed and preserved by the 3GPP (3rd Generation Partnership Project), UMTS is a component of the ITU IMT-2000 standard set and compares with the CDMA2000 standard set for networks based on the competing CDMA-one technology. UMTS uses wideband code division multiple access (W-CDMA) radio access technology to offer higher spectral efficiency and bandwidth to mobile network operators.

UMTS specifies a complete network system which uses, covering the radio access network (UMTS Terrestrial Radio Access Network, or UTRAN), the core network (CN) (Mobile Application Part, or MAP) and the authentication of users via SIM (subscriber identity module cards).

UMTS supports maximum theoretical data transfer rates of 42 Mbit/s when HSPA+ is implemented in the network. Users in deployed networks can expect a transfer rate of up to 384 Kbit/s for Release '99 (R99) handsets (the original UMTS release), and 7.2 Mbit/s for HSDPA handsets in the downlink connection. These speeds are significantly faster than the 9.6 Kbit/s of a single GSM error-corrected circuit switched data channel, multiple 9.6 Kbit/s channels in HSCSD and 14.4 Kbit/s for CDMA One channels.

Since 2006, UMTS networks in many countries have been or are in the process of being upgraded with High Speed Downlink Packet Access (HSDPA), sometimes known as 3.5G. Currently, HSDPA enables downlink transfer speeds of up to 21 Mbit/s. Work is also progressing on improving the uplink transfer speed with the High-Speed Uplink Packet Access (HSUPA). Longer term, the 3GPP Long Term Evolution (LTE) project plans to move UMTS to 4G speeds of 100 Mbit/s down and 50 Mbit/s up, using a next generation air interface technology based upon orthogonal frequency-division multiplexing.

The first national consumer UMTS networks launched in 2002 with a heavy emphasis on telco-provided mobile applications such as mobile TV and video calling. The high data speeds of UMTS are now most often utilized for Internet access: experience in Japan and elsewhere has shown that user demand for video calls is not high, and telco-provided audio/video content has declined in popularity in favour of high-speed access to the World Wide Web—either directly on a handset or connected to a computer via Wi-Fi, Bluetooth, Infrared or USB.[3]

CDMA2000

Emerging out of the standard IS-95, CDMA2000 has tolerated a considerable amount of development, especially in the area of multi channel working. Operators of narrowband CDMA One can evolve services designated as 3G in existing as new spectrum bands.

Wideband code division multiple access (W-CDMA)

Many see W-CDMA technology as the preferred platform for the 3G cellular systems, since it offers seamless migration for GSM networks and can add a migration path for narrow-band CDMA networks. Hence, W-CDMA will be able to cover much of the world with its absolute backward compatibility to these networks (Figure 5).

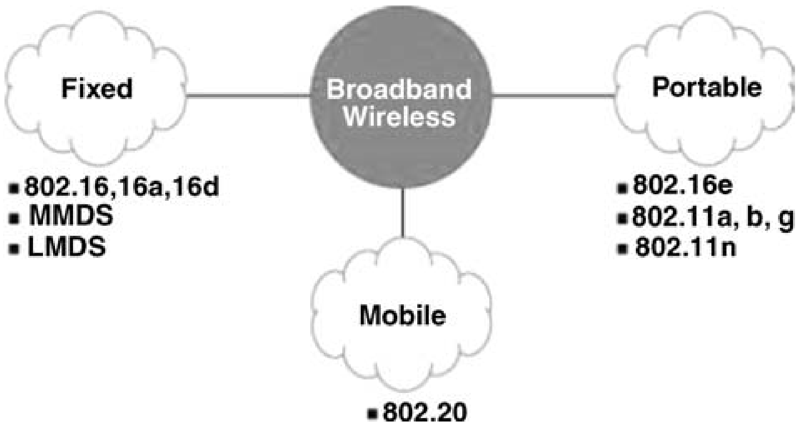

Figure 5 Broadband wireless access technologies

WLAN

WLAN is an acronym for wireless local area network. It is a type of local area network that uses high-frequency radio waves rather than wires to communicate between nodes.

WLANs are casually but absolutely taking hold in small businesses, homes and companies. When you compare the cost of WLAN interface cards and access point, it is easy to see why people are fascinated to WLANs, although one has to take into concentration the backhaul which connects to the access point. If the network interface card (NIC) and access point support roaming, a user can roam around a building and the NIC will automatically switch between APs based on the strength of the beacon signal it receives from nearby access points. Finally, the strongest signal wins.

Growth in WLANs can be imprinted to the creation of 802.11, the IEEE technical standard that enabled high-speed mobile inter-connectiviy. After constant efforts by the WLAN Standards Working Group, the IEEE ratified a new rate standard for WLANs, (802.11b), also known as wireless fidelity (Wi-Fi). Some other WLAN technologies are WiMAX, Bluetooth, HomeRF and Open Air.

Wi-Fi

Wi-Fi was used to refer only to the 802.11b standard, but now also refers to the broader spectrum of WLAN standards, including 802.11a and the emerging 802.11g. This standard was certified by the Wireless Ethernet Compatibility Alliance (WECA). The 802.11a standard – approved by the IEEE at the same time as 802.11b – provides for data rates up to 54 Mbps at 5 GHz frequency. The 802.11g standard, with an even higher data rate, has lately been introduced and functions at the same frequency as 802.11b. Of all these emerging standards, 802.11b has been the most widely deployed.

The 802.11b standard works at the 2.4 GHz frequency of the electromagnetic spectrum and allows users to transmit data at speeds up to 11 Mbps. Despite, a number of wireless products, such as Figure 1.10 Wi-Fi hotspots by type of location WLAN 21 cordless phones and garage door openers, also use the 2.4 GHz frequency and can cause disruptions in the service.

The 802.11a standard works on the 5 GHz frequency, which is nearly exposed and allows data transfer rates up to 54 Mbps, but has a shorter effective range than 802.11b at about 15–22.5 m.

Fourth-generation Mobile Systems (4G)

LTE

LTE, an initialism of Long-Term Evolution, marketed as 4G LTE, is a standard for wireless communication of high-speed data for mobile phones and data terminals. It is based on the GSM/EDGE and UMTS/HSPA network technologies, increasing the capacity and speed using a different radio interface together with CN improvements. The standard is developed by the 3GPP (3rd Generation Partnership Project) and is specified in its Release 8 document series, with minor enhancements described in Release 9.

The goal of LTE was to increase the capacity and speed of wireless data networks using new DSP (digital signal processing) techniques and modulations that were developed around the turn of the millennium. A further goal was the redesign and simplification of the network architecture to an IP-based system with significantly reduced transfer latency compared to the 3G architecture. The LTE wireless interface is incompatible with 2G and 3G networks, so that it must be operated on a separate wireless spectrum. [1]

WiMAX

In the middle of 1990, telecommunication companies developed the idea to use fixed broadband wireless networks for eventual last mile solutions to provide a different mean to deliver Internet connectivity to businesses and individuals. Their target was to produce a network with the capacity, speed, and reliability of a hardwired network, while maintaining with the flexibility, simplicity, and low costs of a wireless network. Furthermore, this technology would act as a adaptable system for corporate or institutional backhaul distribution networks and would attempt to compete with the leading Internet carriers.

The huge potential for this flexible, low cost network generated attention to two types of fixed wireless broadband technologies: Local Multipoint Distribution Services (LMDS) and Multi-channel Multipoint Distribution Services (MMDS). LMDS was primarily intended to speed up and bridge Metropolitan Area Networks in larger corporations and on University campuses.

MMDS was determined to provide a means for local television network distribution and for residential broadband services. However, the high costs, lack of standards, and fear of vendor lock-in prevented LMDS from taking off early on. As a result, in 1999 the Institute of Electrical and Electronics Engineers (IEEE) devised the 802.16 standard for LMDS.

This standard, which was finally released in 2001, operated on a point-to-point radio link network by means of line of sight transmissions, and had a frequency range of 10 GHz to 66 GHz. Though, since this standard was modeled off of Wireless Local Area Network (WLAN) technology and had restricted capabilities, developers focused more completely on the 802.16 standard that functioned in the range of 2 GHz to 11 GHz.

In 2001, the WiMAX Forum was established with the agenda to market and promote the 802.16 standard. There they compose the term WiMAX. In 2003 the IEEE came out with 802.16a, which transmitted data through non-line of sight radio channels to and from omni-directional antennas. Later on, in 2004, the 802.16-2004 standard was released. This standard combined the updates from the IEEE 802.16a, 802.16b, and 802.16c regulations (Table 1). We will see all the past standards of WiMAX in Chapter 3.

Table 1 History of WiMAX

Date	IEEE Standard	Description
Dec 2001	802.16	First standardization for LOS, PMP broadband wireless access applications using 10-66GHz spectrum.
Jan 2003	802.16a	An amendment for NLOS using 2-11GHZ spectrum. Allows both PMP and mesh network architecture. OFDM is adopted.
c2003	802.16b	QoS Provisioning
Oct 2004	802.16-2004	Revised and replaced previous versions and completed the essential fixed wireless standard
Dec 2005	802.16e	Enhancements to support mobility

This broadband system extended the WiMAX service to a 30-mile range and had the ability to disperse its network between hundreds of terminals. Yet the IEEE did not stop there. In 2005, they came out with the first Mobile WiMAX system: 802.16e. This version used a Scalable Orthogonal Frequency-Division Multiple Access (SOFDMA) engine, which supported over 2,000 subcarriers, optimized handover delay and packet loss, and increased network security.

The IEEE continues to update and modify the WiMAX system specifications to further improve its capabilities. They have made a push to publish their next considerable 802.16 standard named 802.16m. One of the targets for this version is to increase data speeds to 1Gbps. IEEE looks ahead to approve and deploy the 802.20 standard in the near future, which has dubbed the nickname Mobile-Fi. WiMAX Forum certified products for fixed and nomadic applications are directly commercially available and are constantly being developed. It is then no wonder why WiMAX is a leader of emerging wireless standards and continues to write its own history.

CHAPTER 2 SYSTEM ARCHITECTURE

The current increase in demand for wireless Internet traffic is the result of expanding popularity of applications such as interactive gaming, VOIP and social networks. This increase is the most important drive behind continuous advances in wireless broadband technologies. IEEE 802.16 is the first true technology for fixed, nomadic and mobile wireless broadband access. Since 2001, the IEEE 802.16 working group has been developing new amendments. An achievement that was concluded by producing the amalgamated IEEE 802.16-2009 standard in early 2009, and the IEEE's response to the IMT-Advanced requirements and which concluded in March 2011 with the IEEE 802.16m amendment.

2.1 IEEE 802.16-2009

The IEEE 802.16 standard describes individual methods of operation, each of which fits a specific deployment objective. In the fused standard document, IEEE 802.16-2009, two modes are described: a mandatory Point-to-Multi-Point (PMP) and an optional Multihop Relay (MR). While both modes describe regular downlink communication, that is, from gateway or BS to mobile terminal, the MR mode utilizes intermediate RSs between a cell's BS and the MT. This last is described in the amendment IEEE 802.16j. [8]

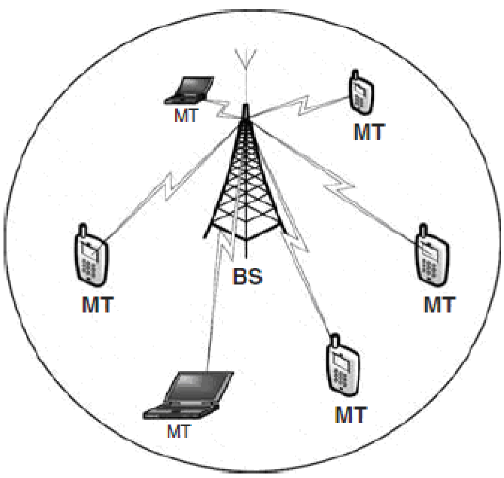

Figure 6 A schematic of a IEEE 802.16-2009 deployment, including a base station and different types of mobile terminals. [5]

In a PMP deployment, BSs provide a continuous coverage through a cellular configuration, with the BSs interconnected through a network management infrastructure that oversees the overall management of network operations.

Through the BSs, Subscriber Stations (SSs) and Mobile Subscribers (MSs) connect to the network and, when applicable, to the Internet.

In the standard, the general term SS describes user equipment capable of using different Radio Interface Technologies (RITs) operating under both, Line of Sight (LOS) and Non LOS (NLOS) circumstances. On the other hand, MSs are equipment sets whose connected mobility is supported in the NLOS network. Mobility is supported only under one IEEE 802.16 interface type, namely OFDMA, and does not require LOS with the BS for communication. More significantly, mobility support is enabled through employing handover mechanisms both within IEEE 802.16 networks and between IEEE 802.16 and other Radio Access Technologies (RAT).Two types of RS are defined: transparent and non-transparent. An example MR deployment is shown in the figure below.

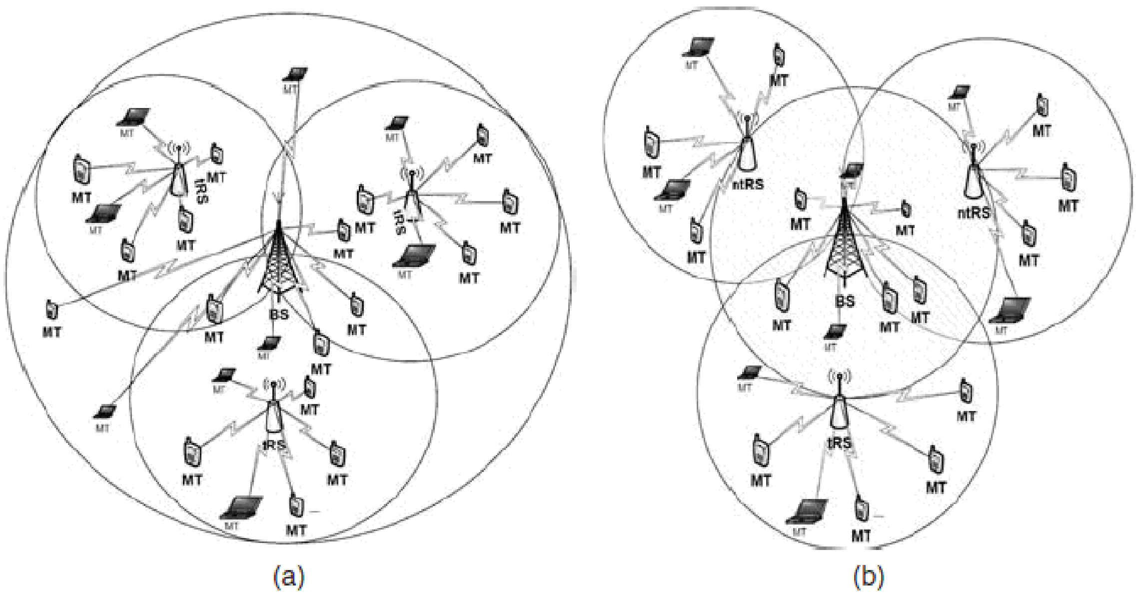

Figure 7 Example deployments of IEEE 802.16-2009 relay networks with (a) showing tRT and (b) showing ntRS. [5]

Management of the air interface in MR networks can be centralized or distributed. In centralized operation, all management functionalities are overlook by the MR-BS while in distributed operation, some autonomy is provided for RSs. tRSs always operate in a centralized mode, while ntRSs can operate in both modes. In distributed scheduling, for example, bandwidth allocations for an ntRS's subordinates are made by the ntRS in cooperation with the MR-BS. An autonomous ntRS in distributed scheduling can be also called a scheduling RS.

The IEEE 802.16j amendment is an extension for OFDMA mobility in IEEE 802.16-2009. A extra feature of the IEEE 802.16j is that an MS is not aware of the underlying operating mode of the network, that is, whether PMP or MR. Accordingly, the procedures and signaling made and processed by an MS in both PMP and MR operation are exactly the same. The amendment also describes how MR infrastructure components, that is, MR-BSs and RSs, should handle a MS's requests and traffic in a manner that achieves this seamlessness.

2.1.1 IEEE 802.16-2009 Air Interfaces

The IEEE 802.16 standard describes different air interfaces for different deployment scenarios. For example, the Wireless Metropolitan Area Networks – Single Carrier (WirelessMAN-SC) interface aims at creating wireless backhaul between dedicated stations that rely on LOS connectivity. Meanwhile, the WirelessMAN-OFDMA goals at cellular mobile communications.

The following air interfaces are defined in IEEE 802.16-2009:

- WirelessMAN-SC, operates in the 10–66 GHz band with either Time Division Duplex (TDD) or Frequency Division Duplex (FDD) schemes. Moreover, it supports only PMP LOS communications with fixed SSs.
- WirelessMAN-OFDM, operates in the licensed bands below 11 GHz with TDD or FDD duplexing. Supports near-LOS and NLOS communications with fixed SSs but only with provisions for power management, interference mitigation and multiple antennas.
- WirelessMAN-OFDMA, operates in licensed bands below 11 GHz with TDD or FDD duplexing. It supports both, PMP and MR1 operation. It also supports near LOS and NLOS communications with either fixed or mobile SSs. In addition, it requires provisions for power management, interference mitigation and multiple antennas.
- WirelessHUMAN, operates in license-exempt bands below 11 GHz (primarily 5–6 GHz) with TDD duplexing. Complies with either the OFDM or OFDMA description. Supports coexistence mechanisms such dynamic frequency selection.

2.2 Technical overview of WiMAX

WiMAX has a lot of admirable features in terms of deployment options and potential service offerings. Some of the main features are as follows.

- OFDM-based physical layer (PHY Layer): The WiMAX PHY layer is based on OFDM. It reduces the multipath interference and makes WiMAX possible to operate in NLOS conditions.
- Very high peak data rates**:** WiMAX can offer very high peak data rates. When using 20MHz wide spectrum, the PHY data rate can reach 70Mbps. When 10MHz wide spectrum is used and operated in TDD with 3:1 downlink-to-uplink ratio, the 25Mbps for downlink and 6.7Mbps for uplink peak data rate can be achieved.
- Scalable bandwidth and data rate support: WiMAX can be scaled to various available bandwidths. The scalability of WiMAX also offers the possibility to support user roaming across different networks that may have different bandwidth allocations.
- Adaptive modulation and coding (AMC): WiMAX can adapt between different modulation and coding scheme based on channel conditions. The adaptation algorithm calls for the use of the highest modulation and coding scheme that can be supported by the signal-to-noise and interference ratio at the receiver such that each user is provided with the highest possible data rate that can be supported in their respective links.
- Link-layer retransmissions**:** WiMAX supports automatic retransmission requests (ARQ) at the link layer. All transmitted packets need to be acknowledged by the receiver. Those unacknowledged packets are assumed to be lost and need to be retransmitted. This feature increases the reliability of the connections.
- Support for TDD and FDD: WiMAX also supports both time division duplexing and frequency division duplexing. We note that currently there is FDD profiling only for fixed WiMAX.

- Orthogonal frequency division multiple accesses (OFDMA): OFDMA is used as the multiple access technique by Mobile WiMAX. In OFDMA, frequency diversity and multi-user diversity are used to improve the system capacity.
- Flexible and dynamic per user resource allocation: WiMAX dynamically allocate the resources based on the demands from users.
- Support for advanced antenna techniques: WiMAX support the use of multiple-antenna techniques, such as beamforming, space-time coding and spatial multiplexing. By deploying multiple antennas at the transmitter and the receiver, the system capacity and spectral efficiency can be improved.
- Quality-of-service support: WiMAX support different services, such as constant bit rate, variable bit rate, real-time, non-real-time traffic flows and so on.
- Robust security: WiMAX supports strong encryption, using Advanced Encryption Standard (AES) and has a robust privacy and key-management protocol. The system also offers very flexible authentication architecture based on Extensible Authentication Protocol (EAP). It allows for a variety of user credentials, such as username/password, digital certificates, and so on.
- Support for mobility**:** The Mobile WiMAX support mobility by improving performance of power control, uplink sub-channelization and frequent channel estimation
- IP-based architecture: The WiMAX defined the network following the IP-based architecture. [9]

2.3 WiMAX System Profiles

A WiMAX system certification profile is a set of features of the 802.16 standard, selected by the WiMAX Forum that is required or imperative for these specific profiles. These list sets, for each of the certification profiles of a system profiles release, the features to be used in typical implementation cases. System certification profiles are defined by the TWG in the WiMAX Forum. The 802.16 standard indicates that a system profile consists of five components: MAC profile, PHY profile, RF profile, duplexing selection and power class. The frequency bands and channel bandwidths are chosen such that they cover as much as possible of the worldwide spectral allocations expected for WiMAX. Equipments can then be certified by the WiMAX Forum according to a specific system certification profile. The two types of system profiles are defined: fixed and mobile.

2.3.1 Fixed WiMAX System Profiles

System profiles are based on the OFDM PHY layer IEEE 802.16-2004. All of the profiles use the PMP mode. The first set of choices decided in June 2004. Each certification profile has an identifier for use in documents. Further system profiles should be defined reflecting regulatory and market development. Among others, new fixed certification profiles should be approved before the end of 2006. It is planned that WiMAX system profiles with a 5 MHz channel bandwidth and 2.5 GHz frequency band schemes will be added. Fixed certification profiles, based on 802.16e, are also planned.

Frequency Bands (GHz)	Duplexing mode	Channel Bandwidth (GHz)	Profile Name
3.5	TDD	7	3.5T1
3.5	TDD	3.5	3.5T2
3.5	FDD	3.5	3.5F1
3.5	FDD	7	3.5F2
3.5	TDD	10	5.8T

Table 2 Fixed WiMAX certification profiles, all using the OFDM PHY and the PMP modes. [7]

2.3.2 Mobile WiMAX System Profiles

Along with the work on the 802.16e amendment, the mobile WiMAX system profiles were defined. These certification profiles, known as Release-1 Mobile WiMAX system profiles, were authorized in February 2006. They are based on the OFDMA PHY Layer (IEEE 802.16e) and all include only the PMP topology. These profiles are defined by the Mobile Task Group (MTG), a subgroup of the TWG in the WiMAX Forum. Release 1 certification will probably be separated in different Certification Waves, starting with Wave 1 having only part of all Release 1 features. In the OFDMA PHY Layer as amended in 802.16e, the number of OFDMA subcarriers is scalable. OFDMA of WiMAX is called scalable OFDMA. The TDD mode is the only one that has been chosen for this first set, one of the reasons being that it is more resource-use efficient. FDD profiles may be defined in the future. The frame length is equal to 5 ms.

2.4 Network Reference Model

2.4.1 Overview and Definitions

The WiMAX network reference model contains of three components interconnected by standardised interfaces or reference points R1 to R5. The three components are:

- MS (Mobile Station).
- ASN (Access Service Network).
- CSN (Connectivity Service Network).

The Mobile Station (MS) is a generic mobile equipment providing connectivity between subscriber equipment and a WiMAX BS. The ASN includes the set of functionalities that provides radio access connection to WiMAX subscribers. One or several ASN, interconnected through reference point R4, may be deployed by a Network Access Provider (NAP). A NAP provides radio access infrastructure to one or several Network Service Providers (NSP). The NSP is a business entity that enables IP connectivity and WiMAX services to WiMAX subscribers in accordance with established Service Level Agreements (SLA). The NSP deploys the Connectivity Service Network (CSN), which provides the IP connectivity for WiMAX subscribers. On the radio access network side, the WiMAX services are provided through contractual agreements with one or several NAPs. On the application side, WiMAX services are delivered thanks to contractual agreements with Application Service Providers (ASP) and/or through direct connection to the Internet. Additionally, an NSP in a given country may have roaming agreements with many other NSPs, which may be in other countries. Hence, a WiMAX subscriber may be attached to a Home NSP (H-NSP) or to a Visited NSP (V-NSP), a NSP with whom its home NSP has a roaming agreement.

2.4.2 ASN Reference Model and Profiles

The ASN includes all the functionalities that enable radio connectivity to WiMAX subscribers.

As a consequence, the ASN mainly provides:

- Layer 2 connectivity to the WiMAX subscribers
- Radio Resource Management (RRM) mechanisms such as handover control and execution.
- Paging and location management.
- Relay functions to the CSN for establishing Layer 3 connectivity with WiMAX subscribers.
- Tunnelling of data and signalling between the ASN and the CSN though reference point R3.
- Network discovery and selection of the preferred NAP/NSP.

The ASN usually consists of several BS connected to several ASN gateways (ASN-GW). Inside the ASN, two additional reference points are described in WiMAX architecture specification Release 1, but only in an informative manner: R6 between BS and ASN-GW and R8 between different BSs. Those interfaces should be the basis for further interoperability points between BS and ASN-GW of WiMAX vendors in subsequent architecture releases.

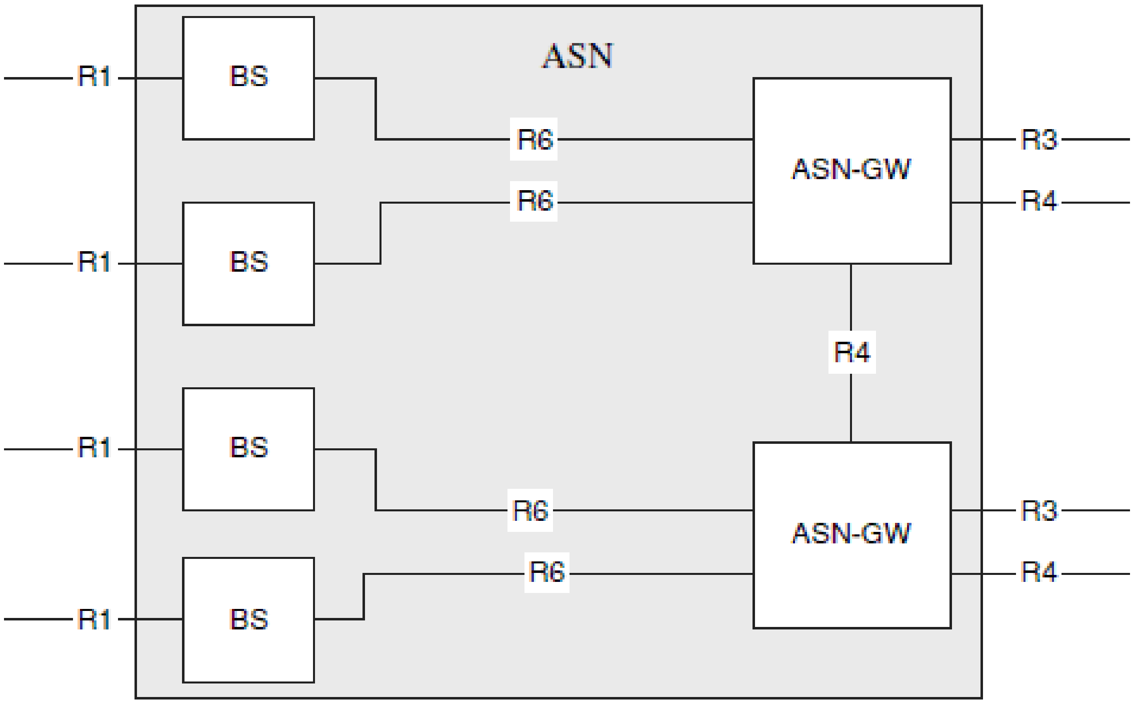

Figure 8 Generic ASN reference model. R3 is between the ASN and CSN while the external R4 is between ASNs. [7]

2.4.2.1 Base Station (BS)

The BS is the entity that implements PHY and MAC features as defined in the IEEE 802.16 standards. As defined by the WiMAX Forum technical groups, the BS is also in charge of the scheduling of user and signalling messages exchanged with the ASN-GW through the R6 interface. Furthermore, it incorporate other access functions according to the ASN profile. In a WiMAX access network, a BS instance is defined by a sector and a frequency assignment.

In the case of a multiple frequency assignment in a sector, the sector includes as many BS instances as frequency assigned. This is similar to 3GPP UMTS or 3GPP2 networks. The connectivity to multiple ASN-GW may be required in the case of load balancing or for redundancy purposes.

2.4.2.2 ASN Gateway (ASN-GW)

The ASN-GW is a logical entity that includes:

- Control function entities paired with a corresponding function in the ASN a resident function in the CSN or a function in another ASN.
- Bearer plane routing or a bridging function.

The ASN-GW takes action as a decision point for non-bearer plane functions and as an enforcement point for bearer plane functions. For implementation purposes, decomposition of ASN functions into these two groups is optional. If this decomposition is done, the two groups are separated by reference point R7. As in any telecom system, the ASN-GW may be designed to provide redundancy and load balancing between different ASN-GW boxes.

ASN is a complete set of network functions needed to provide radio access to a WiMAX subscriber. ASN is owned by a network access provider (NAP). It performs the following functions: [5]

- WiMAX Layer 2 connectivity with WiMAX MS.
- Transfer of AAA messages to WiMAX subscriber's Home Network Service Provider (H-NSP) for authentication, authorization and session.
- Network discovery and selection of the WiMAX subscriber's preferred NSP.
- Relay functionality for establishing Layer 3 connectivity with a WiMAX MS.
- Radio Resource Management.
- For a portable and mobile environment, ASN also needs to support ASN anchored mobility, Connectivity Service Network (CSN) anchored mobility, paging and ASN-CSN tunnelling.

The ASN consists of one or more BS and one or more ASN Gateway (ASN-GW). BS is a logical entity that embodies a full instance of the WiMAX MAC and PHY in compliance with the IEEE 802.16 suite of applicable standards and may host one or more access functions. The ASN-GW is defined as a logical entity that represents an aggregation of Control Plane functional entities that are either paired with a corresponding function in the ASN, a resident function in the CSN or a function in another ASN. The ASN-GW can be optionally decomposed into two groups of functions which are decision point (DP) functions and enforcement point (EP). EP includes bearer plane functions and the DP includes non-bearer plane functions.

NRM defines three different profiles for ASN. The profile maps, the ASN functions into BS and ASN-GW. Table 3 shows the comparison between three profiles.

Table 3 Functional Decomposition of the ASN in Various Release 1 Profiles [9]

2.4.3 CSN Reference Model

The CSN consists of all the functions/equipment that enable IP connectivity to WiMAX subscribers. As a consequence, the CSN includes the following functions:

Functional Category	**Function**	**ASN Entity**		
		Profile A	Profile B	Profile C
Security	Authenticator	ASN-GW	ASN	ASN-GW
	Authentication relay	BS	ASN	BS
	Key distributor	ASN-GW	ASN	ASN-GW
	Key receiver	BS	ASN	BS
IntraASN Mobility	Data Path function	ASN-GW & BS	ASN	ASN-GW & BS
	Handover function	ASN-GW & BS	ASN	BS
	Context Server & Client	ASN-GW & BS	ASN	ASN-GW & BS
L3 Mobility	MIP Authentication Relay	ASN-GW	ASN	ASN-GW
	MIP foreign agent	ASN-GW	ASN	ASN-GW
Radio resource management	Radio resource controller	ASN-GW	ASN	BS
	Radio resource agent	BS	ASN	BS
Paging	Paging agent	BS	ASN	BS
	Paging controller	ASN-GW	ASN	ASN-GW
QoS	Service flow authorization	ASN-GW	ASN	ASN-GW
	Service flow management	BS	ASN	BS

- User connection authorisation and Layer 3 access (IP address allocation for user sessions, AAA proxy server and functions).
- QoS management (policy and admission control based on user profiles).
- Mobility support based on Mobile IP (HA (Home Agent), function for inter-ASN mobility).

- Tunnelling (based on IP protocols) with other equipment/networks (ASN-CSN tunnelling support, inter-CSN tunnelling for roaming).
- WiMAX subscriber billing.
- WiMAX services (Internet access, location-based services, connectivity for peer to-peer services, provisioning, authorisation and/or connectivity to IMS, facilities for lawful intercept services such as CALEA (Communications Assistance Law Enforcement Act)).

To accomplish those functions, the CSN, deployed by the NSP, may include the following equipment:

- Routers (with eventually a HA function for the inter-ASN gateway mobility).
- DNS (Domain Name System)/DHCP servers for IP address resolution and user IP address configurations.
- AAA proxy/servers and user database for WiMAX user access authentication/ authorisation/ accounting and provisioning, with some reports mentioning the use of a (central) Home Location Register (HLR) as in some other cellular systems.
- Interworking gateways for integration/interoperability of a WiMAX network with another network (e.g. a 3GPP wireless network or a PSTN).
- Firewalls for providing protection to the WiMAX network equipments by enforcing access and filter policies on the traffic to and from an external network (especially used for denial of services detection/prevention).

2.4.4 Reference Points

The WiMAX network reference model defines several reference points (RPs) between several entities in the WiMAX network. Those RPs introduce interoperability points between equipments from different vendors. In the scope of the Release 1 WiMAX network architecture, there are six mandatory RPs (R1 to R6) and two informative RPs (R7 and R8). [7]

2.4.4.1 Reference Point R1 (Normative)

Reference point R1 refers to the radio interface between the MS and the ASN. It consequently includes all the physical and MAC features retained in WiMAX profiles from the IEEE 802.16 standard. R1 carries both user traffic and user control plane messages.

2.4.4.2 Reference Point R2 (Normative)

Reference point R2 is a logical interface between the MS and the CSN. It contains all the protocols and other procedures that are involved with authentication (user and device), service authorisation and IP host configuration management. This logical interface is established between the MS and the H-NSP and some protocols (such as the IP host address management) may be performed by the visited NSP in the case of roaming.

2.4.4.3Reference Point R3 (Normative)

Reference point R3 is the logical interface between the ASN and the CSN. It conveys both Control plane messages, (AAA methods, policy enforcement methods or end-to-end QoS, mobility management messages e.g. for MS relocation) and data lane information through tunnelling between the ASN and the CSN.

2.4.4.4Reference Point R4 (Normative)

Reference point R4 interconnects two ASNs (ASN profile B) or two ASN-GWs. It conveys both control and data plane messages, especially during the handover of a WiMAX user between ASNs/ASN-GWs or during location update procedures in the Idle mode. This RP is presently the only interoperable point between ASNs from different vendors. The tunnelling method recommended is to use IP in IP tunnelling mode for R4 based on the GRE (Generic Routing Encapsulation) protocol.

2.4.4.5 Reference Point R5 (Normative)

Reference point R5 is the interface interconnecting two CSNs. It consists of the set of control and data plane methods between the CSN in the visited NSP and in the home NSP.

2.4.4.6 Reference Point R6 (Normative for Profiles A and C)

Reference point R6 is normative in WiMAX architecture Release 1, in the context of specific ASN profiles. In Release 1, ASN profiles A and C decompose the ASN into BS and ASN GW. In each case, normative procedures over R6 are specified in Release 1. R6, of course, is not applicable to profile B. Reference point R6 connects the BS and the ASN-GW. It conveys both control messages and data plane (intra-ASN data path between BS and ASN-GW) information. The tunnelling method used is GRE, MPLS or VLAN. This interface can also conduct, in combination with R4, the MAC state information carried by the R8 reference point when R8 interoperability between BSs is not available.

2.4.4.7 Other Informative Reference Points

In the ASN, there are currently two additional interfaces (R7 and R8) defined for further interoperability points in the scope of the next WiMAX architecture releases. Those interfaces are only informative in the frame of WiMAX architecture Release 1. Reference point R7 is an optional logical interface between the decision function and the enforcement function in the ASN-GW. Reference point R8 is a logical interface between BSs. It conveys the control plane flow exchange that is used for enabling a fast and efficient handover between BSs. Optionally, R8 may also convey data plane information during the handover phase. It should be noted that a direct physical interface is not actually required between BSs. The R8 methods can indeed be conveyed through, for example, the ASN-GW.

2.5 Network reference architecture

The network reference architecture of the WiMAX forum networking group specifies a number of reference points between logical functions of the network. Therefore, network vendors can choose between different options of where to put a number of functionalities in the radio and CN. Similar to other types of wireless wide area networks, a WiMAX network is split into radio access and CN parts. The radio access network part is referred to as the access service network. It is connected to the CN via the ASN-GW and the R3 reference point. A large network can comprise more than a single ASN if several ASN-GWs are required for the management of the radio access network. An ASN contains two logical entities, the ASN-GW and the BSs. The functionalities of this node, such as radio channel management and mobility management, were moved partly to the BSs and partly to the ASN-GW.

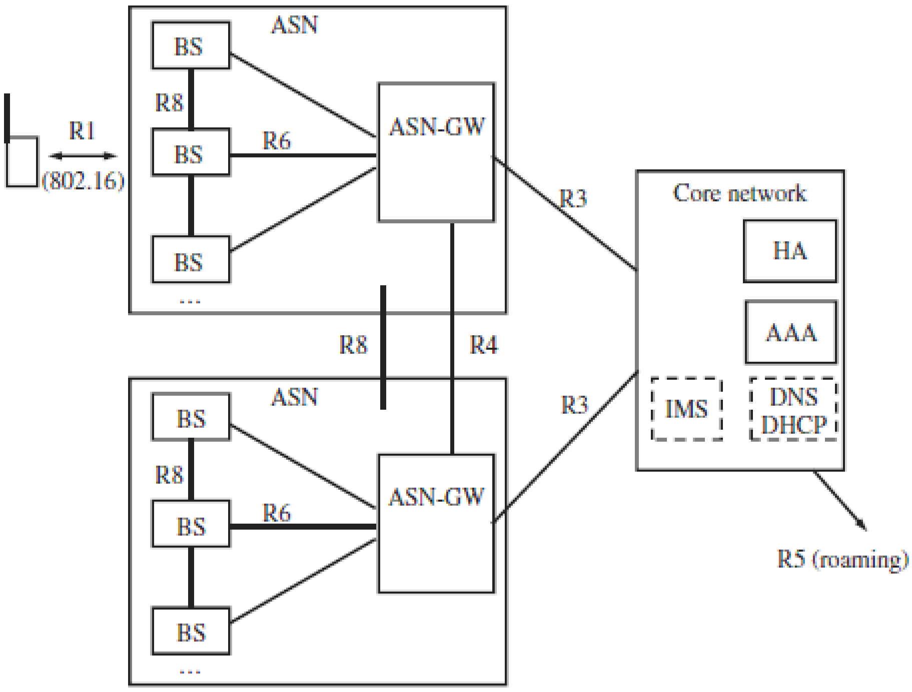

Figure 9 WiMAX network reference architecture

Another difference from networks is the use of the IP on all interfaces between all nodes of the network. This reduces complexity and cost as IP has become the outstanding network protocol and can be used with almost any kind of underlying transport technology. For short distances between nodes, Ethernet over twisted pair copper cables can be used as it is a very cheap transport technology. For larger distances, optical technologies are most suitable, and IP is transported via ATM or via optical Ethernet. As IP is used with all technologies, only a single WiMAX-specific software stack is required for the different transmission technologies. This reduces cost and complexity. As WiMAX networks no longer use circuit-switched connections, using IP on all interfaces is easily possible. The reference points/interfaces inside the ASN (R6 and R8) have not been specified in the first version of the WiMAX network infrastructure standard and thus such solutions are proprietary. Owing to the use of IP on all interfaces, WiMAX network components can be directly connected with each other. For longer distances, standard IP routers can be used to forward both user data and signaling traffic between the components. No special WiMAX software is required in the IP routers. This enables operators to use cheaply available IP hardware. In addition, operators can lease IP bandwidth from other companies, for example, to connect BSs to the ASN-GW. To ensure security and confidentiality, encryption and tunneling mechanisms should be used on these interfaces. Apart from offering direct Internet access, operators may also be interested in offering value-added services such as voice and video over IP, push to talk, voice and video mail, IP television and other advanced multimedia services. It is likely that operators will host a variety of multimedia nodes in their CNs such as the IP multimedia subsystem. Authentication, authorization and accounting (AAA) is another functionality of the CN. It is used to flexibly bill services such as Internet access and IMS services used by the subscriber. To allow subscribers to roam between networks, AAA is another important functionality that has to be standardized in order to be interoperable. For this purpose, the R5 reference point has been defined to allow foreign networks to access the AAA server in the home network of a subscriber.

2.5.1 Micro Mobility Management

When starting a connection to the network, an IP address is assigned to the subscriber device. When moving between BSs, the IP address has to remain the same to preserve communication connections established by higher layer applications. As routing decisions in the network are based on IP addresses and static routing tables, the mobility of the subscriber has to be hidden from most of the network. This is done in particular ways. While moving between BSs of a single ASN, the mobility of the subscriber is managed inside the ASN, and the ASN-GW hides the mobility of the subscriber from the CN and the Internet (R6 mobility). As long as the subscriber roams between BSs connected to the same ASN-GW, all IP packets flow through the same ASN-GW. Inside the ASN, IP tunnels are used to direct IP packets to the BS currently serving a subscriber. Three layers of tunnels are used. On the first layer, each BS is connected to the ASN-GW via a secure and possibly encrypted IP tunnel to protect the data flowing between the two nodes. This allows the use of third-party networks to forward traffic between a BS and the ASN-GW.

Inside the BS IP tunnel, a further IP tunnel is established per subscriber. When a subscriber roams from one BS to another, the ASN-GW redirects this tunnel to another BS tunnel. By tunneling the IP packets through the IP network, only the routing table of the ASN-GW has to be modified when the subscriber roams to another cell. The routing tables of routers in between the ASN-GW and the BSs do not have to be altered, as the routing is based on the IP address of the BSs. The IP packets for a client device including its IP address is embedded in the payload part and is thus not used for the routing process inside an ASN. This micro mobility management concept is similar to that of the GTP, which is used in GPRS and UMTS networks to tunnel user data between the GGSN and the SGSN. It should be noted, however, that in GPRS and UMTS networks IP tunneling is used in the CN while in WiMAX networks IP tunneling is used in the radio access network (ASN). In the WiMAX CN, mobile IP (MIP) is used for subscriber mobility management.

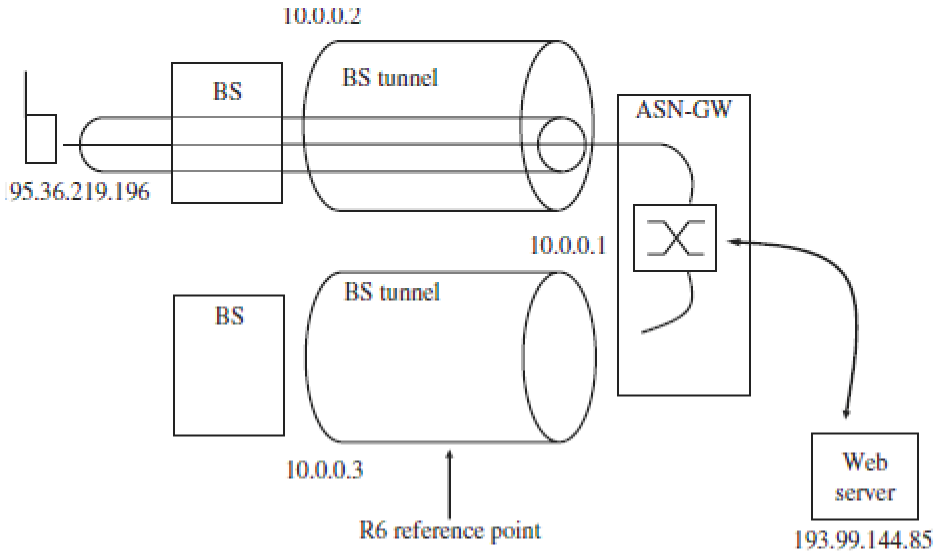

Figure 10 Micro mobility management inside an ASN

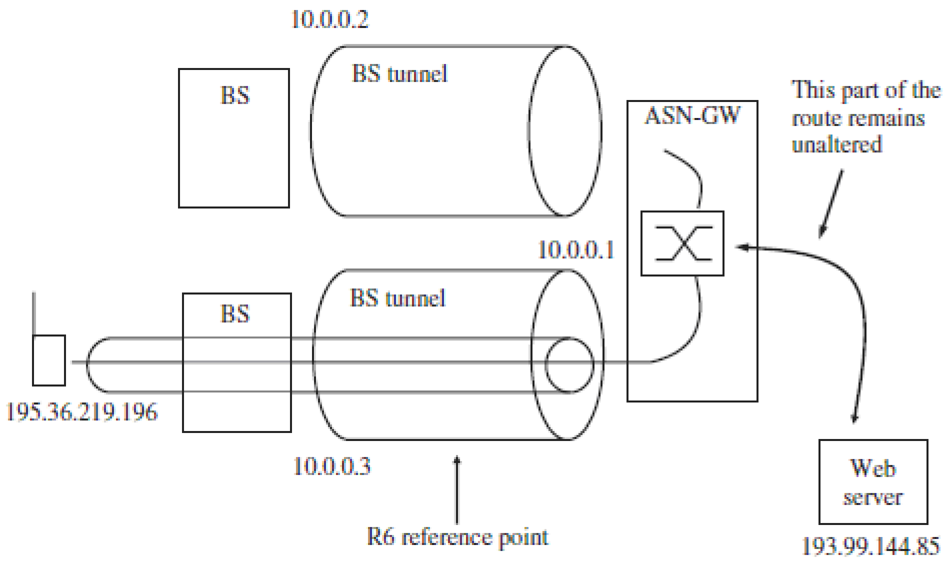

Figure 11 Subscriber tunner after handover to new call

A client device can have several active service flows (SFs), each with its own IP address. To separate these service flows, a third tunnel layer is used. The 802.16 standard offers several convergence sublayers on the air interface to embed IP packets in a MAC frame. The WiMAX networking group has chosen the IP convergence sublayer for its network architecture. This convergence sublayer only generates a small overhead compared to other convergence sublayers and reduces the complexity of developing dual-mode devices capable of seamlessly roaming between WiMAX and other networks.

2.5.2 Macro Mobility Management

If a subscriber roams to a BS of another ASN, traffic needs to be redirected to the new ASN. This can be done in several ways. If the anchor ASN GW is to be maintained, the traffic from and to the CN continues to flow through the ASN-GW of the subscriber's original ASN. The original ASN then forwards all user data frames and management messages to the new ASN via the R4 reference point.

To optimize the routing in the network, it might be helpful at some point to change the route of the incoming and outgoing traffic of a user to flow only through the ASN-GW of the new ASN. For this dynamic rerouting, MIP is used between the ASN-GW and the subscriber's home network. If a subscriber establishes an IP version 4 connection, the ASN-GW acts as a proxy and terminates the MIP connection instead of the mobile device. This allows the use of a standard IP version 4 stacks on the client device without MIP capability. During the connection setup procedure the ASN-GW registers with the MIP home agent (HA) in the user's home network and sends its local IP address to the HA. This IP address is also known as the user's care-of IP address (COA) as it can change at any time during the lifetime of the connection. The HA then assigns an IP address for the user and returns it to the ASN-GW. The ASN-GW in turn forwards this IP address to the client device, which will use it for all incoming and outgoing data packets. The IP address assigned by the HA to the ASN-GW belongs to a local pool of IP addresses, and all data packets that use this IP address as the destination will always be routed to the HA. If an external host sends an IP packet to the mobile device, it is routed to the HA first. There, the packet is forwarded inside an MIP tunnel to the COA, that is, the ASN-GW.

The ASN-GW is the end of the MIP tunnel, which in turn forwards the IP packet through the micro mobility management tunnels described in the previous section. Any change in the COA, that is, a change to another ASN-GW, is transparent to external hosts and routers. From their point of view, the HA remains the destination for the packet. In the reverse direction, mobile devices use the IP address assigned by the HA as the originating IP address of a packet to an external host and not the COA. As routing decisions in an IP network are not based on the originating IP address but on the terminating IP address of a packet, it is routed directly to the external host instead of via the HA.

If a client device uses IPv6, no proxy MIP mechanisms are required in the ASN-GW, as IPv6 natively offers MIP functionality.

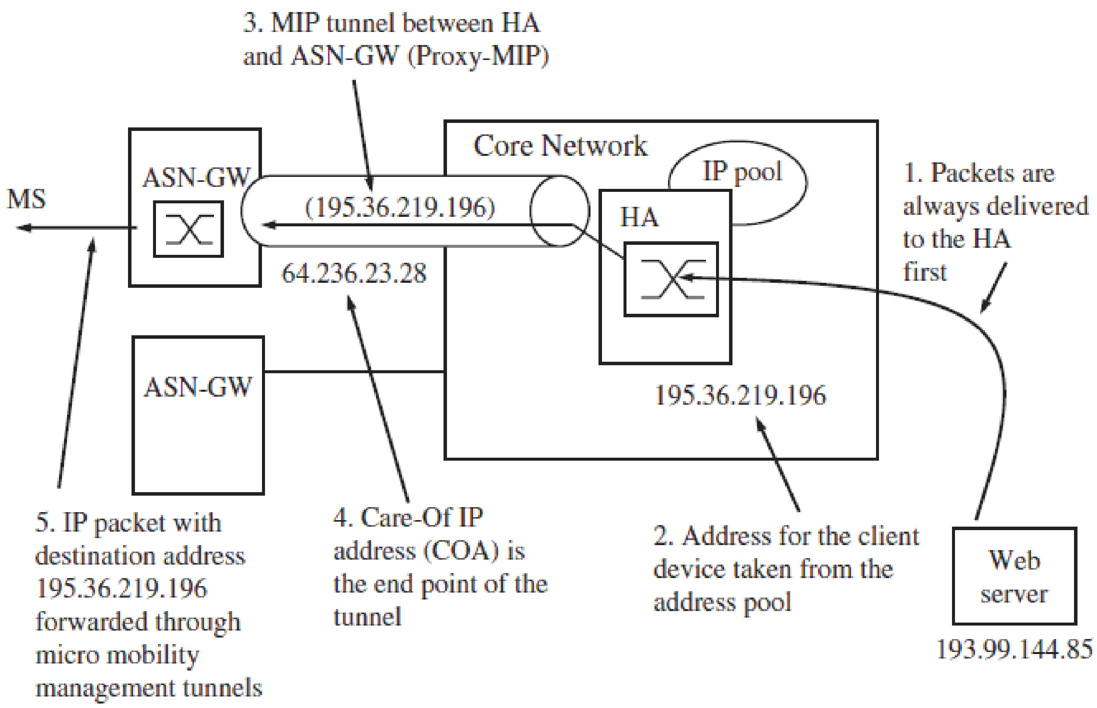

Figure 12 Principle of proxy mobile IP in a WiMAX network

2.6 Network Functionalities

2.6.1 Network Discovery and Selection

This function is required for nomadic, portable and mobile WiMAX services where in the same geographical area the MS may have radio coverage access to an ASN managed by a single NAP and shared by several NSPs or coverage access to several ASNs managed by several NAP/NSPs. To perform network discovery and selection, the MS performs a four-step process:

- NAP discovery. During the scanning of the DCD of the different BSs in the coverage reach from the MS, the MS detects the ‘operator ID’ in the BSID field.
- NSP discovery. The MS discovers the available NSP through the list NSP ID which is broadcast by the ASN as part of the system information identity message. NSP discovery is also possible via solicited request/response messages.
- NSP enumeration and selection. Based on the dynamic information obtained in the coverage area and the configuration information from the subscription,

the MS selects the appropriate NSP. Manual configuration of the NSP may also be available in the case of a visited NSP.

- ASN attachment. After selection of the NSP and associated ASN, the MS indicates its NSP selection by sending an NAI (Network Access Identifier) message used by the ASN to determine the next hop AAA where an MS AAA packet should be routed to.

2.6.2 IP Addressing

WiMAX networks support IPv4 and IPv6 addressing mechanisms. At the end of the procedure, a PoA (Point of Attachment) IP address is delivered to the MS. The IP allocation address modes depend on the WiMAX access service types. In the case of IPv4, the dynamic PoA configuration is based on DHCP. The DHCP proxy may reside in the ASN and the DHCP server in the CSN. In the case of IPv6, stateful IP address allocation is based on DHCPv6. The DHCP server resides in the CSN and the DHCP proxy may reside in the ASN. For the stateless CoA (Care of Address), IP address allocations RFC 2462 and RFC 3041 are used.

2.6.3 AAA Framework

The AAA framework follows the IETF specifications and includes the following services:

- Authentication: device, user or combined user/device authentication.
- Authorisation: user profile information delivery for sessions, mobility and QoS.
- Accounting: delivery of information for pre-paid/post-paid services.

Authentication and authorisation procedures are based on the EAP (Extensible Authentication Protocol). Between the MS and the ASN (the authenticator function), EAP runs over PKMv2, which enables both user and device authentication. Between the AAA server and the ASN, the EAP runs over RADIUS. [7]

2.6.4 Mobility

The WiMAX network architecture need to support mobility requirement. Mobility management is one of the most considerable issues which should be carefully dealt with when the network architecture is designed. Two types of mobility are supported by the WiMAX network architecture. They are ASN anchored mobility and CSN anchored mobility.

ASN anchored mobility or micro mobility is that the MS moves between Data Path Functions while maintaining the same anchor Foreign Agent at the northbound edge of the ASN network. The ASN anchored mobility management has three functions.

- **Data Path Function (DPF):** DPF is responsible for managing data path setup and the procedures for data packet transmission between functional entities. DPF can be decomposed into 4 parts as Anchor DP function, Serving DP function, Target DP function and Relaying DP function.
- **Handoff Function (HO):** HO is responsible for controlling the overall HO decision operation and performing the signaling procedures related to HO. As the DPF, HO function can also be decomposed into Serving HO function, Relay HO function and Target HO function.
- **Context Function:** This function is responsible for the exchange of state information among the network elements affected by handover. Context Relaying Function is used between the Context Client and Context Server.

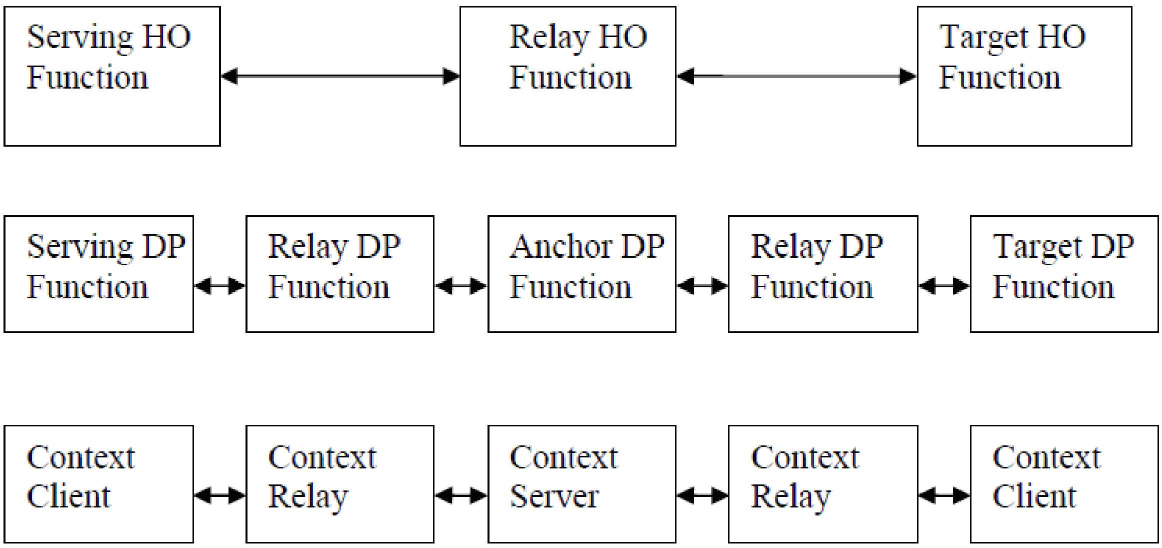

Figure 13 ASN anchored mobility management functional entities

CSN anchored mobility can be called as macro mobility. It refers to mobility across different ASNs, especially when FA changes. The new FA and CSN exchange signalling messages to stabilize data forwarding path. CSN anchored mobility across different IP subsets. Therefore, IP layer mobility management is needed. WiMAX supports IPv4 and IPv6. CSN anchored mobility supports both of them with differences. Two types of Mobile IP (MIP) implementations are defined by WiMAX network for supports CSN anchored mobility. The first one has a MIP client at the MS while the other one has a proxy MIP in the network.

2.6.5 End-to-End Quality of Service

The IEEE standard defines the QoS framework for the air. The WiMAX architecture specifications extend the QoS framework to the complete network where many alternatives for enforcing the QoS on Layer 2 or Layer 3 may exist. The end-to-end QoS framework relies on functions implemented in the CSN (PF (Policy Function) and AF (Application Function)) and in the ASN (SFM (Service Flow Management) and SFA (Service Flow Authorisation)). In the CSN, the AF triggers a SF trigger to the PF based on the information sent by the MS with whom it communicates. The PF then evaluates service requests against a policy database in the NSP. In the ASN, the SFA communicates with the PF and is responsible for evaluating the service request against user QoS profiles. The SFM mainly consists of an admission control function, which decides, based on available radio resource and other local information, whether a radio link can be created. [7]

2.6.6 Security

WiMAX network architecture should be designed in such a way that end-to-end security of the service should be guaranteed. AAA framework is based on IETF specification which defines the protocols and procedures for authentication, authorization and accounting. AAA framework provides the authentication service, authorization service and accounting service to the WiMAX network.

There are three models for AAA. They are agent model, pull model and push model. The main difference between the models is how the suppliant and authentication server communicate and how the control information are configured into the bearer plan MSs. Between these three models, pull model is recommended for AAA deployments in WiMAX networks. In roaming cases, one or more AAA proxy or server are needed between ASN and the home CSN.

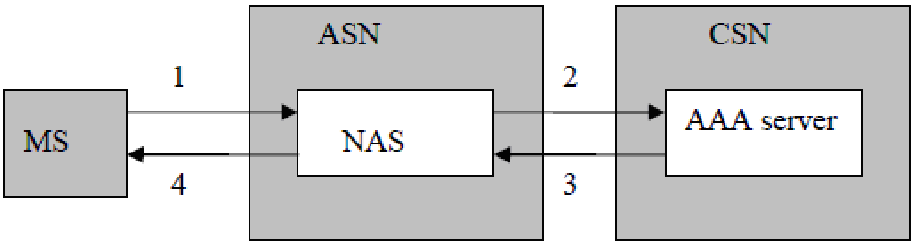

Figure 14 Non-Roaming AAA Framework

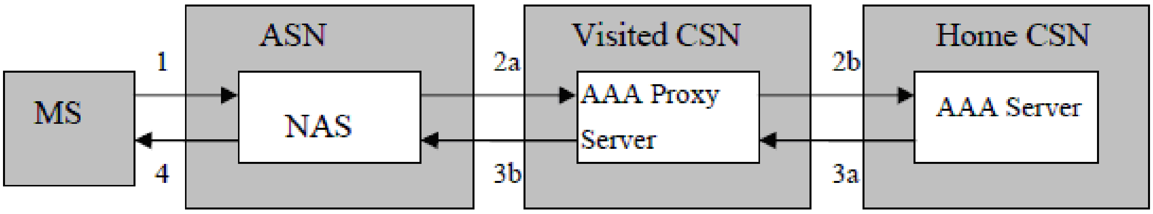

Figure 15 Roaming AAA Framework

WiMAX supports device and user authentication using IETF EAP protocol. PKMv2 is the basis of WiMAX security. PKMv2 supports both user and device authentication between MS and home CSN. In the WiMAX network architecture, authentication and authorization are based on EAP. PKMv2 must be used between MS and ASN. EAP message are transferred within ASN. EAP runs over remote access dial-in user service (RADIUS) between AAA server and authenticator in ASN. There are different EAP methods. These methods support different credential types, such as subscriber root key (SUBC), device certificate and device preshared key (Device-PSK).

2.7 The Protocol Layers of WiMAX

The IEEE 802.16 BWA network standard applies the so-called Open Systems Interconnection (OSI) network reference seven-layer model, also called the OSI seven-layer model. This model is very often used to describe the different aspects of a network technology. It starts from the Application Layer, or Layer 7, on the top and ends with the PHY Layer, or Layer 1, on the. The OSI model separates the functions of different protocols into a series of layers, each layer using only the functions of the layer below and exporting data to the layer above. For example, the IP is in Layer 3, or the Routing Layer. Typically, only the lower layers are implemented in hardware while the higher layers are implemented in software. The two lowest layers are then the PHY Layer, or Layer 1, and the Data Link Layer, or

Layer 2. IEEE 802 splits the OSI Data Link Layer into two sublayers named Logical Link Control (LLC) and Media Access Control (MAC). The PHY layer creates the physical connection between the two communicating entities, while the MAC layer is responsible for the establishment and maintenance of the connection. [7]

The IEEE 802.16 standard determines the air interface of a fixed BWA system supporting multimedia services. The MAC Layer supports a primarily PMP architecture, with an optional mesh topology. The MAC Layer is structured to support many PHY layers specified in the same standard. In fact, only two of them are used in WiMAX. It can be seen that the 802.16 standard defines only the two lowest layers, the PHY layer and the MAC Layer, which is the main part of the Data Link Layer, with the LLC layer very often applying the IEEE 802.2 standard. The MAC layer is itself made of three sublayers, the CS (Convergence Sublayer), the CPS (Common Part Sublayer) and the Security Sublayer. The dialogue between corresponding protocol layers or entities is made as follows. A Layer X addresses an XPDU (Layer X Protocol Data Unit) to a corresponding Layer X (Layer X of the peer entity). This XPDU is received as an (X-1)SDU (Layer X-1 Service Data Unit) by Layer X-1 of the considered equipment.

2.7.1 Physical Layer

The expectation of the PHY is the physical transport of data. We will describe different methods to provide the most efficient delivery in terms of bandwidth and frequency spectrum (MHz/GHz). A number of legacy technologies are used to get the maximum performance out of the PHY. These technologies, include OFDM, TDD, FDD, QAM, and Adaptive Antenna System (AAS).

2.7.1.1 OFDM Basics

WiMAX is based on orthogonal frequency division multiplexing (OFDM). OFDM is a multiplexing technique which divides the bandwidth into multiple frequency subcarriers. In OFDM, a high-bit-rate data stream is divided into N parallel lower bit rate streams. Then those streams are modulated and transmitted in separate subcarriers.

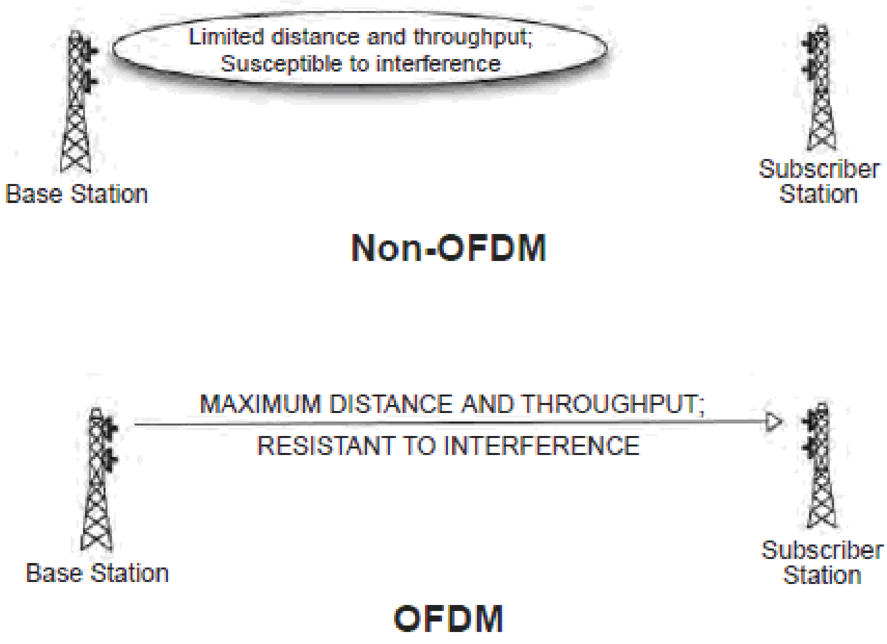

Figure 16 The significance of OFDM: A focused beam delivering maximum bandwidth over maximum distance with minimum interference

Rather than adding the overlapping subcarrier channels, OFDM uses orthogonal subcarriers over the symbol duration to eliminate the intercarrier interference. When the number of subcarriers *N* is large enough to allow the subcarrier bandwidth to be much less than the coherence bandwidth *Bc.*

However, in order to completely eliminate ISI, cyclic prefix (CP) is used as a guard interval between OFDM symbols. As long as CP duration is longer than the multipath delay spread, ISI-free channel can be achieved. The CP is a copy of the last symbols and put it in the beginning of the data symbol. But CP is overhead and it causes power wastage and a decrease in bandwidth efficiency. The amount of power wasted depends on how large a fraction the guard time occupies in OFDM symbol duration. Therefore, larger symbol duration and more subcarrier save power and improve bandwidth efficiency.

Too many resources are used if the subcarriers are transmitted separately on *N* independent radio frequency bands. To solve this problem, OFDM uses an efficient computational technique, discrete Fourier transforms (DFT), and its efficient implementation which is commonly known as the fast Fourier transforms (FFT). The FFT and inverse FFT (IFFT) are used to create a multitude of orthogonal subcarriers using a single radio frequency.

Fixed WiMAX and mobile WiMAX are based on different PHY layer. Fix WiMAX based on IEEE 802.16-2004 uses a 256 FFT-based OFDM PHY layer. Mobile WiMAX based on IEEE 802.16e-2005 uses a scalable OFDMA-based PHY layer. In mobile WiMAX, the FFT sizes vary from 128 to 2048.

Parameter	**Fixed WiMAX OFDM-PHY**	**Mobile WiMAX Scalable OFDMA-PHY**[a]			
FFT size	256	128	512	1,024	2,048
Number of used data subcarriers[b]	192	72	360	720	1,440
Number of pilot subcarriers	8	12	60	120	240
Number of null/guardband subcarriers	56	44	92	184	368
Cyclic prefix or guard time (Tg/Tb)	1/32, 1/16, 1/8, 1/4				
Oversampling rate (Fs/BW)	Depends on bandwidth: 7/6 for 256 OFDM, 8/7 for multiples of 1.75MHz, and 28/25 for multiples of 1.25MHz, 1.5MHz, 2MHz, or 2.75MHz.				
Channel bandwidth (MHz)	3.5	1.25	5	10	20
Subcarrier frequency spacing (kHz)	15.625	10.94			
Useful symbol time (µs)	64	91.4			
Guard time assuming 12.5% (µs)	8	11.4			
OFDM symbol duration (µs)	72	102.9			
Number of OFDM symbols in 5 ms frame	69	48.0			

a. Boldfaced values correspond to those of the initial mobile WiMAX system profiles.
b. The mobile WiMAX subcarrier distribution listed is for downlink PUSC (partial usage of subcarrier).

Table 4 OFDM Parameters Used in WiMAX [9]

2.7.1.2 Symbol structure and sub-channelization

The OFDM symbol structure has three types of subcarriers:

- **Data subcarriers** are used for data transmission
- **Pilot subcarriers** are used for carrying the pilot symbols. The pilot symbols can be used for channel estimation and channel tracking.
- **Null subcarriers** have no power allocated to them. This type includes guard subcarriers at the edge of the spectrum and DC subcarriers. The guard subcarriers are used to reduce the interference between adjacent channels.

The DC subcarriers are used to prevent saturation effects or excess power consumption at the amplifier.

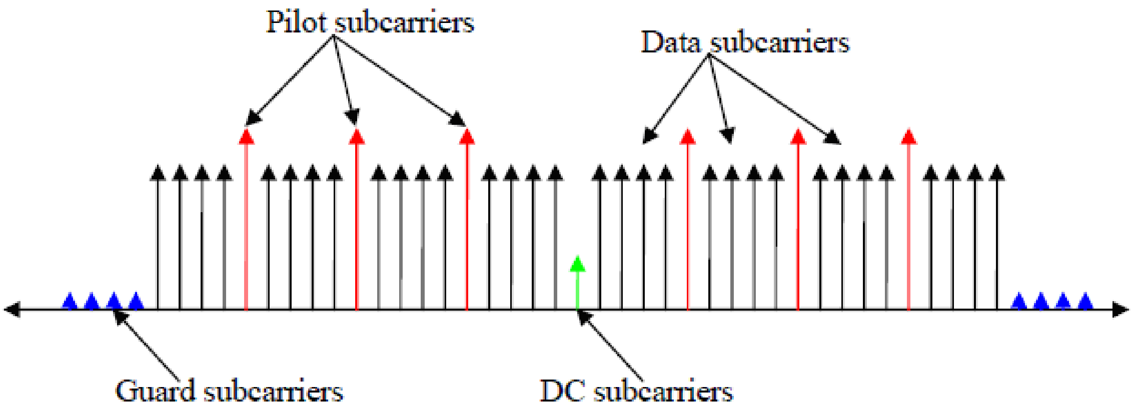

Figure 17 OFDM symbol structure [9]

Fixed WiMAX is based on OFDM-PHY and it only allows a limited form of subchannelization in the uplink. However, mobile WiMAX is based on OFDMA-PHY and it allows subchannelization in both the uplink and the downlink. The minimum frequency resource unit allocated by the BS is subchannel, also called a slot that is equal to 48 data tones (subcarriers). Different subchannels can be allocated to different users according to multiple-access mechanism in Mobile WiMAX.

Subchannels can be either formed by subcarriers which are contiguous to each other or by subcarriers which are distributed pseudo-randomly throughout the frequency band. Those two types of innovations are called as contiguous permutation and diversity permutation. Better frequency diversity is achieved by using diversity permutation. Diversity permutation is more useful for mobile applications. Contiguous permutation is better for beam forming and gaining multi user diversity. It is more applicable for fixed or low mobility applications.

2.7.1.3 Frame Structure

WiMAX supports both time division duplex (TDD) and frequency division duplex (FDD) operation. TDD is a technique in which the system transmits and receives within the same frequency channel, assigning time slices for transmit and receive modes. FDD requires two separate frequencies generally separated by 50 to 100 MHz within the operating band. TDD provides an advantage where a regulator allocates the spectrum in an adjacent block. With TDD, band separation is not needed. Thus, the entire spectrum allocation is used efficiently both upstream and downstream and where traffic patterns are variable or asymmetrical.

In FDD systems, the downlink (DL) and uplink (UL) frame structures are similar except that the DL and UL are transmitted on separate channels. When half duplex FDD (H-FDD) subscriber stations (SSs) are present, the BS (BS) must ensure that it does not schedule an H-FDD SS to transmit and receive at the same time.1

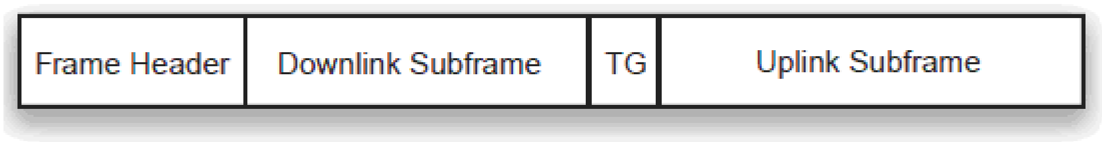

Figure 18 A TDD Subframe

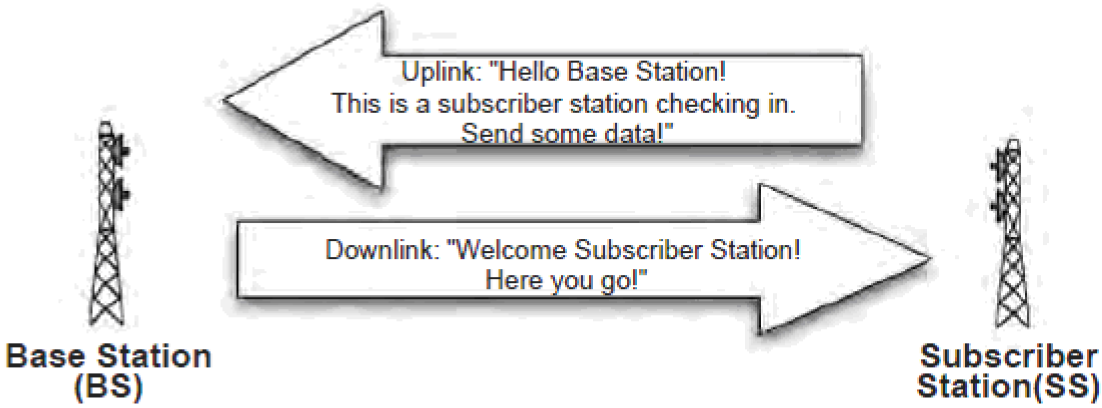

Figure 19 ULs and DLs between BSs and SSs

Adaptive Antenna System (AAS)

AAS is used in the WiMAX specification to describe beam-forming techniques where an array of antennas is used at the BS to increase gain to the intended SS while nulling out interference to and from other SSs and interference sources. AAS techniques can be used to enable Spatial Division Multiple Access (SDMA), so multiple SSs that are separated in space can receive and transmit on the same subchannel at the same time. By using beam forming, the BS is able to direct the desired signal to the different SSs and can distinguish between the signals of different SSs, even though they are operating on the same subchannel(s). [6]

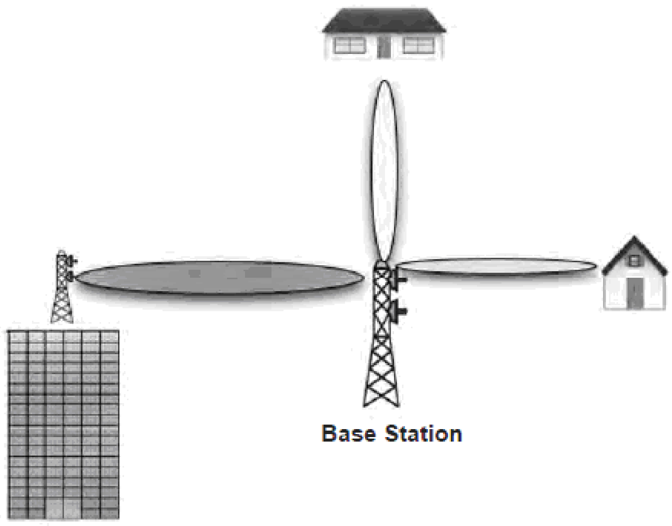

Figure 20 AAS uses beam forming to increase gain(energy) to the intended SS

WirelessMAN-OFDM

This air interface uses OFDM with a 256-point transform. Access is by TDMA. This air interface is mandatory for license-exempt bands.

Designation	Function	LOS/NLOS	Frequency	Duplexing Alternative(s)
WirelessMAN-SC	Point-to-point	LOS	10-66 GHZ	TDD, FDD
WirelessMAN-SCa	Point-to-point	NLOS	2-11 GHz	TDD, FDD
WirelessMAN-OFDM	Point-to-multipoint	NLOS	2-11 GHz	TDD, FDD
WirelessMAN-OFDMA	Point-to-multipoint	NLOS	2-11 GHz	TDD, FDD
Wireless HUMAN	Point-to-multipoint	NLOS	2-11 GHz	TDD

Table 5 Variants of WiMAX PHY layer [6]

The frame is divided into DL and UL subframes. The DL subframe is made up of a preamble, Frame Control Header (FCH), and a number of data bursts. The FCH specifies the burst profile and the length of one or more DL bursts that immediately follow the FCH. The down link map (DL-MAP), uplink map (UL-MAP), DL Channel Descriptor (DCD), UL Channel Descriptor (UCD), and other broadcast messages that describe the content of the frame are sent at the beginning of these first bursts. The remainder of the DL subframe is made up of data bursts to individual SSs. Each data burst consists of an integer number of OFDM symbols and is assigned a burst profile that specifies the code algorithm, code rate, and modulation level that are used for those data transmitted within the burst. The UL subframe contains a contention interval for initial ranging and bandwidth allocation purposes and UL PHY protocol data units (PDUs) from different SSs. Finally, if AAS is used, a portion of the DL subframe can be designated as the AAS zone. Within this part of the subframe, AAS is used to communicate to AAS-capable SSs. AAS is also supported in the UL.

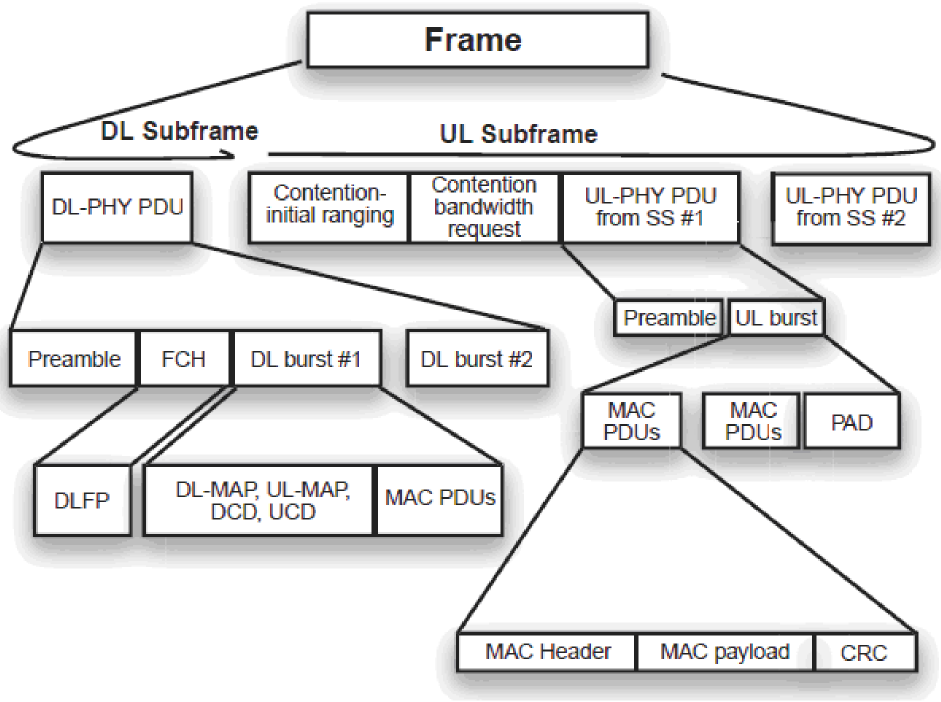

Figure 21 Frame structure for a TDD system [6]

WirelessMAN-OFDMA

This variant uses orthogonal frequency division multiple access (OFDMA) with a 2048-point transform. In this system, addressing a subset of the multiple carriers to individual receivers provides multiple access. Because of the propagation requirements, the use of AASs is supported. The WirelessMAN-OFDMA PHY is based on OFDM modulation. It supports subchannelization in both the UL and DL.

The standard supports five different subchannelization schemes. The OFDMA PHY supports both TDD and FDD operations. The same modulation levels are also supported. STC and AAS with SDMA are supported, as is multiple input, multiple output (MIMO). MIMO encompasses a number of techniques for utilizing multiple antennas at the BS and SS in order to increase the capacity and range of the channel. The frame structure in the OFDMA PHY is similar to the structure of the OFDM PHY. The notable exceptions are that subchannelization is defined in the DL as well as in the UL, so broadcast messages are sometimes transmitted at the same time (on different subchannels) as data. Also, because a number of different subchannelization schemes are defined, the frame is divided into a number of zones that each use a different subchannelization scheme. The MAC layer is responsible for dividing the frame into zones and communicating this structure to the SSs in the DL-MAP and UL-MAP. As in the OFDM PHY, there are optional transmit diversity and AAS zones, as well as a MIMO zone.

Wireless High Speed Unlicensed Metro Area Network (WirelessHUMAN)

WirelessHUMAN is similar to the aforementioned OFDM-based schemes and is focused on Unlicensed National Information Infrastructure (UNII) devices and other unlicensed bands.

DL Subframe The DL subframe starts with a frame control section that contains the DL-MAP for the current DL frame as well as the UL-MAP for a specified time in the future. The DL-MAP specifies when PHY transitions occur within the DL subframe. The DL subframe typically contains a TDM portion immediately following the frame control section. DL data are transmitted to each SS using a negotiated burst profile. The data are transmitted in order of decreasing robustness to allow SSs to receive their data before being presented with a burst profile that could cause them to lose synchronization with the DL.

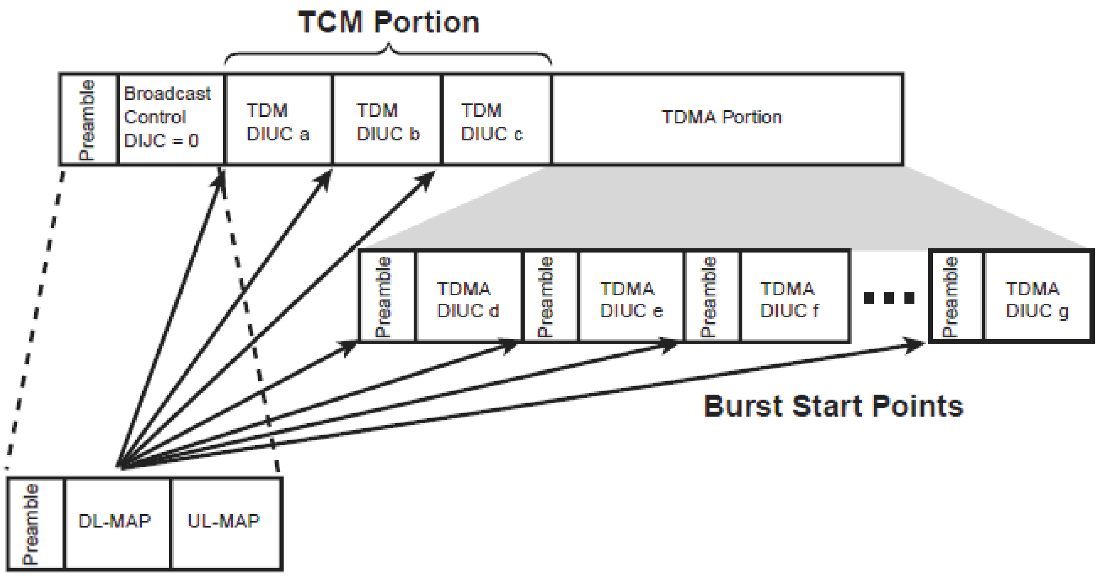

Figure 22 FDD DL Subframe [6]

2.7.2 MAC Layer

The Common Part Sublayer (CPS) resides in the middle of the MAC layer. The PS represents the core of the MAC protocol and is responsible for:

- Bandwidth allocation.
- Connection establishment.
- Maintenance of the connection between the two sides.

The 802.16-2004 standard defines a set of management and transfer messages. The management messages are exchanged among the SS and the BS before and during the establishment of the connection. When the connection is realised, the transfer messages can be exchanged to allow the data transmission. The CPS receives data from the various CSs, through the MAC SAP, classified to particular MAC connections. The QoS is taken into account for the transmission and scheduling of data over the PHY Layer. The CPS includes many procedures of different types: frame construction, multiple access, bandwidth demands and allocation, scheduling, radio resource management, QoS management, etc.

2.7.3 Security Sublayer

The MAC Sublayer also contains a separate Security Sublayer providing authentication, secure key exchange, encryption and integrity control across the

BWA system. The two main issues of a data network security are data encryption and authentication. Algorithms realising these objectives should prevent all known security attacks whose objectives may be denial of service, theft of service, etc.

In the 802.16 standard, encrypting connections between the SS and the BS is made with a data encryption protocol applied for both ways. This protocol defines a set of supported cryptographic suites. An encapsulation protocol is used for encrypting data packets across the BWA. This protocol indicates a set of supported cryptographic suites. The rules for applying those algorithms to an MAC PDU payload are also given.

An authentication protocol, the Privacy Key Management (PKM) protocol is used to provide the secure distribution of keying data from the BS to the SS. Through this secure key exchange, due to the key management protocol the SS and the BS synchronize keying data. The basic privacy mechanisms are established by adding digital-certificate-based SS authentication to the key management protocol. In addition, the BS uses the PKM protocol to guarantee conditional access to network services. The 802.16e amendment defined PKMv2 which has the same framework as PKM, re-entitled PKMv1, with some additions such as new encryption algorithms, mutual authentication between the SS and the BS, support for a handover and a new integrity control algorithm.

The WiMAX DL from the BS to the user operates on a point-to multi point basis. The WiMAX wireless link operates with a central BS with a sectorized antenna that is capable of handling multiple independent sectors simultaneously. Within a given frequency channel and antenna sector, all stations receive the same transmission. The BS is the only transmitter operating in this direction, so it transmits without having to coordinate with other stations except the overall TDD that may divide time into UL and DL transmission periods. The DL is generally broadcast. In cases where the DL-MAP does not explicitly indicate that a portion of the DL subframe is not a specific SS, all SSs capable of listening to that portion of the DL subframe will listen. The MAC is connection-oriented. Connections are referenced with 16-bit connection identifiers (CIDs) and may require continuously granted bandwidth or bandwidth on demand.

Both bandwidths are contained. A CID is used to classify between multiple UL channels that are associated with the same DL channel. The SSs check the CIDs in the received PDUs and retain only those PDUs addressed to them. The MAC PDU is the data unit exchanged between the MAC layers of the BS and its SSs. It is the data unit generated on the downward direction for the next lower layer and the data unit received on the upward direction from the previous lower layer. Each SS has a standard 48-bit MAC address, which serves as an equipment identifier because the primary addresses used during operation are the CIDs. Upon entering the network, the SS is assigned three management connections in each direction. These three connections reflect the three different QoS requirements used by different management levels: [6]

- **Basic connection**—transfers short, time-critical MAC and radio link control (RLC) messages.
- **Primary management connection**—transfers longer, more delay-tolerant messages, such as those used for authentication and connection setup. The secondary management connection transfers standards-based management messages such as Dynamic Host Configuration Protocol (DHCP), Trivial File Transfer Protocol (TFTP), and Simple Network Management Protocol (SNMP). In addition to these management connections, SSs are allocated transport connections for the contracted services.
- **Transport connections**—are unidirectional to facilitate different UL and DL QoS and traffic parameters. They are typically assigned to services in pairs. SSs share the UL to the BS on a demand basis. Depending on the class of service utilized, the SS may be issued continuing rights to transmit, or the BS may grant the right to transmit after receiving a request from the user.

2.7.4 Service-Specific Convergence Sublayers

The WiMAX standard defines two general service-specific convergence sublayers for mapping services to and from WiMAX MAC connections:

- The ATM convergence sublayer is for ATM services.

- The packet convergence sublayer is defined for mapping packet services such as IP version 4 or 6 (IPv4, IPv6), Ethernet, and virtual local area network (VLAN).

2.7.5 Common Part Sublayer

The MAC stores additional connections for other purposes. One connection is reserved for contention-based initial access. Another is reserved for broadcast transmissions in the DL as well as for signalling broadcast contention-based polling of SS bandwidth needs. Additional connections are reserved for multicast, rather than broadcast, contention-based polling. SSs may be instructed to join multicast polling groups associated with these multicast polling connections.

2.7.6 MAC PDU Formats

A MAC PDU consists of a fixed-length MAC header, a variable-length payload, and an optional cyclic redundancy check (CRC). Two header formats are defined: the generic header and the bandwidth request header. Except for bandwidth request MAC PDUs, which contain no payload, MAC PDUs contain either MAC management messages or convergence sublayer data.

There are three types of MAC subheaders:

- **Grant management subheader** is used by an SS to convey bandwidth management needs to its BS.
- **Fragmentation subheader** contains information that indicates the presence and orientation in the payload of any fragments of SDUs.
- **Packing subheader** indicates the packing of multiple SDUs into a single PDU. The grant management and fragmentation subheaders may be inserted in MAC PDUs immediately following the generic header if so indicated by the Type field.

The packing subheader may be inserted before each MAC SDU if so indicated by the Type field.

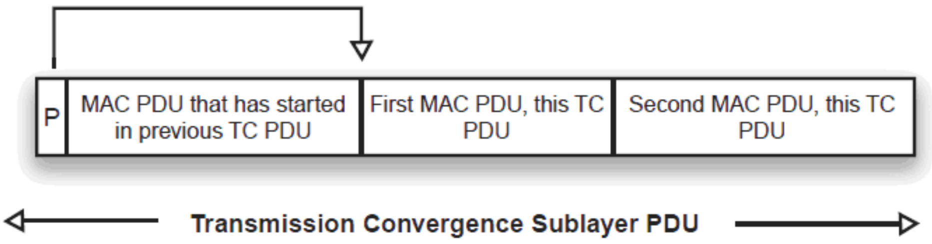

Figure 23 MAC PDU

Transmission of MAC PDUs and SDUs

Incoming MAC SDUs from corresponding convergence sublayers are formatted according to the MAC PDU format, with fragmentation and/or packing, before being conveyed over one or more connections in accordance with the MAC protocol.

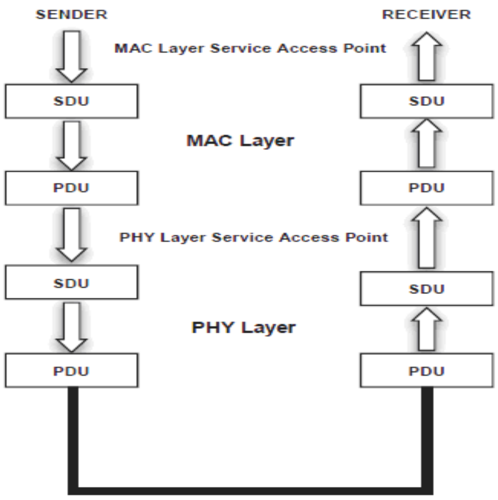

Figure 24 Fragmentation and packing of SDUs and PDUs[6]

2.7.7 MAC Management of User Data

Apart from managing the overall connection between the subscriber station and the network, the MAC layer also performs a number of tasks on the user data being delivered from higher layers of the protocol stack such as IP or 802.3.

2.7.7.1 Fragmentation and Packing

Comparable to other systems that coordinate the use of the air interface from a central point, 802.16 SSs are assigned uplink opportunities by the BS to send their data. The maximum size of MAC frames is 2048 bits. Therefore, it is achievable to put a complete higher layer frame into a single MAC packet. While the uplink is assigned to a SS, it can send several constant and independent MAC frames. This is in particular useful if IP is used as a higher layer protocol as packet sizes can vary from packet to packet and MAC frames that contain only a single higher layer frame may not fit exactly into the uplink opportunity allocated to the SS. [4]

To assist efficient use of resources on the air interface, a sender can split a higher layer packet into two (or more) parts and send them in two (or more) MAC frames. This eliminates transmission gaps as the MAC frame with the first part of a higher layer packet can be tailored to fit exactly into the end of the transmission opportunity. This is called fragmentation. To decrease the overhead created by the MAC header, the standard also allows several small higher layer packets to be bundled together into a single MAC frame. This is called segmentation. A single MAC frame could thus contain the end of a fragmented higher layer packet at the beginning, one or more non fragmented higher layer packets in the middle and the first fragment of the next higher layer packet at the end.

2.7.7.2 Data Retransmission (ARQ)

While other technologies like HSDPA rely on sophisticated data retransmission techniques on lower layers to ensure fast retransmission of erroneous packets, implementation of the 802.16ARQ scheme is purely optional. However, it might be very useful to implement this scheme in both network and SSs as higher layer protocols like TCP interpret any missing data as congestion. This in turn reduces the throughput after an error has occurred. By correcting errors via retransmission on lower layers, which are aware that packets are not missing because of congestion but because of a transmission error over the wireless interface, high TCP throughput can be maintained.

The ARQ scheme can be activated on a per connection (CID) basis during connection setup. The subscriber station signals to the BS during connection establishment that it is capable of using ARQ for the connection and the BS can activate the mechanism if it supports ARQ as well, and if it is beneficial for the connection. If ARQ is activated for a connection, a higher layer packet is split into a number of ARQ blocks. The maximum ARQ block size is 2040 B. Practical, a much lower value is used to allow for quicker detection and retransmission of missing or faulty information. ARQ blocks have a fixed size except for the last ARQ block of a higher layer packet which can be shorter than the others as the length of most packets is not an exact multiple of the ARQ block size. Higher layer packets are divided into several ARQ blocks, which are then mapped onto MAC packets. ARQ can be used in combination with fragmentation and packing. Here, two higher layer packets are first split into several ARQ blocks. Smaller ARQ blocks are used for the remaining bytes at the end of the packets. Fragmentation and packing are then used to fill the first MAC packet with all ARQ blocks of higher layer packet one and the first two ARQ blocks of higher layer packet two. The second MAC packet then contains the remainder of the second higher layer packet. The small parts of the MAC packets in gray are fragmentation and packing subheaders, which mark the beginning of a new higher layer frame and contain the (ARQ) block sequence numbers (BSNs). Fragmentation and packing subheaders with BSNs are also inserted at the beginning of a new higher layer packet in a MAC frame to enable reassembly of the higher layer packets at the receiver. [4]

There are two possibilities for the receiver to return ARQ feedback information to the sender: the ARQ feedback information is sent either in an ARQ-FEEDBACK message over the basic management connection or directly on the user data SF connection. In the latter case, an ARQ extension header is used, which increases the length of the standard MAC header.

The standard offers several reporting formats to acknowledge correct blocks and to send a negative acknowledgment for bad or missing blocks. The simplest format is a selective acknowledgment. This means that the receiver acknowledges the reception of each ARQ block separately. As single block acknowledgments are not very efficient for most scenarios, a cumulative acknowledgment format has been specified. This format is used to acknowledge all blocks up to a certain BSN by specifying only the highest BSN to be acknowledged. If a number of good blocks have been received before a bad block can be reported, the receiver can use a third format, the selective acknowledgment. This is done by returning a selective ACK message that contains a bitmap in which each bit corresponds to one block. If the bit is set to 1, the block is acknowledged. If the bit is set to 0, the block was not received correctly and the sender immediately reschedules the faulty blocks. [4]

2.7.7.3 Header Compression

The MAC convergence sublayer also offers optional higher layer header compression schemes to decrease the signaling overhead. This can be beneficial for VoIP connections, where small IP packets are used to minimize the latency introduced by the packetization of the data generated by the speech coder. In practice, such IP packets carry around 40 B of user data, an IP header of 20B and a UDP header of 8 B. As the headers usually contain the same content during an ongoing conversation, they can be easily compressed and a substantial amount of bandwidth on the air interface can be saved. Header compression can also be very beneficial to speed up call setup times. Commonly, many interactions are necessary between the SS, the telephony server and the device of the called subscriber to establish a voice or video call. As shorter messages can be transported faster over the air interface, call setup times are reduced. [4]

The principle of the 802.16 header compression is to leave out the parts of the payload header that are already present in a previous payload header. Among the parameters of an IP header, which never change for packets sent to the same destination device and application, are the IP addresses, the header length parameter, the time to live field and the higher layer protocol indicator. The recipient of a packet with a compressed header can either be the subscriber station or the BS. To signal that packet header suppression is used for a packet, packet header suppression information is inserted at the beginning of the payload part of the MAC PDU. To enable the receiver to reconstruct the original header of a packet, sender and receiver have to exchange information about which parts of the header were removed before sending and on the content of the removed bytes.

2.7.8 Transmission Convergence (TC) Layer

Between the PHY and MAC is a TC sublayer. This layer transforms variable length MAC PDUs into fixed-length FEC blocks. The TC layer has a PDU sized to fit in the FEC block currently being filled. It starts with a pointer indicating where the next MAC PDU header starts within the FEC block. The TC PDU format allows resynchronization to the next MAC PDU in the event that the previous FEC block had irrecoverable errors.

2.7.9 MAC Management Functions

The MAC common part sublayer is responsible for the management of the link between the SS and the network. This includes the initial setup of the link between the subscriber station and the network as well as the maintenance of the communication session. The MAC layer also includes functionality to update the configuration and software of the subscriber station, and methods to re-establish the link to the network, in case the signal is lost.

2.7.9.1 Connecting to the Network

The first management task of the SS after powering up is to find and connect to a network. This is done in several steps. In the first step, the SS retrieves the last known system parameters from non volatile memory and listens on the last known frequency to check if a downlink channel from a BS can be detected. If unsuccessful, it will start scanning all possible channels in the bands it supports for a detectable signal. The SS recognizes valid downlink signals if it is able to successfully decode the preamble at the beginning of the frames. Decoding the preamble is possible without further information as it contains a well-known bit pattern. The device has found a valid 802.16 channel if several preambles can be decoded. At this point, the device is also aware of the length of the downlink frames. The device then decodes the beginning of the received downlink subframes to get the current system parameters and configuration from the DCD, the DL-MAP and the UL-MAP. This procedure is again executed if the client loses synchronization to the network and is unable to successfully decode DCD and DL-MAP messages for a configured amount of time, which has a maximum value of 600 milliseconds. Network synchronization can be a relatively slow process as the maximum time allowed between two DCD messages is 10 seconds.

Once all parameters for the initial network access are known, the SS starts the initial ranging procedure by sending a ranging request message (RNG-REQ) with a low transmission power in the contention-based ranging area at the beginning of an uplink subframe. The length of the contention based ranging area and other parameters are broadcast via the DL-MAP message. If no answer is received, the message is repeated with a higher power level. The procedure is repeated until a response is received or the maximum number of retries is reached. If no answer is received, the SS goes back to step one and searches for a channel on a different frequency. The maximum time allowed between two ranging regions is 2 seconds. Thus, the ranging process could take several seconds if several RNG-REQ messages need to be sent. The RNG-REQ message also contains a parameter for the network containing the modulation and coding schemes that the SS thinks are suitable to use in the downlink direction. The selection of these values on the client side is based on the downlink reception conditions that the SS has experienced thus far.

2.7.9.2 Power, Modulation and Coding Control

Even though the WirelessMAN-OFDM specification has been designed only for stationary SSs, there is still a need to monitor signal conditions and to adapt to them. Variable parameters are the power output of the SS and the modulation and coding schemes for the uplink and downlink directions. A change of these parameters after the initial network entry procedure might be necessary owing to changing weather conditions or if the SS detects fading on the channel. The current power and maximum possible transmission power is transmitted by a SS to the network during the network attach procedure as part of the SBC-REQ message. If the network needs to increase or decrease the output power of the SS at a later stage, it can do so by sending an unsolicited RNG-RSP message to the SS with a new power value.

For the uplink direction, the BS can change the modulation and coding used by a SS at any time by assigning a different burst of an uplink subframe, which uses a higher or lower modulation scheme. The decision is based on the reception quality of previous MAC packets at the subscriber station.

For the downlink direction, the BS has no direct information about the change in reception quality over time for a SS using a certain modulation and coding scheme. Thus, it is the client’s device responsibility to request a change in the modulation or coding scheme, if required. This can be done by the SS by either sending an unsolicited RNG-REQ message or by sending a downlink profile burst change request (DBPC-REQ). The BS then decides to accept or reject the request and replies with a DBPC-RSP message.

2.7.9.3 Dynamic Frequency Selection

When operating in an unlicensed band, which is, by definition, open for the use of anyone and any technology, other systems like WLAN 802.11 might already use some of the frequencies in that band. Therefore, an 802.16 BS is required by regulatory bodies of some countries to ensure that the frequency band it wants to use is not in use by another system. This also includes BSs of its own network if the use of frequencies is not coordinated by the network or BSs of other 802.16 network operators. This is done by the BS listening for some time on the channel it wants to use for interference caused by another system. If there is measurable interference on a channel, the BS selects another frequency band and repeats the procedure.

There is not exist method to avoid the use of an allocated frequency band by other systems, the 802.16 standard also defines a number of mechanisms for a BS to check for interfering systems once it has selected a frequency band for operation. The best way to detect that a new interferer is now operating in the current frequency band of the cell is to stop transmitting and receiving periodically and listen on the empty channel for interference. If a new interferer has entered the area, the BS can then start to search for a new frequency band and continue its operation on a different frequency. Before it can do so, it has to inform the subscriber stations in the cell of the pending switch to a new frequency by announcing the new channel number in the DCD message. In addition to listening for interferers, the BS can also ask one or several SSs to do the same. This is done by including a report measurement information element in a DL-MAP entry of a SS and then suspending the activity of the cell while the SSs measure their perceived interference of the channel. A measurement report can also be requested by a BS by sending a measurement report request (REP-REQ) message to a SS, which then has to send its report via a REP-RSP message. The BS can also instruct SSs to measure interference in other frequency bands to test their suitability from the point of view of the SSs. This method is quite helpful to ensure that SSs do not experience strong interference if the BS itself is too far away from the source to experience the interference itself. If a SS detects interference, it reports back to the system if it just experiences general interference or if it is caused by another 802.16 BS or subscriber.

2.7.9.4 Security

Security has been emphasized in WiMAX from the beginning. The best security technology has been used to guarantee the security communication in the system. The key aspects of the security features are as follow.

1. **Device/user authentication:** To prevent the unauthorized use, a flexible authentication method is used by WiMAX. The authentication framework is based on the Internet Engineering Task Force (IETF) EAP. It supports many credentials. The operators use this to identify the devices and then use username/ password or smart card for the authentication.
2. **Key management protocol:** The PKMPV2 is used to secure the data exchange between BS and MS. PKM uses X.509 digital certificates and RSA public-key encryption algorithms to securely perform key exchanges between the BS and the MS.
3. **Control message protection:** Control messages are protected by suing message digest schemes, such as AES-based CMAC (cipher-based message authentication code) or MD5 (message digest 5 algorithm)-based HMAC (hash-based message authentication codes).
4. **Support for fast handover:** A pre-authentication is performed between the MS and its targeted BS to reduce the handover time. A three-way handshake scheme is used to optimize the re-authentication mechanisms for supporting fast handover. It prevents the man-in-the middle attacks.

2.7.10 Service Classes and QoS

Within each sector, users adhere to a transmission protocol that controls contention between users and enables the service to be tailored to the delay and bandwidth requirements of each user application. This is accomplished through four different types of UL scheduling mechanisms. These mechanisms are implemented using unsolicited bandwidth grants, polling, and contention procedures. The WiMAX MAC provides QoS differentiation for different types of applications that might operate over WiMAX networks: [6]

- **Unsolicited Grant Services (UGS)**—UGS is designed to support constant bit rate (CBR) services, such as T1/E1 emulation and VoIP without silence suppression.
- **Real-Time Polling Services (rtPS)**—rtPS is designed to support real-time services that generate variable size data packets, such as MPEG video or VoIP with silence suppression, on a periodic basis.
- **Non-Real-Time Polling Services (nrtPS)**—nrtPS is designed to support non-real-time services that require variable size data grant burst types on a regular basis.
- **Best Effort (BE) Services**—BE services are typically provided by the Internet today for web surfing. The use of polling simplifies the access operation and guarantees that applications receive service on a deterministic basis if required. In general, data applications are delay tolerant, but real-time applications, like voice and video, require service on a more uniform basis and sometimes on a very tightly controlled schedule.

For the purposes of mapping to services on SSs and associating irregular levels of QoS, all data communications are in the context of a connection. SFs may be provisioned when an SS is installed in the system. Shortly after SS registration, connections are associated with these SFs to provide a reference against which to request bandwidth. Additionally, new connections may be established when a customer’s service needs change. A connection defines both a SF and the mapping between peer convergence processes that utilize the MAC. The SF defines the QoS parameters for the PDUs that are exchanged once the connection has been established. SFs are the mechanism for UL and DL for QoS management.

Particularly, they facilitate the bandwidth allocation process. An SS requests UL bandwidth on a per connection basis. The BS grants the bandwidth to an SS as an aggregate of grants in response to per connection requests from the SS. The modulation and coding schemes are specified in a burst profile that may be adjusted adaptively for each burst to each SS. The MAC can make use of bandwidth-efficient burst profiles under favourable link conditions then shift to more reliable, although less efficient alternatives, as required to support the planned 99.999 percent link availability (QPSK to 16-QAM to 64-QAM). The request-grant mechanism is designed to be scalable, efficient, and self correcting. The WiMAX access system does not lose efficiency when presented with multiple connections per terminal, multiple QoS levels per terminal, and a large number of statistically multiplexed users.

A fifth one has been added with 802.16e: extended real-time Polling Service (ertPS) class. The purpose of scheduling is to allow every user, if possible, to have the suitable QoS required for his or her application. For example, a user sending an email does not require a real-time data stream, unlike another user having a Voice over IP (VoIP) application. The main mechanism for providing QoS is to associate packets crossing the MAC interface into a SF as identified by the CID. The MAC CS layer makes the classification of different user applications in these five classes of services. Once that operation is made, the role of the MAC CPS layer is to provide the connection establishment and maintenance between the two sides. In the PMP mode, the BS controls both uplink and downlink scheduling. Uplink request/ grant scheduling is performed by the BS with the intent of providing each subordinate SS with a bandwidth for uplink transmissions or opportunities to request the bandwidth. The link adaptation allows a fair performance for the different applications and a good optimisation of using the radio resources, realising the QoS required for the transmission of the data streams. The link adaptation is an adaptive modification of the burst profile, mainly modulation and channel coding types that take place in the physical link to adapt the traffic to a new radio channel condition. If the CINR decreases, change is made to a robust modulation and coding to improve the performance. Differently a less robust profile is picked up. [7]

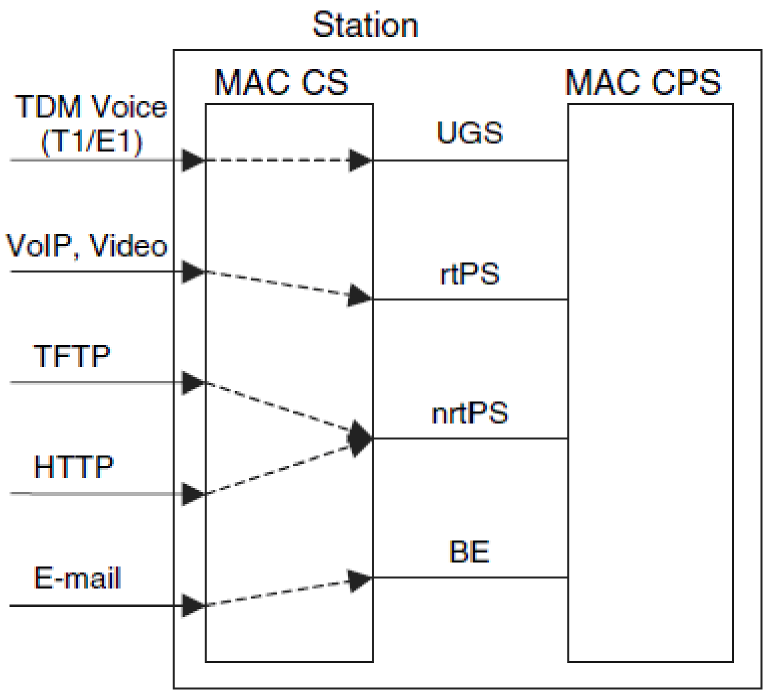

Figure 25 Scheduling mechanisms in a station

2.8 Convergence Sublayer (CS)

The service-specific Convergence Sublayer (CS), often simply known as the CS, is just above the MAC CPS sublayer. The CS uses the services provided by the MAC CPS, via the MAC Service Access Point (SAP). The CS performs the following functions:

- Accepting higher-layer PDUs from the higher layers. CS specifications for two types of higher layers are provided: the asynchronous transfer mode (ATM) CS and the packet CS. For the packet CS, the higher-layer protocols may be IP v4 or v6.
- Classifying and mapping the MSDUs into appropriate CIDs. This is a basic function of the QoS management mechanism of 802.16 BWA.
- Processing (if required) the higher-layer PDUs based on the classification.
- An optional function of the CS is PHS (Payload Header Suppression), the process of suppressing repetitive parts of payload headers at the sender and restoring these headers at the receiver.
- Delivering CS PDUs to the appropriate MAC SAP and receiving CS PDUs from the peer entity.

The service-specific CS is the top sublayer of the MAC Layer in WiMAX/802.16. The CS accepts higher-layer PDUs from the higher layers and transmits them to the MAC CPS where classical type MAC procedures are applied. Classifying and mapping the MSDUs into appropriate CIDs made by the CS are basic functions of the QoS mechanisms of WiMAX/802.16. Among other functions of the CS is the optional PHS the process of suppressing repetitive parts of payload headers at the sender and restoring the headers at the receiver. In the present version of the 802.16-2004 standards, two CS specifications are provided. The first CS specification is the ATM CS. The ATM CS is a logical interface that associates different ATM services with the MAC CPS SAP. The ATM CS accepts ATM cells from the ATM layer, performs classification and, if provisioned, PHS. Then the ATM CS delivers CS PDUs to the appropriate MAC SAP.

The other available CS specification is the packet CS. The packet CS is used for the transport of all packet-based protocols. Also, Classification and PHS are defined for the packet CS.

2.8.1 Connections and Service Flow

The CS provides any transformation or mapping of external network data received through the CS Service Access Point (SAP) into MAC SDUs received by the MAC Common Part Sublayer (CPS) through the MAC SAP. This includes classifying external network Service Data Units (SDUs) and associating them with the proper MAC Service Flow Identifier (SFID) and CID Classification and mapping are then based on two 802.16 MAC layer fundamental concepts:

- Connection. A connection is a MAC Level connection between a BS and an SS or inversely. It is a unidirectional mapping between a BS and an SS MAC peers for the purpose of transporting a SF's traffic. A connection is only for one type of service. A connection is identified by a CID information.
- SF is a MAC transport service that provides unidirectional transport of packets on the uplink or on the downlink. A SF is identified by a 32- bit SFID. The SF defines the QoS parameters for the packets that are exchanged on the connection.

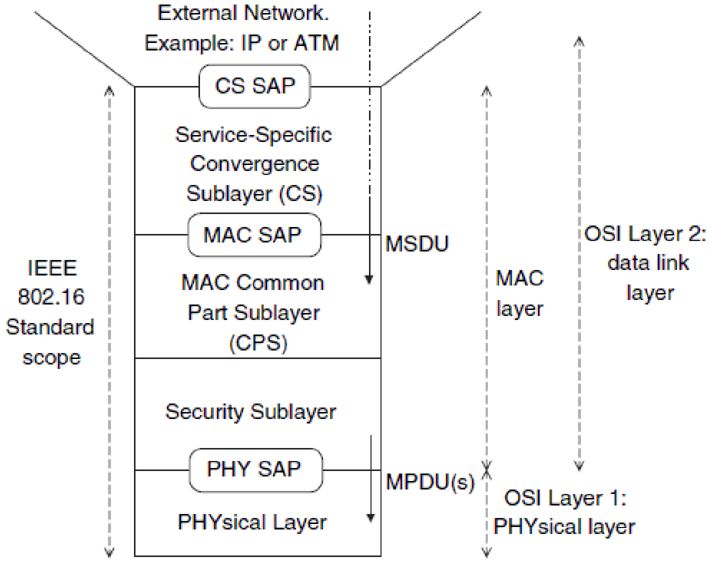

Figure 26 Protocol layers of the 802.16 BWA standard

The relation between the two is the following: only admitted and active SFs are mapped to a CID. In other terms:

- A SFID matches to zero (provisioned SFs) or to one CID (admitted or active SF).
- A CID maps to a SFID, which defines the QoS parameters of the SF associated with that connection.

The definitions of connection and SF in the 802.16 standard allow different classes of QoS to be found easily for a given element (SS or BS), with different levels of activation More details will now be given about connections and SFs.

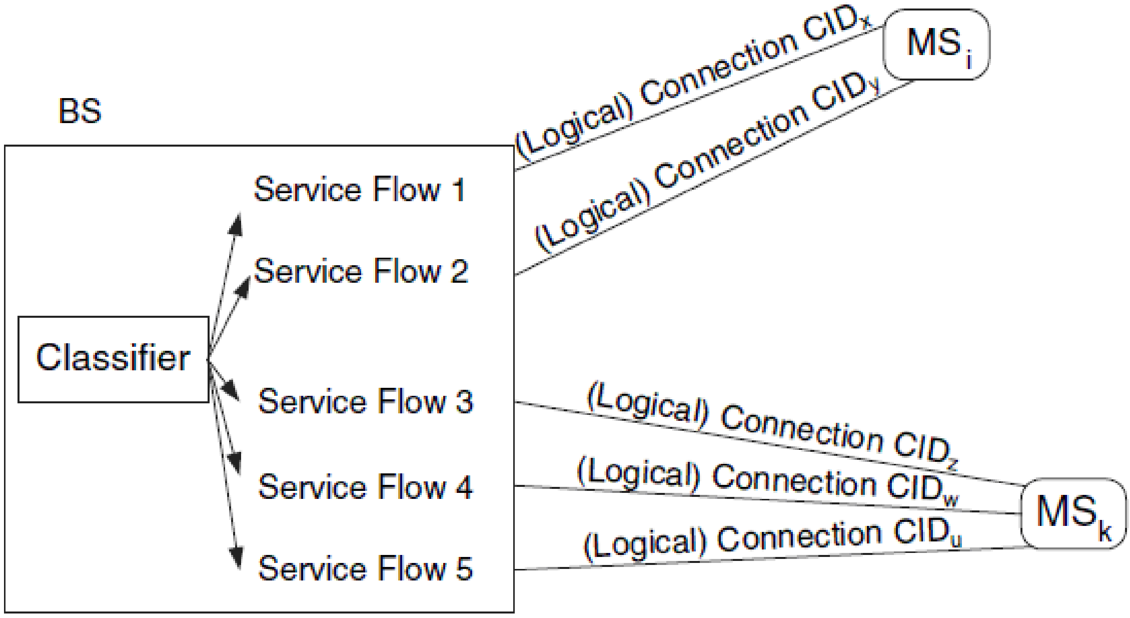

Figure 27 Illustration of service flows and connections

2.8.1.1Connection Identifiers (CIDs)

A CID identifies a connection where every MAC SDU of a given communication service is mapped into. The CID is a 16-bit value that identifies a unidirectional connection between equivalent peers in the MAC layers of a BS and an SS. All 802.16 traffic is carried on a connection. Then, the CID can be considered as a CID even for nominally connectionless traffic like IP, since it serves as a pointer to destinations and context information. The use of a 16-bit CID permits a total of 64K connections within each downlink and uplink channel. There are several CIDs defined in the standard. Some CIDs have a specific meaning. Some of the procedures introduced in this table, such as ranging, basic, primary and secondary management, AAS and others. Security associations (SAs) exist between keying material and CIDs.

2.8.2 Service Flows

A SF is a MAC transport service that provides unidirectional transport of packets on the uplink or on the downlink. It is identified by a 32-bit SFID. A SF is characterised by a set of QoS parameters. The QoS parameters include details of how the SS may request uplink bandwidth allocations and the expected behaviour of the BS uplink scheduler.

2.8.2.1 Types of Service Flow

The standard has defined three types of SF:

- Provisioned SF. This type of SF is known via provisioning by, for example, the network management system. Its AdmittedQoSParamSet and ActiveQoSParamSet are both null.
- Admitted SF. The standard supports a two-phase activation model that is often used in telephony applications. In the two-phase activation model, the resources for a call are first 'admitted' and then, once the end-to-end negotiation is completed, the resources are 'activated'.
- Active SF. This type of SF has resources committed by the BS for its ActiveQoSParamSet. Its ActiveQoSParamSet is non-null.

Each SF class is associated with the corresponding QoSParametersSets. These three types of SFs can be seen as complementary. A BS may choose to activate a provisioned SF directly, or may choose to take the path to active SFs by passing the admitted SFs. The model structure of these three SF types, taken from the standard. Having introduced the concepts of CID and SFID and their attributes, it is now possible to describe the process of classification and mapping made in the CS.

2.8.3 Classification and Mapping

As defined in the standard, classification is the process by which a MAC SDU is mapped on to a particular connection for transmission between MAC peers. The mapping process associates a MAC SDU with a connection, which also creates an association with the SF characteristics of that connection. This process allows 802.16 BWA to deliver MAC SDUs with the appropriate QoS constraints. Classification and mapping mechanisms exist in the uplink and downlink. In the case of a downlink transmission, the classifier will be present in the BS and in the case of an uplink transmission it is present in the SS. A classifier is a set of matching criteria applied to each packet entering the WiMAX/802.16 network. The set of matching criteria consists of some protocol-specific packet matching criteria, a classifier priority and a reference to a CID. If a packet matches the specified packet matching criteria, it is then delivered to the SAP for delivery on the connection defined by the CID. The SF characteristics of the connection provide the QoS for that packet.

The MAC of 802.16-2004 is connection-oriented, where the connections are virtual. For the purposes of mapping simultaneous different services and associating varying levels of QoS, all data communications are in the context of a connection. SFs may be provisioned when an SS is installed in the system. Shortly after SS registration, connections are associated with these service to provide a reference for the process of bandwidth request. Additionally, new connections may be established when an SS service needs change. A connection defines both the mapping between peer convergence processes that utilise the MAC and a SF. The SF defines the QoS parameters for the PDUs that are exchanged on the connection.

CHAPTER 3 STANDARDIZATION OF IEEE 802.16

3.1 IEEE 802.16 Task Groups

3.1.1 IEEE 802.16 Task Group m (TGm)

IEEE 802.16's 802.16 Task Group m (TGm) is chartered to develop an amendment to IEEE Standard 802.16 under the PAR P802.16m and the relevant Five Criteria Statement.

The PAR addresses "Air Interface for Fixed and Mobile Broadband Wireless Access Systems - Advanced Air Interface" approved by the IEEE-SA Standards Board on 6 December 2006.

http://www.ieee802.org/16/tgm/index.html [10]

Core Documents

http://www.ieee802.org/16/tgm/core.html

Other Official Documents - 2010/11

TGm Upload Folder

http://www.ieee802.org/16/tgm/index.html

Older Documents

http://www.ieee802.org/16/tgm/index_older.html

Contributed Documents

http://www.ieee802.org/16/tgm/index_older.html

3.1.2 IEEE 802.16's GRIDMAN Task Group

(Greater Reliability in Disrupted Metropolitan Area Networks)

http://www.ieee802.org/16/gridman/index.html

IEEE 802.16's GRIDMAN Task Group was initiated on 15 July 2010 to develop the P802.16n Project.

Approved Project Authorization Request (PAR) P802.16n (approved 2010-06-17. Expires 2014-12-31) (http://www.ieee802.org/16/pars/P802.16n.pdf)

Official Documents (numbered in the form "IEEE 802.16n-11/XXXX")

http://www.ieee802.org/16/gridman/index.html#contrib

Contributed Documents (numbered in the form "IEEE C802.16n-11/XXXX")

http://www.ieee802.org/16/gridman/index.html#contrib

3.1.3 IEEE 802.16's Machine-to-Machine (M2M) Task Group

IEEE 802.16's Machine-to-Machine (M2M) Task Group was initiated on 11 November 2010 to develop the P802.16p Project.

http://www.ieee802.org/16/m2m/index.html

Official Documents (numbered in the form "IEEE 802.16p-11/XXXX")

http://www.ieee802.org/16/m2m/index.html#contrib

Contributed Documents (numbered in the form "IEEE C802.16p-11/XXXX")

http://www.ieee802.org/16/m2m/index.html#contrib

3.1.4 IEEE 802.16's Maintenance Task Group

IEEE 802.16's Maintenance Task Group is chartered to maintain IEEE Std 802.16 through ongoing maintenance activities, including interpretations, and by leading the development of revision, corrigenda, and maintenance amendment projects

http://www.ieee802.org/16/maint/index.html

Completed Standardization Projects

IEEE Std 802.16-2009 (active standard)

IEEE Std 802.16-2004/Cor1 (obsolete)

http://www.ieee802.org/16/docs/06/80216-06_046.pdf

Database of CRs for 802.16 Maintenance

http://www.ieee802.org/16/maint/index.html#09_0007

Task Group Documents

http://www.ieee802.org/16/maint/index.html#09_0007

Task Group Contributions

http://www.ieee802.org/16/maint/index.html#09_0007

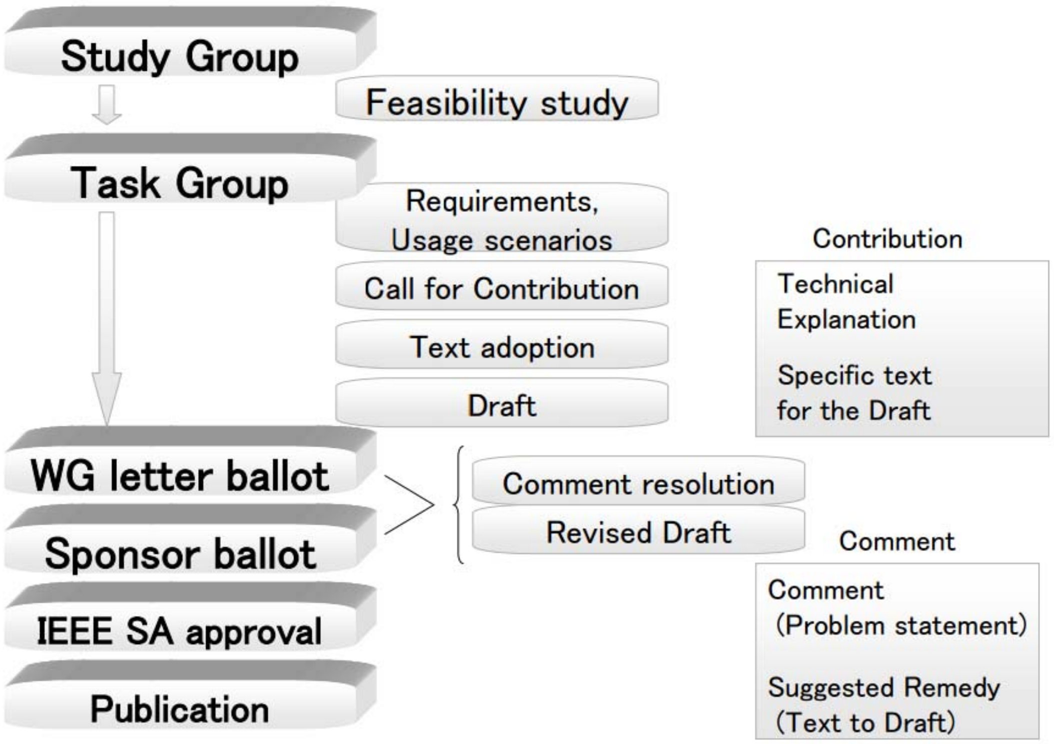

Figure 28 IEEE802 Standardization Process (Fujitsu)

3.2 IEEE 802.16 Study Groups

3.2.1 IEEE 802.16's GRIDMAN Study Group

IEEE 802.16's GRIDMAN Study Group, addressing "Greater Reliability In Disrupted Metropolitan Area Networks," was chartered on 20 November 2009.

The Study Group's initial charter period ended on 19 March 2010. It was then extended through 16 July 2010, when it completed its work and terminated. IEEE 802.16's GRIDMAN Task Group continues the standard development work.

http://www.ieee802.org/16/sg/gridman/index.html

Official Documents

http://www.ieee802.org/16/sg/gridman/index.html

Contributed Documents

http://www.ieee802.org/16/sg/gridman/index.html

3.2.2 IEEE 802.16's Mobile Multihop Relay (MMR) Study Group

http://www.ieee802.org/16/sg/mmr/index.html

IEEE 802.16's Mobile Multihop Relay Study Group was chartered on 22 July 2005. The Study Group expired on 30 March 2006, with the approval of its Project Authorization Request (PAR) P802.16j. The development of the P802.16j project has been assigned to IEEE 802.16's Relay Task Group.

3.2.3 IEEE 802.16's Study Group on License-Exempt Coexistence

http://www.ieee802.org/16/le/le_sg/index.html

IEEE 802.16's Network Management Study Group operated from 16 July through 19 November 2004.

3.3 IEEE 802.16 Standing Committees

3.3.1 IEEE 802.16's Project Planning Committee

IEEE 802.16's Project Planning Committee, initiated following Session #66, is tasked to develop proposed plans and schedules for new standards development projects.

Planning WG Project Schedules

Official Documents

http://www.ieee802.org/16/ppc/index.html

Contributed Documents

http://www.ieee802.org/16/ppc/index.html

3.4 Standards

IEEE 802.16 Standards

Telecommunication equipment manufacturers started introducing products for Broadband Wireless Access (BWA) at the end of the 90’s. But they were still looking for interoperable standard. The National Wireless Electronics Systems Testbed (N-WEST) called a meeting in 1998, about the need of an interoperable standard which resulted in the IEEE 802 standard. A lot of efforts were made in this regard which resulted later in the formation of IEEE 802.16 standard. Initially, the main focus of this group was to develop the radio interface for BWA which used the radio spectrum from the 10-66 GHz range. It also supports the LOS based Point to Multipoint (PMP) broadband wireless system.

State	TITLE	PROJECT APPROVAL DATE	Published	TITLE	COMMENT
superseded	802.16 -2001	11 September 2001	April 2002	Air Interface for 10-66 GHz	Now with drawn. It provided for basic high data links at frequencies between 11 and 66 GHz. Data rates up to 134 Mbps.
superseded	802.16a - 2003	10 November 2001 (draft 1)	1 April 2003 (IEEE)	Renumbering 802.16.3 Superseded to 802.16-2004	IEEE Standard for Local and metropolitan area networks — Part 16: Air Interface for Fixed Broadband Wireless Access Systems — Amendment 2: Medium Access Control Modifications and Additional Physical Layer Specifications for 2-11 GHz
superseded	802.16b		Not published (ieee802.org) October 2002 (https://publications.theseus.fi/bitstream/handle/10024/10234/Lopez%20Vizca%C3%83%C2%ADno.Jorge.pdf?sequence=2)	Called WirelessHUMAN QoS provisioning	Now with drawn. It increased the spectrum that was specified to include frequencies between 5 -6 GHz with also providing for QoS aspects. Licensed Exempt.
superseded	802.16c -2002	24 May 2002	15 January 2003 (ieee802.org)	10 – 66 GHz Detailed System Profiles	Coexistence and Interoperability

Terminated prior to Completion	802.16d	31 March 2003 (Draft 1)	Upgrade the 802.16a		
superseded	802.16 -2004	29 September 2003(Draft1)		Revision incorporating and obsolescing above 3 (revision/including of 802.16-2001, 802.16a,802.16c)	WiMAX Standard with additions in accordance with WiMAX Forum. 2-11 GHz Range. The Standard provided a number of Fixes and Improvements to 802.16a including the use of 256 carrier OFDM. Profiles for compliance testing are also provided, and the standard was aligned with the ETSI HipperMAN standard to allow for global deployment. The Standard only addressed fixed operation. Data rates up to 70 Mbps. Support for Advanced Antenna Systems (MIMO).
superseded	802.16e -2005	3 February 2004(draft 1)		Enhancements to support Mobility	WiMAX for moving SS. Provided for nomadic and mobile use. Lower data rates 15 Mbps. Including handover
superseded	802.16f -2005	30 September 2004(Draft 1)		Amendment for MIBs for fixed Systems (first amendment for 802.16-2004)	Management Information Base. Extension to support Multi hop capabilities required for Mesh Networking.
superseded	802.16g -2007	30 January 2006(draft 1)	31 December 2007 (IEEE)	Management Plane Third amendment for 802.16-2004	Management plane procedures and services
Active	802.16h- 2010	11 October	30 July 2010	Standard for	Air Interface for Broadband

		2006 (draft 1)	(IEEE)	Local and Metropolitan area Networks Second amendment for 802.16-2009	Wireless Access Systems Amendment 2: Improved coexistence mechanisms for Licensed – Exempt Operation.
Terminated prior to Completion	802.16i	10 February 2007(draft 1)			26 March 2008 (withdrawn)
Active	802.16j -2009	8 August 2007(draft 1)	12 June 2099 (IEEE)	First amendment for 802.16-2009	Multi hop relay specification.
Active	802.16k -2007	6 June 2006 (draft 1)	14 August 2007 (IEEE)	Standard for MAC Bridges amendment 2 Amendment for 802.1d-2004	802.16 Bridging
Active	802.16m	30 July 2009 (draft 1)	6 May 2011 (IEEE)	WiMAX 2 Third amendment for 802.16-2009	Air Interface for Broadband Wireless Access Systems Amendment 2: Improved Coexistence Mechanisms for License-Exempt Operation. Product Availability 2010/2011.
Pre-Draft Stage	802.16n	22 March 2010 (PAR : request date)		Air Interface for Broadband Wireless Access Systems Amendment : High Reliability Networks	31 December 2014 (PAR : expiration date)

				Fourth Amendment to IEEE Standard 802.16-2009	
Pre-Draft Stage	802.16p	27 July 2010 (PAR : request date)		Air Interface for Broadband Wireless Access Systems Amendment : Enhancements to Support Machine to Machine Applications	31 December 2014 (PAR : expiration date)
administratively withdrawn after five-year lifespan	802.16 /Conformance 01-2003	21 November 2002 (draft 1)	18 August 2003 (IEEE)	10 – 66 GHz Protocol Implementation Conformance Statement (PICS) applied to IEEE Std 802.16-2001	26 January 2009 (withdrawn)
administratively withdrawn after five-year lifespan	802.16/ Conformance 02 -2003	31 March 2003(draft 1)	25 February 2004 (IEEE)	10 – 66 GHz Test Suite Structure and Test Purposes applied to IEEE Std 802.16-2001	26 January 2009 (withdrawn)

	802.16/ Conformance 03 -2004	6 August 2003 (draft 1)	25 June 2004 (IEEE)	10 – 66 GHz Radio Conformance Tests (RCT) applied to IEEE Std 802.16- 2001	RCT for 10-66 GHz WirelessMAN-SC Air Interface 9 January 2010 (withdrawn)
administratively withdrawn after five-year lifespan	802.16 -2004 / Corl 1 – 2005	11 February 2004 (draft 1)	28 February 2006 802.16-2004/Cor1 not published separately, but only as part of IEEE Std 802.16e-2005	Including OFDMA	Corrigendum to 802.16 -2004
Active	802.16 / Conformance 04 -2006	1 April 2005 (draft 1)	15 January 2007 (IEEE)	Part 4 : Protocol Implementation Conformance Statement (PICS) conformance testing to IEEE Std 802.16-2004	Preformed for frequencies below 11 GHz
superseded	802.16.2 - 2001	September 1999 (IEEE)	10 September 2001(IEEE)	Coexistence for 10-66 GHz	*IEEE Recommended Practice for Local and Metropolitan Area Networks - Coexistence of Fixed Broadband Wireless Access Systems*
Active	802.16.2 - 2004	19 August 2002 (IEEE)	17 March 2004 (IEEE)	Revision of IEEE Std	*IEEE Recommended Practice for Local and Metropolitan Area*

				802.16.2-2001	*Networks - Coexistence of Fixed Broadband Wireless Access Systems*
	802.16.3	9 February 2001 (PAR: request date)		Air Interface for Fixed Broadband Wireless Access Systems	Frequencies range < 11 GHz
superseded	802.16c-2002	24 May 2002 (draft1)		15 January 2003 (IEEE)	*Part 16: Air Interface for Fixed Broadband Wireless Access Systems — Amendment 1: Detailed System Profiles for 10–66 GHz*
Pre-Draft Stage	P802.16Rev3 Project			Revision of IEEE Std 802.16, including P802.16h, P802.16j, and P802.16m (but excluding the WirelessMAN-Advanced radio interface, which is to be moved to a standalone standard).	expires 2015-12-31
superseded	802.16-2004/Cor2	10 January 2007 (IEEE)	22 May 2007 (IEEE)	Part 16: Air Interface for Fixed and Mobile Broadband Wireless	Corrigendum to IEEE Std 802.16-2004

				Access Systems	27 September 2007 (withdrawn)
Active	802.16 -2009	5 April 2007 (draft 1)	29 May 2009 (IEEE)	For MAN + LAN Part 16 : Air Interface for Broadband Wireless Access Systems.	Revision of IEEE Std 802.16. draft title : 802.16Rev2

Table 6 WiMAX Full list of Stadards

The IEEE 802.16 Working Group on Broadband Wireless Access Standards develops standards and makes recommendations to support the development and deployment of broadband Wireless Metropolitan Area Networks. The IEEE 802.16 is a unit of the IEEE 802 LAN/ MAN Standards Committee. This committee is working on developing interoperability standards for fixed broadband wireless access. A similar standard called HIPERACCESS is being developed in Europe by the standardization committee for Broadband Radio Access Networks (BRAN). While the US LMDS bands are 27.5–28.35 GHz, 29.1–29.25 GHz, and 31.075–31.225 GHz, the European standard band is 40.5–43.5 GHz.

The Broadband Wireless Access (BWA) industry is following a similar path to that of IEEE 802.3, IEEE 802.11 through the IEEE Working Group on Broadband Wireless Access, which is developing the IEEE-802.16 wireless MAN standard for wireless metropolitan area networks. This standard, which covers licensed and license-exempt bands from 2 to 66 GHz worldwide, is creating a good foundation for the development of this industry. The Working Group 802.16 began its work in July 1999. This group currently has about 200 members and some observers from over 100 companies.

The charter of the group is to develop standards that:

(a) use licensed spectrum

(b) use wireless links with microwave or millimeter wave radios

(c) are capable of broadband transmission at a rate greater than 2 Mbps

(d) are metropolitan in scale

(e) provide public network service to fee-paying customers

(f) provide efficient transport of heterogeneous traffic supporting quality of service (QoS)

(g) use point-to-multipoint architecture with stationary rooftop or tower mounted antennas.

The IEEE 802.16 group's work has primarily targeted the point-to-multipoint topology with a cellular deployment of BSs, each tied to CNs and in contact with fixed-wireless subscriber stations. Initial work has focused on businesses applications. However, attention has increasingly turned toward residential applications, especially as the lower frequencies have become available for two-way service.

Three subgroups have been established to produce standards for:

- *IEEE 802.16.1. Air interface for 10–66 GHz.*
- *IEEE 802.16.2. Coexistence of broadband wireless access systems.*
- *IEEE 802.16.3. Air interface for licensed frequencies in the 2–11 GHz range.*

The Working Group 802.16 is now completing a draft of the IEEE-802.16 Standard Air Interface for Fixed Broadband Wireless Access Systems. The document includes a flexible MAC layer. The PHY is designed for 10–66 GHz. This latter layer is also called informally the Local Multipoint Distribution Service (LMDS) spectrum. At the time of writing, the standard is still under development, however, the draft has passed the Working Group's letter ballot, pending resolution of comments proposed to improve it and its publication is planned soon.

The Working Group is also developing amendments to the base IEEE 802.16 standard to accommodate lower frequencies. Amendment 802.16a will deal with the licensed bands from 2 to 11 GHz. The primary target in the United States is the Multichannel Multipoint Distribution Service (MMDS) bands. The 802.16b amendment targets the needs of license-exempt applications around 5–6 GHz. The IEEE 802.16 committee maintains a close working relationship with standards bodies in the International Telecommunications Union (ITU) and the European

Telecommunications Standards Institute (ETSI), especially in relation to the Hiperaccess and HiperMAN programs.

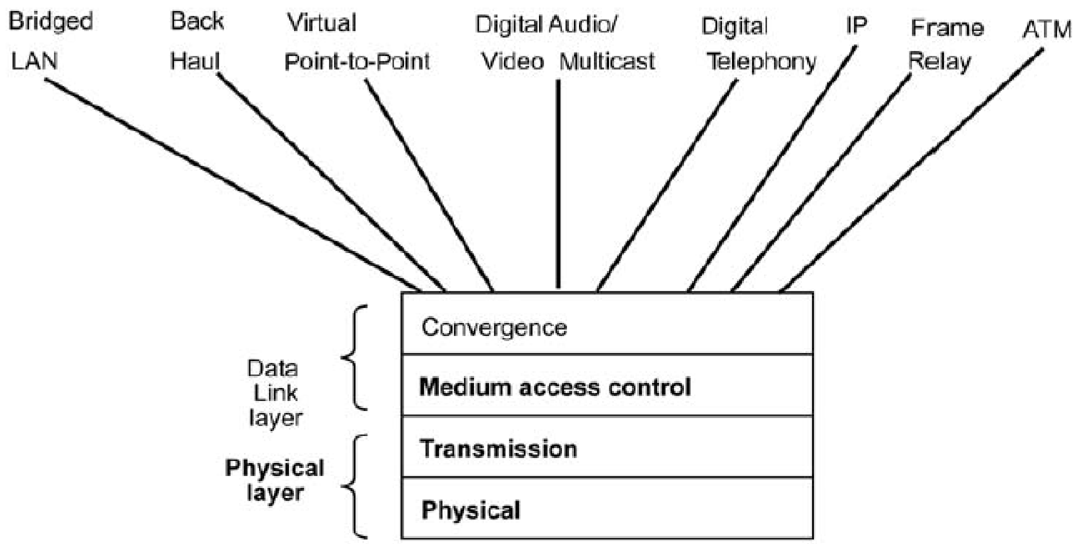

Figure 29 IEEE 802.16 protocol architecture

In the standards, the point-to-multipoint architecture assumes a time-division multiplexed downlink from the BS with subscriber stations in a given cell and sector sharing the uplink, typically by time-division multiple access. The uplink access is controlled by the BS, which has a set of scheduling schemes at its disposal in order to optimize the performance. The MAC protocol is connection-oriented and it is able to tunnel any protocol across the air interface with full QoS support. ATM and packet-based convergence layers provide the interface to higher protocols. However, the details of scheduling and reservation management are left unstandardized. There is a privacy sublayer that provides both encryption and authentication to secure access to these systems and protects them from hackers and unauthorized users. Figure 30 shows a wireless competitive local exchange carrier using ATM for distribution.

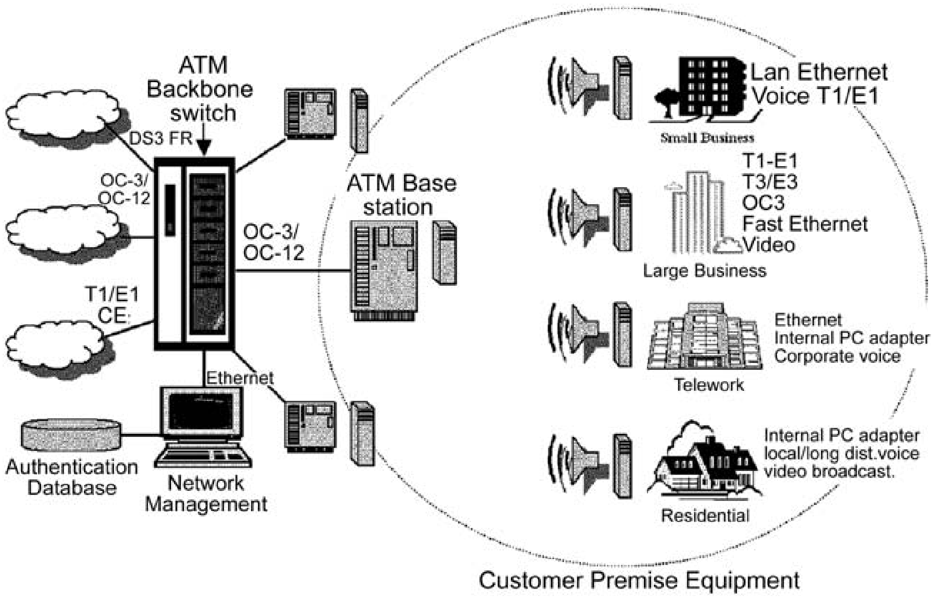

Figure 30 A wireless Competitive Local Exchange Carrier (CLEC) using Asynchronous Transfer

One important feature of the MAC layer is the option of allocating bandwidth to a subscriber station rather than to the individual connections that it supports. This has the advantage of allowing a smart subscriber station to manage its bandwidth allocation among its users. Clearly, this has the potential of making more efficient allocation in multitenant, commercial or residential buildings. Moreover, efficiency is improved by the provision for header suppression, concatenation, fragmentation and packing.

As mentioned earlier, the 802.16 group has been developing a standard for 2-–11 GHz BWA. In the United States, the primary targeted frequencies are in the MDS bands, mostly from 2.5 to 2.7 GHz. In other parts of the world, 3.5 GHz and 10.5 GHz are likely applications. Due to the fact that non-line-of-sight operation is practical and because of the lower component costs, those bands are seen as good prospects for residential and small business services. The spectrum availability is suitable for those uses. The group has decided to support both single-carrier and multi-carrier PHY options. In the single-carrier proposal, submitted by representatives of 16 companies, frequency-domain equalization is used. In the multicarrier proposal, submitted by representatives of 17 companies and an industry consortium, OFDM and OFDMA techniques are proposed. For more details see the proposals on the Web [10].

CHAPTER 4 QUALITY OF SERVICE IN WiMAX

4.1 Introduction

It is common knowledge that over the last decade there has been a major boost in communication networks. In fact, the development of high-performance backbone networks was immediately followed by the rapid dissemination of broadband wired access technologies, such as leased lines based on fiber-optic links, cable modems using coaxial systems, and digital subscriber line (xDSL) access networks. This gave users a whole new class of services that exploit the increasing number of available network resources. Many new services are based on multimedia applications, such as voice over IP (VoIP), video conferencing, video on demand (VoD), massive online gaming, and peer-to-peer. Unlike traditional TCP/IP services, multimedia applications usually require strict network guarantees such as reserved bandwidth or bounded delays.

The broadband access phenomenon has been investigated by the International Telecommunication Union (ITU), which reported in [14] that Broadband Wireless Access (BWA), although still in the early stage of its growth, is one of the most promising solutions for broadband access. Standards for BWA are being developed within IEEE Project 802, working group 16, also referred to as 802.16 [15]. To promote 802.16- compliant technologies, the WiMAX Forum was founded, with more than 300 member companies. According to the WiMAX forum, 802.16 technology is attractive in a wide variety of environments, including high-speed Internet access, WiFi hotspot backhaul, cellular backhaul, public safety services, and private networks. However, in [16], it is envisaged that the first 802.16-compliant products to be deployed will very likely be aimed at providing last-mile Internet access for residential users and small and medium-sized enterprises (SMEs). Specifically, 802.16 technology will address the market segment of high-speed Internet access for the residential customers market, especially in those cases where broadband services based on DSL or cable are not available, such as rural areas or developing countries. Instead, for the SME market, 802.16 will provide a cost-effective alternative to existing solutions based on very expensive leased-line services.

QoS means different things to different end users, as much depends on the application and the use to which the end user is putting it. It's therefore usual to employ a range of measurable performance parameters from which those appropriate to the particular end user can be selected. These parameters are most commonly:

- Bandwidth
- Latency
- Jitter
- Reliability

Bandwidth – the unit-time packet throughput – is probably the most basic QOS parameter for many end users, and is obviously limited by the physical-layer pipe between the BS and the client terminal in WiMAX (and other wireless technologies), and also by the number of clients that are active in parallel, since the overall system bandwidth is shared. Generally, if the overall bandwidth of a given system is big enough, some of the other QOS parameters will be less of an issue. For example, with enough bandwidth, access contention among different users is eliminated, which simplifies protocols and reduces latency.

Other parameters, such as latency and jitter, only come in once you are servicing multiple users in parallel and groups of subscribers to the system.

Latency – the end-to-end packet transmission time – is caused by the granularity of the physical-layer chain, and is typically almost 5ms in 802.16 systems. Latency is also affected by how packet queuing, various QOS protocols, and user characterizations are implemented.

Jitter – the variation of latency over different packets – has to be limited by packet buffering. Since the buffer on the mobile terminal is likely to be small, jitter control in wireless networks tends to fall onto the BS, which has to ensure that different packets receive different prioritization if necessary.

Reliability – the proportion of successfully delivered packets – leads to more complications in wireless networks than in fixed-line ones, and the problems are specifically acute in mobile networks. The issue is that wireless networks have an inherent unreliability because of the vicissitudes of radiowave propagation – especially to mobile terminals with small antennas and low powers in cluttered environments such as urban areas. So packet loss (and numbers of errored packets) will be higher than for fixed-line networks.

4.2 QoS Management

The IEEE802.16d WiMAX standard offers four categories for the prioritization of traffic:

(1) Unsolicited Grant Service (UGS),

(2) Real-Time Polling Service (rtPS),

(3) Non-Real Time Polling Service (nrtPS), and

(4) Best Effort (BE).

Each of these service classes is intended for specific application(s).

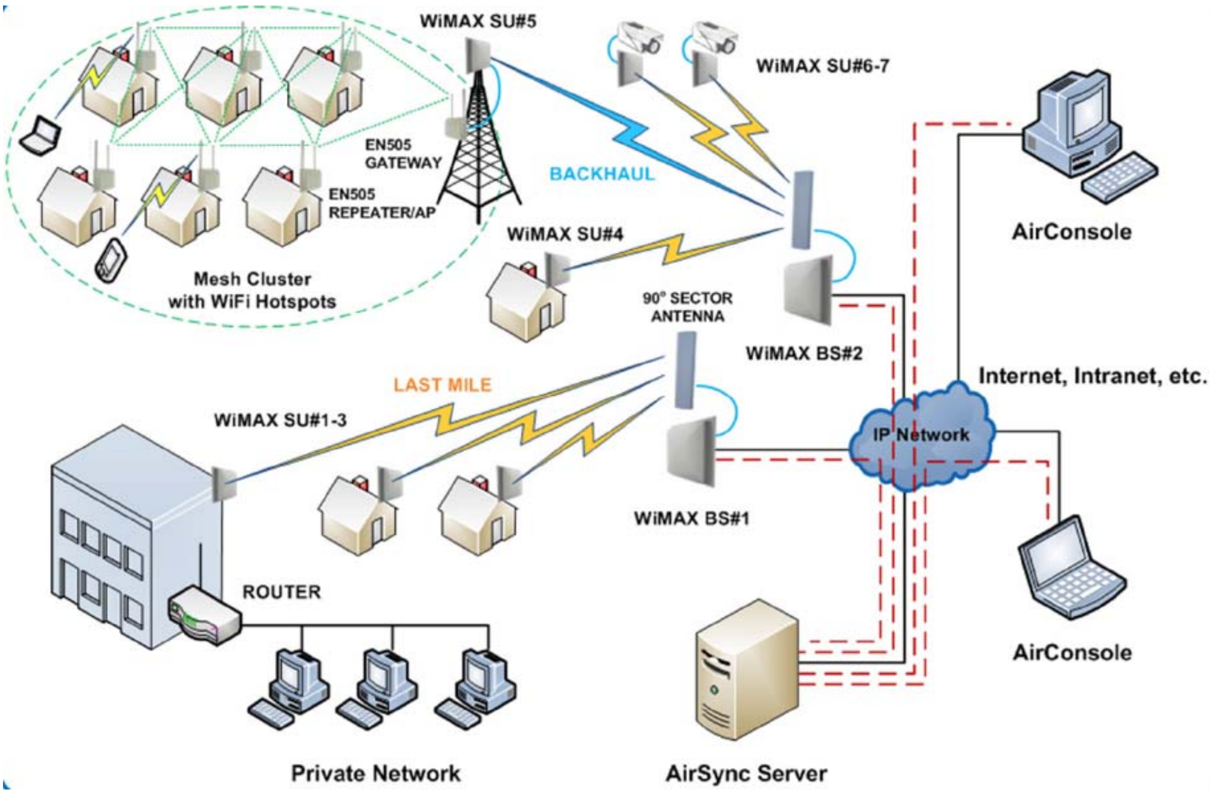

Figure 31 Using WiMAX QoS classes to support Voice, Video and Data Traffic

Unsolicited Grant Service (UGS)

UGS is primarily intended for Constant-Bit-Rate (CBR) services such as VoIP, which means that achieving low latency and low jitter is very important. At the same time, low percentage of packet drops is possible. UGS flows are configured to send fixedsize packets at recurring intervals with as little latency and jitter as possible.

UGS has the following set of features:

- UGS flows are buffered separately from each other and from flows in service classes such as nrtPS and BE.
- UGS SFs are given strictly higher priority versus nrtPS and BE SFs, which implies that the system serves nrtPS and BE packets only after it has finished transmitting all outstanding UGS packets.

In the upstream, the system uses UGS to bypass the normal request-grant mechanism for upstream traffic by allowing the BS to give automatic grants to a UGS flow. Also, over-the-air latency in a WiMAX network is small (5-40 ms) relative to the latency on an IP backbone (100ms), which inherently ensures minimal latency.

Real-Time Polling Service (rtPS)

The Real-Time Polling Service (rtPS) on the other hand is designed to support real-time SFs that generate variable size data packets on a periodic basis, such as MPEG video. The service offers real-time, periodic, unicast request opportunities, which meet the flow's real-time needs and allow the Subscriber Station (SS) to specify the size of the desired grant. A major drawback to using this QoS approach is the impact on the overall sector throughput. Polling overhead can reach up to 60% when using 3.5MHz channel.

This service requires more request overhead than UGS, but supports variable grant sizes for optimum data transport efficiency. Unlike UGS, the polling overhead exists even when the flows are idle, and for as long as they are active.

Best Effort (BE)

The BE service is intended to support data streams that don't require minimum guaranteed rate, and could be handled on best available basis. Unicast polling requests are not guaranteed in this case, requiring contention requests to be used. BE packets may therefore take a long time to transmit during network congestions.

4.3 Scheduling

A scheduler is present in both the BS and (BS) and Subscriber Station (SS). The BS schedule controls all system parameters. It is the role of the BS to determine the burst profile and transmission periods for each connection. The choice of the coding and modulation parameters are decisions that are taken by the BS scheduler based on the quality of the link and the network load and demand.

The BS scheduler continuously monitors the received CINR values of each link, and determines the bandwidth requirements for each station taking into consideration the service class for each connection and the quantity of traffic required. The role of the SS scheduler is to classify all of the incoming packets into the SS different connections.

Application	Service Class
TI/EI (over IP)	UGS
VoIP	UGS
MPEG	rTPS
FTP	nrTPS
TFTP	nrTPS
HTTP	nrTPS
Email	BE

Table 7 Lists the scheduling service types that can be used for some of the standard applications.

4.3.1 Bandwidth Request Mechanism

In the IEEE 802.16 standard, the following types of bandwidth requests are defined [7], [21].

The Bandwidth Request Message, this type of bandwidth request defines the incremental mode and the aggregate mode described.

The *Incremental Bandwidth Request* (IBR) is sent by the subscriber when the amount of bandwidth acquired is not enough for transmission. There is no specific amount of bandwidth indicated. The IBR introduces unfairness when multiple subscribers are to be satisfied regardless of the existing amount of bandwidth.

Unlike the IBR, the subscriber specifies the amount of bandwidth through the *Aggregate Bandwidth Request* (ABR) mode. Thus, ABR is considered as a fair and accurate mode of request in the sharing of bandwidth.

The Implicit Request, commonly designed for UGS scheduling class, is utilized for flows that do not demand for a request message at the connection setup as the bandwidth is automatically assigned by the BS. Thus, a bandwidth request message is not required. It is at this point that the implicit request is sent when a better treatment is required.

The *Piggyback request* is designed for other scheduling classes other than UGS. It consists of a piggyback grant-request sub-header and an extended piggyback request.

4.3.2 Bandwidth Grant Mechanism

In Figure 32, a request/grant mechanism is illustrated. After being admitted into the network and for security purposes, a SF is assigned an authentication number before the BS establishes a connection. The granting mechanism is processed by the BS to various subscriber stations in the network. A grant is defined as the opportunity of transmitting packets within a specific duration of time. Through the grant mechanism, an amount of bandwidth is allotted to subscribers. The BS however ensures that the bandwidth grant would not affect the connection established before the grant process by maintaining the same QoS after bandwidth grant.

The IEEE 802.16 standard defines two types of bandwidth grant:

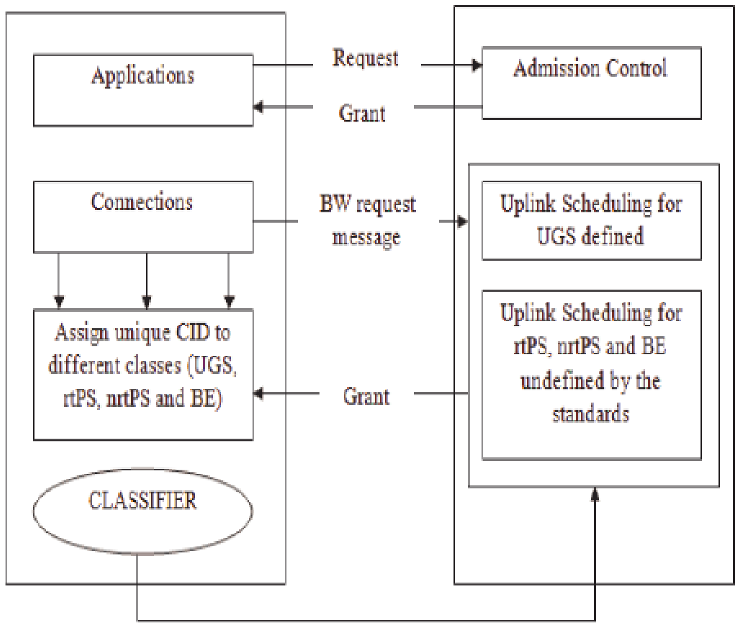

Figure 32 Bandwidth request/grant mechanism [12]

Grant per Connection (GpC) used for an amount of bandwidth granted for a specific requested connection and Grant per Subscriber Station (GpSS) is provided to a large number of subscribers which needs to be shared among multiple connections.

4.3.3 Scheduling Algorithms

The First-in-First-out (FIFO) scheduling algorithm is known for its simplicity of serving packets with no priority considered. The FIFO algorithm [22] does not consider the QoS requirements of all packets in the network which makes it inappropriate for real-time applications. Strictly designed for delay-sensitive packets, the Earliest Deadline First (EDF) prioritizes only packets with deadline regardless of other packets in the network. It thus creates some level of unfairness for delay-insensitive packets especially when a continuous set of delay-sensitive packets are to be served.

Implemented to reduce unfairness in some of the scheduling algorithms, Round Robin (RR) scheduling [23] serves packets in a round robin way (a queue after another) until the complete round is made regardless of the QoS requirements of the applications. RR however is not suitable for variable packets size. An enhancement of the RR algorithm known as Weighted Round Robin (WRR) [23] was developed based on a weight basis to generate some level of priority amongst packets. The heavier the packets weight, the higher the priority to get served at first. In cases when a stream of continuous packets with heavier weight is involved, packets with lower weight suffer from bandwidth allocation.

Based on RR, the Deficit Round Robin (DRR) [4.13, 4.15] attempts to produce the QoS as expected by the user by generating a deficit counter and a quantum value to dequeue its packets. Yet, in a round robin manner, a queue de-queues its packets when the packet size located at the head of the queue is less than the deficit counter. Otherwise, the former is retained in the queue and the later is incremented by the quantum. After serving a queue, the deficit counter is decreased by the number of bits served in the specific queue. In other words, the deficit counter keeps track of the served bits in a circular fashion whereas the quantum defines the number of bits acquired by a queue. On analysis of the DRR performance, it is seen that the algorithm tries to satisfy all packets in a round robin way. However, if many queues that contain delay-sensitive packets are to get served, these would suffer from delay as queues have to wait for the complete round to transmit another bit.

A well established scheduling algorithm defined as Modified Deficit Round Robin (MDRR) scheduling algorithm was designed for Cisco routers. MDRR differs from DRR by the quantum. The former algorithm is assigned a value as given in [23], [16] while the latter algorithm is assigned the packet size in a queue. MDRR was implemented to schedule rtPS and nrtPS scheduling classes and offers same bandwidth sharing to both regardless of their QoS specifications. It improves the DRR algorithm by diminishing the delay present in DRR in serving each queue whenever the queue is visited. No priority of any kind is determined in the MDRR algorithm since the same amount of bandwidth is given to rtPS and nrtPS class. This process stops only under the following conditions. When the deficit counter is zero or when no more bandwidth is available for allocation or when the ULMAP (Uplink-Mobile Application Part) message is ready to be broadcasted to different users in the network [22]. Newer scheduling algorithms are of great importance to satisfy as many constraints as possible in the network.

Scheduling algorithm	Advantages	Disadvantages

FIFO	Simple principle Fast dequeuing process	Same treatment to all packets
PQ	Based on priority level	Unfair to a continuous set of priority with higher level
EDF	Based on deadline Suitable for real-time applications	Unfair to non-real-time applications
RR	Based on round robin	Allocate same amount of bandwidth Unfair to variable packets. Unfair to real-time applications
WRR	Based on weight principle	Packets dropped Unfair to lower weight
DRR	Based on deficit counter and quantum Solves the unfairness in RR	Unsuitable for delay-sensitive packets when many queues are involved Delay
MDRR	Similar to DRR Reduces delay in DRR	Packets dropped Unsuitable for delay-sensitive packets

Table 8 Advantages and Disadvantages of existing algorithms

As seen in the Table 8, each of the algorithms described above presents some advantages and disadvantages that may influence the QoS of heterogeneous traffic. Thus, an enhanced MDRR-based scheduling algorithm realizes the QoS of real-time application while maintaining QoS of non real-time applications in WiMAX networks.

4.4 QoS support in IEEE 802.16

The 802.16 standard specifies two modes for sharing the wireless medium: point-to-multipoint (PMP) and mesh (optional). With PMP, the BS serves a set of SSs within the same antenna sector in a broadcast manner, with all SSs receiving the same transmission from the BS. Transmissions from SSs are directed to and centrally coordinated by the BS.

On the other hand, in mesh mode, traffic can be routed through other SSs and can occur directly among SSs. Access coordination is distributed among the SSs. The PMP operational mode fits a typical fixed BWA scenario, where multiple service subscribers are served by one centralized service provider so that they can access external networks (e.g., the Internet) or services (e.g., Digital Video Broadcasting — DVB). In this study we focus on the PMP mode alone.

In PMP mode, uplink (from SS to BS) and downlink (from BS to SS) data transmissions occur in separate time frames. In the downlink subframe, the BS transmits a burst of MAC protocol data units (PDUs). Since the transmission is broadcast, all SSs listen to the data transmitted by the BS. However, an SS is only required to process PDUs that are addressed to itself or that are explicitly intended for all the SSs. In the uplink subframe, on the other hand, any SS transmits a burst of MAC PDUs to the BS in a time-division multiple access (TDMA) manner. Based on measurements at the PHY layer, any SS adapts over time the interval usage code (IUC) in use, that is, modulation, rate, and forward error correction (FEC) scheme, for both downlink (downlink IUC, DIUC) and uplink (uplink IUC, UIUC) transmissions. Downlink and uplink subframes are duplexed using one of the following techniques, as shown in Fig. 33: FDD is where downlink and uplink subframes occur simultaneously on separate frequencies, and TDD is where downlink and uplink subframes occur at different times and usually share the same frequency. SSs can be either full duplex (i.e., they can transmit and receive simultaneously) or half-duplex (i.e., they can transmit and receive at nonoverlapping time intervals).

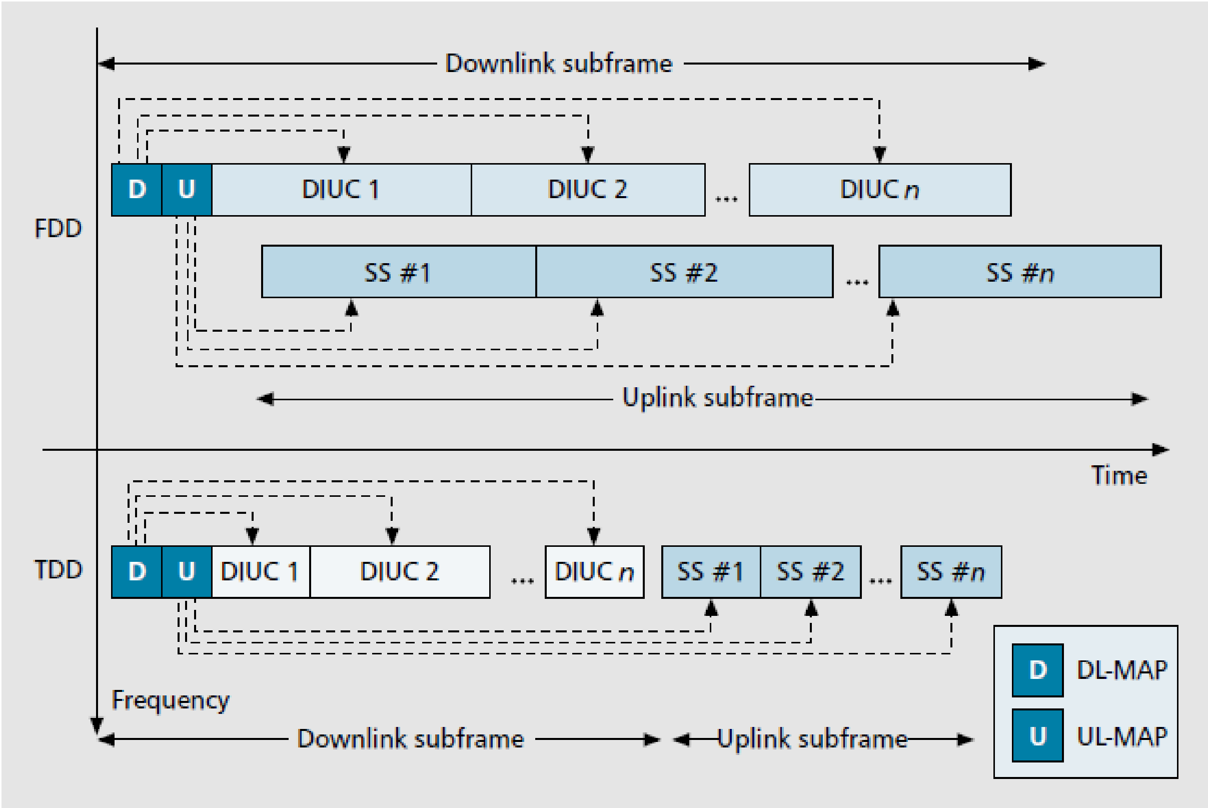

Figure 33 Frame structure with FDD and TDD.

The MAC protocol is connection-oriented: all data communications, for both transport and control, are in the context of a unidirectional connection. At the start of each frame, the BS schedules the uplink and downlink grants in order to meet the negotiated QoS requirements. Each SS learns the boundaries of its allocation within the current uplink subframe by decoding the UL-MAP message. On the other hand, the DL-MAP message contains the timetable of the downlink grants in the forthcoming downlink subframe. More specifically, downlink grants directed to SSs with the same DIUC are advertised by the DL-MAP as a single burst. Both maps are transmitted by the BS at the beginning of each downlink subframe, as shown in Fig.33, for both FDD and TDD modes. Figure 33 shows the blueprint of the functional entities for QoS support, which logically reside within the MAC layer of the BS and SSs. Each downlink connection has a packet queue (or *queue*, for short) at the BS (represented with solid lines). In accordance with the set of QoS parameters and the status of the queues, the *BS downlink scheduler* selects from the downlink queues, on a frame basis, the next service data units (SDUs) to be transmitted to SSs. On the other hand, uplink connection queues (represented in Fig. 33 by solid lines) reside at SSs.

Since the BS controls the access to the medium in the uplink direction, bandwidth is granted to SSs on demand. For this purpose, a number of different bandwidth-request mechanisms have been specified. With *unsolicited granting*, a fixed amount of bandwidth on a periodic basis is requested during the setup phase of an uplink connection. After that phase, bandwidth is never explicitly requested. A *unicast poll* consists of allocating to a polled uplink connection the bandwidth needed to transmit a bandwidth request. If the polled connection has no data awaiting transmission (*backlog*, for short), or if it has already requested bandwidth for all of its backlog, it will not reply to the unicast poll, which is thus wasted. Instead, *broadcast polls* are issued by the BS to all uplink connections. The main drawback in this mechanism is that a collision occurs whenever two or more uplink connections send a bandwidth request by responding to the same poll, in which case a truncated binary exponential backoff algorithm is employed. Finally, bandwidth requests can be *piggybacked* on a PDU. However, this mechanism is effective only if the connection has some backlog for which bandwidth reservation has already been issued.

Bandwidth requests are used on the BS for estimating the residual backlog of uplink connections. In fact, based on the amount of bandwidth requested (and granted) so far, the *BS uplink scheduler* estimates the residual backlog at each uplink connection (represented in Fig. 3 as a virtual queue by dashed lines), and allocates future uplink grants according to the respective set of QoS parameters and the virtual status of the queues. However, although bandwidth requests are per connection, the BS nevertheless grants uplink capacity to each SS as a whole. Thus, when an SS receives an uplink grant, it cannot deduce from the grant which of its connections it was intended for by the BS. Consequently, an *SS scheduler* must also be implemented within each SS MAC, in order to redistribute the granted capacity to all of its own connections (Fig. 34).

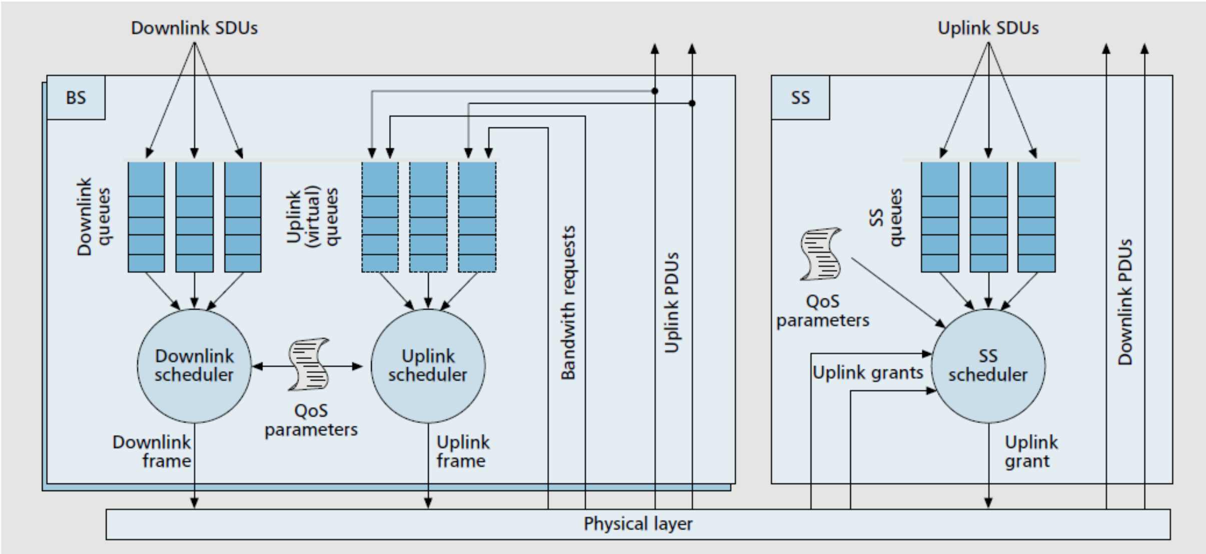

Figure 34 QoS functions within the BS and SSs.

The 802.16 document clearly states that the definition of both the BS (uplink and downlink) and the SS scheduling algorithms is out of the scope of the standard, and is thus left up to the manufacturers [4.5, p. 139]. However, based on the above mentioned functions and mechanisms, the 802.16 MAC specifies four different *scheduling services* in order to meet the QoS requirements of multimedia applications: unsolicited grant service (UGS), real-time polling service (rtPS), non-real-time polling service (nrtPS), and best effort (BE). Each scheduling service is characterized by a mandatory set of QoS parameters, which is tailored to best describe the guarantees required by the applications that the scheduling service is designed for. Furthermore, for uplink connections, it also specifies which mechanisms to use in order to request bandwidth.

4.5 QoS in 802.16e (Mobile WiMAX)

The QoS framework in IEEE 802.16e is based on SFs. An SF is a logical unidirectional flow of packets between the access service network gateway (ASN-GW) and a mobile station (MS) with a particular set of QoS attributes (e.g., packet latency/jitter and throughput) identified by a connection ID [20]. Based on IEEE 802.16e, packets traversing the medium access control (MAC) interface are associated with SFs according to classifier rules. Figure 35 demonstrates SFs in IEEE 802.16e.

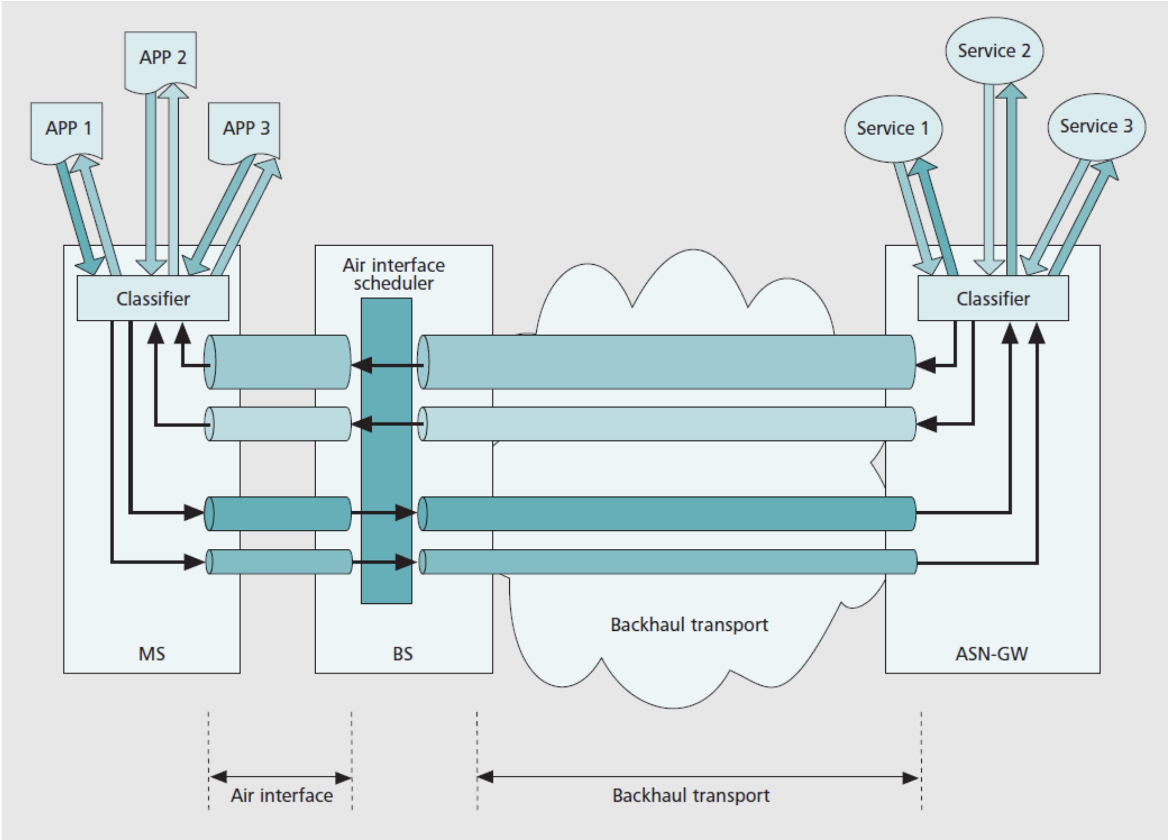

Figure 35 Service flows in the WiMAX QoS framework.

Traffic mapping to appropriate SFs is done at the ASN-GW for downlink (DL) and at the MS for uplink (UL) directions, respectively. Between the ASN-GW and the BS, the QoS of the SFs is supported by backhaul transport QoS. On the air interface, a BS scheduler provides QoS for DL, and cooperation between the BS and MS schedulers provides QoS for UL. This air interface scheduler at the MAC sublayer determines how radio resources are assigned among multiple SFs based on QoS attributes. Resources assigned to an MS enable it to receive traffic over DL and transmit data over UL. Details of air interface scheduler operation are not specified by the standard. Therefore, it is vendor-specific. Traffic classification and mapping from application packets onto SFs in WiMAX is done at the convergence sublayer (CS), based on protocol-specific packet matching criteria like a combination of five-tuple, such as source and destination IP addresses, source and destination port address, protocol, and differentiated services codepoint (DSCP) [20].

IEEE 802.16e supports both QoS control paradigms: *network-initiated*, where SF creation is initiated by the BS, and *terminal-initiated*, where SF creation is initiated by the MS. With network-initiated, an application function (AF) inside the network can trigger messaging signals to set up SFs with appropriate QoS attributes. Consequently, the client application can be left access-agnostic, and there is no need for accessspecific information in application layer signaling [20]. On the other hand, with terminal-initiated QoS control, the MS requests creation of SFs with appropriate QoS attributes. Hence, the client application is aware of the specifications of the access QoS model [20]. Network-initiated SF creation is a mandatory, but terminal-initiated SF creation is an optional capability of IEEE 802.16e [20]. SFs may be created, changed, or deleted through a series of MAC management messages referred to as DSX (i.e., DSA, DSC, and DSD).

4.5.1 Service Flow Types in EEE 802.16e and associated parameters

IEEE 802.16e supports five SF types [20]:

1. **Unsolicited grant service (UGS)**: Supports real-time traffic with fixed-size data packets on a periodic basis
2. **Real-time polling service (rtPS)**: Supports real-time traffic with variable-size data packets on a periodic basis
3. **Extended rtPS (ertPS)**: Supports real-time traffic that generates variable-size data packets on a periodic basis with a sequence of active and silence intervals
4. **Non-real-time polling service (nrtPS)**: Supports delay-tolerant traffic that requires a minimum reserved rate
5. **Best effort (BE) service**: Supports regular data services. The following and Table 3 summarize some key SF QoS attributes in the IEEE 802.16e standard and provide some targeted traffic types for each SF:

Service flow type	MRTR	MSTR	Max latency	Max jitter	Traffic priority	Targeted traffic
UGS		x	x	x		Constant bit rate(CBR)

						services, TDM services
ertPS	x	x	x	x	x	VoIP with suppression or activity detection
rtPS	x	x	x		x	Streaming audio and video
nrtPS	x	x			x	File transfers
BE		x			x	Web browsing, email

Table 9 QoS IEEE 802.16e service flow types, some key QoS parameters, and targeted traffic types.

- **Maximum sustained traffic rate (MSTR)**: Defines capping rate level of an SF
- **Maximum traffic burst**: Defines the maximum continuous burst a system should accommodate for a service
- **Minimum reserved traffic rate (MRTR)**: Specifies the minimum rate guaranteed to an SF
- **Maximum latency**: Specifies maximum packet delay over the air interface
- **Tolerated jitter**: Specifies maximum packet delay variation (jitter) for an SF
- **Traffic priority**: Can be exploited to adjust the priority of packets of different SFs based on a combination of subscribers' profiles and services mapped to SFs
- **Unsolicited grant interval (UGI)**: Defines the time interval between successive data grant opportunities for an SF over DL

- **Unsolicited polling interval (UPI)**: Defines the maximal interval between successive polling grant opportunities for an SF over UL WiMAX uses a BE SF, referred as the initial SF (ISF), to establish IP connectivity during network entry before any packet transmission and reception.

CHAPTER 5 INTERWORKING

The network reference model is based on an IP service model and the network architecture should be unified so it can support fixed, nomadic and mobile deployments.

The total network can be divided logically into three main components:

1. Mobile Stations (MS), which are used by the end user to access the network.
2. Access Service Network (ASN), which consists of one or more BSs 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 CN functions.

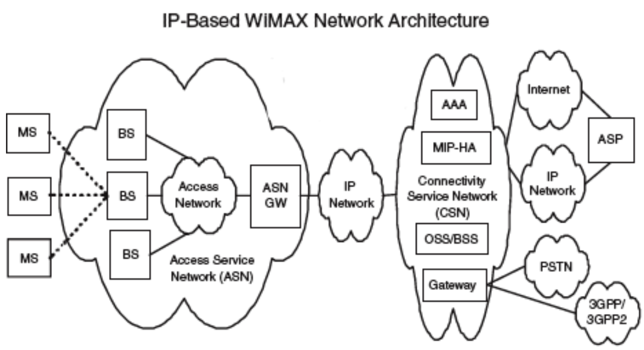

Figure 36 WiMAX Architecture[41]

Below you can see a number of functional entities and interfaces between those entities of the network reference model:[41]

- 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, DHCP (Dynamic Host Control Protocol) 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 BSs, 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.

5.1 Analysis of WiMAX Architecture

The WiMAX network is based on three basic components, like ASN, CSN and MS. The main network has a central IP core which is surrounded by the ASN-gateway. This gateway is connected to the CSN. The main IP core is connected to the backbone network to provide help and coverage. The WiMAX network, which is also known as ASN, handles the micro and macro BSs, which provide WiMAX access to the end users (MS).

The CSN is an important part of the WiMAX architecture, which provides the authentication to the end users. CSN is also responsible for providing roaming among the network service providers. Additionally, is accountable for security and QoS of the end users and for this reason uses several protocols. Finally, CSN handles the IP address management.

The IP network is in the middle of ASN and CSN. The CSN provides the internet and the telecommunications connectivity and thus, the ASP communicates with BSs and mobile stations.

Through WiMAX architecture, end users have further firewall for security and also can make impossible amendments.

5.2 UMTS

The well established Third Generation (3G) network Universal Mobile Telecommunications System (UMTS) made it possible to provide high mobility with wide area coverage but can support low to medium data rate which is not sufficient to satisfy data-intensive applications and the service charge is also very high. In addition, UMTS is not suitable for small indoor and densely populated areas. Recently, WiMAX, IEEE 802.16e was standardized to support mobility to the end user with wider coverage and faster speed. The salient features of the mobile WiMAX (IEEE 802.16e) are high data rates up to 63 Mbps for Down Link (DL) and 28 Mbps for Up Link (UL), QoS scalability, security and mobility supporting handover schemes with latencies less than 50 ms (WiMAX Forum™, 2006). Also the deployment cost of the Mobile WiMAX (IEEE 802.16e) is very low. The average 3G spectrum cost per Hz is 1000 times higher than the average WiMAX spectrum cost per Hz in Europe. However, this convergence of different IP-base networks leads the operators to new challenges in terms of quality and capacity to support QoS with required specifications, even at the cell area running out of bandwidth capacity with so many concurrent users. Henceforth, there should be new opportunities in service handover to other technologies to utilize the spectrum more efficiently. [31]

The mobility between UMTS and WiMAX is referred to a partially overlapping handover since the WiMAX coverage is in order of the UMTS coverage area. Therefore, the handover from one network to another should be done quickly to keep the link, principally when the speed of the mobile terminal is high.

The mobile subscriber (MS) is a mobile node which can be connected with both UMTS network and WiMAX network but not concurrently. As a result, the handover between these two technologies is difficult.

The WiMAX Access network (AN) provides the WiMAX access services for the MS. The mobility inside WiMAX network is managed by the WiMAX HA, placed between the ASN gateway and the WAG. The WiMAX HA is not mandatory included in 3GPP CN to keep its independence from 3GPP system. The Foreign Agents (FAs), located in ASN Gateway are considered as the local FAs in the interworking architecture. The WiMAX AN is connected to the UMTS network via WAG and to the 3GPP AAA server for the WiMAX authentication process.

The WAG is a gateway through which the data from/to WiMAX AN is routed to provide MS with 3GPP services. The functions of WAG include enforcing routing of packets through PDG, representing accounting information and filtering out packets. The premier functions of PDG are to route the packets received from/sent to the PDN to/from the MS and to perform the FA functions.

The mobility within the UMTS network is managed by its own mobility mechanism and the FA functions implemented in the GGSN. For the sake of enabling the vertical handover between these two technologies, the HA is placed in the PDN and controls FAs of both WiMAX and UMTS networks.

In WiMAX network, each time the mobile changes its ASN gateway, it will get a new local IP address through the DHCP server. The ASN GW can know about this new local IP address and also ask to the DHCP server the WiMAX HA's address since it plays the role of the DHCP relay agent in the DHCP discovery process. The ASN GW then informs the serving BS the MS's new local IP address and sends the Mobile IP (MIP) registration to the WiMAX HA. A generic IP-in-IP tunnel such as Generic Routing Encapsulation (GRE) may be used to transfer the IP packets between the WiMAX HA and the FA. [38]

Each time the mobile changes the connection to the UMTS network, it will insert the PDP context activation procedure. No IP address is allocated to the MS at the PDP context activation. The remote address supplied by HA or an external entity in PDN will be kept same and will be informed to the GGSN via PDP context activation. The remote IP address is a global home address that is used to address to the external network and the correspondent node. It may be a static address or a dynamic address gathered from the HA or another external entity when the mobile first time connects to the network, discovers and registers with the HA. The PDG/GGSN is then liable for relaying MS's remote allocated IP address to the MS.

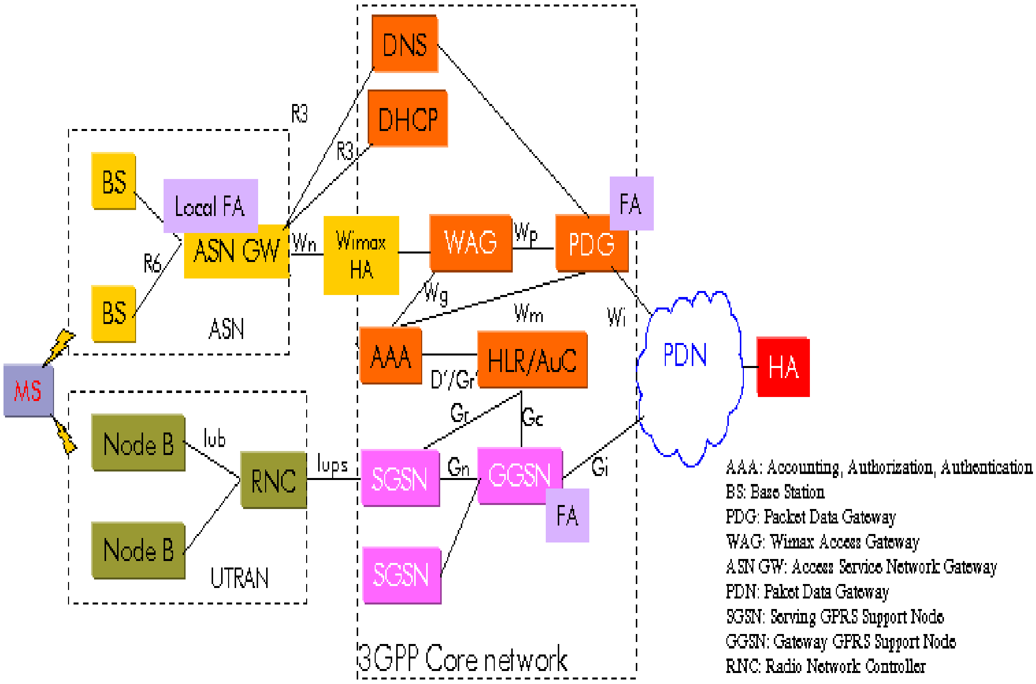

Figure 37 UMTS Architecture

5.3 CDMA2000 (EV-DO)

WiMAX is a fourth-generation access-network technology that has gained significant importance and momentum over the last few years. Many carriers have announced that they would adopt WiMAX, and efforts are underway to deploy these networks in many parts of the world. However, full ubiquitous coverage without service loss is not expected for several years. In the interim, a WiMAX mobile station (MS) must *interwork* with the existing third-generation networks like code-division multiple-access 2000 (CDMA-2000) 1x evolution data optimized (EVDO) to ensure service availability where WiMAX network coverage is not available. Note that an MS must be active in only one network (not both) at any given time, even if service is available in both access networks.

One can consider two different kinds of interworking — the *nomadic* approach and the *full mobility* approach. In the nomadic approach, session continuity between different access technologies is not required. That is, data sessions that exist in the networks of one access technology are not carried over to the other technology when the user switches between the two. In fact, IP sessions that exist in the first network are terminated before the user enters the second. To ensure the user has service in only one network, the IP sessions in the first network are terminated according to the following:

- After the user successfully completes the authentication procedure in the second network
- Before the user obtains an IP address in the second network

Similarly, *service continuity* is not required during handoff across different access technologies. In fact, an end user notices a service disruption during an inter-technology handoff.

On the other hand, in the full-mobility approach, there is seamless mobility across networks of different access technologies — the users can maintain their IP sessions and have service continuity without experiencing any significant degradation in their services (e.g., voice over IP or video on demand), other than the possible difference in access-technology performance.

The network architecture supports full mobility with session and service continuity across WiMAX and EVDO networks. These access networks are sharing one IP CN. [32]

In a loosely coupled model, separate data paths to the CN are used by WiMAX and EVDO networks. This architecture supports full mobility for both access networks, as inter-technology handoffs maintain a MIP tunnel between the HA in the CN and the FA in the access network. If the registration is successful, the FA assigns a temporary care-of-address (CoA) to the MS. The HA creates a MIP tunnel to the FA. That is, the HA creates an extra IP header to the CoA of the MS over the IP packets addressed to the MS home address (HoA). Any correspondent node (CN) can still reach the MS by its HoA. The packets originating from the CN are routed to the HA and then through the MIP tunnel to the FA and to the MS. Hence, the MS still can be reached by its HoA in the foreign network. The concept of MIP tunnels can be extended to enable interworking during handoff across different access networks. For example, whenever an MS enters a WiMAX network from an EVDO network, the HA creates a new MIP tunnel with the FA in the WiMAX network. Incoming packets of ongoing applications (e.g., video on demand, voice over IP, etc.) to the MS are now directed by the HA through the MIP tunnel with the FA in the WiMAX network. Similarly, whenever the MS enters an EVDO network from a WiMAX network, the HA creates a MIP tunnel with the FA in the PDSN and tears down the tunnel with the FA in the ASN-GW. The existing IP sessions between the MS and the CN are still active. The end result is that there is an IP session continuity and hence, service continuity to the end user during the inter-technology handoffs. Inter-technology handoffs can be implemented in three different ways:

- The first of these is “break before make”, where the link in the serving access network is torn down before a new link is set up in the target access network.
- The second is “make before break”, where the link in the target access network is made first, before it is torn down in the serving access network.
- The third is “make-before-break-with-simultaneous-bindings”, where the link in the serving and target access networks are maintained for a brief period of time before the link in the serving network is torn down. Make before break with simultaneous bindings accounts for the best service continuity with a minimum packet loss during handoffs, followed by make-before-break, and then break-before-make.

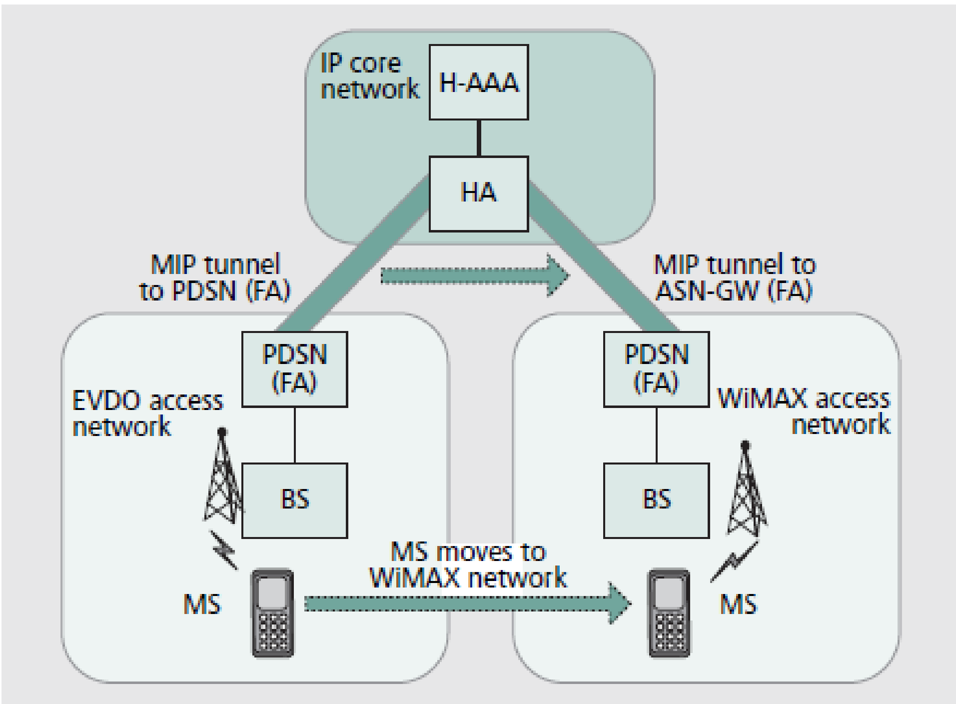

Figure 38 WiMAX_EV-DO Interworking Architecture

5.4 WLAN

In a heterogeneous wireless network, a handoff process will be different from that in a unique network. There could be two types of handoff processes: horizontal handoff (HHO) and vertical handoff (VHO). A HHO happens between different sectors controlled by different BSs (BS) or access points (AP) with the same wireless technology. A VHO is a handoff between different sectors with different wireless technologies. In conventional HHOs, only signal strength is considered for making a handoff decision. But in VHOs, some other metrics could be considered for the handoff decisions, such as QoS parameters. The design of seamless and efficient VHOs is an essential and challenging issue in the development of the 4G wireless networks. The BS of the WiMax network and the access points of WLAN networks can access the same gateway. They belong to the same subnetwork at the IP layer. Each station will be connected to either a WLAN AP or a WiMax BS at a time. The interface that is not serving the station will be in sleep mode.

In the interworking system, the WiMAX network can be supported by either IEEE 802.16d or IEEE 802.16e standard without restriction on the physical and MAC layer of the networks. The WLAN can be supported by any one type of the IEEE 802.11 standards, where the network allocation vector (NAV) mechanism has been employed at the MAC layer.

When mobility is supported in the interworking system, a VHO can be triggered by either a station moving out of the coverage of one cell of WLAN or the lack of available bandwidth to meet the QoS requirement in the current network. Otherwise, when mobility is not supported by the interworking system, a station can perform VHO when bandwidth is insufficient.

When mobility is supported in the interworking system, a station which moves out of the coverage area of one cell of WLAN or the lack of available bandwidth for QoS requirement can both trigger a VHO.

When mobility is not supported VHO is triggered by the station as long as the bandwidth is insufficient.

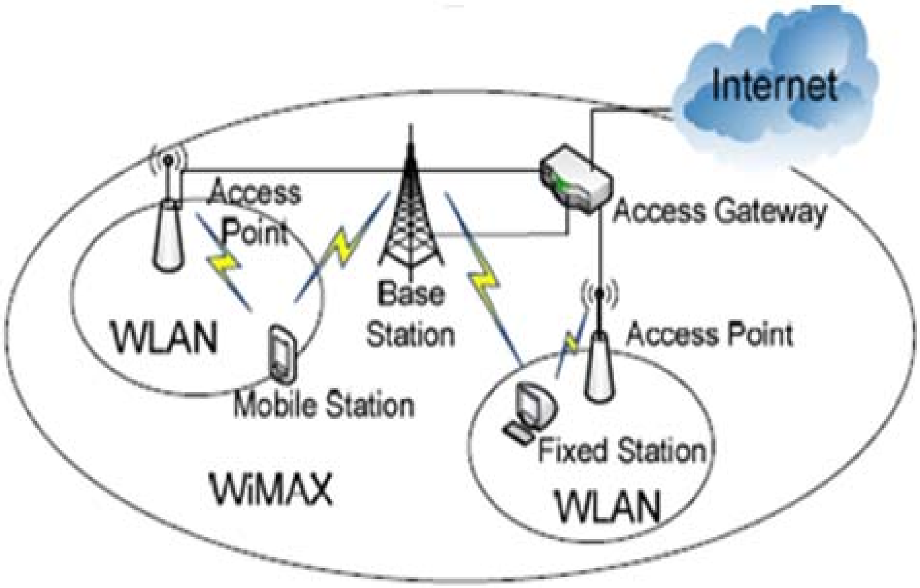

Figure 39 WiMAX_WLAN Interworking Architecture

5.5 WiFi

WiMAX enables service providers to offer “on the go” broadband Internet connectivity beyond WiFi hotspots. Users get disappointed when they subscribe to a WiFi hotspot service but then find themselves in a hotspot which requires payment to a different service provider. This incompatible access is a primary reason users avoid signing up for monthly WiFi hotspot service arrangements in the first place.

For service providers, WiMAX provides the capability to expand broadband services by offering subscribers coverage when not in range of a hotspot. With the integration of both WiMAX and WiFi into mobile devices, service providers can even offer transparency of service between WiFi in hotspots and WiMAX in the broader metropolitan areas.

The high usage of WiFi hotspots at airports and hotels suggests the requirement for broadband connectivity in even larger areas with a high density of Internet users. Deployment of WiMAX in these areas, either they are dense urban areas, campuses, or travel corridors, extends broadband connectivity beyond hotspots to deliver the use and value of mobile Internet services to subscribers. [42]

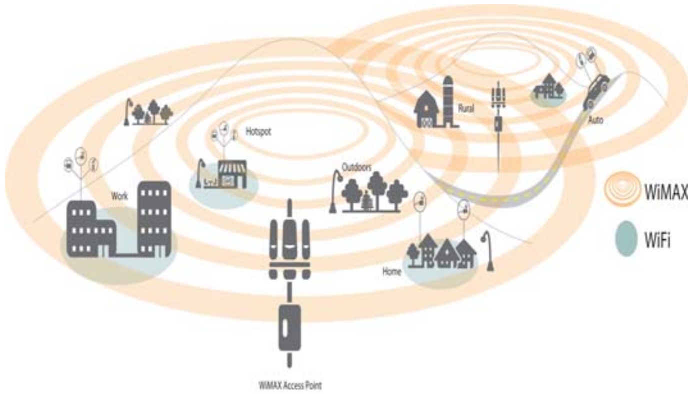

Figure 40 Using Handheld Devices in Mobile, Portable and Public Hotspot Environments

WiMAX and WiFi networks use IP-based technologies to provide connection services to the Internet. This standards- and IP-based network approach, in combination with certification of equipment by the WiFi Alliance and the WiMAX Forum, provides mandatory benefits to service providers and users:

- A common user experience for wireless broadband services, which is a critical enabler in completing rapid user adoption.
- An open network philosophy where any certified WiMAX or WiFi device is able to connect to any WiMAX or WiFi network that supports the same certification profile, improving today's business models for delivering mobile broadband services.
- Vendor agreed-upon certification profiles, facilitating volume production and global economies of scale.
- Wireless client and network equipment subjected to large scale interoperability and conformance testing, enabling an open and competitive multi-vendor environment.
- An all-IP based network infrastructure, enabling cost-effective developments for operators and open Internet services for users.

5.6 TD-SCDMA

As a commercial TDD system, Time Division- Synchronous Code Division Multiple Access (TD-SCDMA) is a new system, which adopts many new techniques, such as TDD, synchronous CDMA, smart antenna, joint detection, software defined radio, baton handover, dynamical channel allocation. All these technologies make TDSCDMA a very advanced 3G standard.

The concept of interworking two or more access networks to provide continual service to mobile users is already in use. There have been a lot of investigations focusing on interworking subjects between WLAN and cellular networks. The advantages of TD-SCDMA consist of their global coverage while their weaknesses lie in their bandwidth capacity and operational costs. However, WiMAX offers higher bandwidth with low operational costs. A WiMAX and TD-SCDMA interworking approach can make best use of advantages of both technologies and can eliminate their stand-alone defects. The operators can deploy low-cost high-speed WiMAX to cover the hotzones that is either an extension of TD-SCDMA or inter-workable with TD-SCDMA so that they can maximize the utilization of already deployed infrastructures. The WiMAX technology can be a complement for TD-SCDMA in term of geographical coverage and QoS.

The UE/MS (MS) has only one active radio interface at a time and the UE/MS is considered to be MIH User and has MIHF. MIH users are entities that use the services provided by the MIH Function.

The service primitives defined in the IEEE 802.21 constitute a seamless handover process.

There are three stages:

a. handover initialized stage

b. link/network selection stage

c. handover execution stage.

The functions of the handover decision engine include the following: collecting information of neighboring networks, link selection, QoS mapping, and handover decision. Because the implementation of handover decision engine is out of the scope of the IEEE 802.21 project work, is used the MIPv6 to implement the handover.

In order to enable the mobility between two access networks TD-SCDMA and WiMAX, it is proposed a solution under some following conditions:

Minimum change of the existing network infrastructure of these two technologies and obtainable solution for short term. By using Mobile IP mechanism and MIHF that hide the heterogeneities of lower-layer technologies, the mobile can connect to multiple networks seamlessly ignoring the heterogeneity of access technologies. Figure 41 shows the proposed interworking architecture. [38]

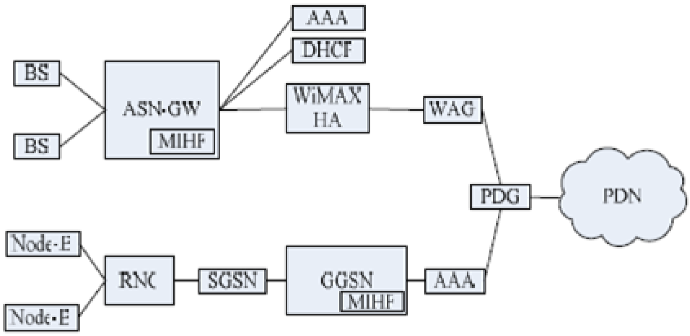

Figure 40 WiMAX_TD-SCDMA Interworking Architecture

5.7 LTE

Main characteristic of this interworking architecture is to assume two overlapped cells of WiMAX and LTE, where both cells are served by a BS and an eNB respectively. Mobile WiMAX supports access to plenty of IP multimedia services via WiMAX radio access technologies which is called ASN. Access Control and traffic routing for Mobile Stations (MS) is entirely handled by Connectivity Service Network (CSN). The LTE network may be dominated either by the NAP or by any other part in which case the interworking is enabled and governed by appropriate business and roaming agreement. 3GPP and Mobile WiMAX accesses are integrated through the Evolved Packet Core (EPC). 3GPP access connections are supported by the SGW and Mobile WiMAX connections are connected to the PGW. The legacy servings GPRS support node (SGSN) are connected to SGW. Also, Logical entities are added to the system Architecture. ANDSF is an entity that promotes the discovery of the target access. The target access supported by the ANDSF can be either a 3GPP or M WiMAX cell. The use of Radio signals for neighbor cell discovery requires the UE, to utilize multiple antennas, which result in power consumption. Additional, FAF (Forward Attachment Function) is necessary entity which added for seamless integration of mobile WiMAX and 3GPP access. FAF Is a BS-level entity and Is located in the target access. Besides supports authentication of the UE before the execution of handover through the IP tunnel. Depending of the type of target access FAF completes the BS functionalities of various networks. Performs the functionalities of WiMAX BS when the UE is moving toward a WiMAX cell, or perform as a 3GPP eNB if the target is 3GPP E-UTRAN.

For WiMAX – 3G interworking there is requirement of: Registration Event to inform user for their registration position and IMS session establish between two users equipment. IMS attempts IP based multimedia service and content based financial charges. Also, it is used for pervasive connectivity between two different networks for next generation mobile network. SIP for IMS session setup, management and transformation.

By offering integrated LTE/WiMAX services, users would aid from the enhanced performance and high data rate. For the providers, this could profit on their investment, captivate an advanced user base and basically facilitate the ubiquitous introduction of high-speed wireless data. The required LTE AN may be owned either by the WiMAX operator or by any other party, which then requires proper rules and Service Level Agreements (SLAs) set up for easy interworking on the basis of business and roaming agreements between the LTE and mobile WiMAX operators.[44]

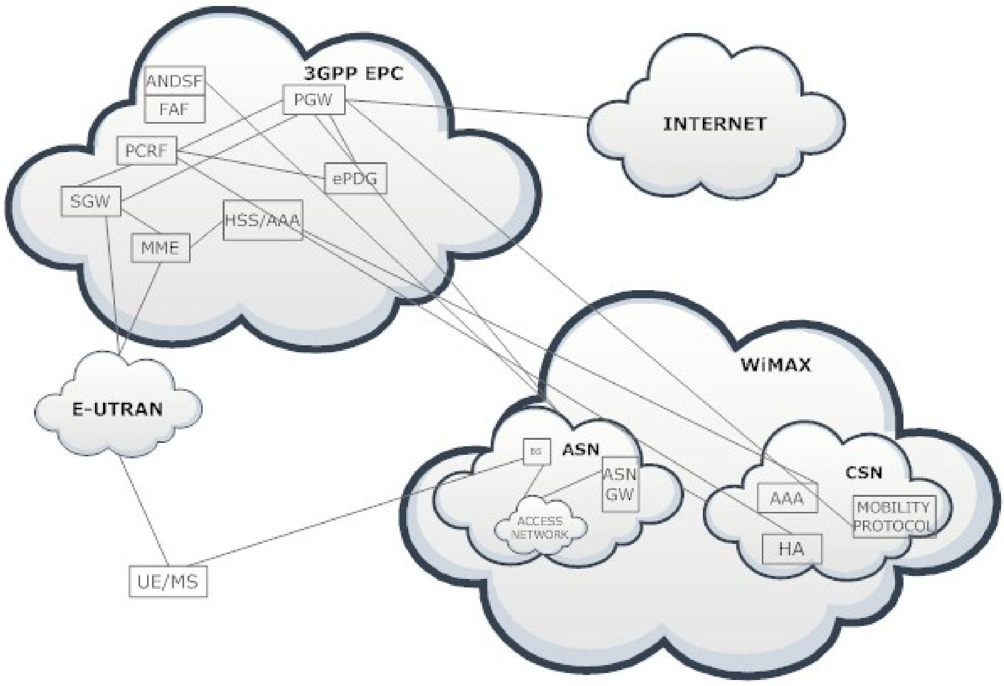

Figure 412 WiMAX_LTE Interworking Architecture

CHAPTER 6 MOBILE WiMAX

The IEEE 802.16e-2005 supports both time division duplexing (TDD) and frequency division duplexing (FDD) modes. However, the initial release of Mobile WiMAX profiles only considers the TDD mode of operation for the following reasons:

- Enables dynamic allocation of downlink (DL) and uplink (UL) radio resources to effectively support asymmetric DL/UL traffic that is common in Internet applications. The allocation of radio resources in DL and UL is determined by the DL/UL switching point(s).
- Both DL and UL are in the same frequency channel to provide better channel reciprocity and to better support link modification, multi-input-multi-output (MIMO) techniques, and closedloop advanced antenna technique such as beam-forming.
- A single frequency channel in DL and UL can provide more flexibility for spectrum allocation.

6.1 Mobile WiMAX, the Wireless Subscriber Line to the Internet

Providing of broadband Internet connectivity wirelessly over a much wider range than a couple of meters around, a Wi-Fi access point is the main idea behind Mobile WiMAX. It is developed to become the respective wireless of the cable and xDSL networks in order to enable a new telecommunication area by opening up the Internet for mobile devices as well as kinds of mobile applications.

The technology is designed to cope with the biggest challenge for operation of a mobile DSL: the enormous increase of data volumes as experienced so far in the wired networks, nowadays also appears in the mobile networks too. Starting mainly from wireless DSL applications, the support of mobility operations like network detection and selection, handover, roaming and paging allows the evolution towards unique and mobile service offerings for notebook computers and handheld devices.

6.2 Mobile WiMAX Specifications

IEEE 802.16 as well as the WiMAX Forum create the technical specifications of Mobile WiMAX. IEEE 802.16 is a working group of the IEEE LMSC, which is in charge of the PHY and MAC specifications of the radio interface. The remaining parts of the access network functionalities are specified by the standardization organizations, such as the IMS system of 3GPP. In addition to the technical specifications, the WiMAX Forum also develops the certification process for Mobile WiMAX equipment to ensure interoperability between different implementations.

Apart from its technical work, the WiMAX Forum is active in the promotion, marketing and regulatory areas to support the worldwide acceptance of the Mobile WiMAX technology.

6.2.1 Specification Areas

Mobile WiMAX technical specifications cover three main areas: radio, network and roaming. For each area one or more interfaces are defined, which provide reference points for interoperability. In the figure below, a schematic picture of an access network, shows the location and the relation of the interfaces to each other.

The three areas of interoperability in Mobile WiMAX consist of:

- **Radio interface:** The radio interface denoted by R1 defines the interface between the mobile terminal or subscriber equipment and the base station (BS) of the access network. The interface consists of three parts: the PHY and MAC according to the IEEE 802.16 specification as well as network layer functions, defined as part of the Mobile WiMAX network specification.

  Certification is provided for all the three parts defining the air interface R1, the PHY layer and the network functions for establishing the IP configuration and carrying user payload over the air.

- **Network interfaces:** Mobile WiMAX defines distinct logical network entities not only for the access serving network, called ASN, but also for the connectivity serving network, called CSN.

  The ASN consists of a number of base stations (BSs) connected to at least one ASN gateway (ASN-GW), which also sets up the interface to the CSN.

A standardized interface between CSNs is developed for roaming purposes. The interfaces named R2, R3, R5 and R6 in the figure below, as well as R4 and R8 (not depicted in the figure 43), denote reference points for interoperability in the network.

Network interoperability tests are provided for all network interfaces to ensure the proper operation of network equipment from different manufacturers.

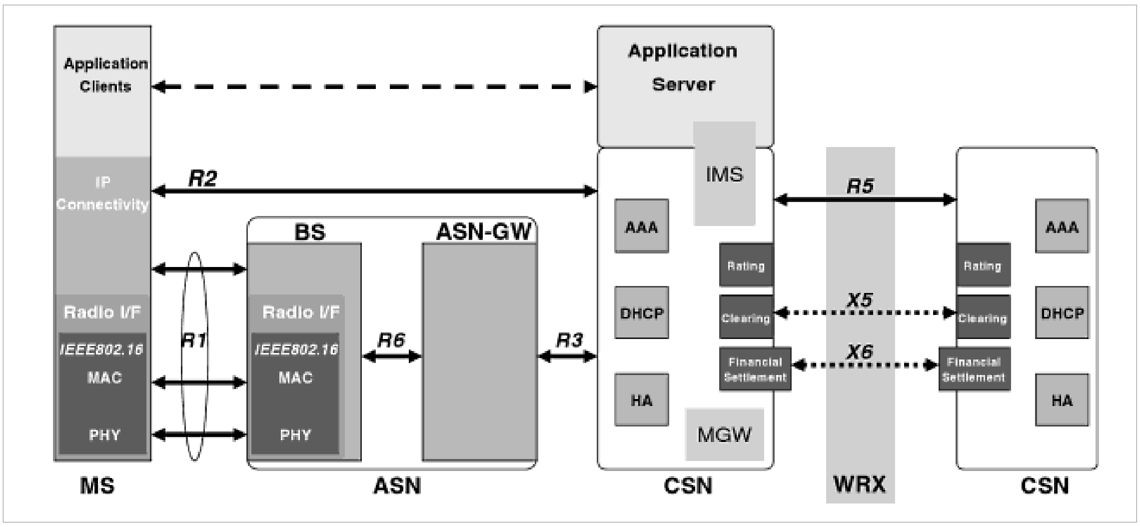

Figure 43 WiMAX specification areas

- **Roaming interfaces:** In addition to the radio and network interfaces, Mobile WiMAX supports standardized roaming interfaces to facilitate worldwide roaming support among the WiMAX operators. Roaming is supported by a WiMAX roaming exchange (WRX) network, which mediates standardized procedures and messages between WiMAX operators to enable connectivity provisioning for subscribers in foreign networks. The roaming architecture is defined by the interface X2-X6 as well as R5. Only depicts X5, X6 and R5, which pass through WRX.

  Interoperability testing is provided across all specified interfaces to ensure proper operation of the Mobile WiMAX roaming exchange.

6.3 Mobile WiMAX Network Reference Architecture

To allow manufacturers of Mobile WiMAX networks to gain competitive benefit in designing the best performing and most economical implementation of the network equipment, additionally providing interoperable products whose specification is based on a logical representation of a network architecture.

Aligned to the functional differentiation of service provider roles in the Internet model, the Mobile WiMAX access network architecture introduces logical network entities, which reflect the networking functions usually performed by the NAP and by the NSP. The logical network models are known as ASN (Access Service Network) and CSN. They only cover the networking parts of the operation of the NAP and NSP, but they comprise neither the business supporting systems nor the operation supporting systems, which are also necessary for successful NAP or NSP business. While the ASN fully covers the networking functions of a WiMAX NAP, the specification of the CSN is limited to the supporting functions which are necessary to allow a NSP to connect to an ASN:

- **CSN:** The specification of the CSN addresses the NSP part of the authentication, authorization and accounting process, the IP address management for the connected MSs, and the policy and QoS management based on SLAs between the subscribers and NSP. It further addresses mobility management across multiple ASNs, supports roaming subscribers by other CSNs and the connectivity of subscribers to the Internet and directly connected ASPs.
- **ASN:** The ASN comprises the IEEE 802.16 radio interface and the related supporting network functions, including the network detection and selection procedures, network entry, admission control and handover support to neighbouring base stations. ASN also covers the functions of radio resource management, QoS and policy enforcement and the session and mobility management of the link to the attached MSs as well as the operation of the foreign agent (FA) in the ASN and forwarding to the selected CSN. Further functions are the accounting client, control of the idle and paging, as well as the client for proxy MIP.

The specification of the Mobile WiMAX network does not command how the functions in the CSN or ASN are to be implemented, but specifies the interface between the functional units. The well-defined interfaces between the functional units establish the reference points of the architecture.

6.3.1 Reference Points in the Mobile WiMAX Network

Interoperability is achieved by the specification of reference points architecture, which represent interfaces between networks or network elements inside a network.

6.3.1.1 Reference Points between Business Entities

Business needs to specify the main reference points in the Mobile WiMAX architecture. Reference points mark the borders of operational units in the distributed Internet access model as shown in the figure below:

- **R1** represents the interface between the terminal or subscriber equipment and the radio access network. The air interface is indicated as the R1 reference point covers IEEE 802.16 PHY and MAC in addition to the network layer protocols for configuration and transportation of user payload across the air interface.
- **R3** declares the interface between the ASN of the Mobile WiMAX access provider and the accounting (AAA) of the subscriber, including IP configuration and policy control functions, as well as for the dynamic establishment and relocation of the user data path to realise network sharing and wide area mobility. The dynamic establishment and relocation of the user data path is an optional function of the R3 reference point, which may not be necessary for smaller networks and fixed and unique usage models.
- **R5** specifies an interface between CSNs of different NSPs to enable network access to roaming subscribers. In the roaming case, foreign networks provide service to subscribers that do not have a direct relation with the NSP of the foreign network. When entering the network, the visited NSP forwards the credentials of the foreign subscriber over R5 to her/his home NSP and receives from the home NSP over R5 the confirmation and the configuration for providing network access. Depending on the

contractual framework between the involved NSPs, either the roaming subscriber may get Internet connectivity directly from the visited NSP or services from the home NSP are provided by the optional data path of the R5 interface.

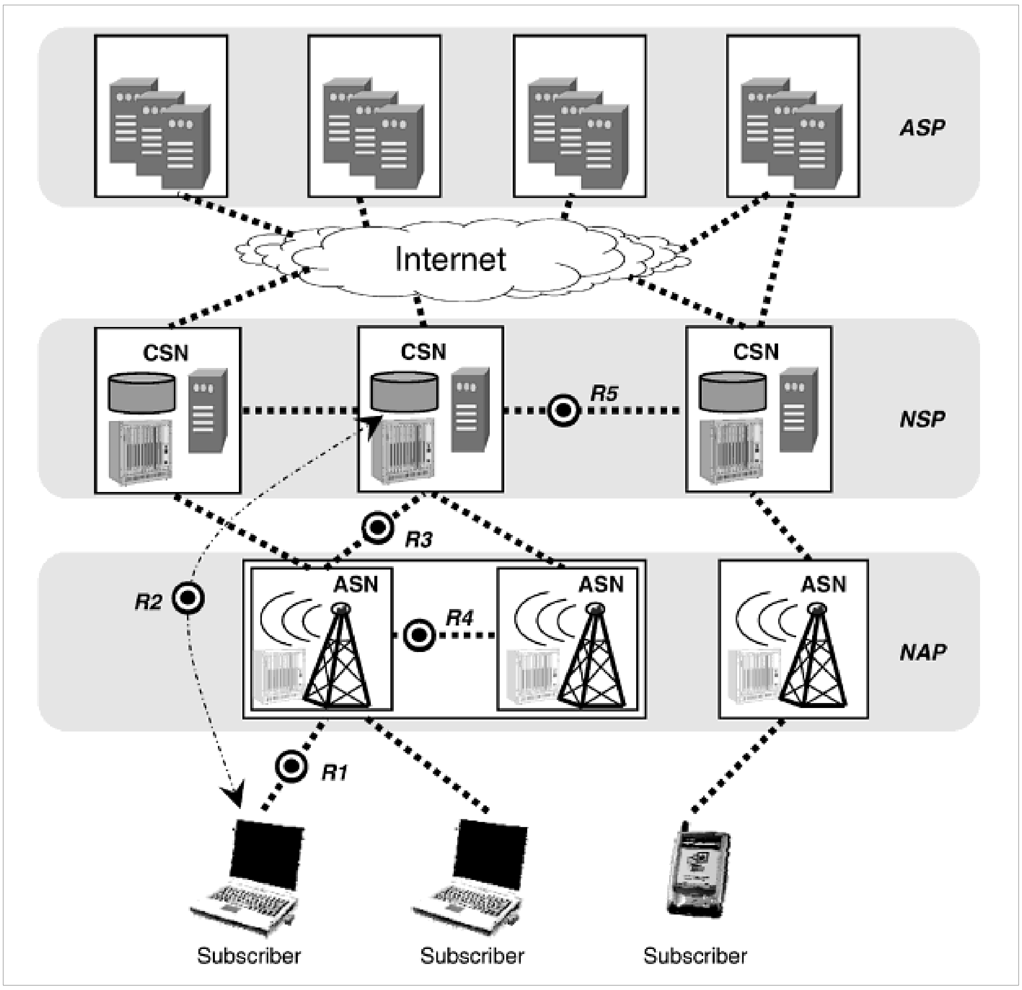

Figure 44 Network Reference Points

- **R2** specifies a direct interface between the subscriber and her/his home NSP, which is necessary, for instance, for the secure exchanges of the credentials of the subscriber in the authentication process to the home NSP. The R2 interface carries control information only.

  The reference points R1, R2, R3 and R5 mentioned above represent business relations between the parties involved in providing and using WiMAX network services.

6.3.1.2 Reference Points between Access Network Entities

In addition to the four reference points for business-related interfaces, three more reference points labelled R4, R6 and R8 specify interfaces inside the ASN to enable interoperable implementations of equipment for the Mobile WiMAX radio access network.

Usually the radio access network is built up of a large number of base stations, each serving an area whose size depends on the design and surrounding of the base station and the used spectrum, and also on the demand of transfer capacity in the area. Base stations are the gateways between the radio links to the subscribers and the wired part of the access network for gathering and forwarding the traffic and for concentrating the links into higher order network interfaces. To hide the specifics of the radio interface to the NSP but allow local control and optimization of the traffic forwarding inside the ASN, the WiMAX architecture deploys a link access concentrator called the ASN gateways (ASN-GW) at the edge of the radio access network to the NSP. The ASN-GW acts as the local anchor of mobile subscriber stations in the ASN to allow handover between base stations of an ASN without any involvement or even notice by the CSN. The ASN-GW also terminates the R3 interface to the interconnected CSNs.

Mobile WiMAX specifies the split of ASN functions into functions located in the BS and those located in the ASN-GW to enable standardised interfaces inside the ASN (Figure 45):

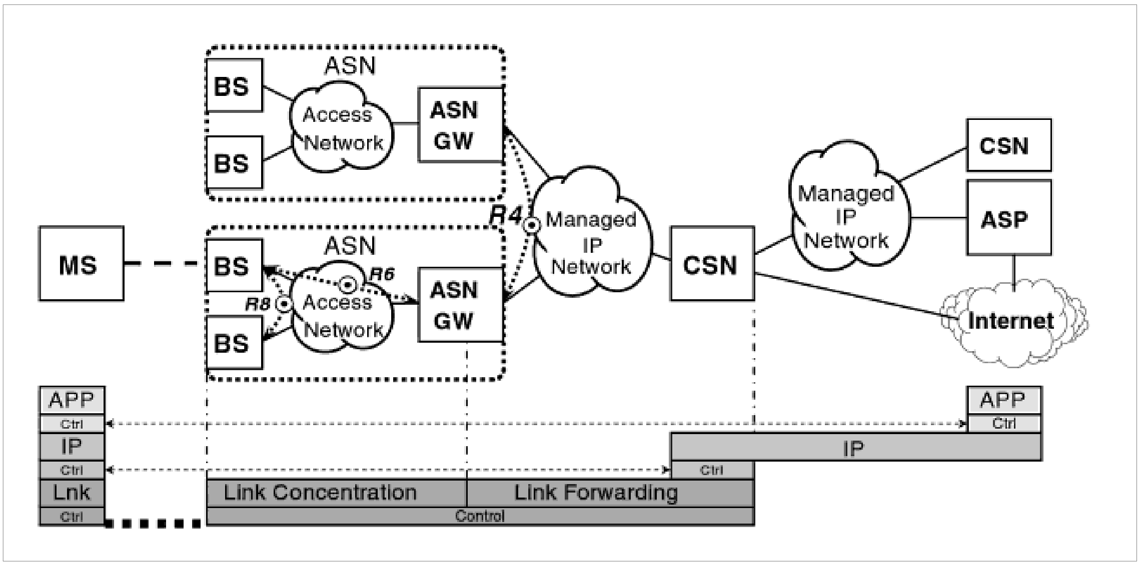

Figure 45 Functional model of the access network

- **BS:** It includes the functions of the PHY layer and the MAC layer of the IEEE 802.16 radio interface including QoS enforcement in the scheduler for transmission over the air and the related radio resource management. Furthermore, the encryption and decryption of the user payload, the paging agent for performing paging and idle mode actions, as well as the data path functions and the handover functions for intra-ASN mobility management, are located in the BS.

  The BS represents one instance of the IEEE 802.16 MAC typically on top of one instance of the IEEE 802.16 PHY, i.e. one cell. Real BS equipment usually serves multiple sectors from one unit, i.e. multiple cells, and represents the equivalent of multiple BSs in the Mobile WiMAX network model.

- **ASN-GW:** It is the location for the authenticator, key generation and key distribution, the paging controller and the service flow management and classification of the user payload.

  In addition to the data path functions and the handover functions for intra-ASN as well as inter-ASN, the ASN-GW includes the access router, foreign agent and PMIP client for the MIP-based R3 interface, the DHCP proxy and a transmission function for RRM messages to other BSs.

When access networks are too large in terms of number of users connected simultaneously or the aggregated data rate is to be handled by a single ASN-GW, the access network can be equipped with multiple ASN-GWs, or can be split into multiple ASNs, when a more distinct operational separation is preferred. Direct interconnection between the ASN-GWs allows local mobility management across multiple ASNs without relocating the forwarding anchor for the R3 interface. Moreover, relocation of the anchor to the new ASN-GW is still possible and may be later performed for optimization of the traffic path.

Figure 45 shows the reference points inside the radio access network and points out that they define logical interfaces between network entities, which do not necessarily require a dedicated physical network interface for each reference point:

- **R4** defines an interface between ASN-GW, which allows extension of the coverage area or the capacity of a WiMAX radio access network by direct interconnection between multiple ASN-GWs, each serving its own ASN or a part of a larger ASN. The R4 reference point includes control signalling as well as a data path for forwarding user traffic.
- **R6** represents the interface between the BS and the ASN-GW. It carries user traffic as well as control information between the ASN-GW and the BS.
- **R8** is the interface between the BS inside an ASN for direct exchange of control information to allow more effective management of the radio access resources inside an ASN.

As shown at the bottom of Figure 45, the ASN just provides the access links of subscriber stations or MSs to the CSNs. Each MS is connected by a dedicated link to its OP anchor in the CSN, where the access router resides and the IP address assignment is controlled. The ASN itself is not influenced by the IP addressing. In the ASN, traffic is forwarded depending on the identity of the MS and the address of the IP anchor in the CSN, the figure also demonstrates the end-to-end principle of IP networking, where applications reside in the hosts at the edge of the network and all application-related information and signalling is transparently carried across the network.

6.3.1.3 Reference Point Details

The structure of the reference points in the WiMAX architecture follows real network interfaces by simultaneously performing multiple message transfers over the same interface. Other network architectures specify reference points for single functions and protocols. In Mobile WiMAX, however, each of the reference points represents the complete set of functions and protocols that are carried between the connected network entities.

Reference points comprise multiple functions and may be a common protocol or multiple different protocols to realise the set of functions is RADIUS for the AAA process, while Mobile IP (MIP) is an example of a protocol for a single function. In addition to the control functions, the transfers of user payload may be part of a reference point, and in present it forms the data part.

- **ASN anchored mobility management** provides the handover support of radio links across BSs inside a single ASN or across ASNs without changing the anchor ASN.
- **CSN anchored mobility management** defines mobility management based on Mobile IP across ASNs with the mobility anchor located in the CSN.
- **Radio resource management** is a function inside an ASN to increase the deployment efficiency of the available radio resources.
- **Paging and idle mode MS operation** covers the control procedures for location update, paging, and entering and leaving the idle mode according to the specifications in IEEE 802.16.
- **IPv6 and simple IP support** provide operational specifics for IPv6 support and the interconnection of ASN and CSN when Mobile IP is not deployed for the R3 interface, respectively.

To facilitate interoperation between networks equipment based on different releases of the WiMAX specifications, negotiation functions are used on R4, R6, R8 as well as on R3 and R5 to determine the most appropriate mode of operation. [45]

Mobile WiMAX was successfully adopted by ITU as one of the IMT-2000 technologies in November 2007. Since then mobile WiMAX (a.k.a. IP-OFDMA) has officially become a major global cellular wireless standard along with 3GPP UMTS/HSPA and 3GPP2 CDMA/EVDO. Mobile WiMAX is an OFDM-based technology available for deployment today, and new WiMAX devices come to market at much lower cost than that of current 3G solutions. Currently over 260 service providers are deploying fixed, portable and mobile WiMAX networks in 110 countries. This article provides an overview of the mobile WiMAX system and its performance under various configurations, channel conditions, and types of data traffic. Furthermore, the article provides an overview of mobile WiMAX evolution.

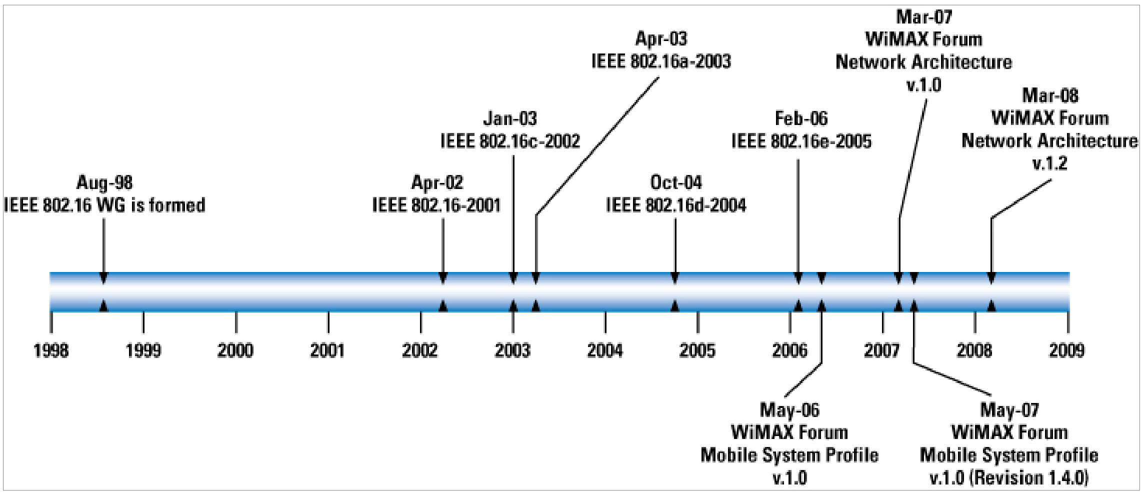

Figure 426 The road toward Mobile WiMAX

The Mobile WiMAX architecture adopts the disintegration of the Internet access network operation into many distinct operator roles. The network access provider (NAP) establishes and operates the radio access network and offers its services to one or multiple network service providers (NSP), which are in charge of customer related functions like authentication, service supply, and billing, and provide the backbone connectivity to services networks like the Internet or application service providers (ASP) running their particular applications.

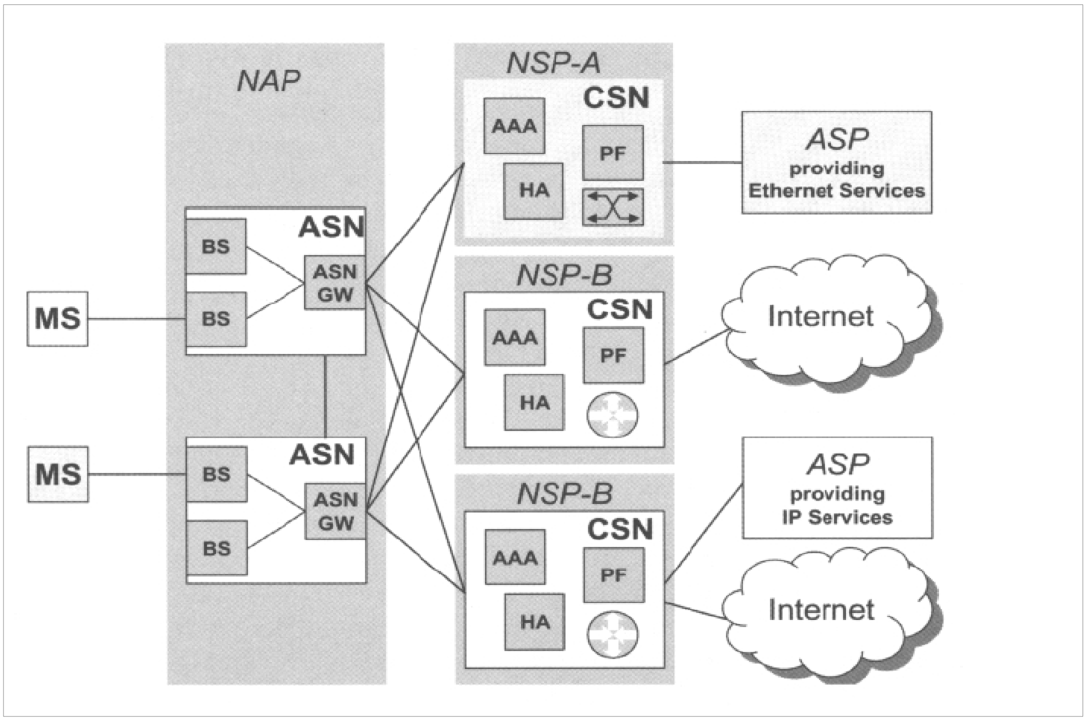

Figure 47 Mobile WiMAX Architecture

Aligned to this role model, the Mobile WiMAX network reference architecture is built upon two logical networks entities: the access service network (ASN) providing link-layer connectivity and local mobility over the IEEE 802.16e radio interface, and the connectivity service network (CSN), comprising all subscriber-related functions for authentication, authorization, and accounting as well as the home agent or the data-path anchor for access to the services. There is a direct relation between ASN and NAP, and CSN and NSP. The ASN represents a logical access network with all the Mobile WiMAX specific functions, which belong to a NAP, and the CSN contains the Mobile WiMAX specific network functions of a NSP.

To facilitate interoperable implementations of equipment for WiMAX access networks, the ASN is disintegrated into a set of base stations (BS) connected to a central control and a data forwarding instance called the ASN-Gateway (ASN GW). The reuse of well- known and widely deployed IP protocols and ISP principles based on a functional specification of the CSN allows NSPs to implement the required functions in their core networks based on a functional specification of the CSN. [46]

The design of the Mobile WiMAX network architecture supports an ASN to connect to multiple CSNs for load balancing as well as network sharing purposes. To become a provider of information and communication services over Mobile WiMAX, the operation of a NSP consisting of a single CSN with connections to one or more ASNs for leveraging the mobile access services offered by WiMAX NAPs is enough.

Even when it is relatively easy to become a WiMAX service provider by implementing just a CSN, the overhead to establish all the contractual framework to become able to use access connectivity of WiMAX NAPs may be too complex, especially for enterprises and smaller operators just looking for some point-to-point connectivity in areas where they do not have a wired infrastructure. Ethernet Services over Mobile WiMAX offer transparent Ethernet connectivity over a wireless access network exactly in the same way as Metro Ethernet Network providers are offering today's wired Ethernet services.

Metro Ethernet Network providers may extend their businesses by implementing the CSN functions for Ethernet services in their networks and may become wireless Ethernet service providers without the need for huge investments to establish their own wireless access infrastructure. [47]

CONCLUSIONS

Wireless networks are expected to include heterogeneous access technologies and the Internet backbone for providing services to both mobile and fixed users. It poses significant technical challenges to enable broadband wireless access with seamless and ubiquitous coverage and Quality-of-Service provisioning.

The WiMAX is a next generation open standard whose purpose is to serve users, enhancing data throughput (broadband) services like streaming media on the internet, mobile TV on computers, handsets and PDAs and live video conferencing. It is expected that WiMAX will be integrated into the next generation mass market end user devices and donate many things that do not exist nowadays (speeds similar to cable and metropolitan area coverage while on the move, all for a much lower cost than we are used to today). WiMAX already offers broadband services in many emerging and rural markets which are not supported by wireline-based technologies. WiMAX started its first deployment in developed countries by replacing common Wi-Fi on one hand and traditional cellular standard such as 3G (based on 3GPP) on the other hand.

The WiMAX Forum is now working on next generation of its technology, giving more attention in business models and having the aim of creating a framework that would allow the use of WiMAX for wireless carrier Ethernet services.

Mohammad Shakouri, WiMAX Forum chairman, described the three main objectives for the 2013 by addressing a note to WiMAX Community, introducing the subject with the work on WiMAX Advanced.

In October 2012, the WiMAX Forum has recognized that most WiMAX operators also interested (or already looking) for other access technologies and announced WiMAX Advanced network evolution map beyond WiMAX Release 1 and Release 2 which contained the harmonization and coexistence multiple wireless broadband technologies. In late 2012 the forum approved WiMAX Release 2.1 to focus on support for multiple radio access technologies. [48]

Release 2 technology is improving with IEEE 802.16m mobile WiMAX standard which is called WiMAX 2. Well Known business leaders make known proposal to speed up WiMAX 2 Technology Solutions built upon IEEE 802.16m.

The main purposes of WiMAX 2 Technology are:

- technology cooperation and mutual presentation benchmarking
- dual testing of 4G Technology requests over WiMAX 2 Technology solution
- untimely network level interoperability testing

Specifications of WiMAX 2 Technology

WiMAX 2 technology is built on specifications of IEEE 802.16m standard and it will be easy merged with the previous standards. Nevertheless, the future of WiMAX is guaranteed by WiMAX 2 technology which is an effective new technology within a long term growth. It will also be much faster than its forerunner. WiMAX 2 technology is expected to use the advanced 4G standards within 1Gbps access speed to fixed and 100Mbps to fast moving mobile nodes.

Features of WiMAX 2 [56]

- WiMAX 2 technology can deliver a blazing speed of 120Mbs down and 60Mbs up without any restriction. WiMAX 2 Technology using 4×2 MIMO antennas with 20 MHz channel enable signals everywhere.
- With the WiMAX 2 technology the speed will be double and user can do much than before.
- The WiMAX technology offer very high speed including numerous devices for the delight of client.
- WiMAX 2 technology network offering VOIP calls with 300Mbit throughput including more bandwidth and less latency.
- Those operators facing explosive the WiMAX 2 technology meets the need of their demand for mobile data and various type of services.
- WiMAX hardly print out a place in the market therefore WiMAX 2 technology offering a low cost network within all IP mobile solution.
- The Data, Voice, and Video transmission are the clear efficiency of WiMAX 2 network technology.

- The WiMAX 2 promises to deliver a matchless amalgamation of linearity, noise presentation, and constituent combination over a remarkably broad band of operation.

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