A TUTORIAL ON FUNCTIONALITY OF WiMAX

AND IT'S PERFORMACE EVALUATION

by

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ABSTRACT

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Recently, there have been tremendous developments on wireless communication technology which have predicted to replace the wirelined system and provide incredible bandwidth to the consumers. The IEEE standard for this technology is known as 802.16e (Mobile WiMAX) which was officially published in the year 2006. WiMAX would provide broadband access to rural and developing countries where the option of DSL, cable and Wi-Fi is unavailable. This Thesis provides a tutorial overview of 802.16. The information for this article is gathered from The Institute of Electrical and Electronics Engineers (IEEE) website, the WiMAX forum website and other resources on the internet. WiMAX is abbreviated as *Worldwide Interoperability for Microwave Access* which provides broadband connectivity by connecting to the Internet Service Provider even when you are roaming outside home. This article starts with Roadmap of 4G technology and later with different features of WiMAX. Features like Physical layer, Network Reference Model and MAC layer with QoS architecture form the basis of WiMAX. A brief overview of network entry procedures is followed by one of most widely used tool for studying the performance of existing systems. It is known as Optimized Network Evaluation Tool (OPNET). The article also covers the most recently updated information that is going on the

market about the battle between Long Term Evolution (LTE) and WiMAX and the opinion. Also, it speaks about the most recent development to be deployed in late 2014 known as WiMAX 2.0 or Release 2 which has amendments and enhancements to the current WiMAX. Last section is very interesting as it gathers some information comparing the various links and its pros and cons and the answer to the awaited question of whether WiMAX will replace DSL or not.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

Figure Page

LIST OF TABLES

CHAPTER 1

AN INTRODUCTION TO 4G WIRELESS MOBILE TECHNOLOGIES

1.1 Introduction

Basic Cell phones use 2G technology after the introduction of digital transmission over Analogue transmission 1G.2G tech features slow transmission of data rate as low as 10kb/s, call setup and transfer of emails and voice mails. Hence there was a need for replacement which came with 2.5G along with the very famous GPRS. This resulted in a better service and quicker approach for transmission. Various application such as WAP access, SMS, MMS, emailing, web browsing were supported. From 10kb/sec the transfer rate came out to be 56kb/sec to 114kb/sec due to up gradation. As the needs and demands kept on increasing, the technology kept on evolving for much better and faster transmission. In order to meet the requirements more development in the mobile technology was done which introduced 2.75G.It featured EDGE; Enhanced Data rates for GSM Evolution. It is not only considered as 2.75G feature but also as 3G feature. Voice mails ,phone calls ,fax ,navigation ,web access was achieved with a speed of 64 kb/s to 144 kb/s.

Currently, the most popular and available technology for cell phones is 3G technology. Since UMTS network was introduced, it helped the most basic needs in an advanced way. It supported internet access, app sharing, video conferencing. Moreover, other supporting features were global roaming, HSPA (High Speed Packet Access), TV streaming with a speed of 144kb.sec to 2 Mb/s. Now a new revolution has risen which has given an edge over all previous techs. It’s 4G which has good modulation technique like multi-carrier modulation, good speed of gigabit.

1.2 Beyond 3G/4G Radio Access Technology and its Roadmaps

Here in this section, different Radio Access Technologies (RATs) of the current and future generations are described over the different regions. It specifies different key features and their comparisons.

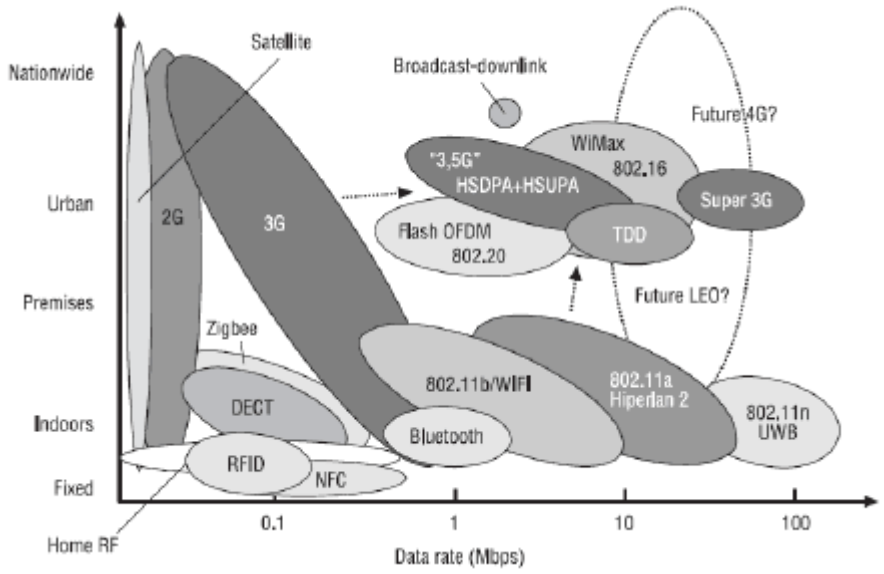

Figure 1.1 International Legacy Wireless Landscape

All the above shown technologies are described with its summary to give a brief description.

1.2.1 Near Field Communication (NFC)

Various Applications in mobile phones like electronic keys, wallets, tickets, identity etc use Near Field communication. Data rate of 106 kb/s, 212 kb/s or 424 kb/s is achieved. In this there are two modes of communication, one is passive and the other is active. In the former one, the initiator device provides a carrier field and the target device answers by performing modulation on the existing field. While in the later mode, the initiator and target device both communicate with each other by generating their own field.

1.2.2 Radio Frequency Identification (RFID)

This technology is used for near field identification of objects or people. Overall, this technology uses just one antenna, one transreceiver and one transponder. A device called reader contains both transreceiver and antenna which when operating activates the transponder (RFID tag). The RFID tag in turn transmits data back to the transreceiver. There are three types of RFID tags: active, passive, semi-passive. Active RFID tags broadcast their information while passive RFID are remote powered by the transreceiver. Semi- passive tags have their own source of power but the

transreceiver triggers their transmission and power. RFIDs come with different types in terms of frequency. They are low frequency RFIDs (125-148 kHz) and high frequency RFID systems (13.56 MHz), but they have short transmission ranges of up to 1m. Ultra high frequency systems can work at 915 MHz and covers up to 10m while the Microwave RFID systems work at 2.45 GHz and range up to 30m.

1.2.3 Bluetooth

This technology is a low power radio standard and communication protocol which offers short range connectivity between different devices with communication speeds of 2.1Mbps. It contains three main classes in terms of transmission levels: Class 1 (max 100mW (20dBm) for a range of approximately 100m), Class 2 (max 2.5mW (4dBm) offers a range of 10m. and Class 3 (1mW (0 dBm) offers a range of 1m). It is a licensed protocol at 2.45 GHz. The Bluetooth protocol has split its band into 79 channels each of 1MHz and hops between the channels up to 1600 times per second in order to reduce the interference.

1.2.4 Wibree

This is a radio technology which works between small devices. It can be embedded into devices like watches, wireless keyboards, gaming and sports sensors which can then be interoperated with devices like mobile phones and laptops. So, Wibree is a missing link between small devices and mobile devices. The usage of Wibree or the need of Wibree in the radio technology is that (a) it allows communication between small button cell battery devices and Bluetooth devices. (b) it is inexpensive which can work with Bluetooth devices like mobile phones and PC. (c) it's a lower cost options for small button-cell battery devices.

1.2.5 Zigbee

This technology works at 868 MHz, 915MHz and 2.4 GHz ISM bands. It is a low data rate wireless application. Even this technology is used for small, low power digital radios based on IEEE 802.15.4 standard. This standard stands for PHY and MAC layers which help in communicating with devices without making use of network delays. Hence we can use this for thousands of devices on a single wireless network. Zigbee is used for low cost, low power and reliable control and monitoring

applications like consumer electronics control, lighting control, access control, HVAC, patient monitoring, security, peripherals management and asset management

1.2.6 Ultra Wide Band (UWB)

Ultra Wide Band also known as UWB, ultraband is a radio technology which consumes low energy and especially for short range communication. It consumes high bandwidth for communication by utilizing great amount of spectrum. It was initially used in radar imaging. But recently it has been used for sensor data collection, precision locating and tracking applications.

This technology doesn't interfere with other traditional narrowband devices. But as per the study, it is seen that the UWB transmitters are putting a load on existing communication systems. This affects the stability of the existing communication systems.

1.2.7 Wireless Fidelity (Wi-Fi)

This is denoted by IEEE 802.11 standard and is commonly known as Wi-Fi which has been developed by Working Group 11 of IEEE LAN/MAN Standards Committee. Originally, the term 802.11 was referred by IEEE 802.11 which is called as "802.11 legacy". The 802.11 family contains multiple over-the-air modulation techniques which use same basic protocol. The family comprises of b/g and they are the amendments to the original standard. Because of clauses by the government, the original standard was weak in security part but it was then amended via 802.11i after the government and legislative changes. The newest amendment has introduced 802.11n which is a multistreaming modulation technique developed recently. Other standards are c-f, h; j. 802.11b was the first widely used wireless networking standard. After this followed 802.11g and then 802.11n.

1.2.8 IEEE 802.16 WiMAX

IEEE standard Board in 1999 introduced and worked on Broadband Wireless Access Standards which aimed for global deployment of broadband Wireless Metropolitan Area Networks. There is enhancement going on with 802.16e which is under development which would be known as WiMAX 2.0 or 802.16m. The family of 802.16 is known as WirelessMAN which also known as "WIMAX" (Worldwide Interoperability for Microwave Access). This is named by an industry group called the WiMAX Forum. The family standardizes tow aspect of air interface- the Physical layer

(PHY) and the Media Access control Layer (MAC). The modulation technique used by 802.16e is Scalable OFDMA supporting channel bandwidths of 1.25MHz and 20MHz and up to 2048 sub-carriers. Adaptive modulation and coding technique is used in which if the environment is of good condition, then a highly efficient coding scheme like 64 QAM is used and if it's of poorer quality, then a robust coding mechanism like BPSK is used. For moderate conditions, 16 QAM or QPSK us used. Other features supported are Multiple Input and Multiple Output (MIMO) antennas for good Non-Line-Of-Sight (NLOS) and for good error correction, Hybrid Automatic Repeat request (HARQ) is used. The MAC layer has Convergence sub layers to encapsulate higher layers like ATM and IP on the air interface and classify the data. There is mechanism for secure communications where secure key exchange takes place for authentication and encryption using AES or DES during data transfer. Additional features like power saving using sleep mode and idle mode is supported. The most important feature of WIMAX is that it is a connection oriented technology. The data is transmitted by the Subscriber station when a channel is allocated by the Base Station. 802.16e also has mechanism for strong Quality of Service (QoS). Each connection between the Base Station and Mobile Station is allocated a specific QoS class. The 5 QoS classes supported are: Unsolicited Grant Service, Extended Real-time Polling Service, Non-real-time Polling Service and Best Effort. The QoS class associated with the service flow ensures that the application data is transported with guarantee.

1.2.9 Second Generation 2G

After the first generation of analogue systems, came the second generation (2G) mobile cellular systems which became the commercial success in the middle 90's. The most important of different technologies in 2G systems are : (1) Global systems for Mobile Communications (GSM) (2) cdmaOne which is also known as IS-95 mainly used in America (3) IS-136 tdma also called D-AMPS in North and South America (4) Personal Digital cellular (PDC) in Japan. All these systems were good for circuit switched voice than the limited data rate. The study showed that about 360 billions of SMS were sent through GSM networks in 2002. Then there was a demand for higher data rate which led the emergence of "2G+" or 2.5G systems. For GSM, the packet switched transmission was introduced by General Packet Radio Service (GPRS) which had bit rates of about 40 kb/s by allocating several time slots of a frame to the same data transmission. With more enhanced modulation techniques, came the second step for GSM known as Enhanced data rated for GSM Evolution (EDGE). This

included features like 8-PSK modulation, multiplying by 3 the on-line data rate compared to GPRS. Actually the 3G-IMT-2000 family includes EDGE. IS-95 and IS-136 evolution was in same direction.

1.2.10 Third Generation 3G

In order to provide high data rare to offer multimedia services, ITU has defined a family of systems, called 3G systems. The frequency bands for these systems were selected by the World Radio Conference (WRC). The five systems composed by the IMT-2000 family are: (1) Wideband Code Division Multiple Access (W-CDMA) including TDD and FDD modes (2) CDMA 2000 1X (3) Time Division – Synchronous Code Division Multiple Access (TD-SCDMA) (4) EDGE (5) Digital Enhanced Cordless Telecommunications (DECT). Then aroused tow new groups of standardization namely (1) 3rd Generation Partnership Project (3GPP) developed by W-CDMA standard which is also known as Universal Mobile Telecommunication System (UMTS) in FDD and TDD modes (2) 3GPP2, which in evolution of IS-95 standards. There have been series of releases for the terrestrial radio interface of UMTS called Universal Terrestrial Radio Access Network (UTRAN). They were from R3 also known as R99 till R7 which had FDD mode in Release 3, TDD modes- High Chip Rate (HCR) and Low chip rate (LCR) in R4, downlink data rate of 14.4 Mb/s –High Speed Downlink Packet Access (HSDPA) in Release 5, HSUPA for uplink and Mobile Broadcast Multicast System (MBMS) in Release 6 and finally MIMO techniques in Release 7. Similarly, there were several releases of CDMA 2000 family which started with CDMA 2000 1xRTT to CDMA 2000 Evolution – Data Optimized (EV-DO) which supports downlink data rate of 3.1Mb/s and uplink data rate of 1.8 Mb/s for Revision A. Revision B had much higher rates exceeding 10Mb/s. The figure below shows the evolution of UMTS air interface. For high mobility data rate of 144 kb/s and 2Mb/s for fixed location were set by ITU for 3G systems in the IMT-2000 framework.

It was in the year of 2002, that High Speed Downlink Packet Access (HSDPA) was introduced which was the part of UMTS release 5. It could achieve substantial increase in network capacity, peak throughputs of 14Mb/s and reduction in latency. For this several techniques were implemented like Adaptive Modulation and Coding (AMC), fast scheduling and Hybrid ARQ. Release 6 introduced what we call it as Enhanced uplink or HSUPA to enhance uplink spectral efficiency and reduce latency. While the enhanced downlink or HSDPA used fast node B scheduling, HARQ and shorted frame size.

Using larger block sizes and shorter frame length of 2ms, an uplink data rate of 5.76 Mb/s is achieved. By combining HSUPA and HSDPA, we get a very attractive and efficient UMTS packet system. Still there is work going on the enhancement of HSPA performance for Release 7 to include Continuous Packet Connectivity CPC and MIMO for the DL achieving 28Mb/s peak data rate. HSPA+ was also introduced in Release 7 with higher order modulation (HOM) for UL and DL.

1.2.11 Long Term Evolution

Now there was a need to reach the full performance set of IMT-Advanced requirements, and hence a new radio interface will be needed. As a result a new spectrum would be required because it was anticipated to get a carrier bandwidth of up to 100MHz. Based on this, 3GPP decided to define a new radio interface and work on the latest developments. This was labeled as Long Term Evolution (LTE). This is going to ensure competitiveness of 10 years and beyond. This technology was sometimes called Super 3G and was introduced to provide service performance on a par with or even exceeding that of current fixed line access at a reduced cot compared to current radio access technologies. The key features of LTE that are being looking forward are:

- Significantly higher data rates than the current 3G evolution (HSDPA and enhanced uplink) with target peak data rate up to 100Mbps for downlink and up to 50Mbps for the uplink
- Three to four times higher throughput and cell-edge throughput as compared to 3GPP Release -6 systems.
- An improvement in spectrum efficiency of order 3 compared to current standards.
- Reduced control and user plane latency with a target of less than 10ms user plane RAN round trip time (RTT) and less than 100ms channel setup delay
- Reduction in cost for operator and end user
- Smooth migration into other frequency bands for e.g. to second generation (2G) cellular technologies such as GSM and IS-95

Long Term Evolution has an air-interface based on OFDM transmission in the downlink and single carrier FDMA (SC-FDMA) in the uplink. It provides peak data rates beyond 300Mbps for downlink and 80Mbps in the Uplink. Multi-antenna transmission technology is used extensively by LTE with beam forming and spatial multiplexing. Beam forming provides improved coverage and

capacity while spatial multiplexing provides higher data rates. In LTE, the spectrum allocation ranges from 1.25 MHz to 20 MHz which gives a very high flexibility in terms of bandwidth. Due to this there is smooth migration of current 3G and 3G technologies to LTE. The current specification of LTE shows that it will provide data rate of 300 Mb/s which has already exceeded the anticipated requirements for IMT-Advanced wide area coverage bit rates. Because of the inherent bandwidth flexibility, LTE in its later releases will be quite complemented with even wider bandwidths and higher bit rates. The most important requirement identified by ITU-R for “System Beyond IMT-2000” was packet based core network for both 2G, 3G and “4G” radio access. Thus, the operators will be ready to roll out the new radio access such that subscriber will be able to optimally connect anywhere and anytime. With this LTE will be able to co-exist with existing 3GPP radio technologies. In future while expanding the bandwidth of the technology to the hot-spot 4G requirements, it will be possible to provide for the legacy LTE terminals on the existing wider carrier because they would be allocated on the part of the bandwidth, hence making the introduction of the LTE hot-spot nodes benefit the existing terminal. The commercial introduction of LTE is expected to start by the end of 2010.

1.2.12 Ultra Mobile Broadband (UMB)

For improvement of CDMA2000 mobile standard for future applications and requirements there is an on-going project within 3GPP2 known as Ultra Mobile Broadband (UMB). This technology also uses OFDMA modulation technique with advanced antenna techniques for peak rates of 280Mb/s. The objectives of UMB are:

- Improving system capacity
- Increasing User data rates throughout the cell
- Lowering costs implementations
- Improving existing services
- Introducing new applications
- Using new spectrum opportunities

This technology is going to be fully IP dependent in a full mobility environment. The commercial introduction of UMB was done in mid-2009. For smooth interworking, UMB supports inter

handoffs with other technologies like CDMA2000 1X and 1xEV-DO systems. The key features of UMB are:

- Ultra: This is an ultra super fast technology that provides great data throughput rates in an economical way for IP-based voice, multimedia, broadband, information technology, entertainment and consumer electronic services within most kinds of devices.
- Mobile: This technology provides wireless services within a full mobility environment and distinguishes itself from Wi-Fi, WiMAX.
- Broadband: This technology provides ultra fast speed of 100s of megabits pr second.

1.3 Features of 4G Technology

The 4G technology has fascinating features because of which its usage is going to increase. Even though the 3G technology is doing better, people still need more better services and hence there is always a room for development to reach the goals. These goals keep on coming one after another.

The main aim of 4G technology is to provide high speed data transmission without interruption. Better streaming will be provided by the ultra-broad band to the users because this network would be packet-switched network. The advantage of 4G is of low cost and high bandwidth. The added feature of video-conferencing will change the whole concept of e-commerce and corporate world. Due to faster transmission of data video streaming will be enjoyable. With this, there will be support for Video-chat also. This will also change the teaching methodology with the provision of distance learning programs. One of the most important aspects of 4G technology is global roaming. This shows that we can expect a seamless, uninterrupted continuous streaming. Taking into account all these features, the kind of people who will be most advantageous are those who have their friends living in different country and cannot see them. They can use these entire combined feature and get the internet access for video chat. As for me, 4G seems to be intelligent and mind blowing technology.

CHAPTER 2

WiMAX's TECHNOLOGY FOR LOS AND NLOS ENVIRONMENTS

2.1 Introduction

WiMAX technology has been designed for both line of sight as well as non-line of sight where many other technologies currently deployed for fixed broadband wireless is designated only for line of sight coverage. WiMAX also provides large coverage area of upto 50km when its LOS environment and cell radius of 5miles/8km for NLOS conditions.

2.1.1 LOS versus NLOS Propagation

In Line of sight environment, the signal travelling through the radio channel of a wireless configuration system is over a direct and unobstructed path from the transmitter to the receiver. The criterion that the signal strength doesn't reduce in the LOS link is that the first Fresnel zone should be free of any obstruction. Also how free the Fresnel zone should be depends on the operating frequency and distance between the transmitter and receiver location.

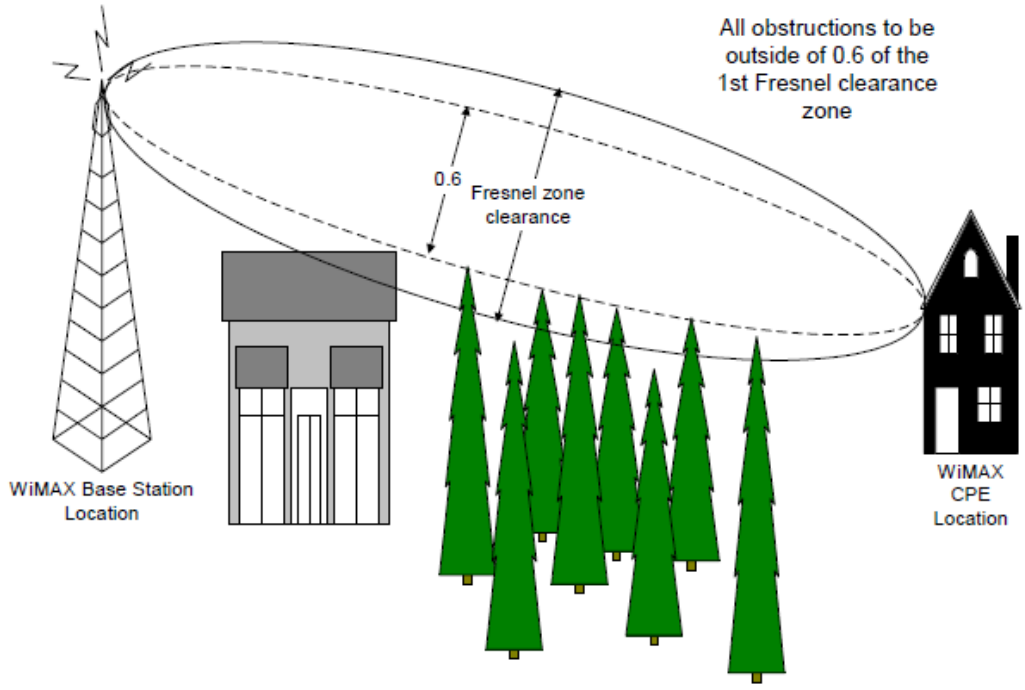

Figure 2.1 Fresnel zone for LOS environment

In non-line of sight environments, due to the obstructions, the signal reaches the receiver through reflections, scattering and diffractions. Hence the receiver receives multiple copies of the signal from the directed path, multiple reflected paths, scattered energy and diffracted propagation paths. All these signals experience different attenuation, polarization, delay spreads and stability.

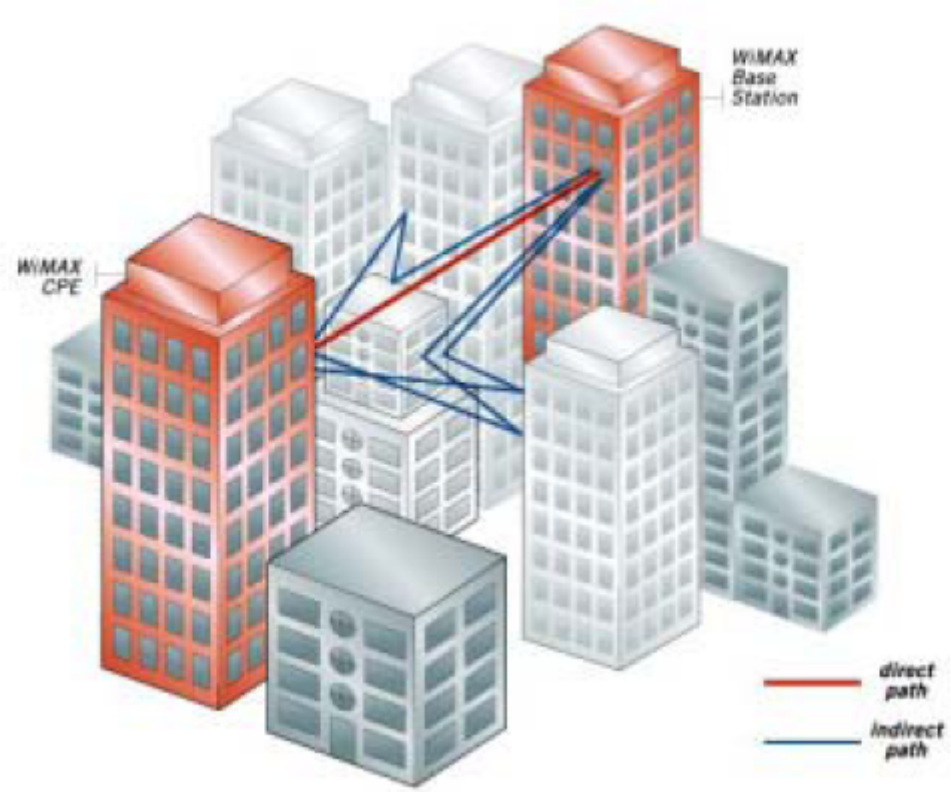

Figure 2.2 Propagation in a NLOS environment

The polarization of the signal changes due to multipath phenomena. Hence, the method of polarization is not used for frequency re-use, which is efficiently used in LOS deployments.

However, new schemes are developed where the wireless system uses these multipath signals to provide efficient data reception in NLOS condition. Now, reception of data precisely by just increasing the power to penetrate obstruction is not related to NLOS technology because everytime it is the direct path only that provides the best possible reception of the data than the indirect signals. The factors related to these NLOS and LOS technology are propagation characteristics of their environment, path loss and radio link budget.

It is seen that NLOS technologies are preferable because of its several advantages. Only the network planning management and antenna height considerations are not the factors to allow the antenna to be positioned for LOS, but different techniques like frequency re-use, lowering the antenna heights can be useful to avoid co channel interference between adjacent cells. Thus, the base stations can be used in the NLOS conditions. In LOS condition, the antenna heights are often not reduced because it impacts the required direct view path from the CPE to the Base Station.

In this case, the NLOS technology plays an important role which reduces the installation expenses. The NLOS technology helps in reducing the pre installation site surveys and also enhances the NLOS planning tools.

Due to several advantages of NLOS technology, the WiMAX can be better used for users which are indoor. But this has two main challenges to conquer. The first one is to reduce the building penetration losses and second is to cover good amount of distances with low transmit powers and antenna gains which reduces the cost implementation. For this, WiMAX uses some enhanced features for NLOS coverage. These technologies are listed below:

- OFDM technology
- Sub-channelization
- Directional antennas
- Transmit and receive diversity
- Adaptive modulation
- Error correction techniques
- Power control

CHAPTER 3

PHYSICAL LAYER DESCRIPTION

3.1 OFDMA BASICS

This multiplexing technique subdivides the bandwidth into multiple frequency sub-carriers. The idea behind this technology is to divide the input data stream into several parallel sub streams with reduced data rate (increased symbol duration).Every sub stream is modulated and is transmitted on a separate orthogonal sub-carrier. Because of this technique the symbol duration increases and improves the robustness of OFDM towards delay spread. For mitigating Inter Symbol Interference (ISI) cyclic prefix is introduced. Mitigation is possible as long as the CP duration is longer than channel delay spread. Repetition of last samples of data portion of the block at the beginning of the data payload as shown in the figure is cyclic prefix. Inter-block interference is prevented by CP and this CP makes the channel appear circular which allows low complexity frequency domain equalization. A direct drawback of this CP is more overhead which reduced bandwidth efficiency. It is observed that the effect of CP is similar to roll-off factor in raised cosine filtered single carrier system. It is seen that the spectrum of OFDM is very sharp almost like brick wall, where a large section of the allocated bandwidth can be utilized for data transmission which helps in reducing the loss in efficiency due to cyclic prefix.

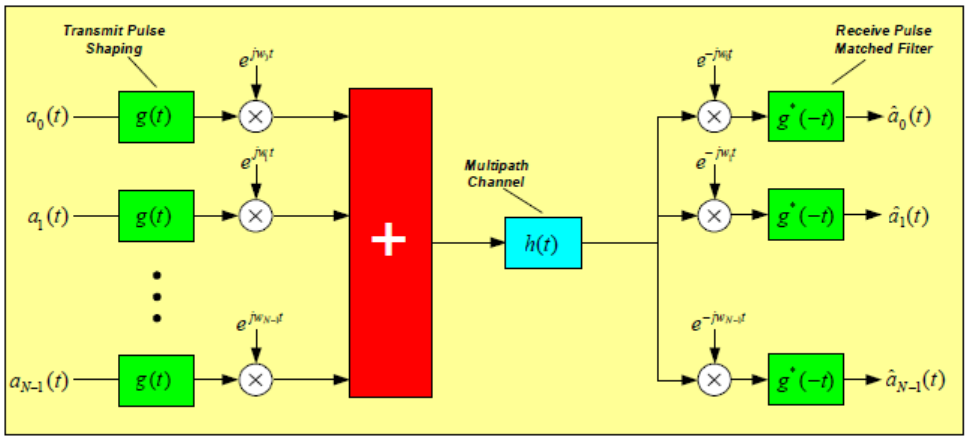

Figure 3.1 Architecture of an OFDM System

OFDM takes the advantage of the frequency diversity of the multipath channel using coding and interleaving properties on the information across the subcarriers before transmissions. OFDM modulation is done by using the effective Inverse Fast Fourier Transform (IFFT), Here large number of sub-carriers (up to 2048) can be used with low complexity. In OFDM, the subcarriers are in the frequency domain while the OFDM symbols are in time domain. Now these time and frequency domain resources are arranged into sub channels for allocation to individual users. For multiple access/multiplexing scheme which provides multiplexing operation of data streams from multiple users, another modulation technique is used which is known as Orthogonal Frequency Division Multiple Access (OFDMA). It can be used for both downlink sub channels and uplink multiple access by means of uplink sub channels.

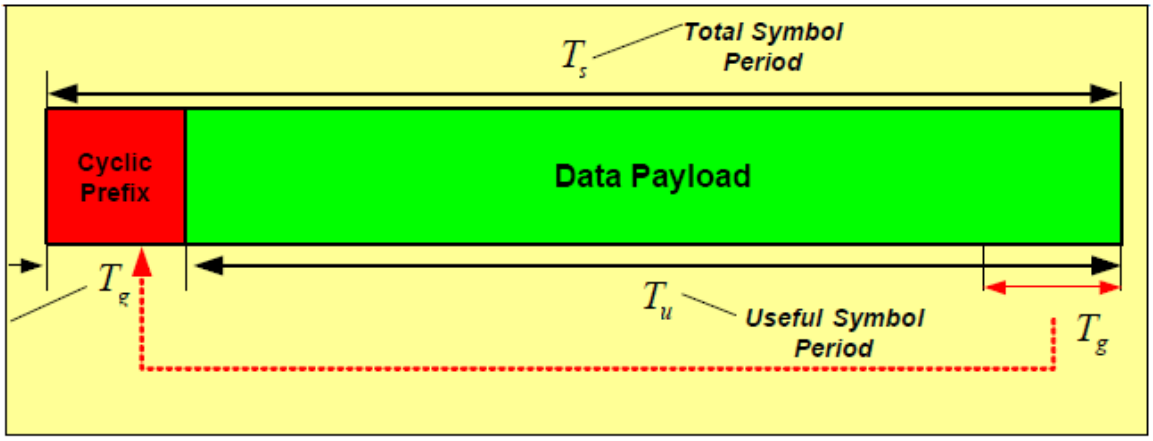

Figure 3.2 Cyclic Prefix insertion

3.1.1 OFDMA Symbol Structure and Sub-Channelization

The symbol structure comprises of three types of subcarriers which is shown in the figure. They are:

- Data subcarrier for data transmission
- Pilot subcarrier for estimation and synchronization purposes
- Null subcarrier for no transmission which are usually used as guard bands and DC carrier

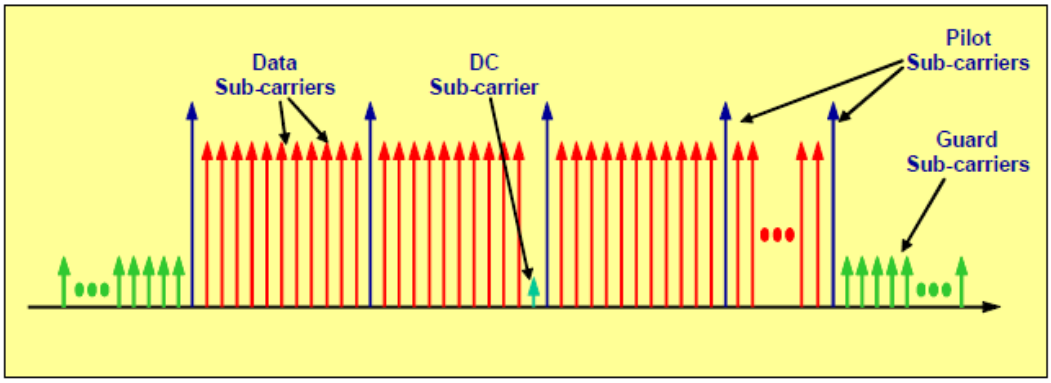

Figure 3.3 Structure of OFDMA sub-carrier

The sub channels showing in the figure are Active (data and pilot) subcarriers which are grouped into subsets of subcarriers. IEEE 802.16 e physical layer has OFDMA which supports sub channelization in both DL and UL. The resource unit for sub channelization is one slot which contains 48 symbols or data tones also known as subcarriers.

The two types of permutations for sub channelization are diversity and contiguous. In diversity permutation, the subcarriers are pseudo-randomly drawn to form the sub channel. This provides frequency diversity as well as inter-cell interference averaging. This type of permutation include DL FUSC (Fully Used Subcarrier), DL PUSC (Partially Used Sub-carrier) and UL PUSC and many other optional permutations. Now in DL PUSC, for each pair of OFDM symbols, the available or usable sub-carriers are grouped into *clusters* containing 14 contiguous sub-carriers per symbol, with pilot and data allocations in each cluster in even and odd symbols as shown in figure.

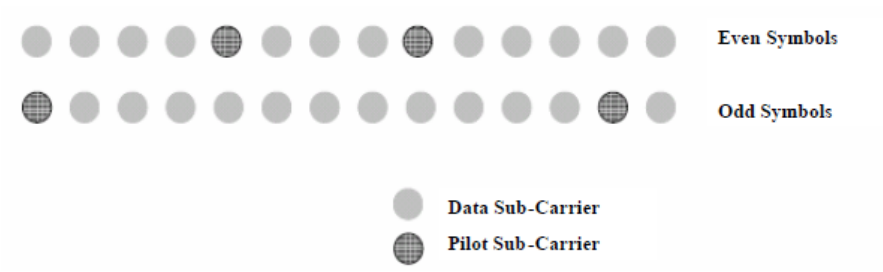

Figure 3.4 DL Frequency Diverse Subchannel

Re-arranging is done to form a group of cluster such that each group is comprised of clusters that are distributed throughout the sub-carrier space. In this, the sub channel has two clusters and is also comprised of 48 data subcarriers and eight pilot subcarrier for channel sounding.

Similar to the cluster structure for DL, the figure below shows the format of a tile structure for UL PUSC.

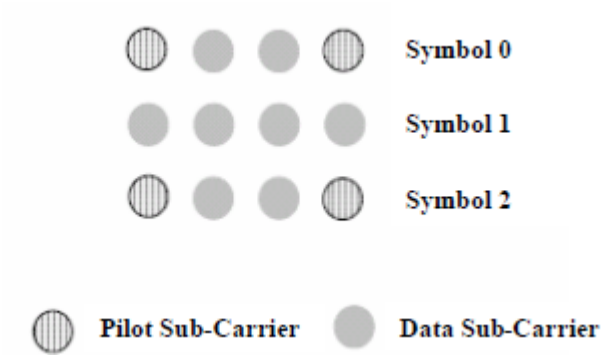

Figure 3.5 Structure of Tile UL-PUSC

Now a slot is formed by splitting the available sub-carrier space into tiles where six tiles are chosen from across the entire spectrum by proper rearrangement and permutation scheme. Hence in 3 OFDM symbols, the slot comprises of 48 data subcarriers and 244 pilot subcarriers.

In contiguous permutation, a block of contiguous sub-carriers are grouped to form a sub channel.

DL AMC and UL AMC are included in the contiguous permutation and they have the same structure. A bin contains 9 contiguous subcarrier in a symbol with 8 assigned for data and one for pilot. A slot in AMC is a collection of bins with N x M =6 where N is the number of contiguous bins while M is the number of contiguous symbols. Thus the possible and allowed combinations are (6 bins, 1 symbol), (3 bins, 2 symbols), (2 bins, 3 symbols), (1 bin, 6 symbols).The multi-user diversity is used by AMC permutation by choosing the sub-channel with the best frequency response.

Hence for mobile applications, diversity sub-carrier permutations performs well while for fixed, portable or low mobility environments, contiguous subcarrier permutation is used. Hence a trade-off is maintained for choosing the options when it comes to mobility for throughput.

3.1.2 Scalable OFDMA

The Mobile WiMAX or Wireless MAN OFDMA mode is based on the concept of scalable OFDMA(S-OFDMA). It supports a large range of bandwidth which efficiently uses the spectrum allocated and other usage model requirements. By fixing the subcarrier frequency to 10.94 kHz, scalability is supported by adjusting the FFT size. While scaling the bandwidth, the higher layers don't have a major impact since the resource unit subcarrier bandwidth and symbol duration is fixed. The parameters for S-OFDMA are presented in the table below. WiMAX forum Technical Working Group for Release-1 has developed system bandwidths for the initial planned profiles for 5 and 10 MHz.

Table 3.1 OFDMA

parameters

Parameters	Values			
System Channel Bandwidth (MHz)	1.25	5	10	20
Sampling Frequency (F_p in MHz)	1.4	5.6	11.2	22.4
FFT Size (N_{FFT})	128	512	1024	2048
Number of Sub-Channels	2	8	16	32
Sub-Carrier Frequency Spacing	10.94 kHz			
Useful Symbol Time ($T_b = 1/f$)	91.4 microseconds			
Guard Time ($T_g = T_b/8$)	11.4 microseconds			
OFDMA Symbol Duration ($T_s = T_b + T_g$)	102.9 microseconds			
Number of OFDMA Symbols (5 ms Frame)	48			

3.1.3 TDD Frame Structure

The Mobile WiMAX PHY supports TDD, FDD and Half-duplex FDD operation. But the initial release of Mobile WiMAX certification profiles include only TDD.FDD profiles are included now by the WiMAX Forum to address specific market opportunities where local spectrum regulatory requirements either prohibit TDD or are more suitable for FDD deployments. In order to counter interference issues, TDD requires system-wide synchronization.TDD is more preferred duplexing mode because:

- It allows efficient support for asymmetric downlink/uplink traffic while in FDD, downlink and uplink are fixed meaning it has equal DL and UL bandwidths
- It provides channel reciprocity for better support of link adaption, MIMO and other closed loop technologies.
- TDD requires only one single channel in contrast to FDD which require a pair of channels. Thus TDD provides greater flexibility for adaptation to varied global spectrum allocations.
- The design implementation for TDD transreceiver is less complex and cheap.

The figure below shows the OFDM frame structure for TDD implementation. The frame is divided into DL and UL sub frames which can be distinguished by Transmit/Receive and Receive/Transmit Transition Gaps (TTG and RTG, respectively) to prevent DL and UL transmission collisions. In order to ensure optimal system operation the frame has following control information:

- Preamble: It is used for synchronization and is also the first OFDM symbol of the frame.
- Frame Control Head (FCH): After preamble come the FCH which provides the frame configuration information such as MAP message length and coding scheme and usable sub-channels.
- DL-MAP and UL-MAP: The DL-MAP and UL-MAP gives the information on sub-channel allocation and other control information for the DL and UL sub frames respectively.
- UL Ranging: This sub channel is for the Mobile station MS only to perform closed-loop time, frequency, and power adjustment as well as bandwidth requests.
- UL CQICH: This channel is assigned for MS to feedback channel state information.
- UL ACK: The UL ACK is assigned for the MS to feedback DL HARQ acknowledgement.

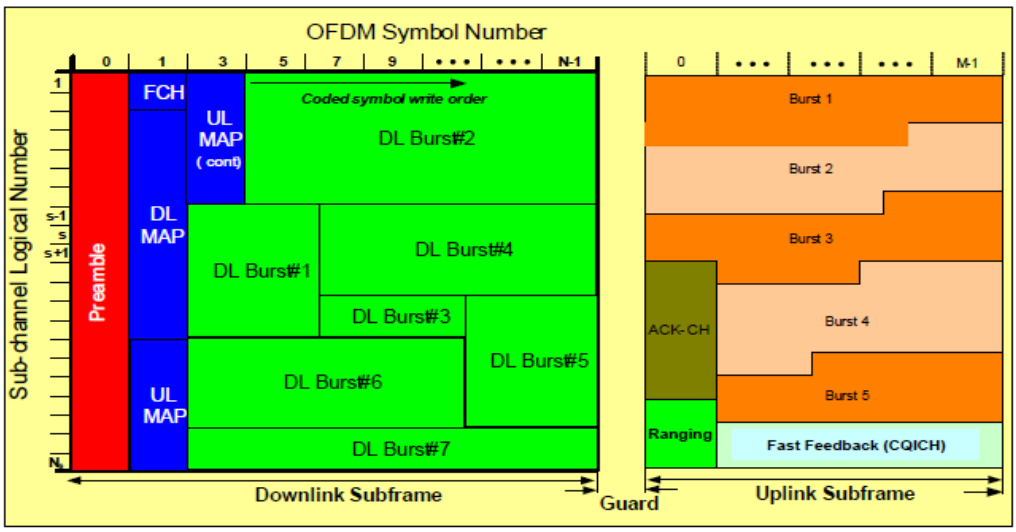

Figure 3.6 OFDMA Frame Structure

CHAPTER 4

NETWORK REFERENCE MODEL

4.1 Overview

The WiMAX forum has presented a logical representation of the network architecture for WiMAX which is known as Network Reference Model. The NRM has functional entities and reference points where interoperability functions are defined between functional entities.

The figure below shows the NRM which consists of logical entities like MS, ASN and CSN. It also defines the reference points R1-R6 and R8.

It may be that these entities work in a single physical function entity or it might be distributed over multiple physical function entities. The ASN contains one or more Base station(s) and at least one ASN-GW.

The main aim of the NRM is to use multiple implementation options for a given functional entity and achieve interoperability among different logical entities. Interoperability depends on the communication protocols and the flow of data between the logical entities to achieve an overall end to end function like security and mobility management. Functional entities have reference points with which they are connected and it includes control and data path end points. Interoperability is based only on protocols exposed across an RP, which depends on the end to end functions.

Thus the information on NRM makes the optimal use of protocols over an RP to support the capability. If the implementation supports the capability and exposes the RP, then the implementation shall comply with this specification. Hence it avoids the situation where protocol entity can reside on either side of an RP or the replication of identical procedures across multiple RPs for a given capability.

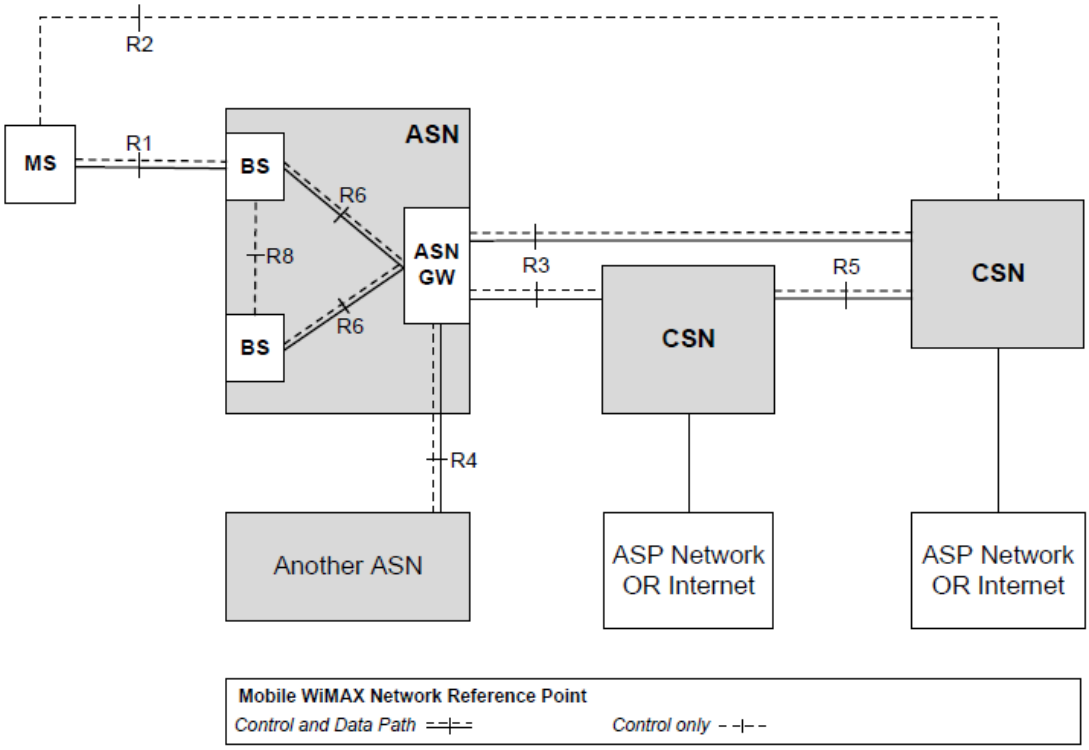

Figure 4.1 Network Reference Model

Both the IP services and the Ethernet services are supported by the network reference model with all its reference points.

4.2 Reference Points

The figure shows the Reference points with several interoperability .A reference point is a logical or conceptual point between the two groups of entities that reside on either side of it. These functions are related to protocols associated with the RP. It could be observed that these protocols associated with the RP might not terminate in the same functional entity that is there is a possibility that two protocols are associated with a RP and they might start and end in different functional entities. Following is the list of reference points between the major functional entities with their description:

4.2.1 Reference Point R1

According to the WiMAX forum Mobile system profile the reference point R1 consists of the protocols between the MS and the BS of the ASN as per the air interface specification.R1 can also include additional protocols related to the management plane.

4.2.2 Reference Point R2

Between the MS and the CSN lies the reference point R2 where authentication, service authorization and IP Host Configuration management protocols and procedures are included.

This reference point is considered to be logical because it doesn't depict a direct protocol interface between MS and CSN. The reference point R2 that runs between the MS and the CSN operated by the home NSP includes the authentication part and IP Host Configuration Management is supported by reference point R2 running between the MS and the CSN operated by either the home or the visited NSP).R2 between ASN and CSN operated by visited CSN may partially process the procedures and mechanisms.

4.2.3 Reference Point R3

A set of control protocols between the ASN and the CSN to support AAA, policy enforcement and mobility management capabilities are controlled by a logical connection known as reference point R3.It also includes the data path methods like tunneling to transfer the user data between the ASN and CSN.

4.2.4 Reference Point R4

A set of control and data path protocols starting and ending in an ASN-GW that synchronizes MS mobility between ASNs and ASN-GWs is supported by Reference point R4. R4 is solely responsible for interoperable function between the ASN-GWs of one ASN or two different ASNs.

4.2.5 Reference Point R5

The reference point that supports a set of control and data path protocols for interoperability between the CSNs operated by the home NSP and that operated by a visited NSP is the R5.

4.2.6 Reference Point R6

The reference point that controls the set of control and data path protocols for communicating between the BS and the ASN-GW within a single ASN is R6. Its an intra-ASN data path between the BS and ASN-GW. The control plane function comprises of data establishment, modification and release control in accordance with the MS mobility events.

4.2.7 Reference Point R7

It is a logical entity within the ASN-GW and represents internal communication within the gateway

4.2.8 Reference Point R8

This reference point is for intra-ASN and consists of the set of control plane messages between the base stations for fast and seamless handover. It contains the inter-BS communication protocol with the WiMAX forum Mobile System Profile and other set of protocols that allow controlling the data transfer between the Base Stations involved in handover of a certain MS.

4.3 ASN Reference Model

4.3.1 ASN Definition

Access Service network ASN comprises of ASN-GW(s) and Base Station(s) which performs functions to provide access service. The ASN has R1 reference point with an MS, R3 reference point with a CSN and R4 reference point with another ASN-GW. The ASN has at least one Base Station (BS) and at least one ASN Gateway (ASN-GW).

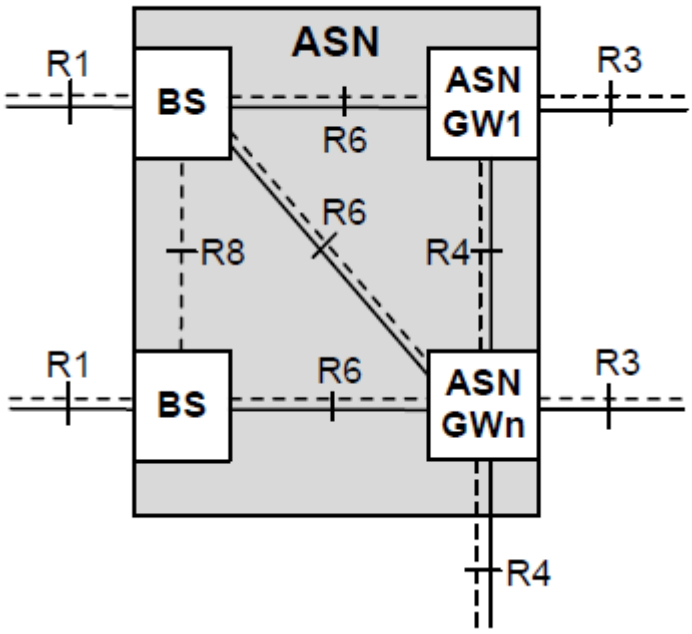

Figure 4.2 ASN Reference Model showing multiple ASN-GWs

One Base Station may be connected to several ASN-GW for different MS. When it comes to one MS then BS is connected to a single ASN-GW.

4.3.2 BS Definition

The Base Station is a logical entity that encompasses a full layer of WiMAX MAC and PHY with compliance to IEEE 802.16 applicable standards and may also perform one or more access functions. A WiMAX BS is assigned one frequency with coverage area of one sector. It performs scheduler functions for uplink and downlink and this is completely dependent on the vendors for which scheduling technique is to be used. It may happen that in order to balance the load during hand-offs, a single BS may be connected to more than one ASN-GW. Thus BS is a logical entity and there can be multiple implementations of physical BSs.

4.3.3 ASN Gateway Definition

This logical entity represents an aggregation of Control plane functional entities that work together with a corresponding function in the ASN perhaps BS, a resident function in the CSN or with a function in a bother ASN. The ASN-GW performs Bearer Plane functions of routing and bridging.

ASN-GW also includes function like redundancy and load balancing with several ASN-GWs for multiple MSs Hand-offs. For one MS, the BS is responsibly connected or associated with only one default ASN-GW. But, internally the ASN-GW functions for every MS among multiple ASN-GWs located in one or more ASN(s).

CHAPTER 5

WiMAX MAC LAYER

5.1 Introduction to MAC layer

In order to support very high data rates for both uplink and downlink, IEEE 802.16 forum developed a MAC protocol. Various algorithms to support several stations per channel simultaneously as well as multiple end users in terms of bandwidth allocation were designed. The mechanism of request-grant proved to be quite proficient and scalable.

The MAC includes two layers namely *Service-Specific Convergence Sub layers* (*CS*) and the core MAC common part sub layer. Higher layers are interfaced by CS MAC layer while common part sub layer provided MAC functions. The service data units are received from external network to Service-Specific Convergence Sub layer through CS Service Access Point (SAP). These are further passed to MAC Common Part Sub layer through MAC Service Access Point. These external data units are classified to proper MAC Service Flow Identifier (SFID) and Connection Identifier (CID). Various MAC functions include Payload Header Suppression (PHS), bandwidth allocation, connection establishment, connection maintenance; system access.

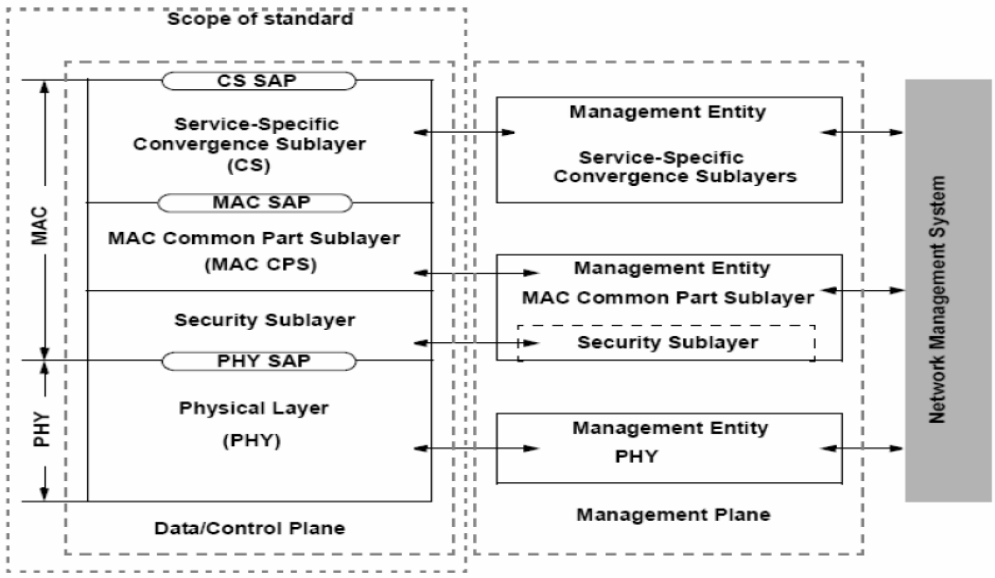

Figure 5.1 IEEE 802.16 protocol layering

There are two sub layers supported for mapping services to and from 802.16 MAC connections. They are:

- Packet Convergence sub layer: Here different packet services like IPv4, IPv6, Ethernet and Virtual Local area Network (VLAN) are supported
- ATM convergence sub layer: These are defined specific to ATM services only.

The major responsibility for the sub layer is to identify the service data units and put them to proper MAC connection, reserve QoS and allow bandwidth allocation. Between the MAC Common Part Sub layer and Physical layer, there is one more layer which provides authentication, secure key exchange and encryption. This layer is known as Security Sub layer. On complying with terms and conditions of service, various features like bandwidth request, allowing QoS and traffic parameters, transporting and routing data are provided by CS to proper convergence sub layer.

There may be two ways for allocation of bandwidth; one may be continuously granted bandwidth to bandwidth on demand. For this connections are required between BS and SS using 16 bit connection identifiers. There is also standard 48 bit MAC address associated with every SS but that is used only as equipment identifier but not for connections. Because it's the CIDs used during operations as primary address. After entering the network, the SSs are assigned three management connections for uplink and downlink. Depending on the several management levels, these three connections are associated with three different QoS levels.

5.2 Service-Specific CS

On the top of the MAC CPS lies the Service Specific Convergence Sub layer. It is through MAC SAP, where the external network data enter CPS from MAC CS.

The numerous functions provided by CS area as follow:

- Higher Layer Protocol data Units (PDUs) are accepted
- The PDUs are classified into proper connection
- After classification, processing is done if necessary
- Payload header information is suppressed if necessary

- The CS PDUs are transported to proper MAC SAP with proper service flow to the peer MAC SAP
- The suppressed payload information is rebuilt if necessary.

The transmitting CS delivers the MAC SDU to the MAC SAP. The MAC protocol functions to responsibly deliver the MAC SDU to MAC SAP with associated QoS, concatenation, fragmentation and other transport functions related to connection's service flow attributes. There receiver CS accepts the MAC SDU from MAC SAP and further sends it to higher layer. Out of the two CS mentioned all the packet based protocols like Internet Protocol (IP), Point to Point Protocol (PPP) and IEEE 802.3 (Ethernet) are supported by packet CS.

5.2.1 MAC SDU Formats

As shown in the figure, higher layers PDUs are encapsulated in the MAC SDU. While a Payload Header Suppression (PHS) rule is used, an 8 bit Payload Header Suppression Index (PHSI) field is set.

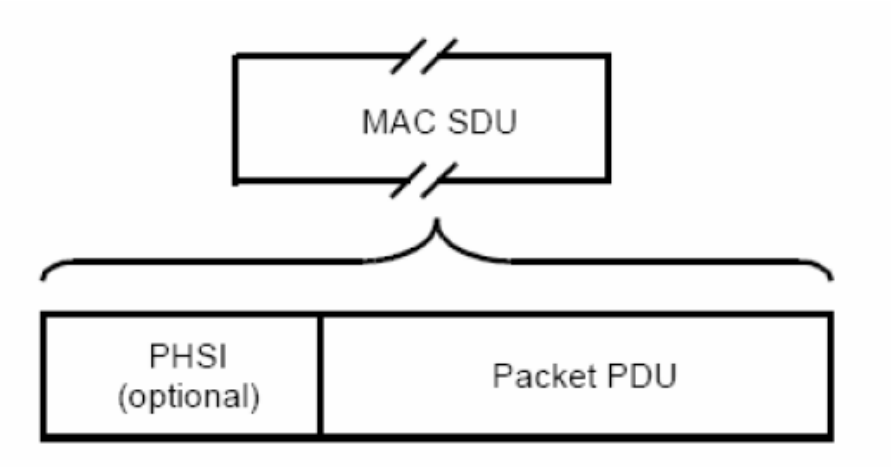

Figure 5.2 MAC SDU format

With the proper connection identifier MAC SDU is mapped properly between MAC peers. With proper association of CIDs, even SIDs is associated with MAC SDU. This helps in guaranteed delivery of MAC SDUs with QoS reserved.

5.2.2 MAC Header

There are two MAC header formats which are distinguished by single-bit Header type field. One is Generic MAC header and the other is Bandwidth request Header.

Generic MAC header

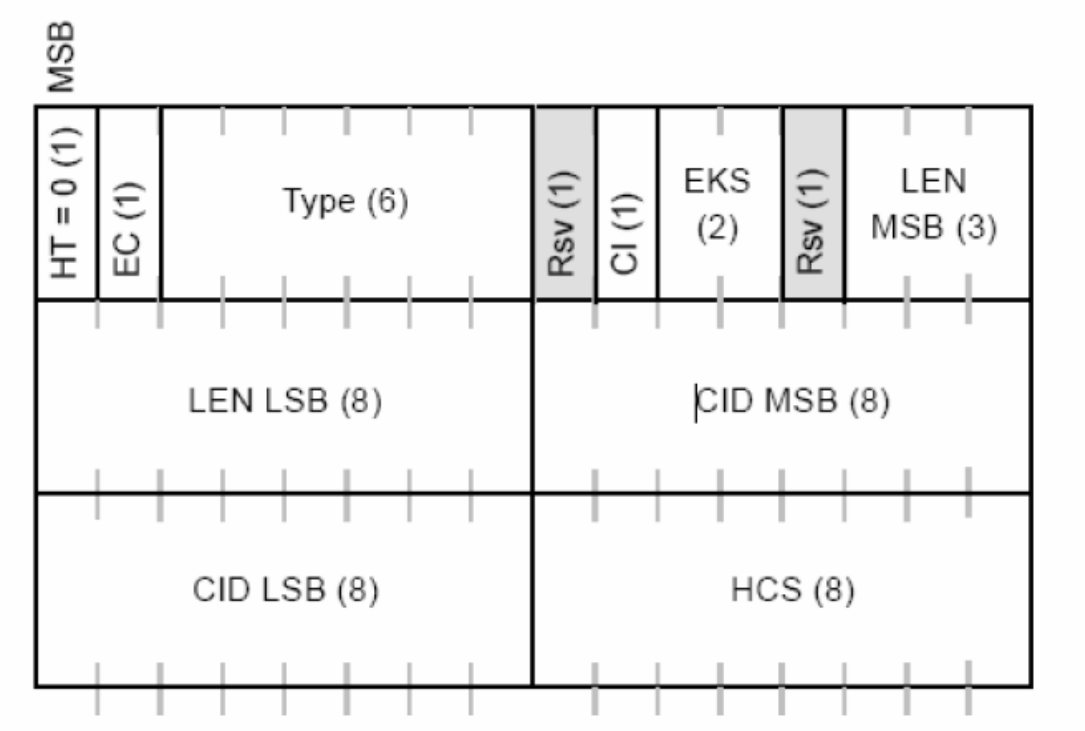

Figure 5.3 MAC header format

Table 5.1 MAC header fields

Name	Length (bits)	Description
CI	1	CRC Indicator 1 = CRC is included in the PDU by appending it to the PDU Payload after encryption, if any 0 = No CRC is included
CID	16	Connection identifier
EC	1	Encryption Control 0 = Payload is not encrypted 1 = Payload is encrypted
EKS	2	Encryption Key Sequence The index of the Traffic Encryption Key (TEK) and Initialization Vector used to encrypt the payload. This field is only meaningful if the EC field is set to 1.
HCS	8	Header Check Sequence An 8-bit field used to detect errors in the header. The transmitter shall calculate the HCS value for the first five bytes of the cell header, and insert the result into the HCS field (the last byte of the MAC header). It shall be the remainder of the division (Modulo 2) by the generator polynomial $g(D = D^8 + D^2 + D + 1$ of the polynomial D^8 multiplied by the content of the header excluding the HCS field. (Example: [HT EC Type]=0x80, BR=0xAAAA, CID=0x0F0F; HCS should then be set to 0xD5).
HT	1	Header Type. Shall be set to zero.
LEN	11	Length. The length in bytes of the MAC PDU including the MAC header and the CRC if present.
Type	6	This field indicates the subheaders and special payload types present in the message payload.

5.2.3 Bandwidth Request Header: This is used to ask for more bandwidth than the granted. Following the BW request header shown

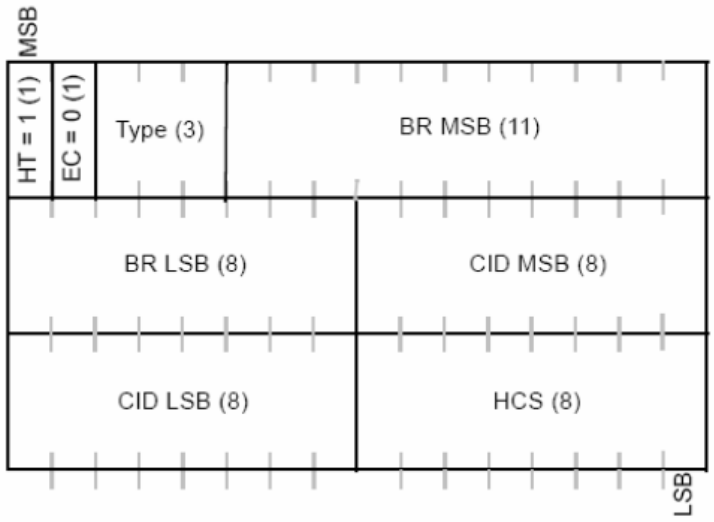

Figure 5.4 Header format for Bandwidth request

Properties:

- Header length is always 6 bytes.
- For no encryption, the EC field is kept 0
- Connections are identified by CIDs which would indicate uplink bandwidth request.
- The Bandwidth Request field in the header is for the number of bytes requested. If the bandwidth requests are ‘000’ then it is an incremental and if its ‘001’ then it’s for aggregate

For generic Header, the HT field is 0 and 1 for bandwidth request header.

5.2.4 MAC PDU Formats

The data units which are exchanged between MAC layers of BS and SSs are known as MAC PDU.

A MAC PDU comprises of:

- Fixed length MAC header
- A payload of variable length. The MAC PDUs are variable in length because the payload information may vary. The payload will have zero or more sub headers and zero or more MAC SDUs. The MAC layer transports different higher-layer traffic types without having the knowledge of the formats or bit patterns of those messages.
- It has cyclic redundancy check (CRC)

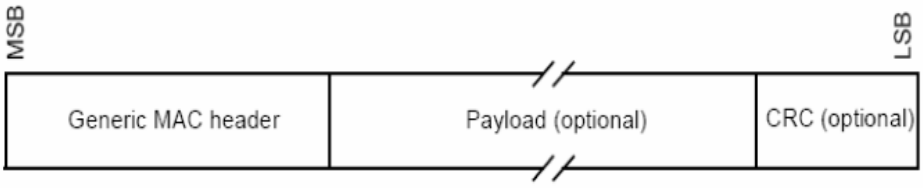

Figure 5.5 MAC PDU

The bandwidth request PDU doesn’t contain payload while the other MAC PDUs have MAC management messages or convergence sub layer data.

The concept of uplink burst transmission is shown. Here multiple MAC PDUs are sent together in a single transmission in both uplink and downlink directions. As unique CID is associated with MAC PDUs, the receiver MAC is able to identify the MAC SDU to correct port of MAC SAP. Concatenation of all the MAC management messages, user data and bandwidth request MAC PDUs are done in one single transmission.

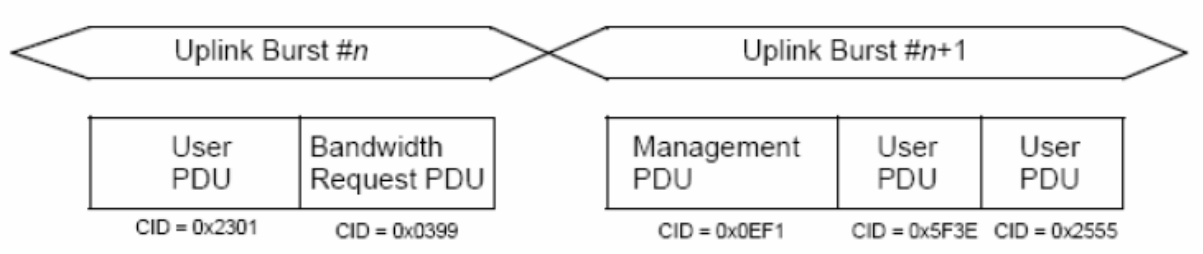

Figure 5.6 MAC PDU showing CIDs

5.2.5 Fragmentation

In order to provide efficient usage of bandwidth with respect to reserved QoS, fragmentation is done to MAC SDUs in to several MAC PDUs. Similarly reassembly is associated with every fragmentation. For downlink it is the BS which decides whether to fragment the SDU or not while SS decides during uplink. The fragmentation is initiated when a connection is created by MAC SAP.

5.2.6 Non-ARQ connections

Sequence numbers are assigned to the transmitted segments in sequence. The receiver receives and if not, detects the loss for any lost packets. When there is a loss, the receiver discards all the PDUs and accepts until it receives the first fragment.

5.2.7 ARQ Connection

In this sequence numbers are assigned to ARQ blocks of fragments for each transmission. They are assigned with adjacent sequence numbers.

5.2.8 Packing

During packing, the MAC protocol packs multiple MAC SDU's into single MAC PDU. It depends wholly on transmitter whether to pack a group of MAC SDU's into single PDU. Unpacking is

done at the receiver side. Packing uses connection characteristics for whether the packets are fixed or variable length. Formation of PDU is different for RQ and non-ARQ when it comes to syntax related to packing and fragmentation.

5.2.9 Cyclic Redundancy Check

Cyclic Redundancy Check is added to each MAC PDU which carries data for a service flow. Here, each MAC PDU has HT=0 and a CRC is attached to the payload of the MAC PDU. CRC is meant for the generic MAC header and Payload of the MAC PDU. It is always calculated after encryption; that is Generic Header and ciphered Payload is protected.

5.2.10 Security Association

The transmitter performs encryption and data authentication on the MAC PDU payload when a MAC PDU is mapped to a Security Association (SA).When the receiver receives such MAC PDU, it decrypts and also performs data authentication on MAC PDU payload, as notified by that SA. The generic MAC header might not be encrypted. But it contains all the information on encryption which is needed to decrypt the PDU at the receiver.

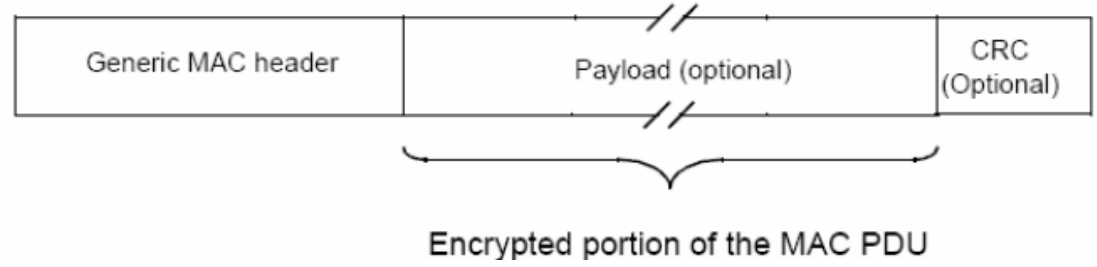

Figure 5.7 MAC PDU encryption

The EC bit field indicates whether the payload is encrypted or not. If the EC bit is set, the PDU is encrypted and the EKS has meaningful data. If the EC bit is reset, it indicates that the payload is not encrypted. So if a MAC PDU on a connection is mapped to an SA is unencrypted then the receiver will just discard it.

5.2.11 Padding

The unused space within the data burst is initialized to a known state. This is perhaps done by setting each unused byte to the stuff byte value (0xFF).Now, if the size of the unused data is same or at least same as the size of a MAC header, the region is initialized by formatting the unused space as an MAC PDU. By doing so, the MAC header CID field is set to the value of the Padding CID and the other fields like CI, EC, HT and the TYPE field are all set to 0.The length field is set to the number of unused bytes in the data burst and the HCS is calculated in the normal way.

5.3 MAC Common Part Sub layer

802.16 standards provide two types or modes for sharing a wireless access medium. One is point to multipoint (PMP) and second is Mesh (Optional).

5.3.1 Point to Multipoint (PMP)

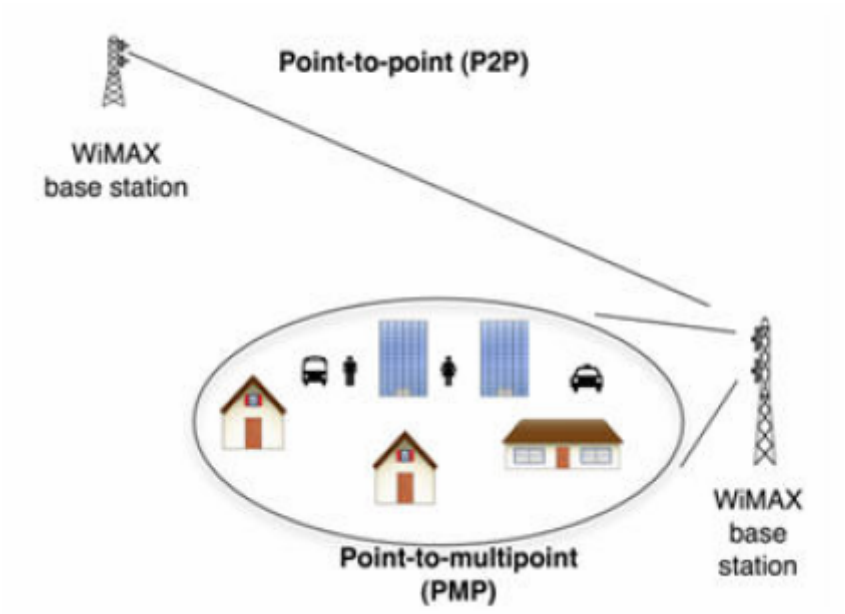

Figure 5.8 Point-to point and point to multipoint configuration

In this configuration, one base station provides services to hundreds of different subscribers with bandwidth as per required.

In PMP, a set of SSs are served with the BS within the same antenna sector, within a given frequency. Hence all SSs receive the same transmission signals. Thus, it can be concluded that in PMP, SS are centrally coordinated by the BS.

The only operating device in the downlink is the Base Station. So, it can transmit without coordinating with other stations. But it has to take care of the overall Time Division Duplexing (TDD) which divides time into uplink and downlink transmission periods.

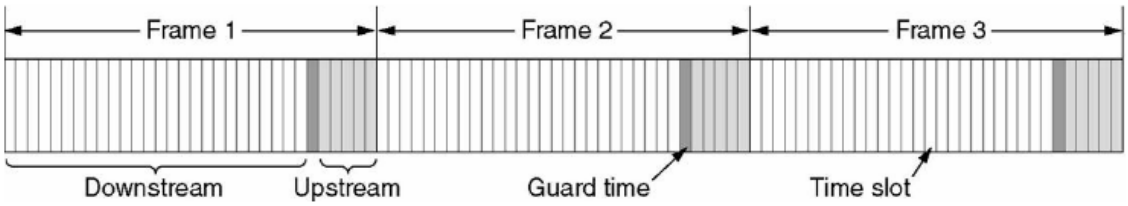

Figure 5.9 Time Division Duplexing

Now, the BS transmits a burst of MAC protocol data units in its downlink. As the transmission is broadcast, all SSs receive the data transmitted by the BS. When the DL-MAP doesn't provide an indication to a downlink sub frame for a specific SS, each and every SS is capable to listen that portion of the downlink sub frame. In order to distinguish for which SS that PDU belongs, all SS checks the CIDs in the received PDUs and keeps only those PDUs addressed to them.

During uplink, the SS transmits the MAC PDUs to the BS in a Time division Multiple Access (TDMA) manner.

Duplexing of Downlink and uplink sub frames are done in one of the following way:

- Frequency-Division Duplex (FDD): Here downlink and uplink sub frames occur on separate frequencies but simultaneously.

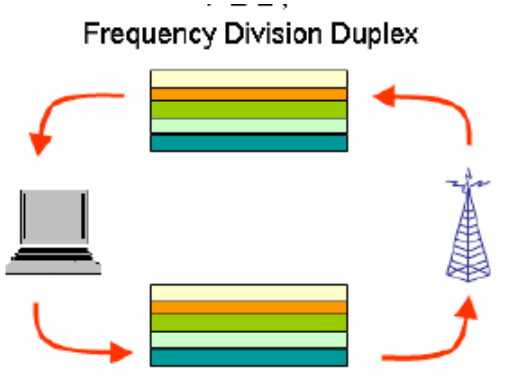

Figure 5.10 Frequency Division Duplex

- Time-Division Duplex (TDD): Here the downlink and uplink occurrence is at different times but they are on same frequency.

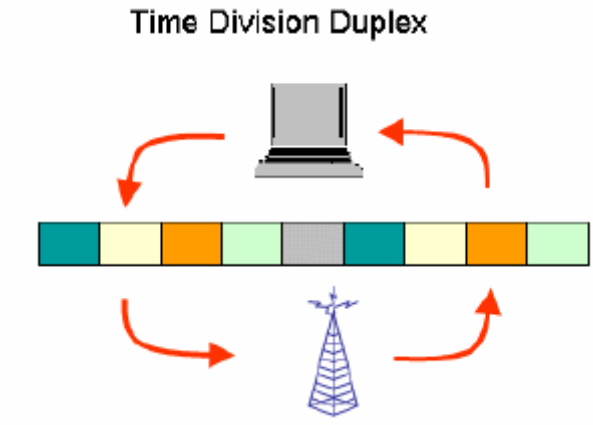

Figure 5.11 Time Division Duplex

FDD and TDD can occur simultaneous. Both the duplexing methods provide adaptive burst profiles where modulation and coding options could be dynamically assigned on a burst by burst basis.

Either full duplex or half duplex can work on the SSs.

The MAC protocol is considered as a connection-oriented service. All the data communication are unidirectional in nature whether its transport or control. In order to meet the guaranteed QoS service, the BS provides the uplink and downlink grants. By using the UL-MAP message, the SS can identify the boundaries of its allocation in its uplink sub frame. At the start of the downlink sub frame, there is

a frame control section that contains the DL-MAP. It contains both the downlink grants and UL-MAP for a specified time in the future.BS transmits DL-MAP and UL-MAP at the beginning of each downlink sub frame for both FDD and TDD modes.

5.4 QoS Architecture

As mentioned about the connection and service flow identifiers, data packets are always mapped into these identifiers while they enter the IEEE 802.16 network based on a set of matching criteria. Based on the QoS parameters of the service flow they belong, the data packets are classified accordingly with a particular QoS level. The QoS level is determined by shaping, policing and prioritizing the data packets at both the MS and BS ends. During connection setup, there BS allocates upstream bandwidth for a particular upstream service flow based on the parameters and service specifications of the corresponding service scheduling class negotiated. There are four QoS service classes defined by IEEE 802.16 standard. They are Unsolicited Grant Service (UGS), Real-Time Polling Service (rtps), Non-Real Time Polling Service (nrtPS) and Best Effort (BE).The characteristics of these four classes is described below.

- To support constant bit rate (CBR) traffic, the UGS service is defined. The CBR traffic may include audio streaming without silence suppression. In this service class, the SS doesn't request for the bandwidth to transmit their PDUs. At periodic intervals to the UGS flows, the BS provides fixed-size data grants. Because there is not request made for bandwidth allocation, the UGS provides hard guarantees in terms of both bandwidth and access delay. The nominal interval length between the successive grants and the tolerated grant jitter, is defined as the maximum tolerated variance of packet access delay.
- For video traffic such as MPEG streams, which are included in Variable Bit Rate (VBR), the UGS grant interval cannot determine the bandwidth requirements at the connection setup time. Hence, the peak stream bit rate based CBR allocation would lead to severe network underutilization; whereas the average bit rate CBR allocation can result in unacceptable packet delay and jitter. So for such flows rtPS has been introduced. Here in this service flow, the BS provides periodic transmission opportunities by basic polling mechanism. The SS uses these opportunities to ask for bandwidth grants; so that the bandwidth request can be

ensured to arrive at the BS within a given guaranteed interval. As a result the QoS parameters related to this service class are the nominal polling interval between successive transmission opportunities and the tolerated poll jitter.

- Now the only difference between the non real time polling service (nrtPS) and rtPS is that the polling interval is not guaranteed but depends on the network traffic load. Otherwise it is almost similar in nature. This helps in bandwidth-demanding non real time service flows with a variable packet size. These applications include large files transfer. Compared to rtPS, the nrtPS flows has fewer polling chances during network congestion, while the rtPS flows are always polled at regular intervals, irrespective of the network load. During heavy traffic conditions, the BS cannot guarantee periodic unicast requests to nrtPS flows, so the MS would need to use contention and piggybacking to send requests to the BS uplink scheduler.
- In Best Effort QoS service class, there are no periodic unicast requests scheduled by the BS.As a result there is no guarantee in terms of throughput or packet delay. Application like telnet or HTTP uses this BE class which provides efficient use of resources as these applications are of low priority and elastic in nature.

Traffic scheduling, policing, shaping and admission control mechanisms is not specified by the standard. Hence their implementations are kept with the vendors to decide.

CHAPTER 6

NETWORK ENTRY AND INITIALIZATION

6.1 Network Entry Procedures

After the MS is powered up, it acquires the network and WiMAX network undergoes following different steps. Figure shows the whole process of network entry.

6.1.1 Scan and Synchronize Downlink Channel

After the MS is powered up, it first scans the allowed downlink frequencies to determine whether it is presently within the coverage area of a WiMAX network. Every MS has a list of operational parameters which is non volatile. Those parameters are DL frequency which is used during the previous operational instance. First the MS will try to synchronize with the stored DL related to the most suitable BS. Every MS also keeps a list of preferred DL frequencies which are then changed to suit a service provider's network.

The MS listens to the DL frame preambles during the DL synchronization. After it has detected one, the MS can now synchronize itself to the DL transmission of the BS. Once this is done, the MS listens to the various control messages like FCH, DCD, UCD, DL-MAP and UL-MAP. These all control messages occur after the preamble which contains the various PHY and MAC related parameters corresponding to the DL and UL transmissions.

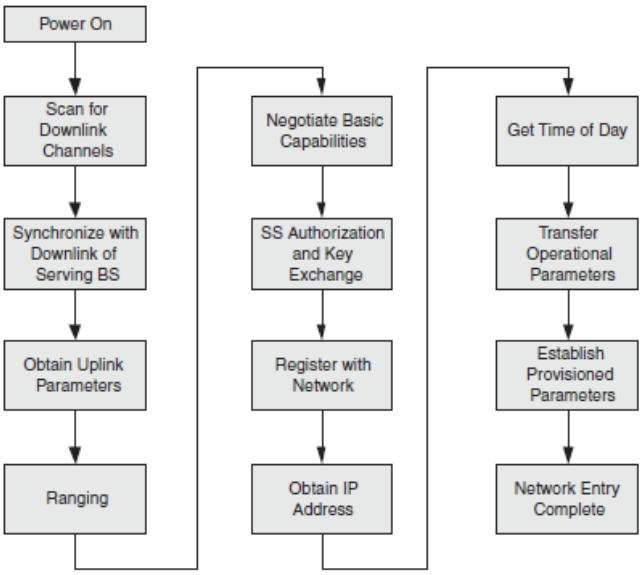

Figure 6.1 Process of Network Entry

6.1.2 Obtain Uplink Parameters

After decoding the UL parameters from the control messages, the decision are taken by the MS whether it find the channel chosen suitable. If the channel in unsuitable, the MS starts the scanning procedure again until it finds one. If the channel is found usable, then it listens to the UL MAP message to gather information related to ranging opportunities.

6.1.3 Perform Ranging

After the initial procedure of scanning is done, the MS now performs initial ranging with the BS to obtain the relative timing and power-level adjustment which are required to maintain UL connection with the BS. After the establishment of UL connection, the MS does a periodic ranging to track timing and power-level fluctuations. The reason for fluctuations is mobility, fast fading, shadow fading, or any combinations. Since the connections have not yet been established as of now, the initial ranging opportunity is contention based.

$P_{TX} = EIRxP_{IRMAX} + BSEIRP - RSSI$

This formula is used by MS to calculate the transmit power level for initial ranging.

Here the parameter *EIRxP$_{IR\ MAX}$ and BSEIRP* are provided by the BS in DCD message, and RSSI is the received signal strength at the MS. For the PHY layer, the MS sends a CDMA ranging code with power level shown by the equation. Now the procedure for ranging takes place. The MS sends a RNG-REQ message with the CID set to initial ranging CID. If no response is received from the BS within a certain time limit, then the MS will consider the previous ranging attempt to be unsuccessful and enters the contention-resolution stage. After that, the MS sends a new CDMA ranging code at the next ranging opportunity, after a back-off delay and it increases the power level to one step. The figure shows the ranging and automatic parameter-adjustment procedure in WiMAX.

Now, the ranging in MS is considered to be successful with status continue message if in the DL, the MS receives a RNG-RSP message which contains the parameters of the CDMA code used or the initial ranging CID for OFDM PHY, The MS then implements the parameter adjustment according to the RNG-RSP message. This message also contains the basic and primary CIDs allocated to the MS. For the case in BS, the initial ranging CID or CDMA code parameter in the DL-MAP message is used to indicate the DL allocation for the MS containing the RNG-RSP message. On the contrary, the MS finds the ranging unsuccessful with the status continue message when it receives an allocation in the UL MAP with the parameters of the CDMA code or the initial ranging CID for OFDM PHY. During this phase, the MS has an opportunity to send another RNG-REQ message using the initial ranging CID in the header.

The BS sends an RNG-RSP message on the reception of RNG-REQ message using initial ranging CID. The basic and primary management CID messages are allocated to the MS. These messages are usually used by the MS and the BS to send most of the MAC management messages. Hence, if needed additional CIDs may be allocated. The additional timing and power offset information is also provided by the RNG-RSP apart from the primary CID. There is a need for further ranging for the MS if the message for offsets is received with status continue message. So, every time the SS waits for a unicast ranging opportunity and at the very first chance the MS on primary CID sends another RNG-REQ message where the BS sends a RNG_RSP message with additional adjustment to power level and timing offset. This continues until the MS receives a RNG-RSP

message with status complete. So this completes the initial ranging and the MS is now ready to start its UL transmission.

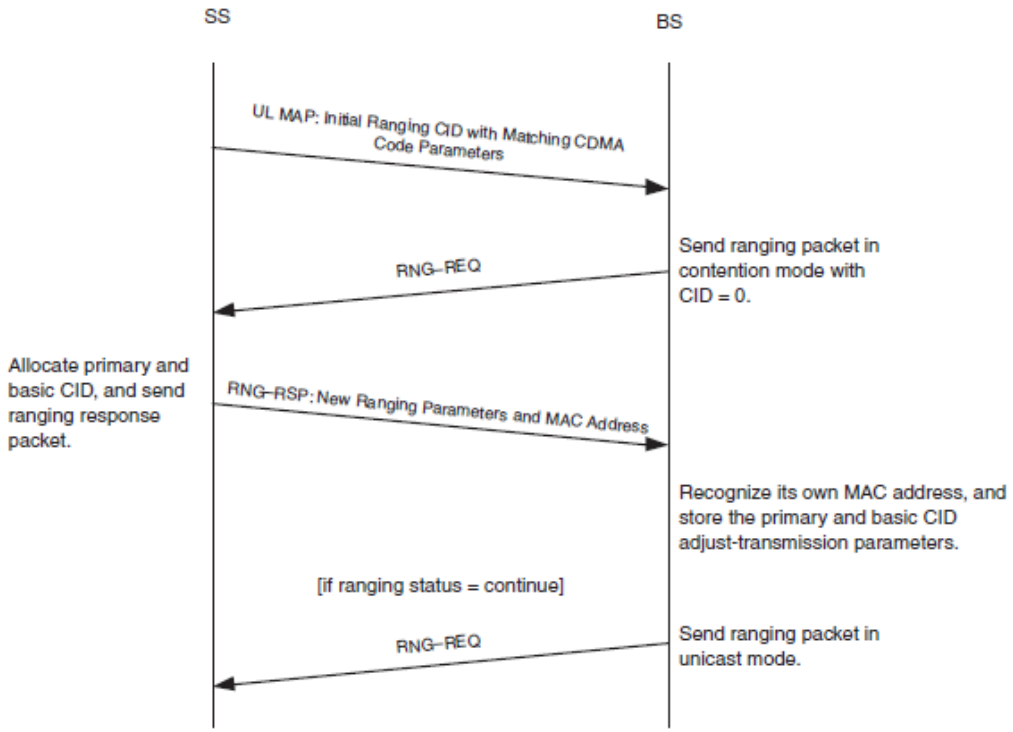

Figure 6.2 Ranging and Parameter-adjustment procedure

6.1.4 Negotiate Basic Capabilities

The MS sends a SBC-REQ message after the initial ranging to inform the BS about its basic capability set. This also includes various PHY and bandwidth-allocation-related parameters which is shown in the Table. To this message, the BS replies with SBC-RSP which provides the PHY and bandwidth-allocation parameters which can be used for UL and DL transmission. It is seen that the operational PHY and parameters related to bandwidth allocation are same as the basic capability set of the SS.

6.1.5 Register and Establish IP Connectivity

The MS registration with network is initiated once all the negotiation of the basic capabilities and exchanging the encryption key is done. In WiMAX, the MS is allowed to enter the network and can receive secondary CIDs after the registration is done. This process is started when the MS sends a REG_REQ message to the BS. For the authentication purposes, the message is encrypted using

hashed message authentication code (HMAC). After determining that the request for registration is valid, a secondary management CID is provided by the BS to MS in REG_RSP message. In the REG_REQ message, apart from secondary capabilities, the MS also indicated the BS about the basic capabilities such as IP version supported, convergence sub layer supported and ARQ support.

Table 6.1: Parameters in Basic Capability of BS and MS

PHY Related Parameters	Meaning
Transmission gap	The transmission gap between the UL and DL subframe supported by the SS for TDD and HF-FDD
Maximum transmit power	Maximum transmit power available for BPSK, QPSK, 16 QAM, and 64 QAM modulation
Current transmit power	The transmit power used for the current MAC PDU (containing the SBC-REQ message)
FFT size	The supported FFT sizes (128, 512, 1,024, and 2,048 for OFDMA mode; 256 for OFDM mode)
64 QAM support	Support for 64 QAM by the modulator and demodulator
FEC support	Which optional FEC modes are supported: CTC, LDPC, and so on
HARQ support	Support for HARQ
STC and MIMO support	The various space/time coding and MIMO modes
AAS private MAP support	Support for various AAS private MAP
Uplink power–control support	Uplink power-control options (open loop, closed loop, and AAS preamble power control)
Subcarrier permutation support	Support for various optional PUSC, FUCSC, AMC, and TUSC modes
Bandwidth-Allocation-Related Parameters	
Half-duplex/full-duplex FDD support	Support for half-duplex and full-duplex FDD modes in case of FDD implementation

The supported versions for IP are indicated by MS to BS in the REG-REQ message, wherein BS indicates the IP version to be used in the REG_RSP message. Only one version of IP is allowed for the use by the BS. By default IPv4 is used if the information about the supported IP version is not indicated in the REG_REQ message. The SS now uses DHCP to obtain an IP address after receiving the REG-RSP message from the BS.

6.1.6 Establish Service Flow

The service flows are created either by the MS or the BS depending on whether its an uplink traffic or a downlink traffic. If its uplink traffic, then the MS sends a DSA_REQ message containing the required QoS set of the service flow. On the reception of this message, The integrity of the message is first checked by the BS and then a DSX_RVD message is sent which indicates whether the request for a new service flow was received with its integrity preserved. After this the BS finds whether it supports the QoS and finally creates a new SFID. It then sends an appropriate DSA-RSP indicating the admitted QoS set. The process is completed by sending a DSA_ACK message by the MS.

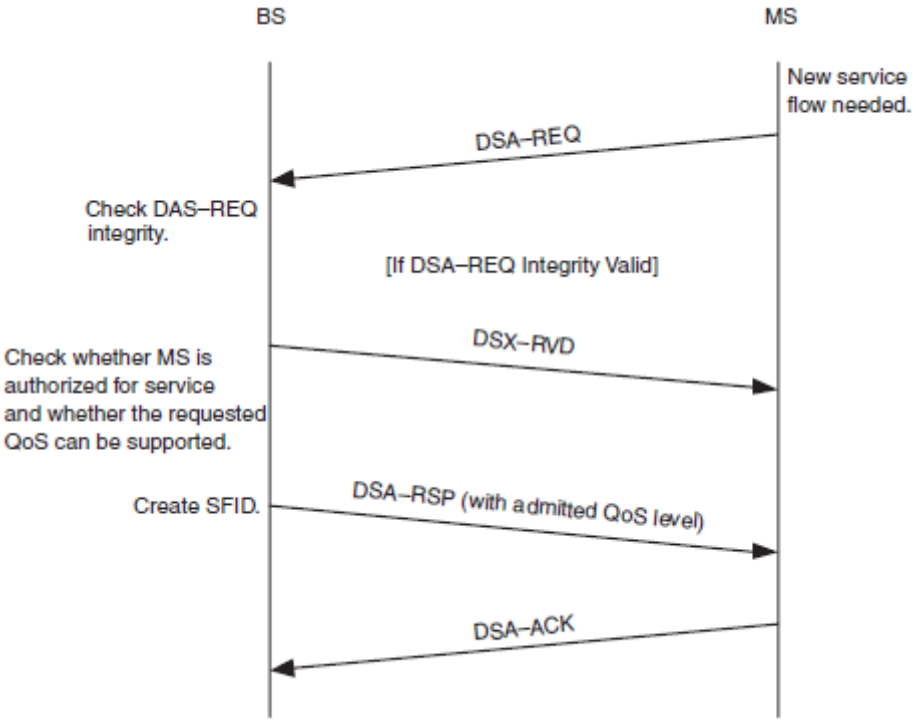

Figure 6.3 Service Flow creation initiated by MS

So the criteria for the MS to initiate the creation of service flow is decided by the BS by first checking whether the MS is authorized for such service and whether the requested level of QoS can be supported. But most of the time, this service is required to be executed only by higher layers and hence it's out of scope of the IEEE 802.16e.2005/802.16-04 standard. After finding whether the MS is authorized for the service, the BS creates a new SFID and sends a DSA-REQ message with the admitted QoS set and the CID to be used. On the reception of this message, the MS sends a

DSA_RSP message to indicate its reception. And the process is completed by the BS by sending a DSA_ACK message. Hence the requested service flow is finally created and the MS and BS are now ready to exchange data and management messages over the specified CID.

6.2 Power-Saving Operations

The two of the most fundamental concepts introduced in a mobile wireless network for the Mobile WiMAX standard are mobility management and power management. Even though these concepts are always referred together, they mean totally different. A critical feature in a mobile device is its battery resources. Power management is done for this, whereas retention of connectivity to the network while moving from the coverage area of one BS to the next is done by mobility management.

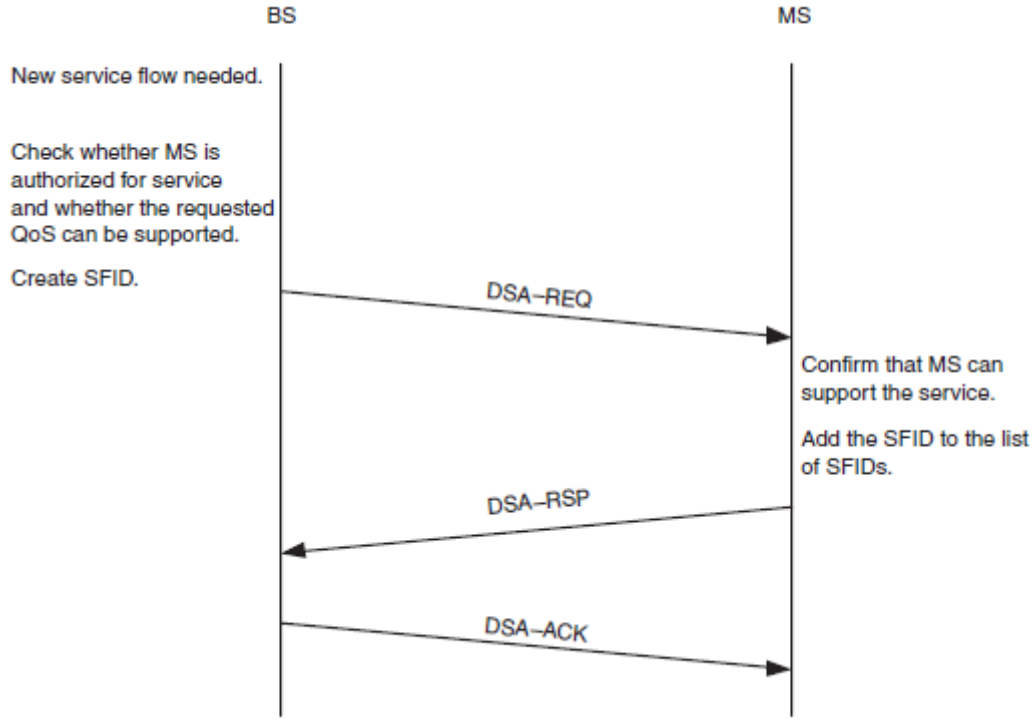

Figure 6.4 Service flow creation initiated by BS

6.2.1 Sleep Mode

This mode is an optional mode in Mobile WiMAX. The predetermined amount of time for which a MS interrupts its active connections (having one or more CIDs) temporarily over the air interface is called the sleep window. After the sleep window, there is a listen window. This is where the MS restores the connection. It is seen in the figure that MS can go to sleep and listen mode now

and then. It is the power saving class of the sleep mode operation, where the length of the sleep and listen mode is determined between the MS and BS. When the MS is in unavailability interval, the period when the MS connections are in their sleep windows, the MS cannot receive any Dl transmission or do any UL transmission. And when the MS connections are not in sleep mode, it receives and sends all the DL and UL transmissions normally on the CIDs which are in their listen windows. So its during the unavailability interval, B doesn't schedule any DL transmissions to the MS, as a result the MS can power down one or more hardware components required for the communication. For unicast transmission BS buffer or drops all the arriving SDUs while in the multicast transmission, the BS delays all the SDUs until the availability interval is common to all the MSs in the multicast group.

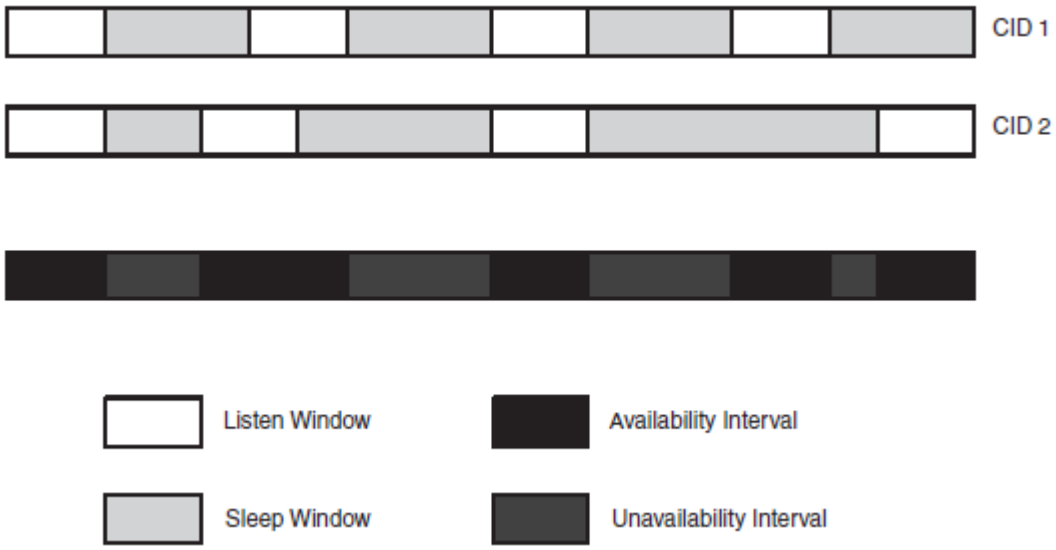

Figure 6.5 Sleep-mode operation

Depending on the parameters, the sleep mode operation is carried on in one of the three power saving classes.

1. Power saving Class1: In this class the listen window is of fixed length which is followed by a sleep window such that its size is twice as the size of the previous step window but it is not greater than a final sleep window size. At the very beginning of the power saving class 1, the BS specifies to the MS the initial sleep window size and the final sleep window size. When the final sleep window size is reached, all the following sleep windows are of same length.In this

sleep mode operation, it is BS who can reset the window size to the initial sleep window size and the process of doubling continues later. When the amount of listen window is not adequate to send all the traffic, the BS resets the window for DL allocation. While in UL allocation, the reset is under control of the MS. This power saving class 1 is mostly used for best-effort or non-real-time-traffic.

2. Power saving Class2: In this class, the sleep windows are of fixed length and they are followed by the listen window which is also of fixed length. At the very beginning of the power saving class 2 modes, the BS initializes the sleep and listen windows for the MS. This power saving class 2 is mostly used for sleep mode operation for UGS connections.
3. Power saving class3: In this class the power saving mode has single sleep window. At he very beginning of the class, BS indicates the start and the length of the sleep window. This class operation is in inactive mode at the end of the sleep window. This power saving class operation is mostly used for multicast traffic or for MAC management traffic. In multicast service, the BS estimates when the next portion of the data will appear. After this, the BS allocates a sleep window for all times when it is not expecting the multicast traffic to arrive. After the exhaust of the sleep window, multicast data may be transmitted to the relevant SSs. Then, the BS may reinitiate power saving operation.

6.2.2 Idle mode

In this mode, even if the MS is not registered with the Network, it can still receive broadcast DL transmission from BS. As a result, the optional idle mode in WiMAX avoids the need for handoff when it is not involved in any active data session. The advantage in the mode is that it allows the BS to conserve its PHY and MAC resources, since there are no handoff related procedures or signaling for MSs that are in idle mode.

It can be seen in the diagram, that groups of BSs are assigned to a paging group. When in idle mode, the MS monitors the DL transmission of the network to find the paging group of its current location. After determining that it has moved to a new paging group, the MS performs an update which is known as paging group update. During this update period, it informs the network of the current paging group about where it is present. Now while the downlink traffic is pending, the network establishes a connection with a MS in idle mode, and then the network pages the MS belonging to the

BSs which are currently in the paging group of the MS. Hence, the concept of paging introduced is quite helpful because the network will then page to the MS in all the BSs within the entire network. The network is designed in such a way that the paging area is large enough so that MS doesn't keep on updating the paging area now and then. Also the paging area should be so small that the paging overhead associated with sending the page on multiple BSs is low enough.

In this idle mode of operations, the MS remains in tow modes one is in MS paging-listen interval and MS paging unavailable interval. In MS paging-listen interval, the MS comes to know when the broadcast paging message is scheduled by listening to the DCD and DL MAP message of the serving BS. When a broadcast paging message is paged to the MS responds to this message and terminated the idle mode operation. If the broadcast paging message is not paged to the MS, the MS will enter the next MS paging-unavailable interval. While in the MS paging-unavailable interval, there is no paging and the MS powers down conducts ranging with a neighboring BS, scans the neighboring BS for the received signal strength and SNR ratio.

6.3 Network Discovery

Selection of the network is either manual or automatic which is based on the preference of the users. It is assumed that there are multiple networks available in a particular environment where the MS is located and also there are multiple service providers are supporting the services over the available multiple networks. The procedure to support such operation, the WiMAX standard has offered a solution for network discovery and selection. It consists of four steps: NAP discovery, NSP discovery, NSP enumeration and selection, and ASN attachment.

6.3.1 Network Access Provider discovery

In this discovery mode, the MS discovers all the available NAPs within the coverage area. The MS scans and decodes the 24 bit value of the "operator ID" from the DL MAP of the ASNs on the entire detected channel. This operator ID which is present in the base station ID in DL MAP is the NAP identifier.

6.3.2 Network Service Provider discovery

In this discovery mode, the MS is able to discover all the NSPs. A unique 24-bit NSP identifier or 32-byte NAI (network access identifier) is used to identify a NSP. These NSP IDs are broadcasted

by the ASN as the system identity information advertisement (SII-ADV) MAC management message. The MS listens to these messages and dynamically discovers the NSPs during initial scan or network entry. In response to an SBC-REQ message, the BS sends the NSP-IDs to the MS. On the other hand the MS can also have a list of NSPs which are listed in its configuration message. The configuration information maps the NSP-IDs to an NSP realm in the MS or the MS can also get the list by querying it. Now, here if the lists of NSPs are compared to the Network broadcast message, and if it doesn't match, then the MS must use the information obtained from the network. This mapping is avoided at only one instance when there is one-to-one mapping between the NAP and NSP.

6.3.3 Network Service Provider enumeration and selection

A suitable algorithm is used for a proper selection of the NSP for an MS from the list of available NSPs. Even here there are two types of selection: automatic and manual. The manual one is used only for initial provisioning and for "pay-per-use" service only.

6.3.4 ASN attachment

After the selection of NSP, the MS specifies the ASN associated with the selected NSP. It provides the home NSP domain which is in the form of a Network Access Identifier. The next AAA hop is determined by the ASN by checking the realm portion of the NAI in order to send the AAA packets of the MS.

6.3.5 IP Address Assignment

The most common mechanism to allocate a dynamic point of attachment IP address to the MS is the Dynamic Host Control Protocol (DHCP). The other way is by the home CSN. IT allocates the IP address to the ASN via AAA, but it is actually delivered to the MS via DHCP. But here, the problem faced is by the ASN is for DHCP proxy function as opposed to a DHCP relay function. The point of attachment IP address is allocated to the gateway or the host respectively, if the MS is acting as an IP gateway or host. But the IP address is allocated to the hosts behind the MS, if the MS is acting as a layer 2 bridges (ETH-CS).It is from the address space in the CSN of the home NSP, that an IP address is selected and allocated as static or dynamic to the MS for fixed kind. The dynamic IP address from either the home or the visited CSN is selected and given to the portable, nomadic and mobile MS. It depends on the roaming agreements and user subscription profile and policy.

There is a support for IPv6 as well. Here the ASN uses IPv6 access router (AR) to provide a globally routable IP address from the AR to the MS. There are two addresses given to the MS while using mobile IPv6.The one is the care-of address (CoA) from the ASN and the other is a home address (HoA) from the home CSN. Various features of IPv6 like static IP address, stateful auto configuration based on DHCPv6 or stateless DHCP. In the stateful configuration, the DHCP server is located in the serving CSN, and a DHCP relay in the network path to the CSN. While in the stateless configuration, neighbor discovery is done or the MS uses the DHCP to receive network configuration information.

Because there is no support for the link-local multicast in IEEE 802.16e air interface, there is a known issue with the use of IPv6 in WiMAX. There are various multicast packets in IPv6. They are neighbor solicitation, advertisement, router solicitation and router advertisement that have a link-local scope. In WiMAX, the all the packet transmission is based on a connection identifier (CID) as opposed to the 48-bit hardware MAC address; there is a need to create new mechanisms to share multicast CIDs among the multicast group members in a WIMAX network.

6.4 Mobility Management

The following is the reason for WiMAX mobility-management architecture

- To support seamless handover at vehicular speeds by minimizing packet loss and handoff latency and maintain the packet ordering.
- To provide security and trusted architecture of IEEE 802.16 and IETF EAP RFCs during mobility events.
- To support macro diversity handover (MOHO) and fast base station switching (FBSS)
- To reduce the number of round-trips of signaling to execute handover
- To separately control handover and data path.
- To support multiple deployment scenarios.
- To support both IPv4 and IPv6 based mobility management and allow mobiles with multiple IP addresses and concurrent use of IPv4 and IPv6 connections.
- To provide vertical handovers and roaming between the NSPs

- To allow a single NAP to serve multiple MSs which are using private and public IP domains of the different NSPs
- To support static and dynamic home address configuration
- To support various features like route optimization and load balancing by allowing policy-based and dynamic assignment of home agents.

There are two types of mobility supported by the WiMAX network: (a) ASN-anchored mobility and (b) CSN-anchored mobility.

The ASN-anchored mobility is also known as intra-ASN mobility or micro mobility. In this mobility, the foreign agent is maintained to be the same and the MS moves between two data paths. The reference points exposed in this handover are R8 and/or R6 reference points. In this handover, there is migration of R6 and R8 is used to transfer the undelivered packets from the buffer after handover. It is possible to maintain the layer 3 connection by keeping the same BS (anchor BS) in the handover session and detour the data from the anchor BS to the serving BS throughout the session. CSN-anchored mobility is also known as inter-ASN mobility or macro mobility. Here the MS takes help of a new anchor FS called FA migration and during this process there are exchanges of signaling messages between the new FS and CSN to establish data-forwarding paths. Here, R3 is the reference point exposed and R4 is used to transfer the undelivered packets. The following diagram shows the various handover procedures supported by WiMAX

MS moves from one base station to another due to radio conditions and this makes the need for mobility management. It may also be used when the MS wakes up from the idle mode at a different ASN. It may also be used when the network wants to transfer R3 reference points for an MS from the serving FA to the new FA for optimizing the resources.

Sometimes, both the ASN and CSN anchored mobility is needed. For this, first the ASN-anchored mobility takes place and after its successful completion; the CSN-anchored mobility is initiated.

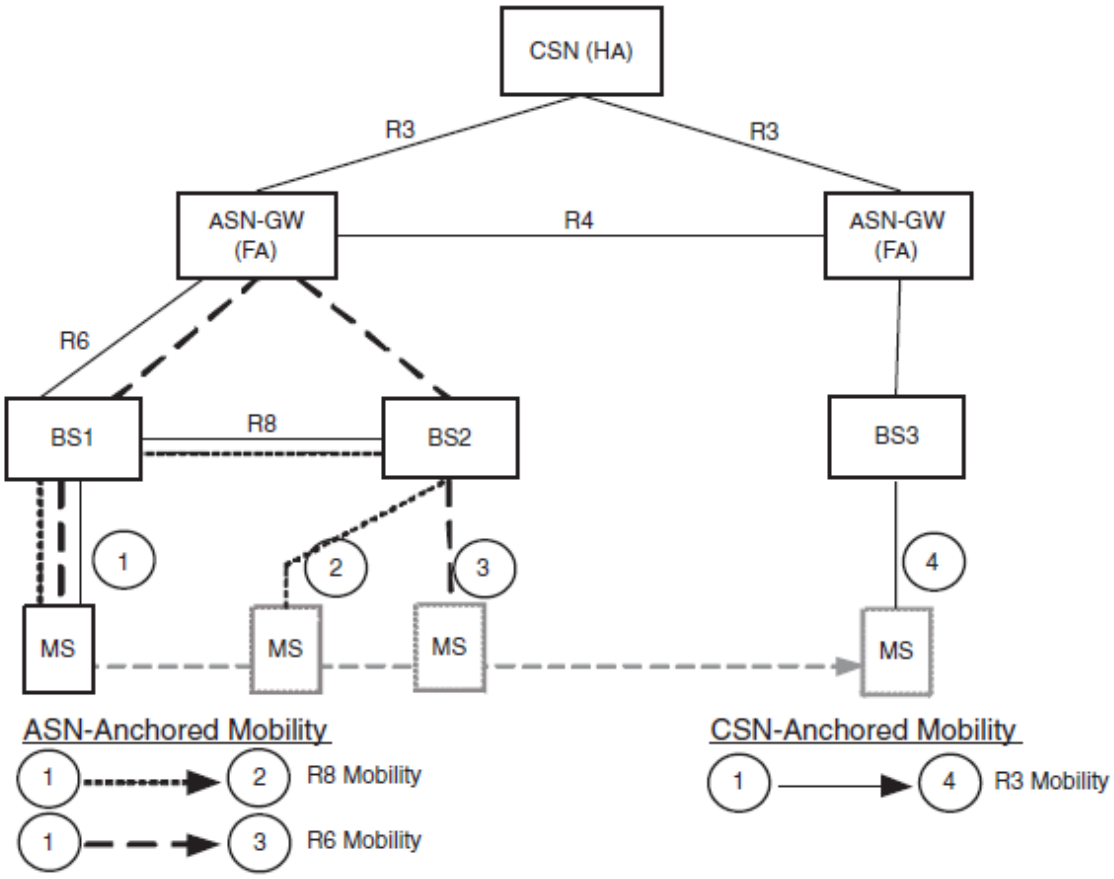

Figure 6.6 Handover scenarios

6.4.1 ASN-Anchored Mobility for IPv4

This mobility or handoff arises when the MS moves its attachment from one BS to another but within the same ASN. This is not visible to the CSN and hence there are not much needed changes in the network to be made. Hence there is no need for any network-layer software on the MS for the ASN-anchored mobility.

There are three functions for ASN-anchored mobility management defined by the IEEE 802.16 standard. They are data path function, handoff function and context function.

- Data path function: This function is used for connecting and managing the bearer paths which are needed for the data packet transmission between functional entities like BSs and ASN-GWs which are involved in a handover. For this handover, there are several functions performed like packet forwarding, ensuring low latency and handling special needs such as

multicast and broadcast between the entities. Actually, in WiMAX there are four DPF: (1) anchor data path function: It is related to the data path at one end that anchors the data path associated with the MS across handovers. (2) Serving data path function: This is related to the BS that is attached to the MS via IEEE 802.16e link. (3) Target data path function: This path function serves as the target for the handover. (4) Relaying data path function: This DPF acts as an intermediate between serving, target and anchor DPFs to provide information.

- Hand-off function: This function makes the decisions for HO and performs the procedures necessary for HO. The HO can be initiated by both MS and network which are known as MDHO and FBSS respectively. But these handovers are not supported in WiMAX release 1. Similar to functions related to DPF, even the HO functions are distributed with entities like serving HO function, target HO function and relaying HO function. The overall HO decision, signaling procedures, signaling the target HO function is controlled by the serving HO functions. Relaying HO functions control the signaling between the serving and target HO function. The IEEE 802.16 has defined some standards for messaging on HO. They are HO request, HO responses, HO confirm.
- Context Function: This function controls the exchange of state information between the networks elements related to the handover. At all handover execution procedures, there has to be an update on MS-related state information in the network and network-related state information in the MS. Example would be where there is a need for security update in the BS for an MS being attached to it. The context function is executed using a client/server model. The updated session context information is present in the context server which is retrieved by the context client on the IEEE 802.16e air link during the hand over. Between the context server and context client, there could be a relaying context function. There can be exchanges of various session-context information between the context client and server which are MS NAI, MS MAC address, AAA server, anchor ASN_GW associated with the MS, home agent IP address SFID and associate parameters, CID, CoA, DHCP server, security information related to PKMv2 and proxy MIP.

There are two types of bearers for packet transfer between the DPFs. They are Type 1 and Type 2. In Type 1, the IP or Ethernet packets are forwarded using layer 2 bridging (e.g. Ethernet or

MPLS) or layer 3 routing between tow DPFs. In Type 2 bearer, the forwarding procedure of the IEEE 802.16e MSDUs is done using layer 2 bridging or layer 3 routing. These MSDUs are appended with additional information like connection ID of the target BS and ARQ parameters. It is seen that Type 1 is simpler to use than Type 2 by the ASN. Forwarding of data can be done on various conditions like per service flow per subscriber, per subscriber or per functional entity. There are several technologies used for forwarding individual streams using tagging. These technologies are GRE, MPLS, 802.1Q which are used within ASN.

Of all this procedures, the DPF guarantees the data integrity and synchronization during handoff. The originator or the terminator DPF stores the data which require integrity during handoff period or always. Multicasting at the anchor DPF to the serving DPF and one or more target DPF is an alternate way to get data integrity, but its applicable to only downstream traffic. On the other hand, sequence numbers are used for synchronization of data packets during handoff. When the final target BS is known, the serving BS returns all the unsent packets to the anchor DPF and to the target BS all the unacknowledged packets because these data packets are buffered by the anchor DPF.

6.4.2 CSN-Anchored Mobility for IPv4

Here this mobility arises when the MS moves between different ASNs especially across multiple foreign agents. In WiMAX Release 1, the standard allows CSN anchored mobility to between FAs belonging to the same NAP. In this mobility, there is involvement across different IP subnets and hence a need for IP-layer mobility management is required. The protocol declared by IETF for managing the mobility across IP subnets is known as Mobile IP (MIP). This protocol is used to enable CSN-anchored mobility.

IEEE 802.16e has made measures for implementation of MIP for supporting CSN anchored mobility in two ways. The first one is having MIP client (MN) at the MS and the other is having a proxy MIP in the network that implements the MN in the ASN on behalf of the MS. Due to the proxy MIP, the IP mobility is transparent to the MS. WiMAX supports the coexistence of the proxy MIP and client MIP in a network. When both the measures are supported by the network, the MS then supports either one of them that is either mobile IP with client MIP or regular IP with proxy MIP.

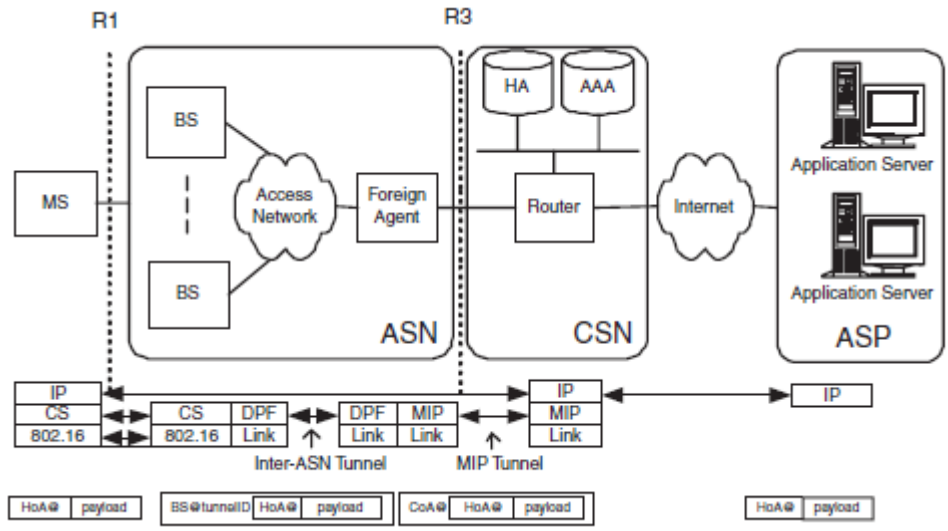

Figure 6.7 Protocol stack of Client MIP data plane

CHAPTER 7

BATTLE OF WIMAX AND LTE

7.1 WiMAX vs LTE battle: The War of 4G Technology

While seeing the current market prospects, we see that the industry is constantly pitting WiMAX over LTE which has now become an epic battle, but the truth is that 4G future is not a proposition. Different people have different opinions on this. This could be seen when one googles to find “WiMAX vs LTE” and finds 3-4 million results. This proves that there is lot of resources on the so-called battle between the existing next generation technologies. Current scenarios shows that various carriers and vendors are promising to support one technology over the other and how one group of companies will affect the future of these technologies. But according to me, where nationwide there is a battle between two technologies; each and every organization making you believe about an epic battle for the future wireless networks, the conclusion is

The WiMAX vs LTE “battle” is not a battle at all

It will be proved later on that none of these technologies will emerge as being victorious over one another and neither will be in a monopoly in the archives of the tech-history. So, the future of wireless networks is these two technologies which will be widely deployed and they are WiMAX and LTE. It had been proposed that one can use these technologies partly. Suggestions were that WiMAX would be used as a backhaul technology for 4G networks while LTE can be used for access technology. But, now I don’t think there is a need to provide or categorize WiMAX and LTE.

As per the current scenario, one can perceive that even though both these tech are viable 4G technologies, WiMAX is named better to be an ideal backhaul technology. But, LTE or WiMAX are racing against each other for an access perspective.

Now after an individual’s perspective, if we see from the market point of view, then the two largest carriers of North America and the GSM carriers in the world, LTE is certainly seen as the future of the wireless access. Hence, some organizations have buried WiMAX as a 4G access

technology. One of the major contributor as a service provider Clearwire still is rolling out WiMAX in major metro cities of US, while plans to cover 120 million people by the end of 2010.

The reason behind the burial of WiMAX is because if its hype when no AVAILABLE networks were there to speak of. It was talked all over the market and people were longing to use it but they couldn't. There are presently 14 networks for the people to use. Hence, it has regained its flavor once again. On the other-hand the second technology which is LTE is more preferable in public. Because there are many carriers in US supporting LTE, it has started reaching its peak. But as per the surveys among the public for preference, it is seen that LTE also is losing in the same way as WIMAX in terms of opinion. Seemingly, the market is going to pass through the same phase for LTE as WiMAX. So as of now the current scenario can be predicted as if people like the service, the time may change for LTE and it might be in the reigning thereafter.

So, the main subject of this topic is about the debate that is going on and on between LTE and WiMAX. It has been seen that LTE deployment is in progress but there has already been large deployment for WIMAX in this 1 to 3 years. But this statement doesn't mean that WiMAX has overpowered LTE because WiMAX is not available nation-wide but LTE will be covering a larger scale area than WiMAX. Hence, my opinion says that neither of the technology will win. It is because of its availability. In some places, consumers will have access to only WiMAX when it comes to 4G, while in some places people might have only the option of LTE for 4G. As seen about the deployment, perhaps by 2013-14, people might get lucky to use either of the tech- WiMAX or LTE. Above all there will be huge competitors in the market for service providers same as that we see today for 3G networks. It's going to be difficult for the people to make choices then but one thing is sure that none of the technology will displace.

Originally, WiMAX was deployed a wireless backhaul technology. Hence, even though WiMAX doesn't come out to be the future or next-generation wireless access technology of choice, it will always be used as a backhaul technology for 4G and Wi-Fi networks all over the world. The reason is because of the study that WiMAX plays a better role as a backhaul.

So the future could be predicted as neither the WiMAX nor the LTE are going to dislodge each other or Wi-Fi. The WiMAX and LTE comparison should be avoided. For several applications which consume large bandwidth WiMAX has proven to be great support to be a backhaul and ideal wireless access technology. Those applications are wireless video surveillance, traffic synchronization etc. So as by the end of this year LTE is going to be deployed, it is quite clear that WiMAX technology will be used the wireless backhaul for those networks, while LTE will be used as the access. Also, as more and more enhancement will be made, Wi-Fi will be used as an outdoor technology where WiMAX may play a key role as the backhaul.

CHAPTER 8

INTRODUCTION TO THE OPNET

8.1 Overview

This section describes the basics of using Opnet Modeler. It includes important information for the usage of the Modeler. It is for OPNET modeler with release 16.0 with wireless suite for WiMAX

8.1.1 About Modeler

This section describes the Modeler Workflow, the workspace, and the editors.

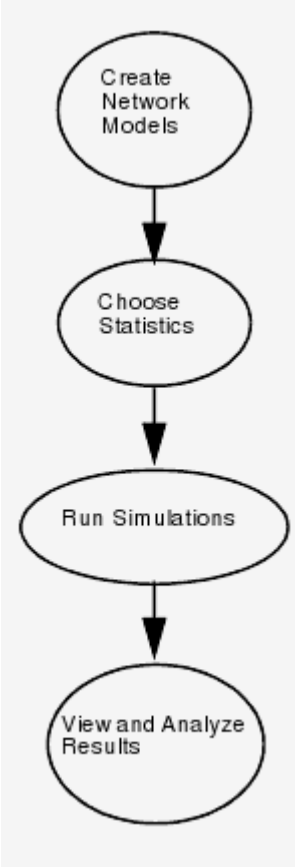

Figure 8.1 Flowchart on executing network model

Workflow: This module is used to build a network model and run the simulations. One can choose different statistics to collect from each network and run a simulation to view the result. Below is the description of editors one by one which can be used for modeling a network.

8.1.2 Project Editor

The project editor is used to create the network model using the standard library. One can create nodes and process models, packet formats, filters and parameters

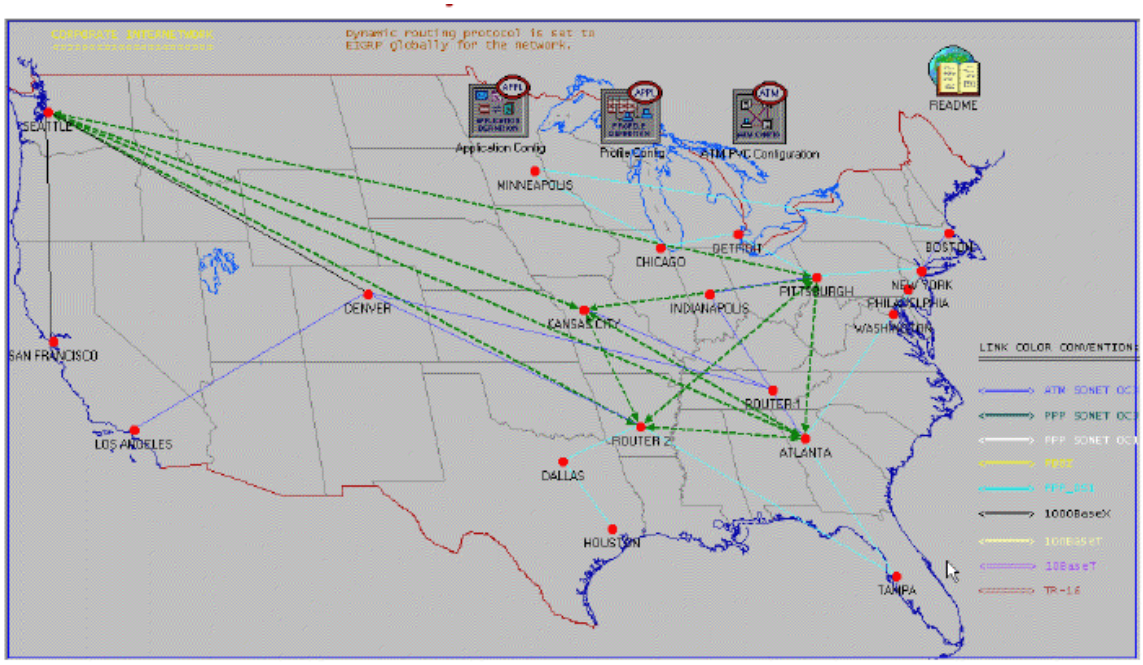

Figure 8.2 Network Model in Project Editor

8.1.3 Node Editor

This editor defines the behavior of each and every network object. This describes some internal aspects of node behavior like data creation, data storage. There are multiple modules which make up a network object to define the behavior of the node connected to each other with packet streams and statistic wire.

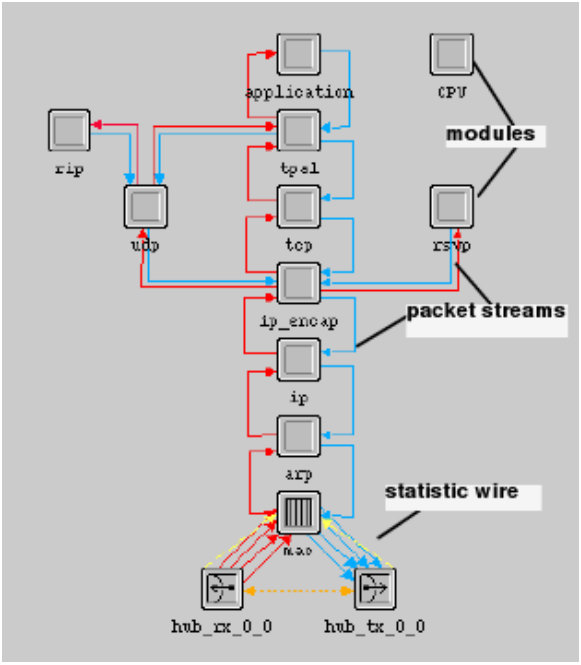

Figure 8.3 Node Model

8.1.4 Process Model Editor

In this editor, the process models are created whose functions are controlled using the node models created in the Node Editor. These models are defined using finite state machine (FSMs). The FSMs are characterized using states and transitions between the states.

8.1.5 Link Model Editor

This editor is related to the link objects. There is general description which describes the new type of link.

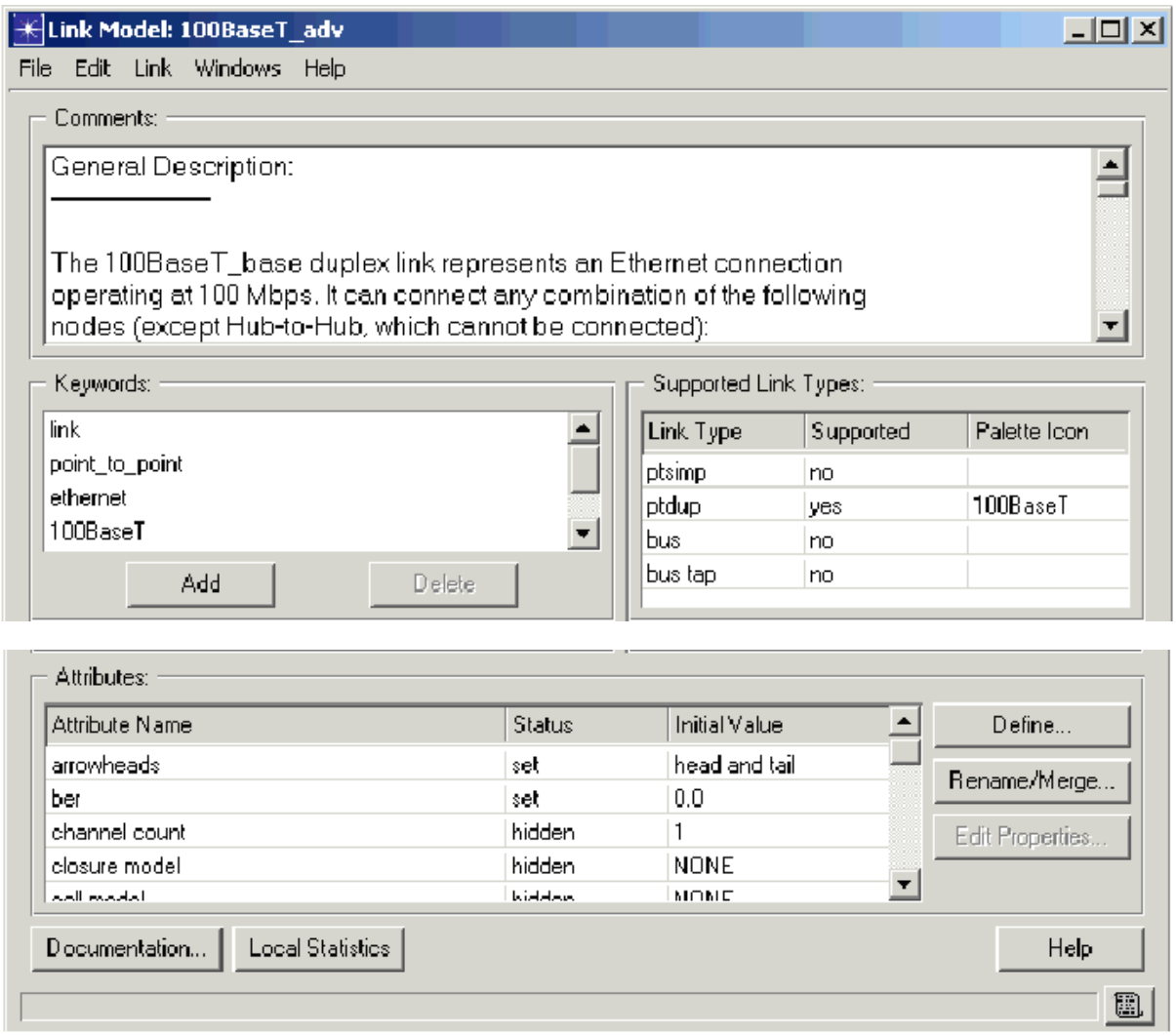

Figure 8.4 Link Model

8.1.6 The Demand Editor

This editor describes the demand models. The attributes, presentation and behavior of the demand models are described in this editor. One can create or alter the specification of demand model in the dialog box.

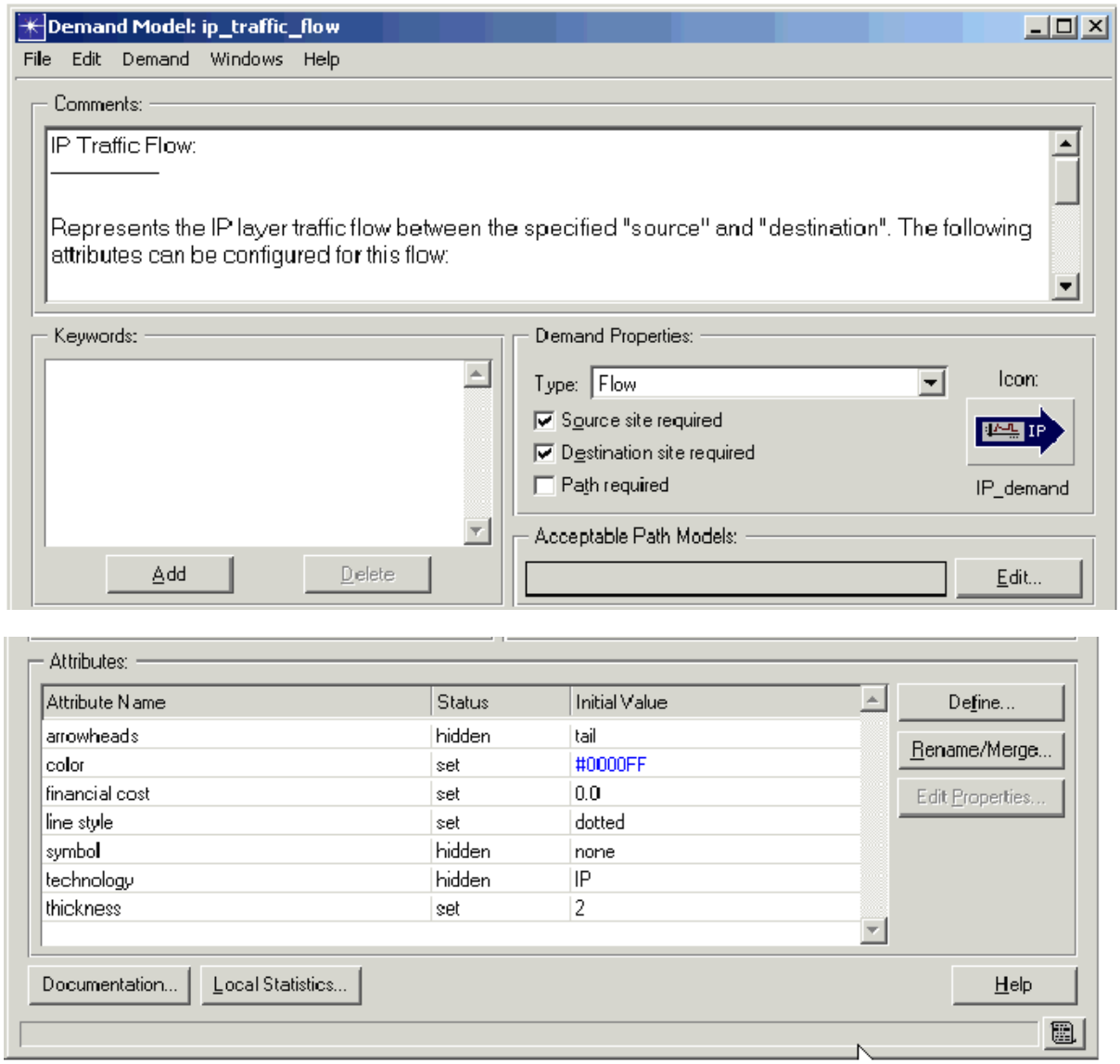

Figure 8.5 Demand Editor

8.1.7 Path Editor

This editor is used to define a traffic route where one can create new path objects. Different protocols whether its virtual circuit or logical connection like MPLS, ATM, Frame Relay use paths to route traffic.

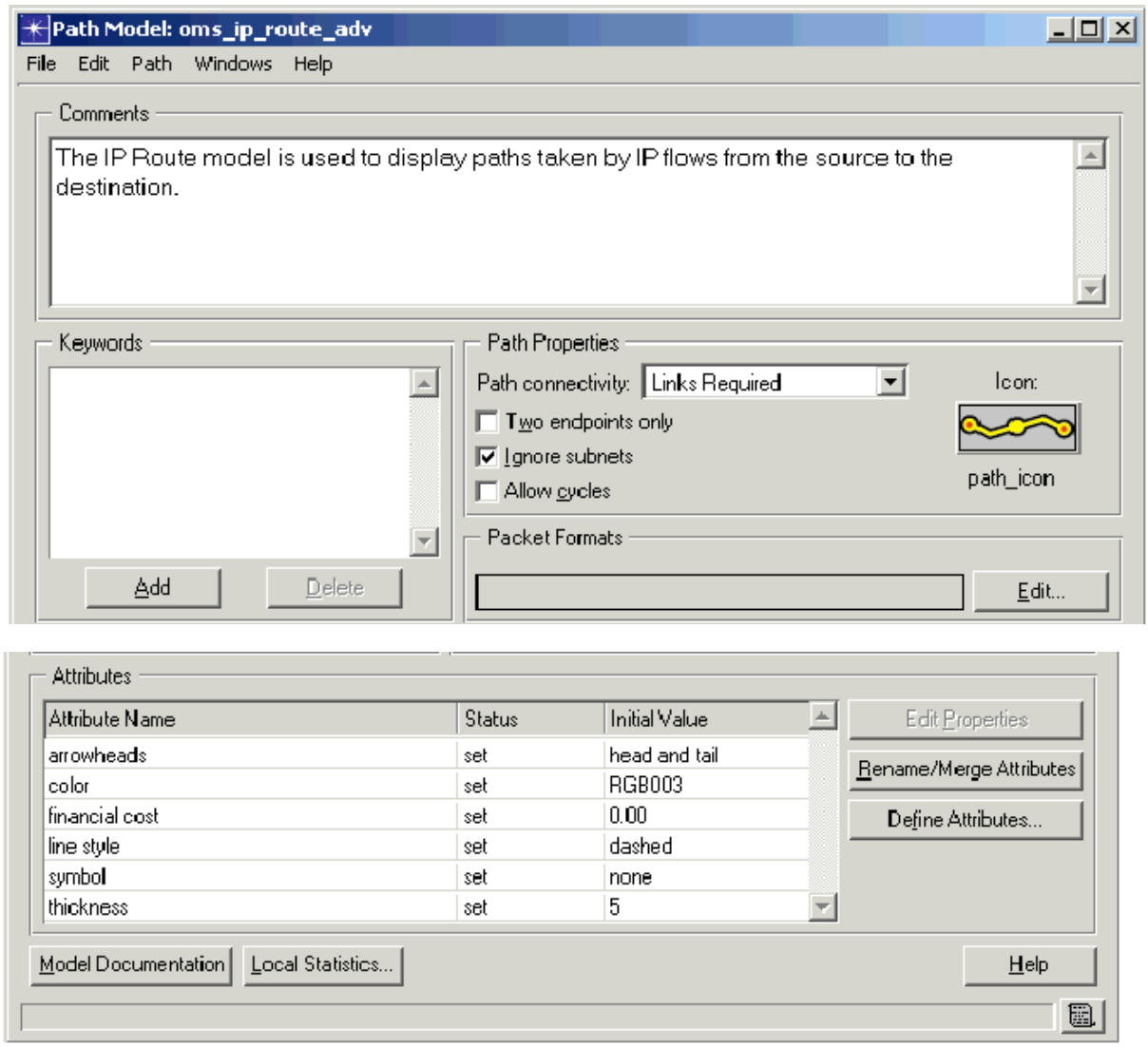

Figure 8.6 Path Model

8.1.8 Packet Format Editor

This editor's dialog box shows the internal structure of a packet with its set of fields. It contains one or more fields and its size is shown as number of bits. Depending on the number its proportional size is shown. These fields are shown as colored rectangular boxes.

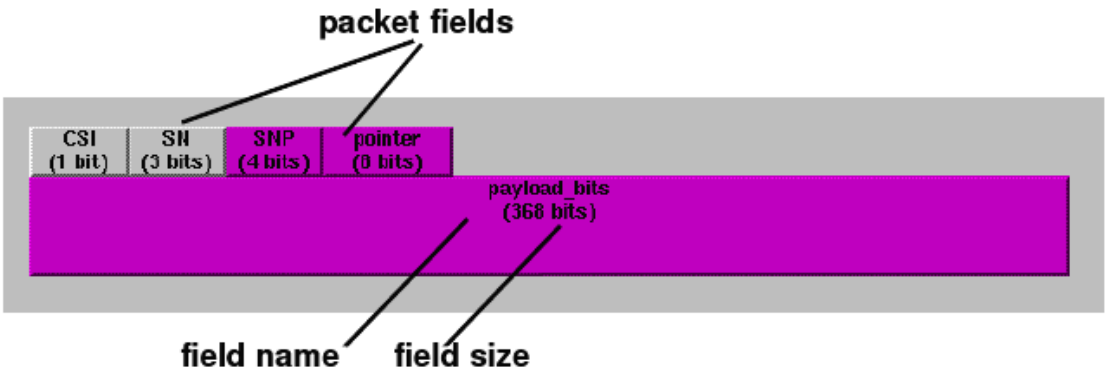

Figure 8.7 Packet Format editor

8.1.9 Antenna Pattern Editor

This editor is solely related to antenna wit wireless module. It gives you information on properties like direction-dependant gain patterns. These properties help to observe gain values and other related parameters.

8.1.10 Modulation Curve Editor

This editor works after simulating a network model when one wants to plot the bit error rate (BER) of the baseband signal as a function of Carrier to Interference Noise Ratio (CINR).

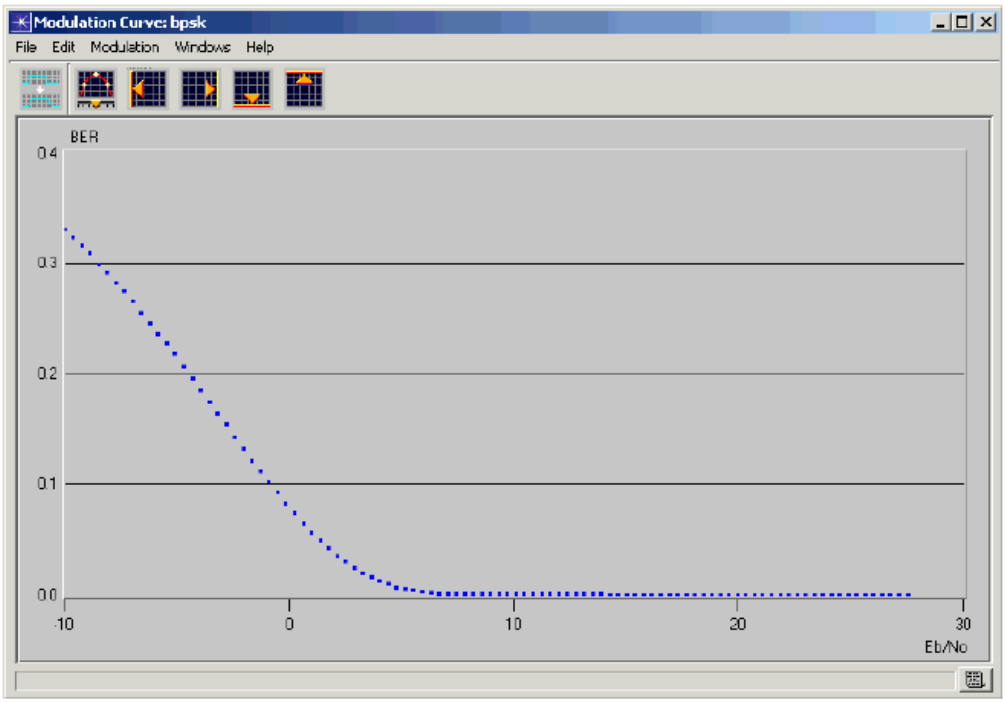

Figure 8.8 Modulation Curve

8.1.11 Probe Editor

This editor collects the statistics during the simulation. By probing, one can collect statistics like global statistics, link statistics, and node statistics, attribute statistics etc.

8.1.12 Analysis Tool

An additional feature with simulation result of the Project editor is the Analysis tool. This tool can be used for various purposes to study the results for example by making the graphs scalar or make templates where you can save the analysis configuration and view it later.

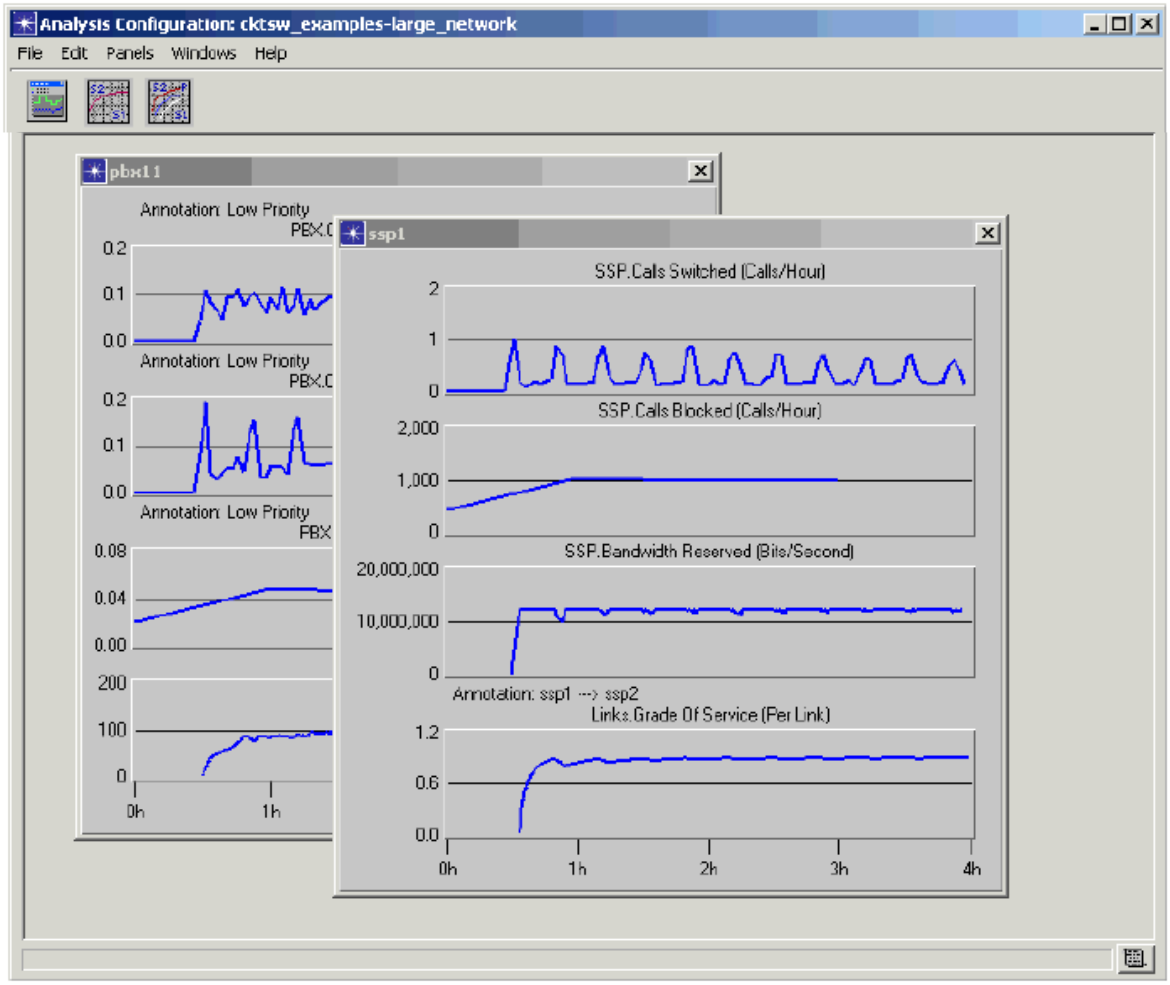

Figure 8.9 Analysis Tool

8.1.13 Project Editor Window

This editor window is used for creating and executing a model. The following diagram shows when a saved project is opened.

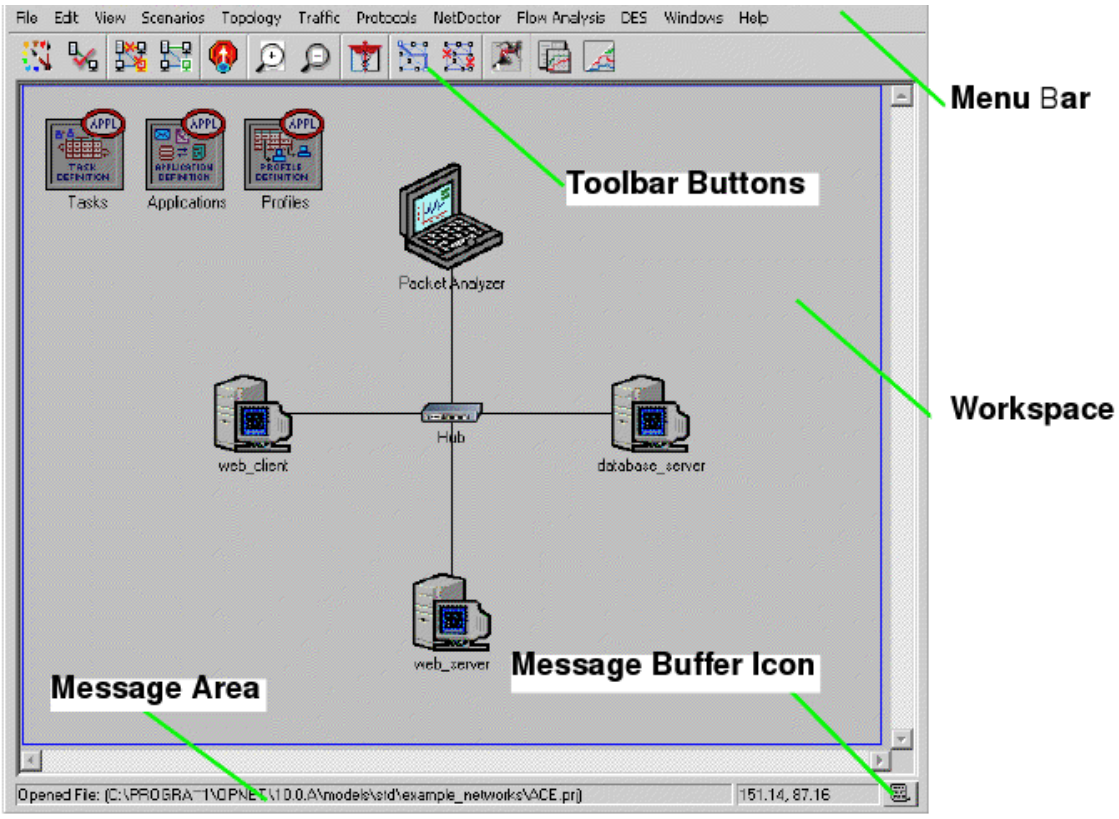

Figure 8.10 Project Editor Window

8.1.14 Menu bar

At the top of the editor window, there is a menu bar. It shows all the non-context-sensitive editor operations in a proper set of relevant menus. Depending on what product modules are used, the set of menus and menu operations change. On right-clicking on the object, the context-sensitive editor operations are available. They can also be accessed on the background of the workspace.

8.1.15 Toolbar Buttons

There are few commonly used selections available which can be used from the tool bar. The diagram below shows the tool bar in the Project Editor:

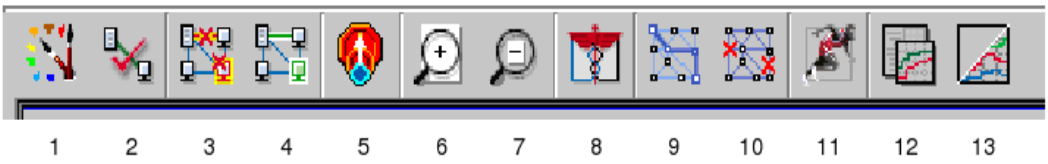

Figure 8.11 Toolbar buttons

Table 8.1: Toolbar table

1	Open Object Palette	**8**	Configure/Run NetDoctor
2	Verify Links	**9**	Configure/Run Flow Analysis
3	Fail Selected Objects	**10**	Configure/Run Failure Analysis
4	Recover Selected Objects	**11**	Configure/Run Discrete Event Simulation (DES)
5	Go to Parent Subnet	**12**	View Results
6	Zoom to Rectangle	**13**	Hide/Show Graph Panels
7	Zoom to Previous		

8.1.16 Workspace

Here is the place where a network is modeled. One can work, select, drag network objects, choose context-sensitive operations as and when required. It is the core region of the Modeler.

8.1.17 Message Area

At the bottom of the editor window, there is a message area. One can find the status of the tool over here

Figure 8.12 Message area

The icon below shows can be used to see the message buffer window. It is done by left-clicking on the icon.

The buffer window has list of messages. If the message is not fully visible, one can open the buffer window to observe the message or check the latest message, alert or notification.

CHAPTER 9

WiMAX 2

9.1 Introduction to WiMAX 2

The release 1 WiMAX systems have proven to be more preferable over their 3G competitors. This is because WiMAX has more advantages when it comes to deliver all IP based packets over wireless. If we have observed any substantial increase in wireless, then that is in the mobile data and traffic which increases at the rate of 108 percent between 2009 and 2014. Thus, there is a significant growth in the market in terms of volume and value. That growth is in voice and data services.

It is seen that digital information consumed by the customers' increases in several ways or either the network capacity is increasing at a double digit factor or higher. Cisco had estimated an increase of 160 percent from 2008 till 2009.

The statistics shows that mobile broadband is the second largest access technology behind DSL. It consumes 18% of the total subscribers worldwide. Various operators of different countries have observed the reports and concluded an abrupt increase of mobile data traffic.

IEEE 802.16e-2005 is the ever first Mobile WiMAX deployed using modulation technique named OFDMA and antenna configurations like MIMO. Now due to predictions and observations of ramp increase in data traffic, there is a need to work on enhancements of WiMAX. IEEE 802.16 working group is hence working on the new standard to provide a efficient path for WiMAX operators. This new standard is known as 16m or WiMAX 2.0.

Following are the features of WiMAX 2.0:

- Support for users worldwide and new trends in technology
- An efficient path for mobile WiMAX release 1.0 operators to deliver some challenging thigns to deliver new services.
- It has update its IEEE 802.16 standard so that it can achieve the target by supporting IMT-A requirements

In this section, we are going to see how the various parameters of WiMAX are essential. Over 70 Mobile WiMAX deployments in 2.3, 2.5 and 3.5 GHz, the following parameters must be worked on

- Spectral efficiency
- Security
- Quality of service
- Improved latency
- Low cost of deployment

Thus WiMAX release 2.0 is going to enhance data rates, high coverage and aloow new services as compared to the current Radio networks.

9.2 Availability of WiMAX 2.0

Depending on how fast he suppliers work on the past standardization experience of 16e, it can be predicted that WiMAX 2.0 systems would be deployed by 2012. The chips for WiMAX from Intel, Sequans have shown that the chips can be made available by 2012.

The study on the experiences on 802.16e and even some learning's from LTE has allowed the working committee to provide a progressive development on the new Release on WiMAX.

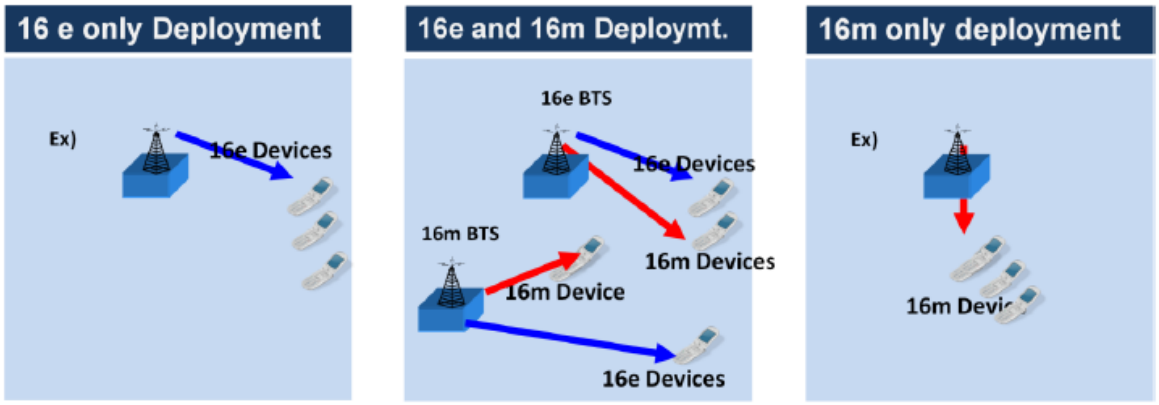

Figure 9.1 Deployment possibilities in WiMAX 2.0

9.3 Features of WiMAX 2.0

Compatibility and co-existence

The base stations for IEEE 802.16m will have an interoperable support for the IEEE 802.16e systems. Similarly, the Mobile stations of 802.16m will operate with the BS of 802.16e same as 16e MS.

So, the compatibility is kept in the mind where a 16m Base Station can work with both 16e and 16m device. Also, the support for 16e systems will be done where they can work seamlessly with 16m systems. There is co-existence between 16m frame structure and legacy frame of 16e systems.

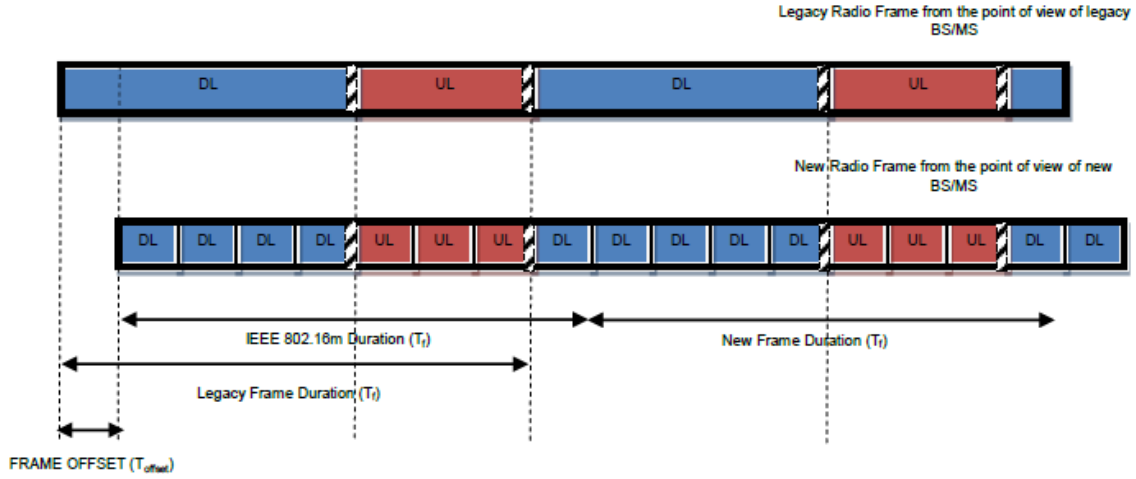

Figure 9.2 Frame difference in 16m and 16e

Above is the diagram that shows the frame offset illustration. It shows that there is an offset between the start of the legacy frame and the IEEE 802.16m frame as defined in the units of sub frames. This feature is the most important one for the operators as it is a step for 16m migration.

9.4 WiMAX Frequency band

The most common frequencies used by WiMAX TDD are 2.3, 2.5, 3.5 GHz bands in the Release 1.0. In the Release 1.5, there was an additional support which provided FDD and H-FDD with new spectrum of 1.7 and 2.1 GHz. As per the requirements and operators priority, the Release 2 which is 16m introduced FDD and TDD frequency bands which are shown in the table below.

Table 9.1 WiMAX 2.0 Frequency bands

Band Class	UL AMS Transmit Frequency (MHz)	DL AMS Receive Frequency (MHz)	Duplex Mode
1	2300-2400	2300-2400	TDD
2	2305-2320, 2345-2360	2305-2320, 2345-2360	TDD
	2345-2360	2305-2320	FDD
3	2496-2690	2496-2690	TDD
	2496-2572	2614-2690	FDD
4	3300-3400	3300-3400	TDD
5L	3400-3600	3400-3600	TDD
	3400-3500	3500-3600	FDD
5H	3600-3800	3600-3800	TDD
6	1710-1770	2110-2170	FDD
	1920-1980	2110-2170	FDD
	1710-1755	2110-2155	FDD
	1710-1785	1805-1880	FDD
	1850-1910	1930-1990	FDD
	1710-1785, 1920-1980	1805-1880, 2110-2170	FDD
	1850-1910, 1710-1770	1930-1990, 2110-2170	FDD
7	698-862	698-862	TDD
	776-787	746-757	FDD
	788-793, 793-798	758-763, 763-768	FDD
	788-798	758-768	FDD
	698-862	698-862	TDD/FDD
	824-849	869-894	FDD
	880-915	925-960	FDD
	698-716, 776-793	728-746, 746-763	FDD
8	1785-1805, 1880-1920, 1910-193, 2010-2025, 1900-1920	1785-1805, 1880-1920, 1910-193, 2010-2025, 1900-1920	TDD
9	450-470	450-470	TDD
	450.0-457.5	462.5-470.0	FDD

9.5 Different MIMO schemes and its Architecture

9.5.1 MIMO Schemes in Release 2.0

There has been a number of varieties of schemes introduced in the Release 2.0 WiMAX. They were single and multi-user MIMO with beam forming and different transmit diversity schemes. The different between the single user MIMO(SU-MIMO) scheme and multi-user MIMO scheme(MU-MIMO) is that the former one has user using only one resource unit while in the later one there are multiple users using one resource unit.

9.5.1.1 Single User MIMO (SU-MIMO)

The advantage of SU-MIMO is that both the spatial multiplexing and transmit diversity can be achieved. This improves the link performance. It provides large peak data rate to a single MS and beam forming gain. There are two kinds of 16m MIMO one is open loop and the other is closed loop.
In open loop SU-MIMO, spatial and transmit diversity schemes are supported. And in closed-loop SU-MIMO, there is a support for code-book based precoding in TDD and FDD systems. For the base-station scheduling, resource allocation and rate adaptation decisions, the MS sends information like Channel Quality Information and rank feedback. These parameters sent are independent of frequency. In closed loop SU-MIMO, sounding based precoding techniques is used for TDD systems.

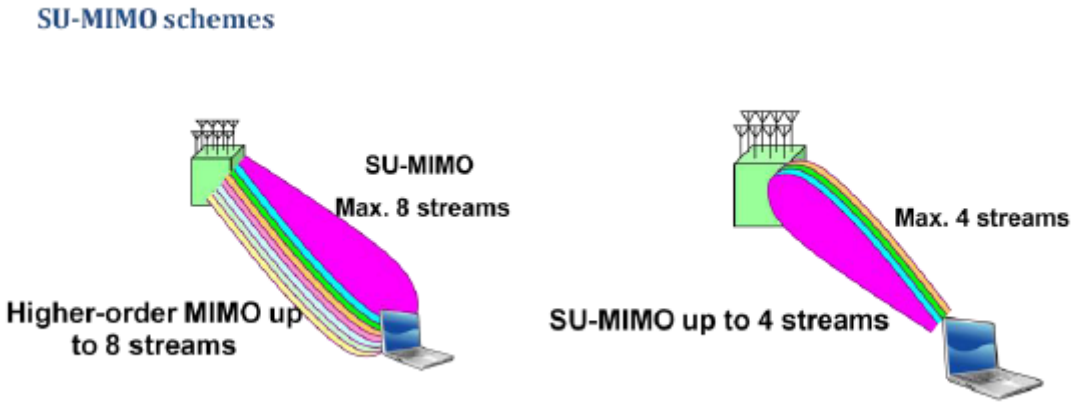

Figure 9.3 Single-User MIMO

9.5.1.2 Multi-User MIMO (MU-MIMO)

In this scheme, there are multiple users which are allocated single resource unit. Hence, more than one or two MSs communicate data. As a result, the throughput of the system increases.
So, the support of MU-MIMO is by using multiple antennas. If there are 2TX antennas, then 2 users are supported, if there are 4Tx or 8Tx antennas then up to 4 users can be supported. In this scheme linear precoding techniques are supported.

Similar to the SU-MIMO, here also the MS sends CQI and stream index feedback to the base station to support scheduling, transmission mode switching and rate adaptation. But here it is seen that CQI is dependent on frequency.

Similarly, for closed loop MU-MIMO, code book based precoding is used for TDD and FDD systems. CQI and PMI feedback are sent by the MSs to help the base station for scheduling, resource allocation, and rate adaptation decisions. CQI and PMI feedback may or may not depend on the frequency. In closed loop, sounding based precoding is used for TDD systems.

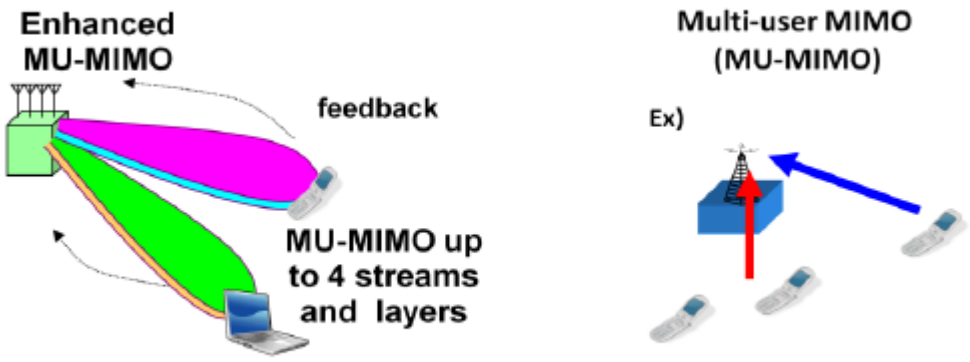

Figure 9.4 Multi-User MIMO

9.5.1.3 Multi Base Station MIMO

In order to enhance sector throughput and cell-edge throughput, WiMAX Release 2.0 has introduced support for Multi-BS MIMO techniques through multi-BS collaborative precoding, network coordinated beamforming and inter-call interference nulling. Similar to MSs Techniques of MIMO, even here closed and open loop MIMO are supported. In closed loop MIMO, Channel state information feedback via code book based feedback and sounding channel are supported. This feedback information can also be used by the neighboring Base stations.

In order to mitigate the interference, there has been an introduction to new class of transmission schemes in the WiMAX Release 2.0. It is known as Coordinated multi-point (COMP). This supports key feature like network synchronization, cell and user pilots, feedback of multicell CSI and data exchange between the base stations. Hence interference problem is mitigated and macro diversity gain is achieved. Also there are some few more techniques which could be considered and they are collaborative MIMO (Co-MIMO) and the closed loop macro diversity (CL-MIMO). In the Co-MIMO, the multiple base stations transmit to multiple MSs which are located in different cells. It is

seen that each and every BS will achieve multi user precoding towards multiple MSs which helps the each and every MS as they receive multiple streams from multiple BSs.

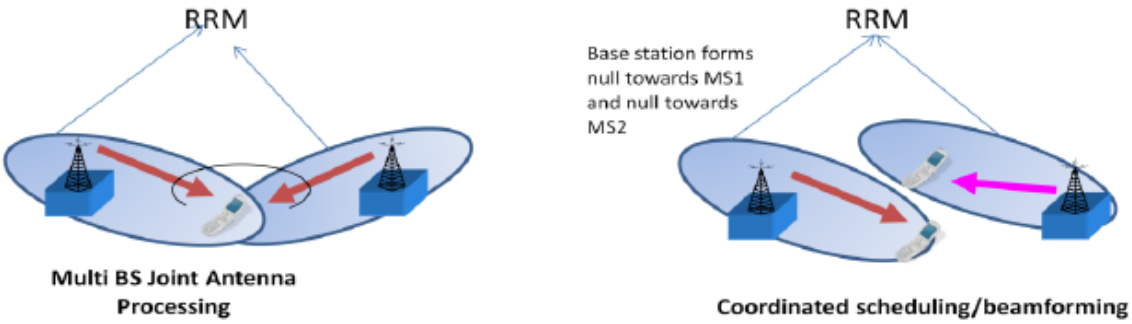

Figure 9.5 Multiple BS MIMO

9.6 Relays

One of the important deployment tools that can provide efficient methods to deliver high data rate and avoid coverage holes in deployments areas are Intelligent Relays. The higher data rates can be achievable in a network by increasing the signal-to-interference plus noise ratio at the front-end of the receiver.

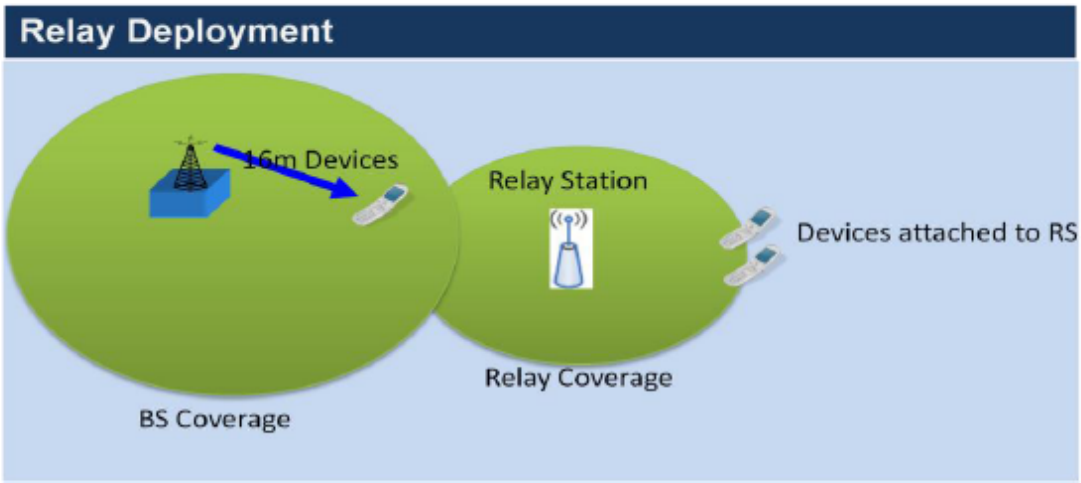

Figure 9.6 Relays in WiMAX 2.0

The deployment of relays is one the traditional solution to increase the SINR of the receiver and serve the coverage area holes with the required data rates. But the cost of deployment of the BS is high and also arranging the backhauls is a challenging thing for serving coverage holes. While using RF repeaters, they simply amplify the interference with no signal control and processing. Hence the solution to the problem is to use relay stations (RS) which are capable of decoding and forwarding the signals from source to destination through radio interface. This helps the mobile operators to achieve higher SINR.

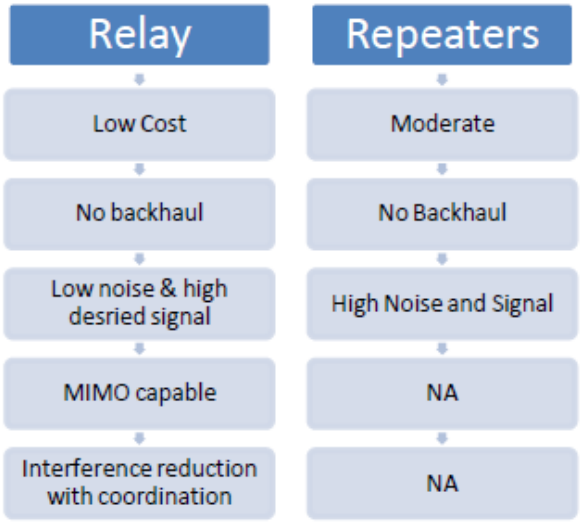

Figure 9.7 Relay versus Repeaters

Above all the relay stations do not need a wire line backhaul as a result the cost of deployment of RSs is much lower than the cost of BSs. With this, the performance of the system also enhances with deploying intelligent relays which provides resource scheduling and cooperative transmission.

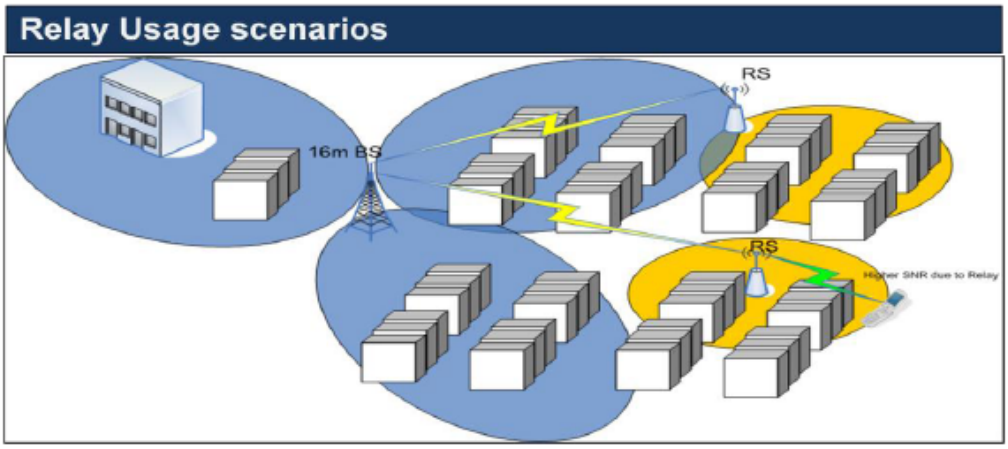

Figure 9.8 Relay Usage Scenarios

The figure above shows different advantages of using Relay stations within the WiMAX Release 2.0. The BS for Release 2.0 can work as 16m BS and 16e. Multihop relay BS can work as 16e BS with 16j RS support functionality. And the MS for release 2.0 can work as 16m MS as well as 16e MS. Advanced RS can work as 16m RS and RS is a 16j RS. As shown in the figure, the solid lines interworking between the entities support protocols like 16e, 16j and 16m. But no protocols are supported in dashed lines.

There is one type of relaying known as cooperative relaying. In this technique, the 16m BS and one or more 16m RS or multiple 16m RS cooperatively transmit or receive data to/from one or multiple subordinate stations

9.7 Multi Carrier Aggregations

By the use of scalable OFDMA multiple access scheme in DL and UL, flexible spectrum use can be achieved. Hence by the use of multiple component carriers, one can achieve up to 100MHz of transmission bandwidth. These accumulated components can be continuous or non-continuous in the frequency domain. So WiMAX 16m supports channel bandwidth of 5, 10, 20, and 40 with multicarrier aggregation up to 100MHz.

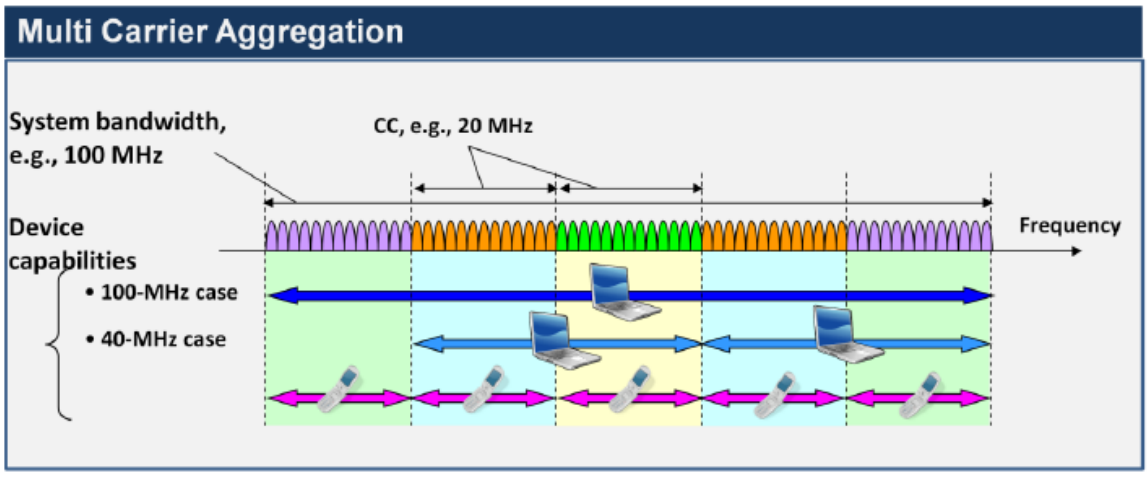

Figure 9.9 Multicarrier aggregation

9.8 Quality of Service

In WiMAX 16m, the following are the typical QoS parameters that are used with the scheduling services:

- Traffic priority
- Maximum sustained traffic rate
- Minimum reserved traffic rate
- Maximum latency

And the classes supported by 802.16m are:

- Unsolicited Grant Service (UGS): This QoS class was designed for real time data which is usually for fixed size and periodic in nature.
- Real-time Polling Service (rtPS): This QoS class was designed to support real time data but of variable size and periodic in nature
- Extended rtPS (ertPS): This QoS class combines the features of both UGS and rtPS. The 16m BS provides unicast grants in an unsolicited manner like in UGS. But the UGS allocation are fixed in size and ertPS are dynamic in nature.

- Non-real time polling service (nrtPS): This QoS class provides unicast polls on a regular basis and it provides the service flow even during network congestion. The 16m BS polls nrtPS connections on an interval on the order of one second or less.
- Best Effort: Provides service of lowest priority traffic.

New parameters introduced by 16m base stations are

- Tolerated packet loss rate
- Indication of Associated flows
- Adaptive polling and granting
- Scheduling Services
- Persistent Allocation
- Group Resource Allocation

The other key features of WiMAX 2.0 are:

- Radio specification for FDD and TDD
- Support of IMT-A identified frequency bands
- At least 2 times the average data throughput of current Release in similar spectrum
- Advanced interference management methods to support true reuse 1 deployments as compared to current reuse 3 deployments
- Round trip access latency is reduced to less than 10-20 ms levels which will allow more demanding services like online gaming etc.
- Support for self organizing networks
- Support for femtocells
- Support of Relays stations
- Multicarrier aggregation upto 100 MHz
- Co-exsistence of 16e and 16m base stations and backword compatibility
- Over 70 VoIP call per MHz
- Coexistence of multi-technologies like Bluetooth, Wi-Fi and WiMAX
- Inter Radio Access technology handovers(3GPP)
- Improved scheduling and new QoS class

- Support for enhanced multicast and broadcast services
- Support for Location based services

CHAPTER 10

INTRODUCTION TO TEST ANALYSIS:

10.1 WiMAX and Wi-Fi

- The IEEE 802.16e standard is known as WiMAX and IEEE 802.11 standard is known as Wi-Fi. WiMAX provides high speed internet access to the last mile. WiMAX is referred as Wi-Fi on steroids. But Wi-Fi remains to be the technology to be used in LAN environments while WiMAX has been designed for Metropolitan Areas.
- The Deployment of WiMAX network is similar to Wi-FI. The Base Station or Tower beams or focuses signal to a WiMAX Receiver which is quite similar to Wi-Fi access point sending a signal to a laptop.

10.2 WiMAX and DSL cables

- Theoretically, WiMAX base stations can provide internet access to hundreds of homes with DSL/Cable speed. But practically, it has been observed that though WiMAX can cover upto 30miles in real world it can go up to 4-8 miles of radius.

10.3 Speed Test Performance

Below are several Speed tests performed and compared:

1. WiMAX USB Modem which can provide Internet on the *MOVE*
2. WiMAX Modem used at home where the signal is received to the modem through WiMAX and then to the PC or laptop via *Ethernet*.
3. WiMAX Hotspot generally used at public places where the received signal strength is through WiMAX and then to the PC or laptop via *Wi-Fi*.
4. Internet Access through Wi-Fi.
5. Internet Access via Ethernet to the PC or laptop mostly via CAT5 cable using DSL modem

10.3.1 WiMAX USB Modem which can provide Internet on the MOVE

The following picture of 4G/3G mobile USB modem is used for the 4G internet on-the-go where there is coverage area provided by CLEAR. The modem provides great speed and coverage. It is quite simple to use where the user just has to plug it into the USB port on the PC or laptop for fast internet access on the move. The USB modem is portable.

Figure 10.1 WiMAX USB Dongle

Specification: The following test is performed on the laptop with 2.00 GHz processor speed with 3 GB of RAM and 250 GB of Hard Drive

Supported OS: Windows 7

Hardware: CDMA chipset—Qualcomm QS6085 and WiMAX chipset—Beceem BCS250

Bands supported: 1x EVDO Rev A—850/1900 MHz; WiMAX—2500 MHz

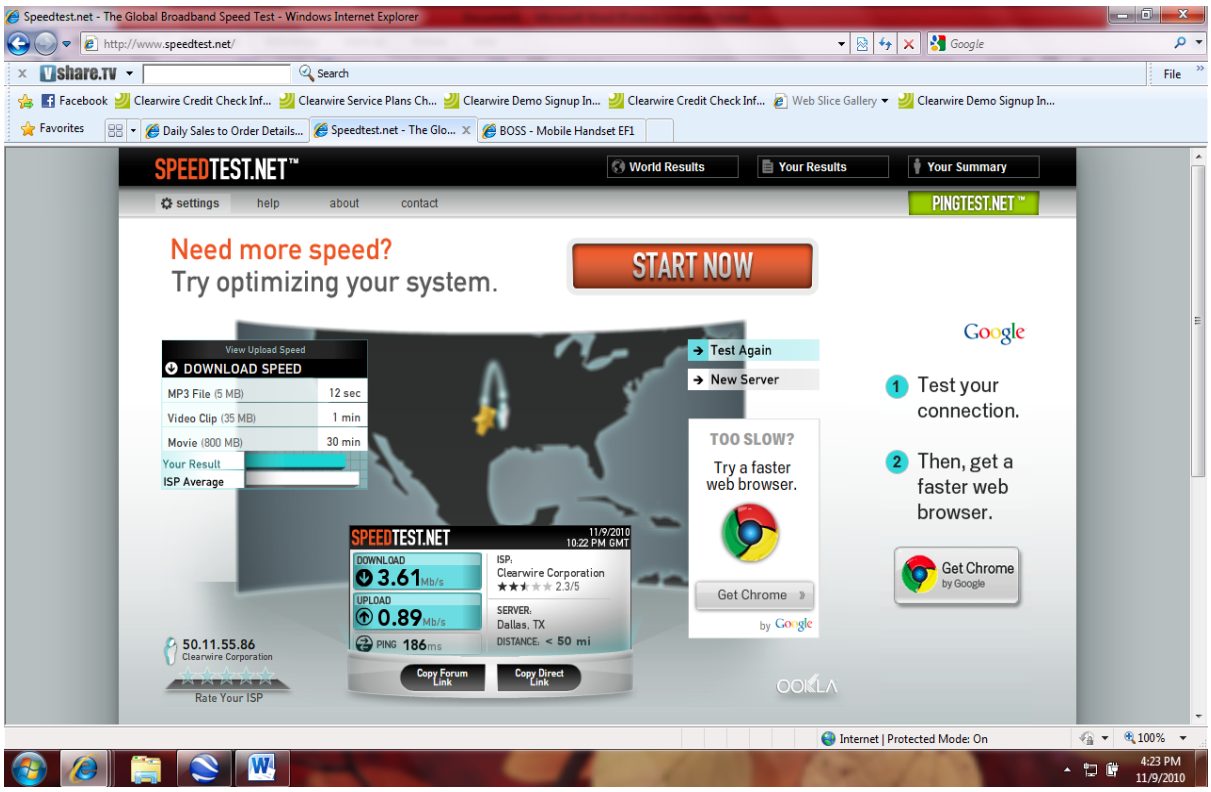

Figure 10.2 Speed Test Screenshot using WiMAX Dongle

It is seen that the download speed of 3.61 Mbps and an upload speed of 0.89 Mbps is achieved. The ping or the latency time is 186ms.

10.3.2. WiMAX Modem used at home where the signal is received to the modem through WiMAX and then to the PC or laptop via Ethernet.

Figure 10.3 WiMAX Modem

The above picture is of CLEAR Modem series G for fast internet access in homes. It has 5 LEDs which portray signal strength of which one is for network and other for power. It has directional antennas where the signal strength varies on rotation of the Modem because of the reception of the signal

The WiMAX works on a licensed frequency band where Clear uses around 2.5 GHz and OFDM as the physical layer. These two features makes the internet secure

.

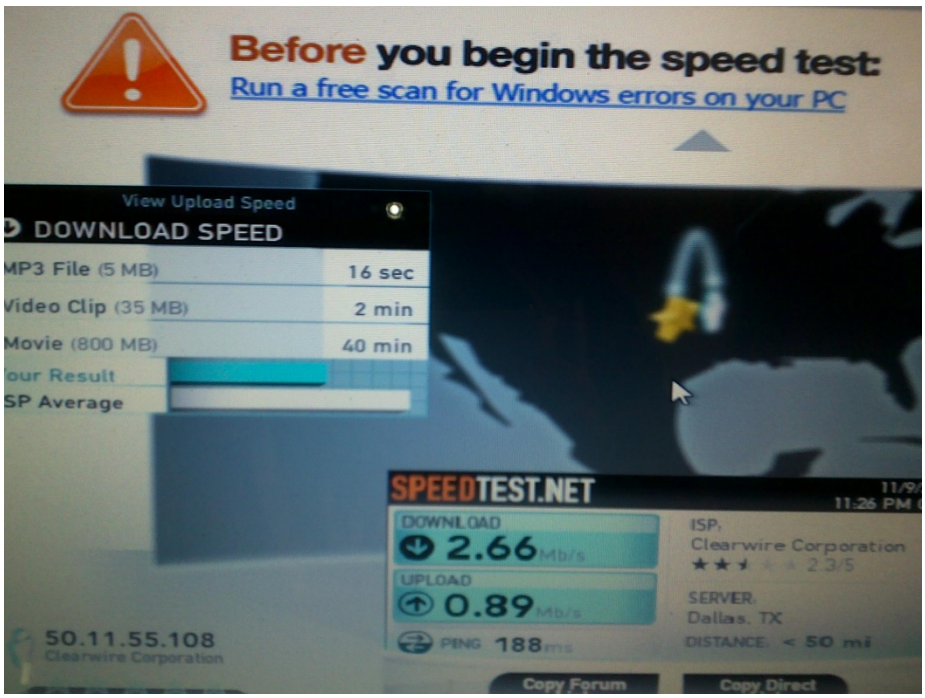

Figure 10.4 Speed Test Screenshot using WiMAX modem

It is seen that the download speed of 2.66 Mbps and an upload speed of 0.89 Mbps is achieved. The ping or the latency time is 188ms.

10.3.3 WiMAX Hotspot generally used at public places where the received signal strength is through WiMAX and then to the PC or laptop via Wi-Fi

Figure 10.5 WiMAX Hotspot

The above picture shows a battery-operated hotspot which provides a pure 4G speed. As shown it can connect 8 Wi-Fi devices simultaneously. It works with any kind of Wi-Fi devices.

The internet connection is quite secured because it provides a password controlled access with key exchanges. The security keys are same as Wi-Fi like 64 bit and 128 bit WEP, WPA and WPA2. It works on the battery for 4-5 long hours but it depends on the WiMAX signal strength and transmit power level of Wi-Fi. It supports 802.11b/g.

So this hotspot is same as Wi-Fi giving a coverage area of 150 feet but is affected by obstructions, weather and atmospheric conditions.

Figure 10.6 Speed Test Screenshot using WiMAX Hotspot

It is seen that the download speed of 4.05 Mbps and an upload speed of 0.87 Mbps is achieved. The ping or the latency time is 155ms.

10.3.4. WiMAX enabled laptop

Figure 10.7 WiMAX enabled Laptop

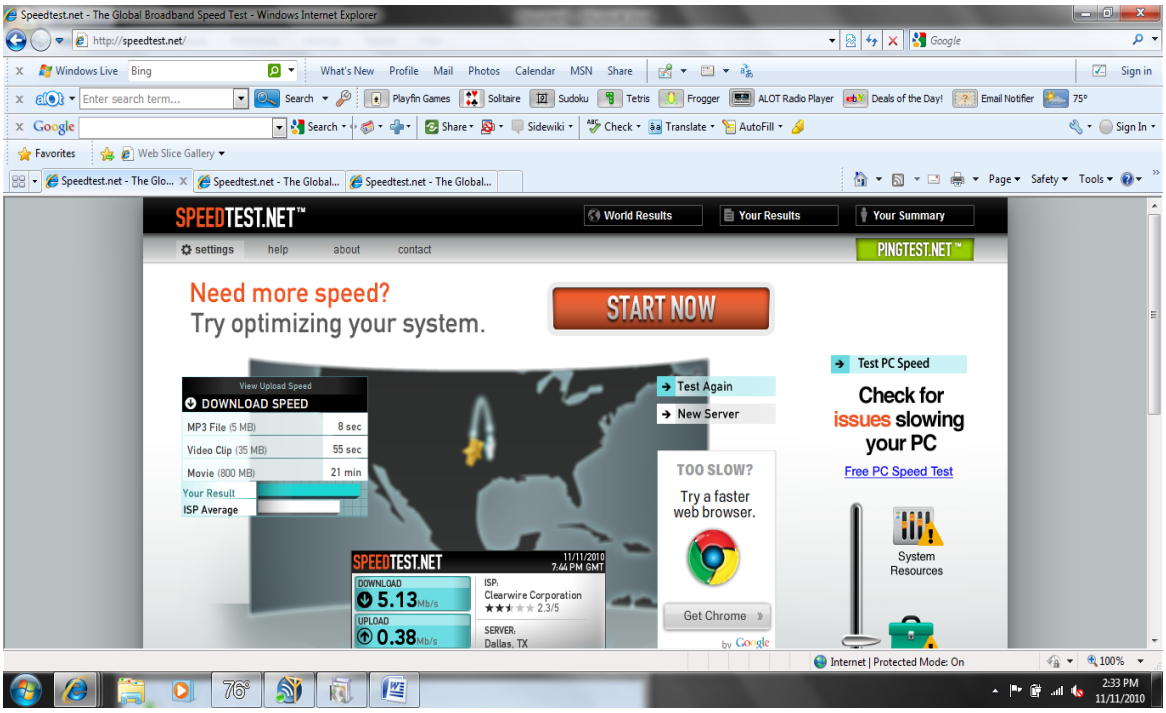

Figure 10.8 Speed Test Screenshot in WiMAX enabled laptop

It is seen that the download speed of 5.13 Mbps and an upload speed of 0.38 Mbps is achieved. The ping or the latency time is 536ms.

10.3.5. Internet Access through Wi-Fi.

Figure 10.9 Speed Test Screenshot using Wi-Fi

It is seen that the download speed of 0.39 Mbps and an upload speed of 0.16 Mbps is achieved. The ping or the latency time is 409ms.

10.3.6 Internet Access via Ethernet to the PC or laptop mostly via CAT5 cable using DSL modem

Figure 10.10 Speed Test Screenshot using Ethernet via DSL cable

It is seen that the download speed of 82.86 Mbps and an upload speed of 39.11 Mbps is achieved. The ping or the latency time is 7ms.

10.4 Conclusion

1. Of all the links used for Internet, Ethernet provides the best possible speed followed by WiMAX and then Wi-Fi.
2. The speed between USB modem and Residential modem of WiMAX is approximately similar but the only difference between them is one can be used while being mobile while other is used at fixed place.

   The reason for lower speed in Residential modem is that signal strength was weaker due to directional antennas. If they were beamed perfectly to the Tower then we could get an achievable speed with USB modem.
3. The WiMAX enabled Laptop shows a good speed of over 5Mbps. The speed test was performed in an open space and being mobile. The reason for increased speed is very few obstructions and fading effects for WiMAX signal strength from the Tower being in open space. It can be concluded that WiMAX can provide a satisfactory speed while being MOBILE.
4. Comparing the WiMAX speeds (let's take the Hotspot which was available in public) with ATT Wi-Fi Hotspot (router) which was available in public. With same number of users, the Wi-Fi didn't provide the speed expected. It is because of the signal strength or coverage area from both the Hotspots. This shows that WiMAX Hotspot has good coverage area than the Wi-Fi Hotspot.

So the question arises: Will WiMAX be able to replace DSL?

This answer will vary from region to region. It is seen that as of now many developing countries do not support either cable or DSL broadband technologies. While many such countries are using the broadband wireless technologies widely. As per the market demands, it is seen that the cheapest solution will prevail. It's inferred that many areas in developing nations would prefer to use Cable and DSL as a cheaper solution at least in the cities for fixed applications, whereas WiMAX is provided outside of major towns.

REFERENCES

[1] Beyond 3G / 4G Radio Access Technologies (RATs) and Standards Roadmaps eMobility Technology Platform Whitepaper

[2] Ultra-Wideband http://en.wikipedia.org/wiki/Ultra-wideband

[3] C. Cicconetti, V. Gardellin, L. Lenzini, E. Mingozzi, A. Erta, End-to-End Bandwidth Reservation in IEEE 802.16 Mesh Networks, in Proc. Of MeshTech'07, Pisa, Italy, October 22, 2007.

[4] WiMAX's technology for LOS and NLOS environments- WiMAX forum

[5] http://www.scribd.com/doc/6578711/WiMAX-Technical-Report

[6] WiMAX Forum® Network Architecture Architecture Tenets, Reference Model and Reference Points Base Specification

[7] Mobile WiMAX – Part I: A Technical Overview and Performance Evaluation Prepared on Behalf of the WiMAX Forum

[8] Air Interface for Fixed Broadband Wireless Access Systems," IEEE STD 802.16 – 2004, October, 2004.

[9] Hassan Yagoobi, "Scalable OFDMA Physical Layer in IEEE 802.16 WirelessMAN", Intel Technology Journal, Vol 08, August 2004.

[10] Richard Van Nee and Ramjee Prasad, "OFDM for Wireless Multimedia Communications," Artech House, 2000.

[11] Mobile WiMAX – Part II: Competitive Analysis", WiMAX Forum, February, 2006

[12] Fundamentals of WiMAX Understanding Broadband Wireless Networking Jeffrey G. Andrews, Ph.D. *Department of Electrical and Computer Engineering The University of Texas at Austin* Arunabha Ghosh, Ph.D. *AT&T Labs Inc.* Rias Muhamed *AT&T Labs Inc.*

[10] T. S. Rappaport. *Wireless Communications: Principles and Practice,* 2nd ed. Prentice Hall, 2002.

[13] www.WiMAX.com

[14] www.WiMAX.com/lte/why-the-WiMAX-vs-lte-battle-isnt-a-battle

[15] WiMAX 2.0 for Operators by BP Tiwari

[16] www.beyond4g.org

[17] http://www-ee.ccny.cuny.edu/wwwb/web/ee421/Lab/intro.pdf

[18] www.speedtest.net

[19] http://www.clear.com/shop/devices/devicedetails/equipment_id/62/#specifications

[20] http://www.clear.com/shop/devices/devicedetails/equipment_id/53/#specifications

[21] http://www.clear.com/spot/4g#specifications

BIOGRAPHICAL INFORMATION

Amay Umradia has received his Bachelor of Science degree from University of Mumbai, India in 2004 in Electronics and Telecommunication. He then pursued his Master of Science in Electrical Engineering from University of Texas at Arlington in 2008 where he structured his course work by opting a Thesis option under Dr.R.Stephen Gibbs. He received his Master of Science degree in Electrical Engineering from the University of Texas at Arlington. His major interest in Telecommunication since past 4 years made him chose this interesting topic on Functionality of WiMAX. In his Master's, his major courses are related to Telecommunication with Computer Networking which made his deep insight to focus and narrow down to a particular topic. In this thesis, he has studied the complete structure of WiMAX for which he could implement his ideas practically. For this he performed several tests in order to evaluate the reliability of number of wireless links used. His current interests are Next Generation Mobile Architecture, Mobility Management while his future plans are to work with the integration of Long Term Evolution (LTE) and WiMAX where LTE will be used as access and WiMAX may be used as backhaul technology.