UNIVERSITY OF VAASA

FACULTY OF TECHNOLOGY

TELECOMUNICATION ENGINEERING

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HANDOVER ANALYSIS OVER MOBILE WiMAX TECHNOLOGY
Case study: Network performance and parameters evaluation using OPNET simulator.

Master's thesis for the degree of Master of Science in Technology submitted for inspection, Vaasa, September 09th, 2014.

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ACKNOWLEDGEMENT

First, I want to thanks God for giving me strength and the most important health to accomplish successfully this master thesis.

I hereby thank my supervisor Prof. Timo Mantere for his advice and support during this thesis work.

Beside my supervisor, I would like to thanks every member of faculty of technology, department of computer science who contributed with the completion of my academic studies, Professor Mohammed Elmusrati, Ruifeng Duan, Tobias Glocker, Mulugeta Fikadu, my thesis instructor Reino Virrankoski and to all my academic fellows.

I also wish to express my gratitude to the University of Vaasa and to the Finnish government for the opportunity granted to be part of this academic program with no tuition fee charges.

My acknowledgement will be incomplete without expressing my gratefulness to my beloved Millaray Santana and her charming family for their unconditional orientation and guidance during my last year.

Finally but not least, my deepest appreciation goes to my family, my lovely parents (Edgar and Nancy) and my siblings who have always been an endless source of inspiration, encouragement, and support during my studies in Finland.

Vaasa, Finland, August 2014
Miguel Angel Chourio Chavez

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ABBREVIATIONS

3GPP2	Third Generation Partnership Project 2
3GPPP	Third Generation Partnership Project
AAA	Authentication, Authorization and Accounting Management
AAS	Adaptive Antenna System
AMC	Adaptive Modulation and Coding
ARQ	Automatic Retransmission Request
ASN	Access Service Network
BER	Bit Error Rate
BS	Base Station
BWA	Broadband Wireless Access
CAC	Call Admission Control
CDMA	Code Division Multiple Access
CID	Connection Identifier
CINR	Carrier To Interference-Plus-Noise Ratio
CP	Cyclic Prefix
CS	Convergence Sublayer
CSN	Connectivity Service Network
DL	Downlink
DSL	Digital Subscription Line
EBB	Entry Before Break
FBSS	Fast Base Station Switching
FCH	Frame Control Information Channel
HO	Handover
HHO	Hard Handover
IEEE	Institute of Electrical and Electronics Engineers

IETF	Internet Engineering Task Force
IFFT	Inverse Fast Fourier Transform
ISI	Inter-Symbol Interference
ITU	International Telecommunication Union
KMP	Key Management Protocol
KPI	Key Performance Indicators
LOS	Line of Sight
MAC	Medium Access Control
MAC CPS	Mac Common Part Sublayer
MAC PDU	Protocol Data Units
MAC SDU	Service Data Units
QoS	Quality of Service
TDD	Time-Division Duplexing
MAP	Mobile Application Part
MBS	Multicast and Broadcast Service
MDHO	Macro Diversity Hand Over
MIMO	Multiple Input Multiple Output
MMS	Multimedia Message Service
MS	Mobile Station
MSL	Minimum Signal Level
NLOS	Non Line of Sight
NSP	Network Service Provider
NWG	Network Working Group
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Division Multiple Access
OSI	Open System Interconnection
PDU	Packet Data Unit
PHY	Physical Layer

RAN	Radio Access Network
RF	Reference Point
RRM	Radio Resource Management
RS	Relay Station
RSS	Receive Signals Strength
RSSI	Received Signal Strength Indicator
RTT	Receive Transmit Transition
SAP	Service Access Point
SC	Single Carrier
SINR	Signal to Interface Plus Noise Ratio
SNR	Signal-to-Noise Ratio
SS	Security Sublayer
TDD	Time Division Duplex
TRT	Transmit Receive Transition
UL	Uplink
WMAN	Wireless Metropolitan Area Network
WiMAX	Worldwide Interoperability for Microwave Access

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Degree Program:	Master in Telecommunication Engineering
Major Subject:	Telecommunication Engineering
Year of Entering the University:	2011
Year of completing the Master's thesis:	2014 **Pages: 83**

ABSTRACT

As new mobile devices and mobile applications continue to growth, so does the data traffic demand for broadband services access and the user needs toward mobility, thereby, wireless application became today the fastest solution and lowest cost implementation unlike traditional wired deployment such as optical fibers and digital lines. WiMAX technology satisfies this gap through its high network performance over the air interface and high data rates based on the IEEE 802.16-2004 standards, this original specification does not support mobility.

Therefore, the IEEE introduces a new standard that enables mobility profiles under 802.16e-2005, from which three different types of handovers process are introduced as hard handover (HHO), macro diversity handover (MDHO) and fast base station switching (FBSS) handover.

The objective of this master thesis is to analyze how the handover process affects network performance. The analysis propose three scenarios, built over OPNET simulator to measure the most critical wireless parameter and performance indicator such as throughput, handover success rate, packet drop, delay and network usage.

KEYWORDS: Base station, Scenarios, Handover, IEEE, MAC Layer, Mobile Station, Network, Performance, Physical Layer, QoS, Simulation, Throughput, WiMAX

1. INTRODUCTION

Since communication represent a basic need in humans beings, the communication process becomes more complex when it comes to digital and wireless system. In order to ensure a reliable and high quality communication, the wireless provider must pay more attention within the channel media and thereby, avoid any type of interruption between the transmitter and receiver. As a result, diverse types of wired and wireless technologies, networks, systems, protocols, standards and smart devices have emerged in current times.

Mobile worldwide interoperability microwave access (WiMAX) technology arises as a solution and alternative to the original standard associated to IEEE 802.16, this was originally designed to provide fixed networks over broadband access networks such as digital subscriber line (DSL) and optical fiber cable, and therefore, it became a broadband wireless access enhancement and solution through IEEE 802.16e standard.

As wireless users continues to growth rapidly, mobility represent the big challenge and main focus in the telecommunication industry, hence, mobile WiMAX networks is expected to deliver mobility in a wireless interface as a variation to the original standard. Assume a user is using streaming video or downloading a file from a virtual drive and this has to move from A to B, so this connection should switch successfully along different base stations and technologies.

Due the fact WiMAX is an IP-based technology and all IP connections belongs to network layer, the entire IP connection including all its setting and attributes between the mobile user and the applications sources are always forced to switch and exchange information though the new base station, so this requires a precise synchronization among the physical (PHY) layer and the medium access control (MAC) layer (Kumar 2008:305).

In the last years, a large numbers of wireless technologies have been developed and deployed to satisfy the needs of users to be connected and active all the time and feel the freedom to move long distances with no interruption. Hence, in order to achieve this target and ensure continues communication to the mobile users, the telecommunication industry brings to the field, such term known as handover or handoff process.

1.1 The thesis topic

This master thesis handles the worldwide interoperability for microwave access (WiMAX) technology from the air interface approach and the mobility aspects provided by the standard. The main part of this research focus on how the handover process affects the measures indicators in questions and how distance and mobility speed affects the global WiMAX networks performance over simulation.

WiMAX is a broadband wireless technology that belongs to 802.16 standards family developed by the Institute of Electrical and Electronics Engineers (IEEE) for broadband Wireless Metropolitan Area Networks (WMAN), the standard specifies the air interface, the medium access control layer (MAC) and physical layer (PHY), and combined fixed and mobile point-to-multipoint broadband wireless access (BWA) systems configurations with high data rates and wireless performance. The MAC is structured to support wireless metropolitan area networks (MAN) as single carrier under orthogonal frequency division multiple access specifications, each configurations are linked to a particular operational environment.

1.2 The objectives

The objective of this master thesis is to analyze the network performance in WiMAX technologies during the handover or handoff process from the air interface and the access network point of view. This analysis handles essential parameters measurement such as throughput, global delay, handover (HO) delay, packet drop rate and network usage. The parameters are tested within pedestrian and vehicular user speed, both moving from different locations, distance and speeds aims to achieve seamless connection and ensure the quality of service (QoS) expected for the end users at all times.

Usually, the handover process is done when the signal quality level is degraded at the mobile station (MS) side and this level is below the signal quality level of a neighbor base station.

The handover (HO) process may be initiated in two ways, either by the mobile station or by the base station. If the handover is initiated by the MS, this sends an initiation command to the serving BS. In response, the serving BS employ a specific command (handover initiation) to the MS to make this possible. The process is just a mirror in the opposite direction, when the BS initiates the handover, the serving BS sends a notification to the MS. In both cases, the handover command sent contains one or more target base stations.

If only one target BS is involved in the handover process, then the MS does execute the handover right away as directed by the BS, meanwhile the mobile station exchange information with the target BS before the time disconnection expires by using a HO indicator message, thereby, to accomplished this process, the serving BS simply stop sending data and providing UL allocation to the MS by following the HO-IND message, meaning that the transition has been completed successfully.

If the scenario involves more than one target BS, so the MS selects one of those target BSs upon the criteria and parameters established by the mobile operator (Threshold rate), and then this decisions is informed to the serving BS by sending the indication message before the disconnection time happens (Ahmadi S. Mobile WiMAX, 2011:200).

More details about the handover process are introduced within the third chapter about mobility management and handover mechanism, however a briefly representation may be observed in figure 1.

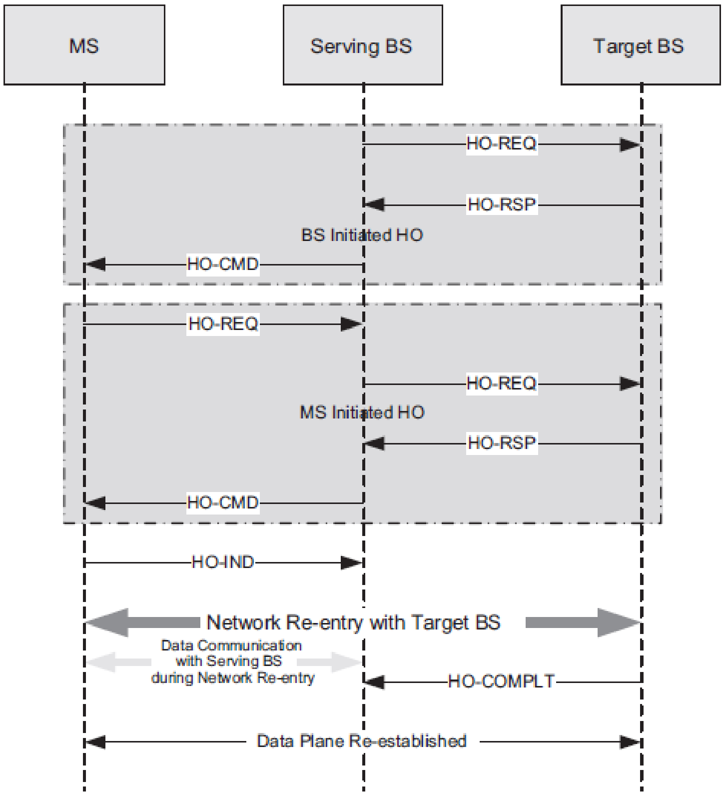

Figure 1. General handover process (Sassan Ahmadi, 2011:200).

1.3 Thesis topic motivation

The impressive facts achieved by the telecommunication industry such as 6.6 billion mobile subscriptions worldwide, millions of tablets and mobile devices sold in the last 2 years only by Samsung and Apple companies, and new applications developed lately in this sector, have been one of the main reason to decide this thesis topic oriented to mobile mobility and most precisely handoff or handover process.

Additionally, the personal experience as a radio frequency engineer demonstrated the importance to evaluate certain parameters such as call failures, bit error rate (BER) and HO disconnection, throughput, packet drop which represent a challenge and a critical point of view for the mobile operator in order to ensure a high quality of service (QoS) and achieve high customer satisfaction feedback.

The WiMAX technology provides an IP-based architecture, which protocol is today a future trend in the mobile industry in order to ensure high speed data transmissions at all times and the handover process follows similar criteria and link adaptation scheme compare to alternative mobile wireless technologies. These are the main reasons to cover this subject.

1.4 Scope

The network performance analysis and parameters evaluation, lead the following three (3) scenarios deployment over OPNET simulator

- The first scenario carried out a single mobile station (MS) walking across a predefined route between Palosaari, Vaasa Kauppatori and Suvilahti Area. This mobile station moves within pedestrian user speed of 5 km/h, defined as Pedestrian A by the international telecommunication union (ITU).

- The second scenario belongs to a mobile station moving at vehicular speed up to 120 km/h within a cluster involved with several base stations with total distance of 20 km that connects two municipalities in Finland (Vaasa and Laihia).

- The thirds scenario aims to calculate the maximum distance to be achieved and the optimum WiMAX topology within wide area networks.

2. THE WiMAX TECHNOLOGY

The name worldwide interoperability microwave access (WiMAX) was created by the WiMAX Forum; this organization was formed in 2001 to promote the network deployment, compatibility and interoperability of the original standard based on IEEE 802.16 working group.

The standard specifies the air interfaces of fixed broadband wireless access (BWA) systems. The medium access control layer (MAC) is designed to support point-to-multipoint architecture and structured to support the physical layer (PHY) specifications. WiMAX operates over 10-66 GHz frequencies under the single-carrier modulation, defined as Wireless MAN-SC PHY, and frequencies below 11 Ghz with non-line-of-sight (NLOS); this last suits the standard wireless MAN-OFDM.

The IEEE 802.16 standard provides access bound for fixed and mobile subscribers in line-of-sight (LOS) and non-line-of-sight (NLOS) configuration. Its main features are the high-speed transmission rate, large coverage, support mobility, quality of service (QoS) and an all-IP architecture. The WiMAX forum describes WiMAX technology as an alternative to cable modem, digital subscription line (DSL) and T1 access services.

The original WiMAX standard, also called fixed WiMAX, provides an adaptive end-to-end architecture that employs single carrier (SC), orthogonal frequency division multiplexing (OFDM) and orthogonal division multiple accesses (OFDMA).

In theory, the IEEE 802.16 standard offers up to 30 miles (50 km) with a throughput of 72 Mbps and up to 4 miles (7 km) in non-line-of-sight (NLOS) in a point-to-multipoint distribution (Frank Ohrtman, WIMAX HANBOOK, 2005:2).

The link between the base station (BS) and the mobile station (MS) is reached by several command parameters and network functions which are used to handle the upstream and downstream process in mobile WiMAX.

In 2005, the 802.16e was released by the IEEE as an alternative and solution for the original standard to provide wireless mobility within WiMAX coverage. Hence, this thesis covers the main aspects and network features in mobile WiMAX technology based upon IEEE 801.16e-2005 standard.

2.1 WiMAX protocol architecture

The WiMAX protocols layer model is defined by IEEE Std 802.16™-2004 specifications since the initial publication in 2001 to support all IP-layer, WiMAX is designed over the physical (PHY) and medium access control (MAC) layers, this technology provides features to deliver quality of service (QoS) and security.

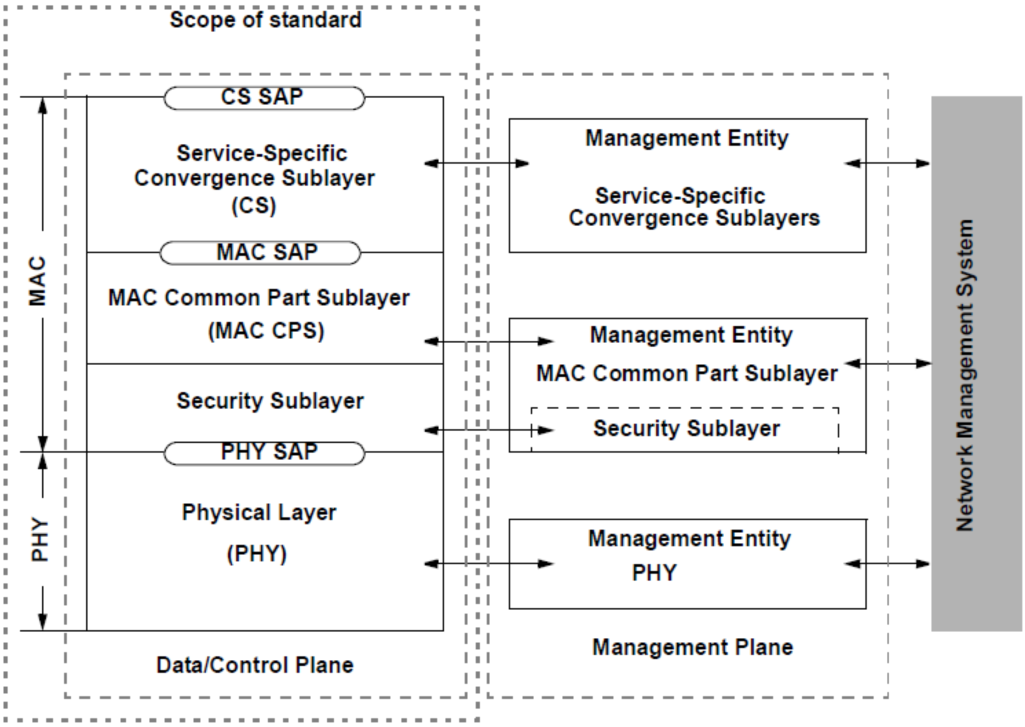

Figure 2. WiMAX Protocol layering model by IEEE 802.16 (IEEE 802.16-2004: 3).

Furthermore, the MAC layer has been designed especially to encounter the QoS parameters set for each connection established within the protocol model. These parameters may be defined as delay, bit error rate (BER), network usage, call drop rate. The MAC layer then assign resources in the form of OFDM symbols or subchannels to ensure that the package are delivered successfully with the present parameters (Kumar 2008: 81).

In order to provide reliable communication, the MAC layer, services access point (SAP) comprises three sublayers under IEEE 802.16-2004. These sublayers are defined below:

- The Convergence Sublayer (CS) is responsible to provides communication to the higher layers to external data networks such as ATM, TDM-based networks, among other.

  The CS layer is also responsible to accept the MAC service data units (MSDUs) from the external networks and converting them to MAC Protocol Data Units (MPDU) oriented to transmit the data over the air interface.

  Additionally, the CS therefore accepts external data networks frames, each of which is identified with a connection identifier (CID) and each connection is associated with certain bit rates and QoS.

- MAC Common Part Sublayer provides the main functions of connections control, access to physical layers and bandwidth allocation.

- The Security Sublayer provides authentication and key management.

The physical (PHY) layer comprises multiple specifications, of which suits a particular frequency range and physical implementations.

The WiMAX network implementation are subject to the available spectral resources, such as Amitabh Kumar describes, the author of mobile broadcasting WiMAX book, mobile WiMAX profiles are defined only for the frequency bands of 2.3 to 2.4, 2.5 to 2.7 and 3.3 to 3.4GHz, while fixed WiMAX implementations are possible within the range from 2 to 11Ghz frequency band. The figure 3 shows an eventual evolution and band frequency allocation.

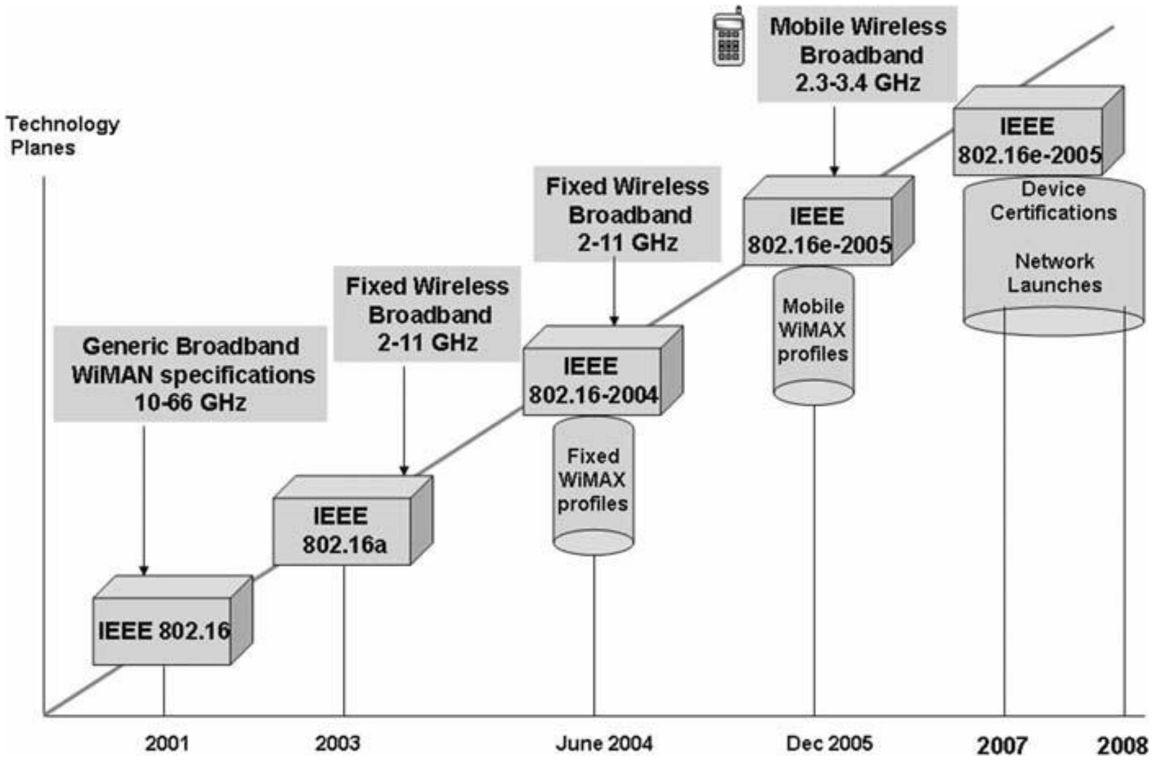

Figure 3. WiMAX Technology evolution and frequency usage (Kumar 2008:49)

2.2 The 802.16e-2005 standard

In 2005, IEEE released the standard 802.16e or mobile WiMAX (IEEE); this new standard introduced new features such as mobility and portability capabilities, improved non-line-of-sight (NLOS) coverage by using adaptive antenna system (AAS) with multiple inputs multiple outputs (MIMO) technology, increased system gain and improved indoor penetration by sub channelization. This standard emerged in the telecommunication industry as an alternative of the fixed and original standard IEEE 802.16 to support mobility between users.

The standard was approved by the international telecommunication union (ITU) as an IMT-2000 (3G technology) under the name OFDMA time division duplex (TDD) for Wireless Metropolitan Area Network (WMAN).

Such as the basic standard, the 802.16e protocol layering structure shows its particular layer to support mobility and handoff or handover process, the figure below illustrates this fragment defined as mobility agent.

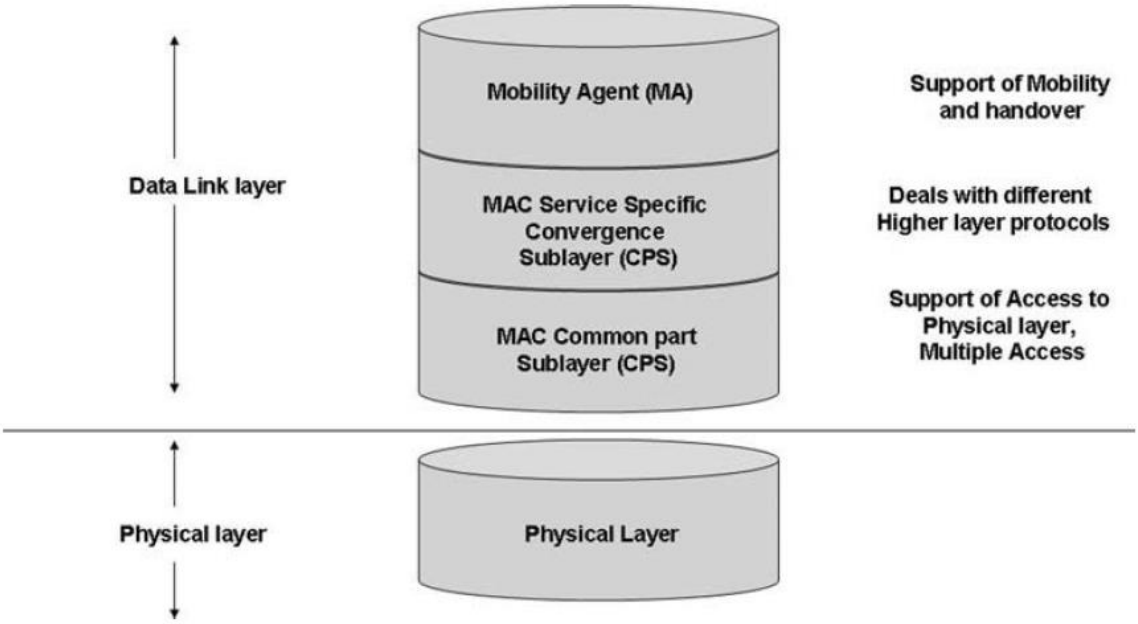

Figure 4. Mobile WiMAX protocol layers (Kumar A, 2008:84)

A non-line-of-sight (NLOS) propagation or full mobility is achieved in WiMAX technology thanks to the orthogonal frequency division multiple access (OFDMA) technique, which process consists in a subchannels assignation in both the uplink and downlink to several subscribers as multiple access arrangement. This mechanism increases the number of end-users due the fact the radio frequency spectrum is utilized in logical manner. In addition, the energy consumption is based on the distance from the base station, lower power is transmitted for the mobile users near the BS and higher power is available for the MS farther from the BS. More details about this modulation technique are addressed in the physical layer part.

2.3 WiMAX network architecture

The IEEE 802.11e-2005 standard only defines the air interface access aspects such as PHY and MAC layers but this does not define the end-to-end WiMAX network architecture, by this reason the WiMAX Network Working Group (NWG) plays essential role to develop the end-to-end network requirements, architecture and protocol suited for the WiMAX technology.

The WiMAX architecture and network reference model are standardized by the network working group and the packet-switched architecture is based upon IEEE 802.16-2009 standard and its respective amendments, as well as the proper use of internet engineering task force (IEFT) protocols and IEEE Ethernet standards such as the IP addressing, routing and connectivity management procedures.

The WiMAX network architecture support access to different internet service provider through internetworking functions, this communication may be done between the MS, ASN and CSN to enable multivendor interoperability. In the network reference model part these networks elements are covers in details.

In mobile WiMAX new design considerations has been followed in order to provide mobility and handover aspects. Some of them shall be mention such as inter-technology handover (Wi-Fi, 3GPP, 3GPP2 when the MS enables these capabilities), IPv4 and IPv6 supports and quality of services considerations such as the admission control and bandwidth assignments.

2.4 WiMAX network reference model

The network reference model is a logical representation of the network architecture, therefore, the WiMAX working group is responsible to develop this architecture aimed to ensure interoperability and compatibility within the industry and mobile vendors and unify the IP-based network architecture. As illustrate in figure 5, the WiMAX architecture is divided into three logical entities:

- The mobile station (MS) represents the end users or mobile subscribers.
- The access service network (ASN), embraces one or more base stations and the ASN gateways both belongs to the radio access network entity.
- Connectivity service network (CSN), supports all the IP network connectivity.

Each particular entity provides protocols and the whole network access connectivity through specific elements such as the base station (BS), the ASN entity, ASN-GW gateways and external CSN. Figure 4, shows those entities connected and provide a basic understanding about the WiMAX architecture, furthermore, all these entities are connected through the reference point defined as R1, R2, R3, R4 and R5 in the basic architecture.

The reference points establish the communication among the network elements through the air interface, these reference points provides specific protocols and functions by which the whole architecture is defined. A brief explanation about those reference points are introduced in the following statements.

Reference point R1 established the connection between the mobile station and the access service network (ASN) linked to the physical and MAC specifications by IEEE 802.16.

Reference point R2 connects the mobile station and the CSN, this ensures the user authorization / authentication and IP host configuration management, operated by either the home network service provider (NSP) or the visited NSP.

Reference point R3 established the communication between the ASN and the CSN to support authentication, authorization, and accounting management (AAA) and mobility capabilities.

Reference point R4 consists in the control and bearer plane protocols that address the MS mobility between ASNs and ASN-GW. This link is the only interoperable connection between the similar ASNs.

Reference point R5 Reference Point R5 consists of the set of Control Plane and Bearer Plane protocols for internetworking between the CSN operated by the home NSP and that operated by a visited NSP. (WiMAX Forum® 2009: 27-28).

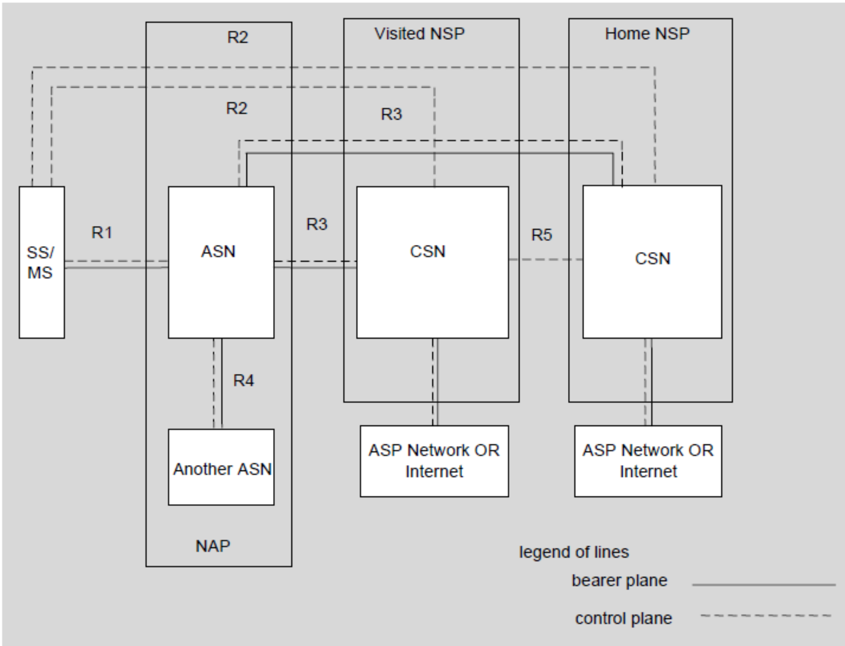

Figure 5. Network reference model (WiMAX Forum® Network Architecture2009: 24)

Several types of configuration may apply over the WiMAX network architecture, usually; diverse access service networks (ASNs) are linked to a single CSN through the R3 interface, as well as several CSN might share the same ASN. However, the WiMAX working group proposes the illustration below, whereas multiple CSNs share the same groups of ASNs and vice-versa. In this scenario, the ASN and MS will exchange information, so that the ASN may determine in which CSN any MS should be attached to in order to provide access and connectivity. Hence this CSN may be operated by the same operator or may belong to different operator (WiMAX Forum® Network Architecture 2009: 32).

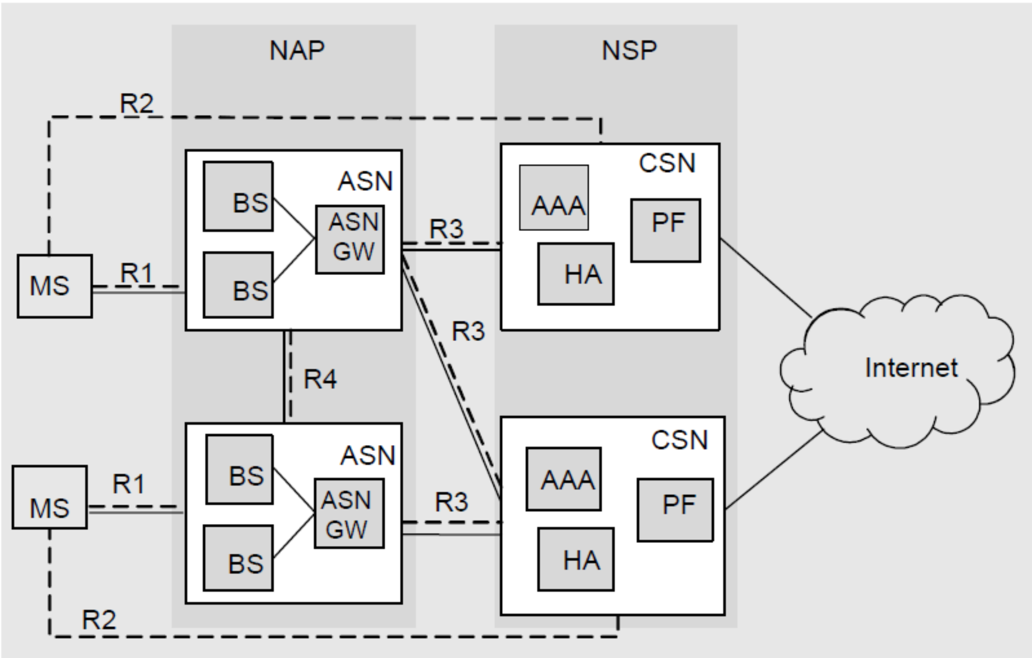

Figure 6. Multiple ASNs to multiple CSNs model (WiMAX Forum® Network Architecture 2009: 29).

The network elements illustrated in figure 6 are introduced and briefly explain in the next part.

2.4.1 Mobile station or subscriber station

The mobile station (MS) or subscriber station (SS) are all the users handset connected to the mobile network, this interface is defined in mobile WiMAX as the reference point R1 and established the connection to the base station (Base station).

2.4.2 Access service network entity

The ASN is as a logical entity and allows the mobile stations or users get access to the network, within an ASN, at least one single base station (BS) and one ASN Gateway (ASN-GW) may be logically connected. A BS is logically connected to one or more ASN Gateways such as illustrate figure 7 by the WiMAX working group (WiMAX: Network architecture, 2009:28-29).

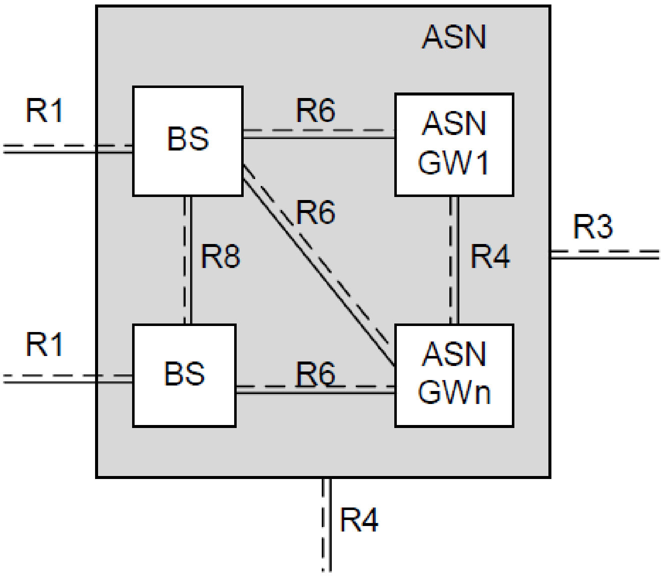

Figure 7. ASN reference model with multiple ASN-GW

The access service network (ASN) utilizes R1 reference point (RP) within the MS and the BS, R3 interface with the connectivity service network (CSN) and R4 with another ASN. The interface R4 is the only control and bearer planes for interoperability among similar ASNs.

An architecture compose with several ASN –GWs requires an specific method defined as intra ASN mobility through the R4 interface and this is called inter-ASN mobility when the R3 interface does not exists.

ASN Gateway

The ASN gateway represents an aggregation in the control plane segment which comply a specific function either with the ASN, with the CSN or any other ASNs. The base stations within the ASN-GW are connected through R8 reference point. Such as seen in the figure 7 and these are straight connected to the any ASN-GW via R6 interface.

Base station (BS)

This is a logical element within the ASN entity that establishes the communication in the middle of the MS and the ASN. This entity involves the PHY and MAC layer specifications to ensure an adequate function under the IEEE 802.16 standard. Usually, a base station represents three sectors with one frequency assignment. This provides schedule function for uplink and downlink resources. A physical implementation may include multiple base stations.

2.4.3 Connectivity service network entity

Mostly the CSN entity provides IP connectivity to the WiMAX users. The CSN is integrated by several network devices, just to mention a few AAA proxy/servers, routers and internetworking devices that support multicast and broadcast services. Normally, the CSN may be deployed as part of the WiMAX home NSP or external NSP (WiMAX: Network architecture, 2009:32).

The following describe the key functionalities for the CSN entity:

- IP address management
- QoS policy and admission control
- ASN and CSN tunneling support over the reference point R3
- Inter-CSN tunneling for roaming
- CSN-anchored inter-ASN mobility.

2.5 Physical layer description

The physical (PHY) layers establish the communication between the MAC layer and the air interface, this entity provides the signal transmission and reception in base band frequency.

Such as the open system interconnection (OSI) model, the physical layer receives the MAC protocol data units (PDU) and processes them into specific functions and protocols specified in IEEE 802.16 standard.

As documented before, the IEEE 802.16e physical layer adopts the orthogonal frequency division multiple access (OFDMA) technique by which the multi-path performance is achieved in non-line-of-sight.

Occasionally, OFDM and OFDMA appellation misspelled or even misinterpreted by engineer and mobile network administrator, but the different between them must be clarify; OFDMA is a form of OFDM, which is the based technology. Both techniques divide the main signal into subcarriers to be transmitted in order to avoid distortion and recover the original signal, if necessary, at the receiver side.

Mainly, OFDM is bound for fixed or point-to-point systems, while OFDMA provides true mobility and thereby, provides a unique interface in the emerging technologies such as the long-term evolution (LTE), hence, the point-to-multipoint systems in mobile WiMAX architecture uses OFDMA.

Technically, the difference among OFDM and OFDMA is the way that the subcarriers are assign to the users, OFDMA has the ability to dynamically assign a subset of those subcarriers to individual users, using either time division multiple access (TDMA) or frequency division multiple access (FDMA) for multiple users (4G Americas organization, white paper presentation, 2009).

In the next part, the OFM and OFDMA technique is cover with details to understand the main structure in mobile WiMAX networks.

2.5.1 OFDM and OFDMA principles

As the main purpose of the physical layer is to transport the data, two methods already described are used to ensure a highly bandwidth and frequency spectrum usage, this methods are OFDM and OFDMA. Out of the physical layer, a wireless infrastructure requires different types of technologies, time division duplex (TDD) and frequency division duplex (FDD) operation as well as the modulation process done by BPSK, QPSK, 16-QAM and 64-QAM, more details about these modulation and operations are introduced further on.

Orthogonal frequency division multiplexing (OFDM) is a multiplexing technique that subdivides the bandwidth into multiple frequency subcarriers as shown in figure 8. In OFDM systems, the input data stream is divided into several parallel sub-streams with reduced data rate and each one is modulated and transmitted separated orthogonal subcarriers as illustrates figure 6. Additionally, the introduction of the cyclic prefix (CP) may completely eliminate inter-symbol interference (ISI) as long as the CP duration is longer than the channel delay spread. The CP is a repetition of previous data, so that, this method prevents interference and improve the channel quality in terms of low-complexity frequency domain equalization. In spite, the CP reduce the bandwidth efficiency, the impact is pretty similar in a single-carrier system when filters are integrated. However, the benefits are higher, since OFDM may reduce the loss of data due the cyclic prefix by the coding scheme before he transmission (WiMAX Forum – Part I, 2006: 11-12).

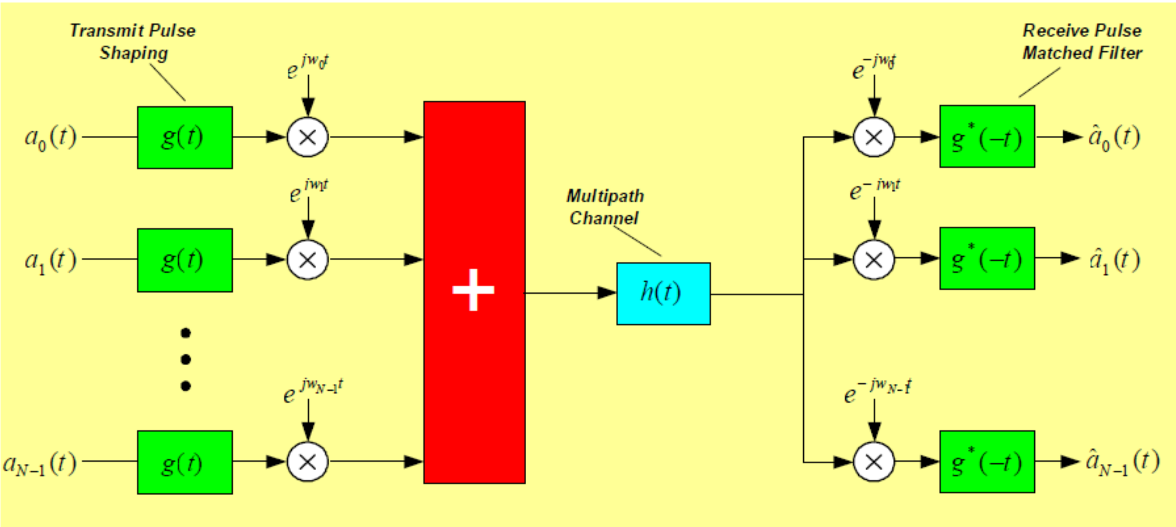

Figure 8. OFDM Architecture by the WiMAX working group in 2006.

The popular mathematical function known as the inverse fast fourier transform (IFTT) provides an efficient OFDM modulation with a large number of subcarriers (up to 2048 carriers). The resources in OFDM shall be available in time domain in terms of OFDM symbols or in frequency domain in terms of subcarriers. Either the time or frequency resources are arranged into sub-channels for allocation in individual users.

The OFDMA provides the same based structure of OFDM but this assign the resources to multiple users onto the downlink sub-channel and provides multiple uplink access as uplink sub-channel.

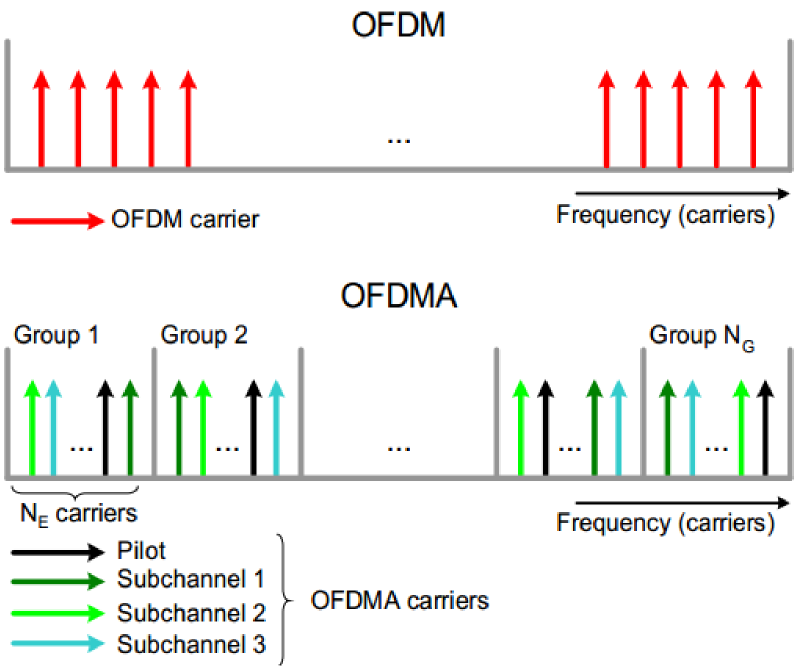

Figure 9. Comparison between OFDM and OFDMA (Senza F. White paper, 2005:8)

OFDMA provides more flexibility and scalability to terminal users, in addition, this modulation supports and enhances the network deployments by the advanced antenna systems, beam-forming and multi input multiple output (MIMO) antenna systems.

The frequencies defined under the mobile WiMAX profiles release-1 cover the 5, 7, 8.75 and 10 MHZ channel bandwidths for licensed worldwide spectrum allocations in the 2.3 GHz, 2.5 GHZ, 3.3 Ghz and 3.5 GHz frequency bands.

The WiMAX Forum has classified the OFDMA symbol structure and sub-channelization into three different types:

- Data sub-carriers are responsible to transmit the data.
- Pilot sub-carriers are employed for the channel synchronization and estimation.
- Null sub-carriers do no provide transmission and these employed to protect the bands as “brick wall” terminology defined by IEEE 802.16 based standard.

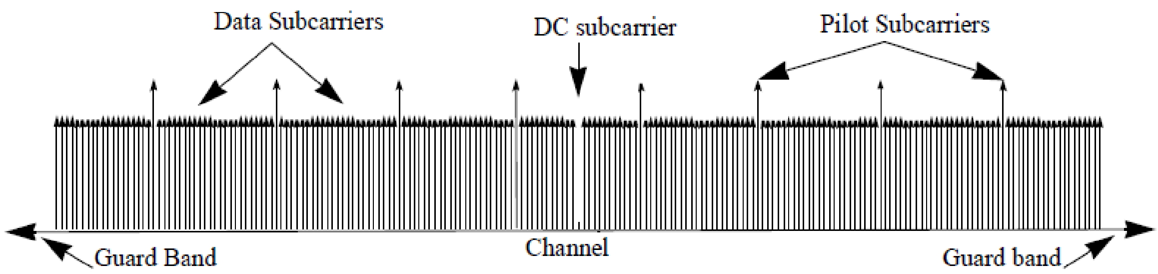

Figure 10. OFDM frequency structure (IEEE 802.16-2004: 428)

The guards bands are employed to enable the signal to recover the original signal by creating the "brick wall" shaping through the fast-fourier transform (FFT) (IEEE 802.16-2004: 428).

Scalable OFDMA or SOFDMA was introduced in the IEEE 802.16e-2005 Wireless MAN Amendment to support scalable channel bandwidth from 1.25 to 20 MHz, hence, SOFDMA has an advantage, due the fact the scalability may be fluctuate by adjusting the FFT to the channel bandwidth to keep the distance between the subcarriers alike. As lower is the space between as higher will be the spectrum efficiency in wide channels. This thesis will consider the scenario under the 10 MHz frequency.

As revealed previously, 802.16-2004 was originally designed for fixed and nomadic application in the 2 – 11 GHz frequencies and OFDMA was later introduced, two modulation techniques are supported under this standard, OFDM with 256 carriers and OFDMA with 2048 carriers and 32 subchannels (Senza F. 2005:4).

2.5.2 Duplex mode operation

Duplex is the process wherein the transmitter and the receiver achieve a bi-directional communication, this is defined as half-duplex mode and full-duplex mode.

In half duplex communication, the transmission over the channel is process by separately, in other words, while the transmitter is sending data, the receiver must wait until the whole data is received in order to response or start a new transmission.

Full duplex mode is related to bi-directional communication at the same time; both the transmitter and the receiver may send and receive data simultaneously. Traditional landlines and cell phones operate under this method. In spite, this mode is more complex and expensive to implement than half duplex, full duplex mode is the most expected communication scheme consider by network operator. Two full duplex mode are well-known, the frequency division duplex (FDD) and the time division duplex (TDD).

WiMAX systems supports both time division duplex (TDD) and frequency division duplex (FDD) in half and duplex mode, denoted as H-FDD and F-FDD, nevertheless, the original release of mobile WiMAX consider only the TDD mode. In short, when the same frequency carrier is employed for downlink and uplink communication, the operation mode is called time division duplex (TDD), while frequency division duplex (FDD) employs two separates frequency and channel to achieve the communication between two devices. FDD profiles were considered by the WiMAX forum to address specific market opportunities where the TDD is prohibit by the local regulation, besides, TDD is the most common method used in the 802.16 networks and this is the operation mode considered in this thesis. The WiMAX working group describes the main features of TDD (Mobile WiMAX, 2006:16):

- TDD provides adjustment in the downlink / uplink ratio to efficiently support asymmetric traffic, this is why normally, in mobiles network and broadband services, the bandwidth is higher in downlink than uplink, unlike FDD where the traffic is generally the same, both for DL and UL.
- TDD guarantees channel reciprocity for better support of link adaptation, multi-input and multi output and closed loop antenna systems.
- As implied before, FDD requires 2 channels to establish the communication between two devices, while TDD only requires a single channel for downlink and uplink, this offers higher efficiency.

The figure 11, illustrates the TDD frame structures, each frames represent the downlink subframe and uplink subframe. The gap between them represent the transmit receive transition (TTG) or a receive transmit transition (RTT) in order to avoid collisions. The downlink subframe initiates with a preamble for synchronization, this is followed by the frame control information channel (FCH), which includes information about the mobile application part (MAP) messages, coding scheme and the subchannel information. This is followed by the DL and UL map. The MAPs carry information about the subframe structure that will be used and about the time slots that will be assigned to the mobile station. A subchannel is also available to all mobile users to measure the ranging. Thus, mobiles users may use this channel for closed loop adjustment and new mobile station request. The DL process is done by the base station and this contains subchannels for individual mobile station (Kumar A. 2008:100).

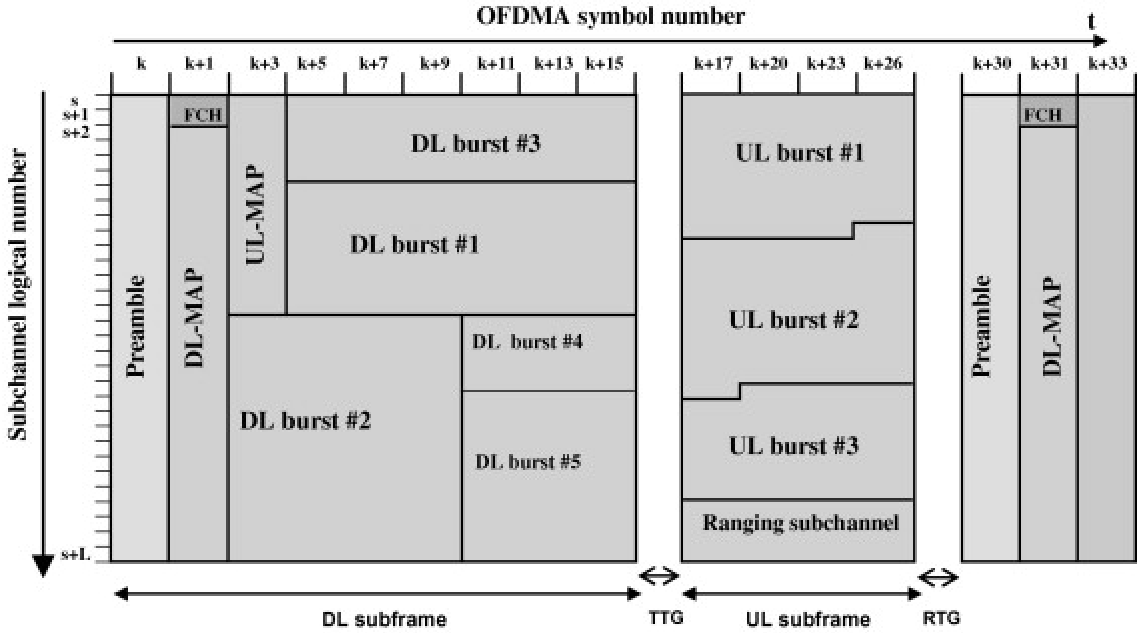

Figure 11. TDD frame structure (Hyung S, Sooyoung Y. Tiny Map 2007).

In TDD technically speaking, the downlink and uplink subframe are transmitted simultaneously which is an advantage to the network provider to distribute the bandwidth efficiently that represent a critical resources. The process to assign a subchannel and time slot to individual mobile users is flexible and shall be different from frame to frame.

The MAP messages frame is responsible to allow or deny access to the network, this entity authorize the mobile users to transmit or receive in specific time slot using the assigned subchannel and the data is transmitted with the proper modulation scheme based on QPSK, 16 QAM, and 64 QAM. Each modulation technique are associated to the burst profiles allocation of WiMAX technology, which changes dynamically and possibly very fast, based on the PHY conditions. The burst profiles represent a fraction of the total transmission frame both for DL and UL transmission; and are employed for the link adaptation procedure. The link adaptation procedures are covered in the next part.

In the other side, the UL subframe also contains burst slot by which the user information is stored and the raging channel is integrated in this part to be responsible for network entry, connection maintenance, bandwidth request and efficient handover (HO). The access to this slot is achieved by the code division multiple access (CDMA) scheme, up to 256 set of ranging code may be generated (each 144 bits). (Kumar A. 2008: 100-101)

As the data is delivered within the burst slots either DL or UL, a logical scheme is followed to ensure optimal system operation, hence, a particular mobile user assigned to burst 2 may receive only the data attached to burst 2 and may transmit only on the subchannel or subcarriers assigned for burst 2 (Loutfi Nuaymi, Technology for broadband wireless access, 2007: 78).

2.5.3 Adaptive modulation and coding

In wireless environments, the quality of a signal received by the mobile station is subject to path loss, interference, fading and noise. Thereby, adaptive modulation and coding (AMC) scheme was introduced in Mobile WiMAX technology to mitigate these factors and improve the network coverage and capacity. Therefore, the adaptive modulation and coding (AMC) scheme not only enhance the capacity but allows an efficient bandwidth usage by which the data rate achieve optimum performance and ensure quality of service (QoS) between the base station and the mobile station. Technically, this process is also known as link adaptation scheme for downlink and uplink transmissions and it goes from 64-QAM to BPSK (Ohrtman F., 2005:54-55).

The adaptive modulation and coding (AMC) scheme in mobile WiMAX are described in the table 1 and this are specified by the WiMAX working group, downlink and uplink transmissions support the same categories, but only the 64 QAM is optional in UL, due the fact that, the mobile station itself may detect an error along the threshold of the coverage range and eventually switch to 16 QAM or QPSK.

The level of the received signal (RSS) is proportional to the distance; hence, the adaptive modulation technique is employed to increase the system capacity and network performance. When the link quality is high, WiMAX uses the highest modulation scheme with highest coding scheme. As higher is distance between the BS and MS, the signal is exposed to higher noise and fading, thereby, WiMAX may move to the lower order modulation with lower coding scheme (E. Kacerginskis, L. Narbutaite, Capacity and HO in mobile WiMAX, 2012).

Table 1. Modulations scheme and code rate (WiMAX Forum™ 2006:18)

		DL	UL
Modulation		QPSK, 16QAM, 64QAM	QPSK,16QAM, *64QAM*
Code Rate	CC	1/2, 2/3, 3/4, 5/6	1/2, 2/3, *5/6*
	CTC	1/2, 2/3, 3/4, 5/6	1/2, 2/3, *5/6*
	Repetition	x2, x4, x6	x2, x4, x6

In short, this modulation scheme plays an important role within the TDD frame structure, thereby, every single mobile station has a burst slot assigned that includes the code rate and modulation level according to data transmitted in the channel as specified the following figure. The typical link adaptation scenarios in wireless network interface satisfy the following criteria, as the distance from the base station increases, the signal-to-noise ratios fall and thereby the adaptive modulation scheme (code rate) is automatically adjusted according to the quality of the channel. Hence, as the distance from the base station increases, the mobile users in different areas will obtain the lower density modulation schemes as QPSK or BPSK and this will eventually obtain a lower data rate. This behavior is commonly applied for omnidirectional antennas such as the wireless fidelity (Wi-Fi) networks. (Kumar A, 2009:90-91)

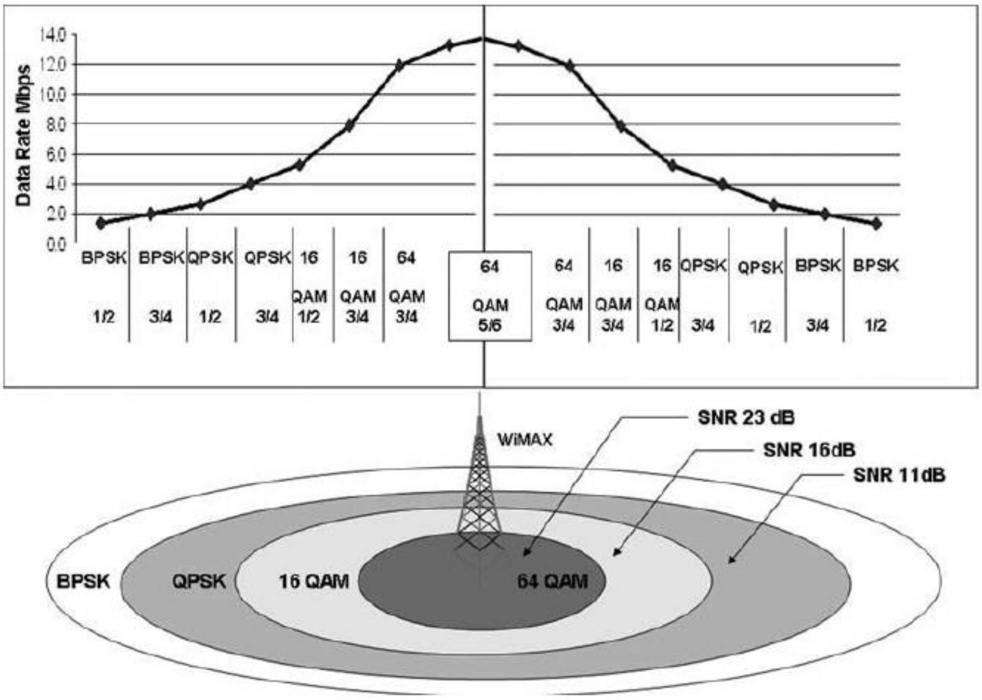

Figure 12. Modulation schemes and coverage (Kumar A. Mobile Broadcasting 200:91)

The IEEE 802.16e standard MAC layer, defines 34 different modulation and coding scheme for the DL burst profile and 52 different coding schemes for UL burst profile, which are the combination of the modulation scheme (BPSK, QPSK,16-QAM or 64-QAM), the coding (CC, ZT CC, CTC, BTC, CC with optional interleaver) and the coding rate (1/2, 2/3, 3/4 and 5/6).

The modulation technique choice or burst profile, became a challenge for the wireless operator as the radio channel must choose the most suitable link connection to assign the MS, therefore, an efficient path selection algorithm must be implemented based on the weight for each link connection between the BS and the MS. The weight of the link corresponds to the modulation and coding rate employed on that link which is proportional to the distance between the MS and the BS or, if any, relay station (RS) (Rohaiza Y., Mohd D., Muhammad I. Ruhani Ab. And Naimah Isa, ACEEE Int. 2012:13).

The decision is taken based on the following condition

$$Wr + Wp < Ws \quad (1)$$

Where, Ws: Weight of the MS to BS for UL,

Wr: Weight of the MS to RS for UL (If apply) and

Wp: Weight of the RS to BS for UL.

The burst profiles implementations satisfy the Shannon's theorem bound to measure the channel capacity in bits per second over the available bandwidth and the signal-to-noise ratio (SNR) in dB of the link (Sklar Bernard, Digital Communications, 2007:525).
The capacity equation is defined as:

$$C = W \log_2 (1 + SNR) \quad (2)$$

The SNR values may be taken from the received SNR threshold values proposed in some test condition by the IEEE.

Table 2. Received SNR threshold proposed by IEEE 802.16-2004 Standard

Modulation	Coding rate	Receiver SNR (dB)
BPSK	1/2	6.4
QPSK	1/2	9.4
	3/4	11.2
16-QAM	1/2	16.4
	3/4	18.2
64-QAM	2/3	22.7
	3/4	24.4

2.5.4 End-to-end quality of service

The quality of service (QoS) determine the service that the end users will experience within the wireless channel, thereby, QoS address the most common parameters such as throughput, bit error rate, jitter, latency, minimum throughput, call drop that define the wireless network performance. Since WiMAX technology was designed to support high demands applications, to mention few video calls and voice over IP (VoIP) with highly QoS requirements, the IEEE 802.16 standard employ an efficient scheduling functions to handle such traffic. (Seok Yee T., Peter Muller, Hamid R. WiMAX Security and Quality of Service, 2010:188).

2.6 Medium access control layer

The WiMAX medium access control layer (MAC) protocol was designed for point-to-multipoint broadband wireless applications. This interface covers the needs for high data rates, both from the base station as DL and to the base station as UL. The MAC layer provides network functionalities to the PHY layer and bring features to provides mobility, power saving and quality of service (QoS) to the mobile users. One of the most relevant features is the dynamic bandwidth allocation by which the signal interference is mitigated. As mentioned in part 2.1, The MAC is logically divided into three sublayers under the IEEE 802.16-2004 standard and these are defined as convergence sublayer (CS), MAC common part sublayer (MAC CPS), and security sublayer (SS).

The upper layer is responsible for mobility control and resource management such as network discovery, selection and entry, paging and idle mode, radio resource management (RRM), mobility management and handover protocols, QoS, scheduling and connection management and, multicast and broadcast service (MBS), while the lower layers for control and support to the physical layer (PHY) and includes features associated to security, sleep mode management, link control and resources allocation functions. The PHY entity within the MAC handles ranging, measurement/ feedback and HARQ ACK/NACK in order to support the link adaptation process (Kamran E and Mingo Y, 2010:46).

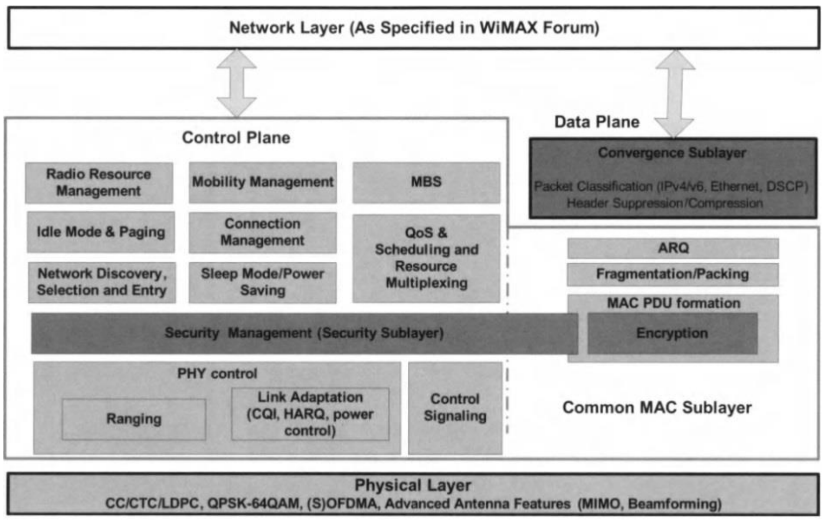

Figure 13. MAC layer functionalities (Kamran E and Mingo Y. 2010: 45-46)

Initially, The WiMAX forum has integrated the PHY and MAC layer in order to support all IP-based architecture and ensure network scalability, therefore, by using the convergence sublayer; the MAC has the capacity to support any future IP protocol. A brief illustration about the MAC layer entity is present in figure 14 by Kumar A.

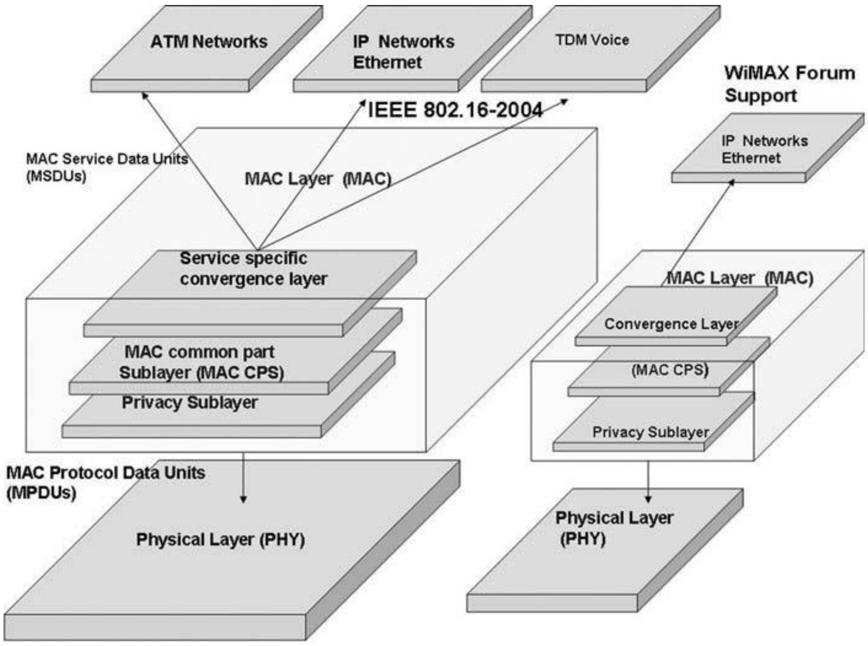

Figure 14. MAC layer in mobile WiMAX technology (Kumar A, 2008: 83)

Furthermore, the WiMAX MAC employs an error mechanism system namely the automatic retransmission request (ARQ) which operates between the MAC and PHY layers, this mechanism request retransmission of the packages received with error, this process reach high data rates as the error detected are not corrected at higher layer and consequently make the protocol a bit more efficient (Kumar A. 2008: 82-83).

2.6.1 MAC convergence sublayer

The convergence sublayer is responsible to establish a connection with higher layer, by which different types of networks and technologies converged, one of these networks are ATM, IP network and Ethernet, TDM-based voice, among others. Thereby, the CS accept the MAC services data units (MSDU) from these networks and convert them into MAC protocol data units (MPDUs) for transmission over the air interface.

Consequently, the services and tasks provided by the convergence sublayer are classified as follow (IEEE 802.16-2004 standard):

- Admission control to the protocol data units (PDUs) from the upper layers.
- Network classification and PDUs processing.
- Transmission and reception with respect to PDUs.

The IEEE 802.16 standard specified two types of services insight the convergence sublayer, known as ATM CS and packet circuit switching.

2.6.2 MAC common part sublayer

The common part sublayer (CPS) provides functions as connection control, access to physical layer, and bandwidth allocation, additionally, the MAC CPS has a relevant impact over the air interface and execute different task, such as MAC PDU operations, call admission control (CAC), QoS provisioning, automatic repeat request (ARQ), mobility support, multicast and broadcast services (MBS) and modulation and coding selection.

As the WiMAX MAC layer interface is connection oriented with reliable QoS and security support features capable of concatenation, fragmentation and reassembly, and packing the service data units (SDU) received from higher layer, so reliable mechanism are addressed to ensure compatibility, all package transmitted from higher layer as SDUs to the MAC CPS are assembled to create a single MAC PDUs. Multiple SDU may be carried in a single MAC PDU or a single SDU may be fragmented to be transfer into multiples MAC PDUs. Each MAC PDU comprises a 6 bytes generic MAC header (GMH), followed by payload information and 4 bytes CRC, which maximum total size up to 20148 bytes. (Kamran E and Min-Yee L. 2010:79).

The connection between the base station and the mobile station over the air interface is reachable through an unidirectional logical link call MAC connection, each connection is identified by 16 bit as connection ID (CID). Within the MAC connection the QoS parameter is carried out by a service flow (SF) and the security features is responsible by a security association (SS). In mobile WiMAX, such as any network interface card, each mobile station holds a MAC address with 48-bit IEEE MAC and each BS has a 48-bit base station ID, of which 24-bit are reserved as operator ID (IEEE 802.16 standard).

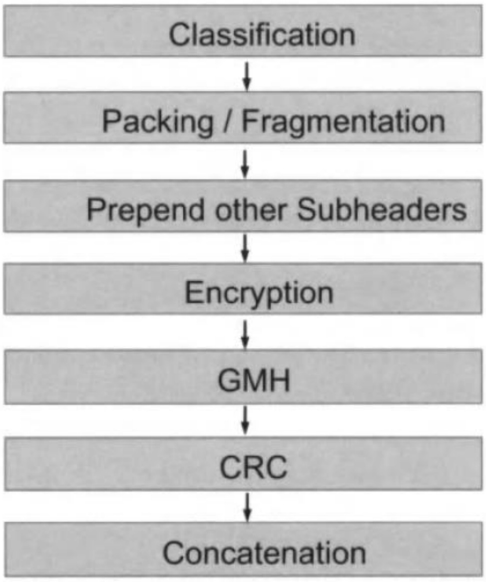

Figure 15. MAC PDU operation (WiMAX Technology and network evolution)

The quality of service (QoS) over the air interface is measured by these parameters packet latency, throughput, packet loss, among others and those are supported by MAC management, scheduler and ARQ modules in this sublayer. In the first group, the network may accept or reject a certain request according to subscriber's profile and the required resources against the network resources available namely as bandwidth. In the second group, the scheduler allocates bandwidth to the MAC connection based on the scheduled transmission; The transmission process is well-known as uplink or downlink and based on the algorithm designed, the network simply decide which MAC connection or mobile station may transmit, when to transmit, how many subchannel are required and which modulation techniques and coding is used to transmit the package. Hence, to enhance the network performance and quality of services the mobile operator shall implement efficient algorithms for call admission control, scheduling, bandwidth request. The automatic repeat request (ARQ) module plays an important role and this is a relevant aspect to consider whereas, the MAC PDUs or package are retransmitted to control to transmission loss and mitigate the air interface interference, usually this error mechanism inactivate real time applications, which are delay sensitive and loss tolerant, and active for data applications (Kamran E and Min-Yee L. 2010:80).

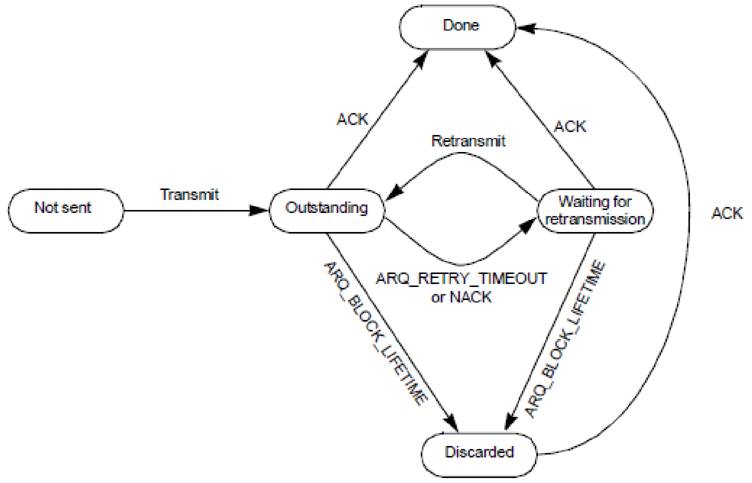

Figure 16. ARQ mechanism sequence (IEEE Std 802.16™-2004, 134)

2.6.3 MAC Security sublayer

The security layer increment the network reliability and established a privacy protection to prevent unauthorized users over the air interface by using encryption mechanisms within the wireless channel (Mobile station and base station). Privacy employs an authenticated client-server system to verify the user authenticity and therefore accept or deny the access to the network; this process is done through the base station and the server in which the information of the mobile user is stored or backed.

Privacy has two protocols namely as packet data encryption and key management protocol (PKM). The packet data encryption is used for the security along the network, and includes data cryptographic techniques which pair the data encrypted, execute an authentication algorithm and apply this to a MAC PDU payload, this process is defined by the IEEE Std 802.16™-2004 standard. A single mobile station uses the PKM to obtain authorization and traffic keying material from the base station, the key management protocol uses X.509 digital certificates (IEFT RFC 3280), the RSA public-key encryption algorithm and a strong encryption algorithm to perform exchange between the MS and BS and define certain condition to access to the network services.

3. MOBILITY MANAGEMENT AND HANDOVER MECHANISMS

Mobile WiMAX IEEE 802.16e standard brings the wonderful features known as handover (HO) or handoff process that provides wide-area mobility and link adaptation to the mobile subscribers. Handover is required as the mobile station moves out from the range of one base station and into the range of the neighbor base station. The fact that mobile user move over different coverage area, become today a network challenge to the mobile supplier. Further details regarding the handover process are given in the HO management part.

3.1 Mobility management

Mobility management is one of the features that distinguish mobile WiMAX from fixed WiMAX, beyond the capacity that allow the users to communicate from various locations while moving. Two basics mechanism are required to make this possible, first the packets delivery transition from the base station to the mobile stations, requires a process to identify and track all mobile stations connected to the network, including idle status stations, so this process is called *location management*. Second, to maintain an ongoing session as the mobile stations moves out of the coverage area from one base station to another base station, requires a process well-known as handover or hand off, hence, this procedure represent the *handover management*. Both, location and handover management constitute mobility management (Jeffrey G. Andrews, 2007: 251-252).

3.1.1 Location management

Location management involved two processes. The first process is called location registration or location update is the first process from which the MS periodically informs the network about its current location, this step leads the network to authenticate the user and update its location profile in the databases that are typically centralized based on the mobile provider requirements and planning. As the networks requires a report from every mobile stations all the time, including the idle MS, when this moves from different coverage range, so that, the load on the network might be affected, especially in those areas where the number of mobile subscribers are large and the target areas are covered by microcells. Therefore, to mitigate the load issue, the mobile provider typically implements in larger locations areas, several base stations.

The frequency location is also an important aspect to consider, if the location update is performed infrequently, then the MS face the risk to be moving out of its current location without a prior notification to the network, so this leads the mobile users having inaccurate information about the mobile location. By this reason, the mobile providers establish roaming agreements with different mobile operators to enables the location management wider and successful global roaming (Jeffrey G. Arunabla Ghost, Mohamed R., Fundamentals of WiMAX, 2007:278-279).

The second process is defined as paging. When a request for session initiation such as incoming and outgoing calls reach the network, this search the location in the database to determine the receipts' current location area and then pages all the base stations within the mobile subscriber area. As larger is the number of base station, greater the paging resource in the network. Thereby, the mobile providers are required to trade-off agreements between them to avoid network resources wastage.

3.1.2 Handover management

Handover management has much higher real-time performance requirements than location management, in order to cover the traffic demand by many mobile apps such as VoIP and high definition video streaming, thereby the handover process should be done with a small delay to avoid packet loss, by this the mobile WiMAX architecture determines a handover latency less than 50ms with a packet loss rate below 1% (Jeffrey G. Andrews, 2007: 251).

The handover process is defined as having two phases, first the network detects the need for a handover process and makes the decision to transfer the connection to new base station, the second phase, the handover is executed and make sure that the mobile station and base station involved in this process are synchronized and therefore meet the suitable protocols in the network.

The handover procedure may be initiated by either the mobile station (MS) or the base station (BS), whoever initiates the process, the final decision is typically made by the MS and the decision is based on signal-quality measurements collected and reported by the MS. Usually, the MS scan the neighbor cells within the range and measure the signal quality. In WiMAX Technology, the BS assists in this process through a list of neighbor cells and the receive signals strength (RSS) or signal-to-interface plus noise ratio (SINR) may be used as a measure of signal quality.

The illustration below shows a common scenario with two base stations and a mobile station moving ahead from base station A (serving BS) to base station B (target BS). The minimum signal level (MSL) is the threshold employed to measure the signal quality of the base stations and sometimes is denoted as Δ, when the serving BS quality level is below this MSL, packet loss or call drops takes place. In theory, the handover process is perform when the quality of the signal drops below the MSL point and if and only if exists neighbor cells by which the signal quality is higher than the MSL. Technically, the MSL level may vary depending on the QoS requires by the applications usages, for instance, high throughput applications may have a higher MSL unlike low-data-rate application such as mobile browsing which are tolerance failures (Jeffrey G., Arunabha G., Rias M., Fundamentals of WiMAX, 2007: 251).

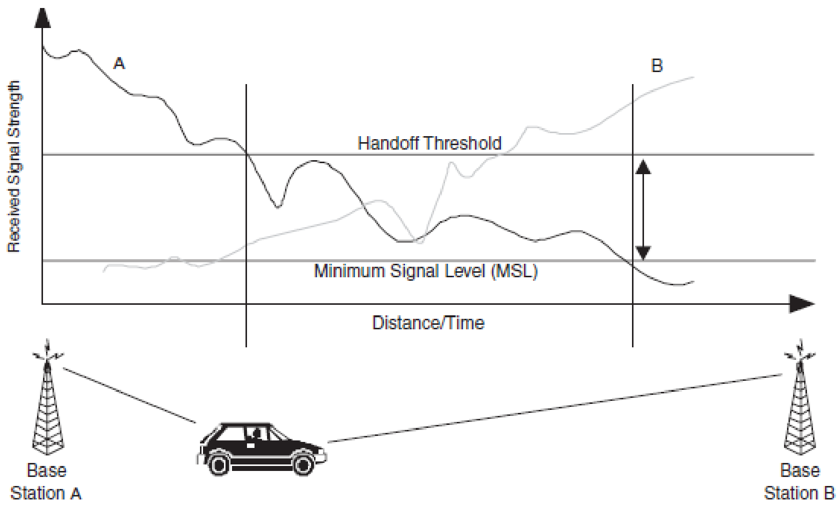

Figure 17. Handover process based on the signal strength (Jeffrey G. Andrews, 2007)

Commonly, two key performance indicators (KPI) are employed to measure the handover performance within the mobile network, these are the handover success rate and the dropping probability or packet drop, since then, the first indicator quantify how many HO decisions are made and the second quantify the HO failures when the signal level drops the MSL level. In consequence, in order to minimize the handover failures, an efficient algorithm shall be implemented by the mobile operator.

In order to avoid a packet drop and call failure, the handover process must be executed fast, and the MLS level or Δ point must be set higher with the interest of minimize the dropping probability of the signal. The algorithm implementation must take into consideration the relation among the dropping probability and handover success rate. Few handover may lead to call drops and too many handover may degrade the service quality and cause signaling overload (Jeffrey G. Andrews, 2007: 252).

3.2 Handover process in mobile WiMAX

The WiMAX Networking Group has developed several techniques in order to optimize the handover performance within the framework defined in the IEEE 802.16e standard; therefore, these enhancements have been developed in first order to establish a handover delay time to less than 50 milliseconds in layer 2 and this defined three handover process known as hard handover (HHO), fast base station switching (FBSS) and macro diversity handover (MDHO), of which, the HHO is the default handover and does not employed any additional scheme. The soft handover are optional and comprises the FBSS and the MDHO modes (WiMAX Forum, 2006:23).

3.2.1 Hard handover process

The hard handover process is based upon the received signal strength indicator (RSSI) measurements, from which the MS continuously measures the RSSI and inform this values periodically to the serving BS. This process is also defined by some authors as break-before-make a connection, whereas, the mobile station breaks or interrupt the connection with the serving BS first and thereafter establish a new connection with the target BS, therefore, the time delay defined during this period at 50ms makes this process possible and avoid any call failure.

The handover process is performed with respect to the RSSI quality level, when the MS detects that the RSSI is below a certain threshold, then the MS immediately scans the channel and sends a MOB_SCN-REQ message to the serving BS. Consequently, the serving BS response by sending a MOB_SCN-RSP message that contains the scanning time intervals. The minimum and maximum threshold range are defined and specified by the mobile operator according to the network load and performance.

Along with the scanning period, the mobile station also measures the RSSI for all neighbors with the aim of select the greater link quality. The neighbor BSs receive periodically notification by the serving BS via a broadcast message defined as MOB_NBR-ADV. During this scanning period, the MS receive only periodically notifications and metric status of every single BS to calculate the RSSI level, but not package data are switched within the channel. (Ahmadi Sassan, 2011:14-186).

Technically, the HHO is performed if the RSSI level of the serving BS is considerably low and the RSSI level link to a neighbor BS is greater than the serving BS, thereby, if the MS initiates the HHO, the MOB_MSHO-REQ message is sent to the serving BS, who response with a MOB_BSHO-RSP message. On the other side, if the serving BS initiates the HHO, the MOB_BSHO-REQ message is sent.

Generally, the handover is considered technically completed when the BS receives the MS_HO-IND message from the MS and the MS establish a successful connection with the new serving BS by the accomplishment of the network re-entry process (Shahab S and Schumacher J., 2010:198).

3.2.2 Fast base station switching process

Fast base station switching (FBSS) and macro diversity handover (MDHO) are both optional handover process supported in IEEE 802.16e. FBSS is considered by Kumar Amitabh as a soft handover method.

In this process, the MS and the BS establishes and maintain a connection only with the list of base stations or diversity set involved in FBSS, the list of base stations is defined as *diversity set*. Therefore, the MS continuously scan the active cells within the range and keep a valid connection ID with each of them. The communication between the MS and the active cell is achieved by the MOB_MSHO-REQ message from the MS and the immediate responds by using the MOB_BSHO-RSP message from active BS also known as anchor BS. If a new connection is required, this will be achieved by using the handover messages or triggered the anchor selection feedback. Thereby, the MS reports the selected anchor BS on the channel quality information channel (CQICH) list (Amitabh Kumar, 2008:113).

Generally, a common scenario where a MS communicates only with the anchor BS for UL and DL transmission is considered as FBSS operation mode with diversity set, this condition does not requires disconnection upon the transition from the old to the new anchor BS. The BS supporting FBSS sends a broadcast message to the neighbor cells to determine whether a HO request should be sent to request changing the diversity set. When the main carrier to interference-plus-noise ratio (CINR) of an active BS in the current diversity set is less than a certain threshold, the MS may send a MOB_MSHO-REQ message to request leave this BS from the diversity set. When the channel quality of a neighbor BS is superior to a certain threshold defined by the network provider, a MOB_MSHO-REQ command is sent by the mobile station to request the aggregation of a new neighbor BS to the neighbor list or diversity set. As a result, the anchor BS sent a MOB_BSHP-RSP message with the diversity table updated.

Once the MS completes the handover process and the initial network entry/ re-entry step is done, the current BS becomes an anchor BS. Thereby, the diversity set is initialized and the old base station is set to zero through the TEMP_BS-ID parameter. The anchor update process starts when MOB_MSHO-REQ is sent by the MS or MOB_BSHO-REQ is sent by the anchor BS. An acknowledgement message should be always received.

This process may also starts with an anchor switching indication via fast-feedback channel. If the MS is sending a handover request through the MOB_MSHO-REQ message and this detects an incoming message from the base station MOB_BSHO-REQ, this will simply ignore and deny the request. Certain parameters are required to enable a fast base station switching between the MS and the group of base stations involved.

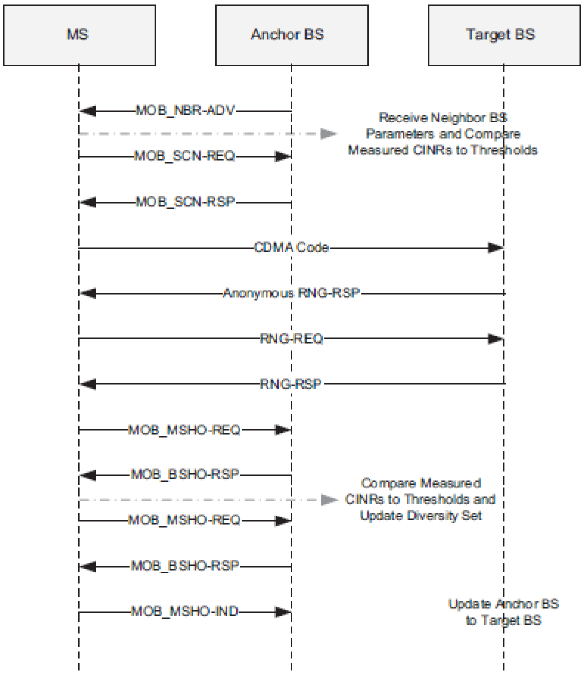

Figure 18. FBSS operation messages (Ahmadi S. Mobile WiMAX, 2011:192)

The base stations involved in the FBSS process demands a real time synchronization in favor of updated the diversity set or neighbor BS list periodically. Accordingly, a common clock rate and frequency must be set to allow any BS from the diversity set reach the MS within the OFDM cyclic prefix interval. The synchronized channel not only operates at the same frequency but share the same information during the network entry/ re-entry. (Ahmadi S., Mobile WiMAX, 2011:191-193).

3.2.3 Macro diversity handover process

In macro diversity handover (MDHO) process, the MS may connects with one or more base station in the diversity set in the same interval, while the FBSS process permit the communication with only one single BS from the diversity set. The handover process in this method shall be initiated with a MOB_MSHO-REQ or a MOB_BSHO-REQ message. In spite of, MDHO keeps a list of BSs or diversity set that is involved with the BS. Since the MS communicates with all base stations of the diversity set for both uplink and downlink streams, two procedures has been defined by Sassan Ahmadi to monitor and control the broadcasting messages sent and received for both mobile and base stations.

The first procedure, the MS monitors only one single BS in downlink, while the channel interface from the anchor BS in uplink and downlink, embrace burst allocation information bound for other active cells.

The second one, the MS monitors all the base stations of the diversity set in downlink transmission, while the channel interface from any active BS embrace information bound for any active BS. Both procedures are achieved by the following messages REG-REQ and REG-RSP messaging.

The MDHO operation is executed when the MS decide to send and receive unicast messages and traffic from multiple base stations during a specific interval. In DL transmission, the MS is synchronized with two or more base stations, so that the MDHO decision may be done by the MS. while in UL transmission, the package set from an MS is received by multiple BSs so that the decision shall be taken by multiple base stations involved.

The base station that support MDHO, broadcasts the system information that consist of the commands H_add and H_Delete. These commands are employed to determine whether MOB_MSHO-REQ should be sent or not from the MS. When the CINR of an active BS in the current diversity set is lower than the H_Delete, thus a MOB_MSHO-REQ message is sent by the MS to remove this active BS from the diversity set. When the CINR of a neighbor BS is higher than the H_Add threshold, the MS sends a MOB_MSHO-REQ to add this neighbor BS to the diversity set.

The decision to update the diversity set or base station list is accomplished with the following notifications employed by the mobile stations and base stations, denoted as MOB_MSHO-REQ and MOB_BSHO-REQ messages respectively. Both cases require an acknowledgement message from the BS, denoted MO_BSHO-RSP. If the MS wish to request a handover, this employ the MOB_MSHO-REQ message and the MS will not transmit any other message or command prior to expiration of the internal timer, set by the *MS_handover_retransmission_timer* command.

Therefore, the timer is disabled when the MS receive the MOB_HO-IND message sent by its own or the MOB_BSHO-RSP message sent by the BS. Such as the FBSS process, the anchor BS update may also begin with anchor switching indication via fast-feedback channel. If the MS is wish to transmit any request via MOB_MSHO-REQ message and this detects an incoming request from the BS, so that the MS immediately ignores this request and allow access to the BS transmission. The same occurs in the other side, if a BS wishes to transmit a MOB_BSHO-REQ message and detects an incoming request either a MOB_MSHO-REQ or a MOB_HO-IND, so the MS discards its own request.

As the MDHO operation mode involves several base stations with a single BS, the use of a unique connection identifier (CID) is mandatory. Hence, the BS may assign a new set of CIDs to the MS during the update of the diversity set via MOB_BSHO-REQ or the MOB_BSHO-RSP messages. However, in order to accomplished a successful macro diversity handover process, the following criteria should be followed by the group of base stations and the mobile station involved in this operation (Sassan Ahmadi, Mobile WiMAX: A System approach... 2011:193-194):

- Real- Time synchronization upon the clock frequency source.
- Consider the same RF carrier frequency.
- Share the MAC/ PHY PDUs received in the diversity set with the MS.

3.3 Mobile station operation modes and handover procedures

Every mobile device needs to save power to have a long battery life. By this purpose, two stages have been defined by IEEE 802.16e-2005 as sleep mode and idle mode. These two stages have a similar operation and allow the MS to enable or disabled physical operations with the base station in DL and UL frames.

In sleep mode, the mobile station remains unavailable for a period of time that is also known by the base station. Eventually, the MS switch to listening period whereas is able to transmit and receive data over connections between the BS and MS, this process is thereby followed again by a sleep mode period. During the unavailable period, the MS disables its wireless interface to reduce its power consumption and at the same time the BS may decrease its processing load to avoid network traffic load. The sleep mode is suitable for low-data rate and continues data communication such as short video streaming and instant mobile messaging application which shall tolerate latency (Iseda K., Tsuruoka T., Tsuguo K. Power consumption control, 2008: 257-258).

In idle mode, the mobile station does not communicate with the active BS and is only available to receive incoming traffic in the DL burst from the base station that has the paging controller function within the cluster. In this mode the mobile station can move across that cluster or coverage area without the need of handover process at every base station. Under this condition the BS maintain the context of the MS to establish a immediate communication when is required (Iseda K., Tsuruoka T., Tsuguo K. Power consumption control, 2008: 257-258).

The handover network entry and re-entry process is followed by the message sent from by either mobile station or the base station side. This procedure is shown in figure 19 and symbolizes the command used by each element. The left side symbolize the process when the connection remains active between the MS and the target BS, while the right side symbolized the procedure then the connection is broken before the network entry or re-entry.

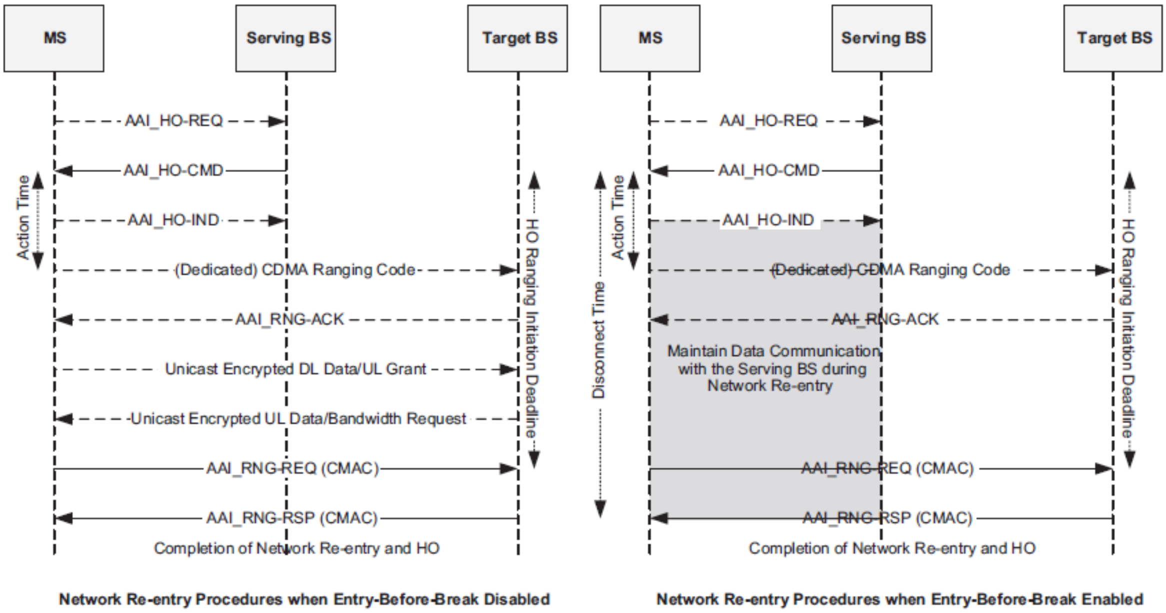

Figure 19. Handover network re-entry process (Ahmadi S. 2011:201-204)

Technically, this procedure is achieved by the following network stage:

3.3.1 Handover initiation

The handover initiation represents the first phase to trigger and execute the whole process. Whoever initiates the handover, the decision is always made by the serving BS whether the communication between them is allowed or denied. Accordingly, the network entry / re-entry phase is allowed with the target BS when HO_Re-entry_Mode is set to 1 and this is deny when HO_Re-entry_mode is set to 0.

If the HO process is initiated by the base station the handover preparation is done before the handover initiation, however, the process is accomplished by the following command AAI_HO-CMD that contains information about network parameters and raging resource allocation to be assigned to the target BS.

During the HO preparation, the serving BS exchange information with the potential target base station such as MS identity and security context to enable a successful transition through the core network. This potential target BS is found within the diversity set defined and configured by the mobile operator.

Additional network resources may be reserved for the MS if and only if, the information about the target BS is not prepare in advance before the HO transition, such information may include the adaptive modulation code and range. Whenever a mismatch is detected between both MS and target BS, the missing or lack of information may be completed by the serving BS during the handoff process.

The handoff decision is made by the serving BS when only one target BS is involved in this process, so that the serving BS sends a HO command to the MS as acknowledgement, while the decision is made by the mobile station when multiple target BS are involved in this process, so that, the BS informs to the serving BS the target selection through a HO indicator message.

In that way, the HO command facilitates the information to be exchanged with the purpose to complete the HO process as smooth as possible and enable the permission to the mobile user against the target BS. This command mainly indicates when the serving BS should stop the data transmission or not.

The handoff process is finally execute when the HO_Re-entry_mode command is set to 1 and the serving BS negotiate the resources with the target BS, therefore the entry before break (EBB) procedure is triggered.

In traditional single carrier formats, the EBB HO procedure contains the following commands aimed to hold the connection between the MS and serving BS, the commands or message used are HO_Re-entry_Interleaving_Interval and HO_Re-entry_Iteration.

While multicarrier formats, the information is sent to the target BS prior the MS network re-entry process and the connection remains active with the serving BS upon the completion of EBB HO (Ahmadi S. Mobile WiMAX, 2011:201-202).

3.3.2 Handover execution

The mobile network re-entry against the target BS may be performed as soon as the handover command is triggered. So this command, allow or reject network resource allocation to MS. When this HO is triggered by the serving BS, meaning that the serving BS does not assign more resource to the MS, so that, the MS performs the network re-entry with the target BS successfully and the communication with the serving BS or the active cells is immediately cancelled.

Thereby, the handover execution phase decide in a way whether the MS continues or interrupt the communication with the serving BS prior to the HO process with the target BS (Ahmadi S. Mobile WiMAX, 2011:203).

3.3.3 Handover cancellation

Once the handover initiation is initiated, this may be cancelled by the mobile station according to the received signal strength indicator, as long as the signal received remains within an optimum range, so the MS and the current serving BS may resume their normal operation upon a HO cancellation action.

4. WiMAX NETWORK SIMULATION

4.1 OPNET modeler simulator

OPNET modeler 14.5 is the simulator employed in this master thesis work to evaluate the handover performance over a multipath channel model defined as vehicular speed at 120 km/h and as mobile user or Pedestrian A by the international telecommunication union (ITU).

The OPNET Modeler network simulator provide a graphic user interface (GUI), this enables researchers and developers to analyze and evaluate several technologies, devices and protocols over wired and wireless technologies.

OPNET enables users to customized models and evaluate diverse types of scenarios. The modeler is object-oriented and employs a hierarchical approach to model communication networks. The GUI is known as editors to capture the specifications and attributes set over the deployed networks, devices and protocols. The main editors are project, node and process editors (OPNET Modeler online documentation).

Simulation Boundaries

The following features have not been implemented in the OPNET modeler 14.5 simulator; therefore, it becomes a model limitation or boundaries over the WiMAX simulation.

- Frequency division duplex (FDD) mode
- Network-assisted initial ranging during handover
- Base station periodic ranging during network entry
- Individual access service network (ASN) and connectivity service network (CSN) functionalities.

4.2 Simulation layout overview

The simulation involves three (3) model scenarios that lead to the WiMAX handover performance analysis in terms of delay, load, throughput, and data dropped.

The WiMAX network architecture over the scenarios built, follows the WiMAX reference model, thereby, the element defined as WiMAX IP Cloud Ostrobotnia integrates the core network elements known as Access Service network (ASN), Connectivity Service Network (CSN), and simultaneously home + visited network service provider (NSP) are being used in the simulation to measure the package sent and received through the network, so the illustration above introduce the reader a logical representation of the WiMAX Radio Access Network (RAN) employed for every single scenario in analysis in this master thesis.

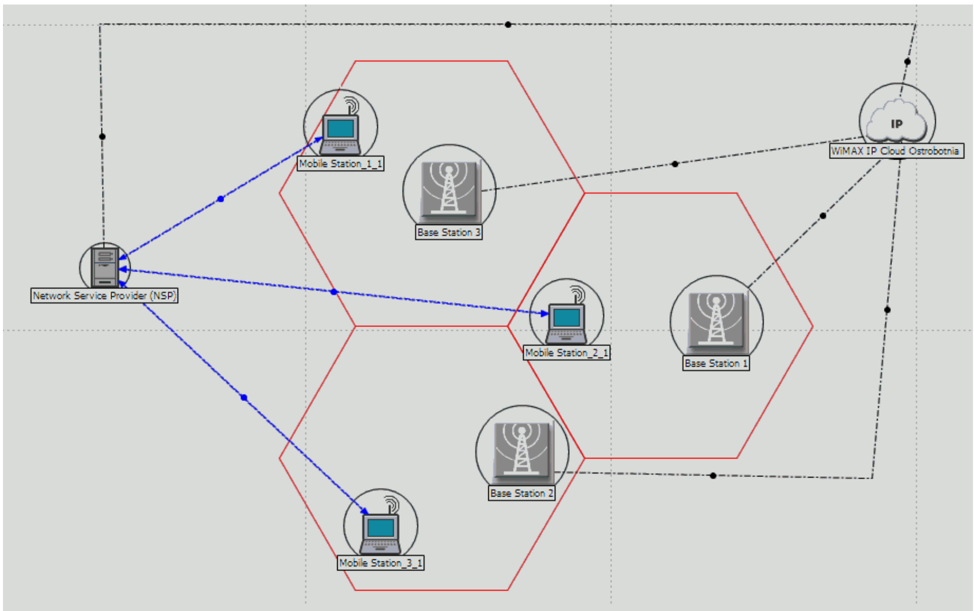

Figure 20. WiMAX Network topology employed to the scenarios.

The Vaasa region maps used as background over the simulation layout are provided by the national land survey of Finland (NLS) body or Maanmittauslaitos in Finnish with the following features:

- Map sheet number: P3411R
- Basic map raster extract from Finnish NLS open data license in TIFF format
- Map resolution 1000 pixels / km – 12000 x 12000 pixels, 12x12 km

- Global position 63º05'43,45" N ; 21º37'01.10"

4.3 Simulation plan

The configuration and parameters considered in the simulation are defined this part

4.3.1 Efficiency mode configuration

As the simulation study requires analyze the handover process over the mobile WiMAX technology, the efficiency mode is adjust as mobility and ranging which comprises the features of "Physical Layer Enabled" with Mobility and Ranging enabled, better known as adaptive modulation and coding technique (AMC).

OPNET Modeler support two types of coding scheme (AMC), name as convolutional turbo coding (default scheme) and convolutional coding. The modulation and coding schemes supports and define in this master thesis are QPSK ½, QPSK 3/4 , 16-QAM 1/2 , 16 QAM 3/4 , 64-QAM 1/2 , 64 QAM 2/3, 64 QAM ¾ and 64 QAM 5/6.

The adaptive modulation and coding (AMC) features for UL and DL profile adjust over the scenarios are based on the following values specified in OPNET simulator 14.5.

Table 3. Adaptive modulation and coding defined by OPNET WiMAX Config panel

Profile configurations for Uplink (UL)			
Profile Set	Mandatory Exit Threshold (dB)	Minimum Entry Threshold (dB)	Modulation and Coding
0	-20	2	QPSK 1/2
1	5	5.9	QPSK 3/4
2	8	8.9	16-QAM 1/2
3	11	11.9	16-QAM 3/4
4	14	14.9	64-QAM 1/2
5	17	17.9	64-QAM 2/3
6	19	19.9	64-QAM 3/4
Profile configurations for Downlink (DL)			
Profile Set	Mandatory Exit Threshold (dB)	Minimum Entry Threshold (dB)	Modulation and Coding
0	0	4	QPSK 1/2
1	5	10	QPSK 3/4
2	12	18	16-QAM 1/2
3	19	24	16-QAM 3/4
4	25	26	64-QAM 1/2
5	27	28	64-QAM 2/3
6	29	30	64-QAM 3/4

4.3.2 WiMAX network elements

Mobile WiMAX network elements employed for every scenario

Table 4. WiMAX Node models (Riverbed OPNET Modeler, Online library)

Node Model	Description
wimax_bs_ethernet4_slip4_router	Fixed base station node model with router functionality. This node has 4 Ethernet interfaces, 4 SLIP interfaces, and one WiMAX interface.
wimax_ethernet_slip_wlan_router	Fixed subscriber station node model with router functionality. This node has one Ethernet interface, one WLAN interface, one SLIP interface, and one WiMAX interface.
wimax_ss_server	Mobile subscriber station node model with server functionality.
wimax_ss_workstation	Mobile subscriber station node model with workstation functionality.
wimax_ss_wlan_router	Mobile subscriber station node model with router functionality. This node has one WiMAX interface and one Wireless LAN interface.
WiMAX_Config	Global configuration object used to configure parameters such as service classes and PHY profiles.

4.3.3 OFDMA configuration

In order to meet the 802.16e standard, the WiMAX system was set according the Wireless OFDMA parameters defined in the table 5.

Time division duplex (TDD) is the duplexing profile supported in OPNET simulator for WiMAX technology and this is in reality the most common profile implemented due the great advantages of asymmetric rates both for uplink and downlink.

Table 5. WiMAX Parameters

OFDMA Parameters	Value
Base Frequency (GHz)	5.8
Bandwidth (MHz)	20
Frame duration (second)	0.005
Symbol duration (microseconds)	100.8
Number of Subcarriers	512
TTG (microseconds)	100.8
RTG (microseconds)	302.4
Duplex Technique	TDD

4.3.4 Handover configuration

The following handover parameters are defined for every single scenario. The scanning interval may be initiated by either the mobile station or the base station with the following values.

Table 6. Mobility parameters

Scanning interval Definitions	**Value**
Scanning Threshold	27 dB
Scan duration (Frames)	4
Interleaving Interval (Frames)	240
Scan Iterations or repetitions (T)	10
T44 (Scan Request Retransmission Timer)	50 milliseconds
Maximum Scan Request Retransmissions	8

The software simulator follows the attributes specified in the table below.

Table 7. Scanning Parameters

Attribute	**Value**
MS Handover Retransmission Timer	30 milliseconds
Maximum Handover Request Retransmissions	6
Handover Threshold Hysteresis (dB)	0.4 dB
Multitarget Handover Threshold Hysteresis (dB)	0 dB
Maximum Handover Attempts per BS	3

4.3.5 Access service network messages

The access service network (ASN) messages supported in OPNET simulator between the mobile station and WiMAX IP Cloud (Backbone) through the ASN-Gateway are defined as follow

Table 8. Handover messages

Message	**Description**
HO_Req	Handover request from serving BS to target BS
HO_Rsp	Handover response from target BS to serving BS
HO_Cnf	Handover confirmation from serving BS to target BS
Data_Path_Reg	Sent from serving BS to ASN gateway to update the current position of a MS

4.4 First scenario

The WiMAX network topology architecture proposed to this scenario carried out 3 base stations located in Vaasa region from Palosaari, Vaasa Kauppatori and Suvilahti area, only 3 cells cover the Vaasa region in this scenario. This scenario invokes a single base station (pedestrian user) along the route defined in figure 21.

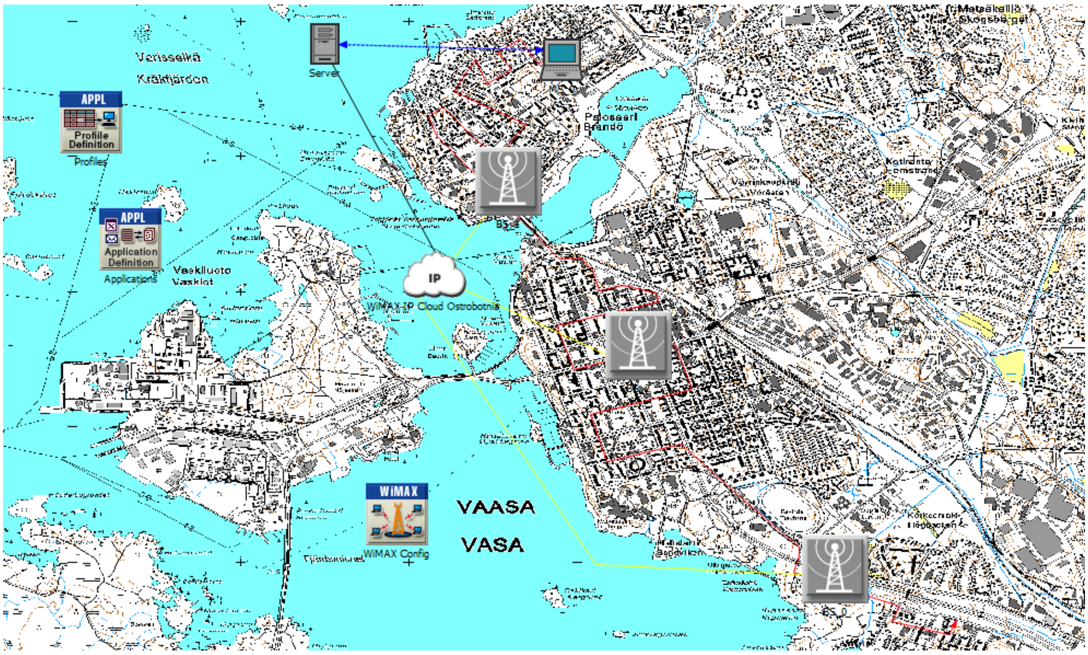

Figure 21. Scenario 1 – WiMAX pedestrian user at 5 km/h.

The MS user walks over the trajectory with an average speed of 5 km/h and a total distance of 11.22 km along the red route in Vaasa region.

The mobile station (MS) trajectories are planned as describe the following table with its global position and distance respectively.

Table 9. Trajectory positioning in scenario 1

Trajectory	X Pos (km)	Y Pos (km)	Distance (km)	Traverse Time	Accum Time
1	25.048478	44.841091	n/a	n/a	00.00s
2	24.888138	44.928335	0.183133	2m11.86s	2m11.86s
3	24.765525	44.756205	0.210569	2m31.61s	4m43.47s
4	24.614616	44.848165	0.177322	2m07.67s	6m51.14s
5	24.708934	44.96842	0.152264	1m49.63s	8m40.77s
6	24.536804	45.06038	0.195775	2m20.96s	11m01.73s
7	24.468423	44.892966	0.180363	2m09.86s	13m11.59s
8	24.315157	45.112255	0.268496	3m13.32s	16m24.90s
9	24.807968	45.33626	0.539779	6m28.64s	22m53.55s
10	24.619332	45.550833	0.28679	3m26.49s	26m20.03s
11	24.466065	45.442368	0.187091	2m14.71s	28m34.74s
12	24.244418	45.218363	0.31394	3m46.04s	32m20.78s
13	24.147742	45.284385	0.117479	1m24.58s	33m45.36s
14	24.201975	45.406999	0.133702	1m36.27s	35m21.63s
15	24.33402	45.541402	0.187707	2m15.15s	37m36.78s
16	25.032208	46.243834	0.986608	11m50.36s	49m27.13s
17	25.172271	46.238647	0.140199	1m40.94s	51m08.08s
18	25.25527	46.319053	0.115109	1m22.88s	52m30.96s
19	25.304551	46.461709	0.150567	1m48.41s	54m19.36s
20	25.467957	46.422803	0.168272	2m01.16s	56m20.52s
21	25.693613	46.477271	0.231716	2m46.84s	59m07.35s
22	25.701394	46.53174	0.054962	39.57s	59m46.93s
23	25.011459	46.697739	0.710894	8m31.84s	1h08m18.77s
24	25.128177	46.99602	0.319466	3m50.02s	1h12m08.79s
25	25.812925	46.819645	0.708447	8m30.08s	1h20m38.87s
26	25.932237	47.130894	0.332448	3m59.36s	1h24m38.23s
27	25.244895	47.296894	0.708383	8m30.04s	1h33m08.27s
28	25.356426	47.618518	0.339595	4m04.51s	1h37m12.77s
29	25.859612	47.496612	0.518683	6m13.45s	1h43m26.23s
30	26.220143	47.82083	0.482927	5m47.71s	1h49m13.93s
31	26.658485	48.194329	0.57356	6m52.96s	1h56m06.90s
32	26.658485	48.246204	0.051877	37.35s	1h56m44.25s
33	26.616985	48.365516	0.126651	1m31.19s	1h58m15.44s
34	27.338046	48.591171	0.753745	9m02.70s	2h07m18.13s
35	27.286171	48.694921	0.116391	1m23.80s	2h08m41.94s
36	27.672954	48.782348	0.395815	4m44.99s	2h13m26.92s
37	27.724198	48.688646	0.107187	1m17.17s	2h14m44.10s

4.5 Second scenario

The second scenario aims to measure the global and MS throughput, base station delay against the MS handover delay, and the WiMAX frame usage (%) ratio by every single base station.

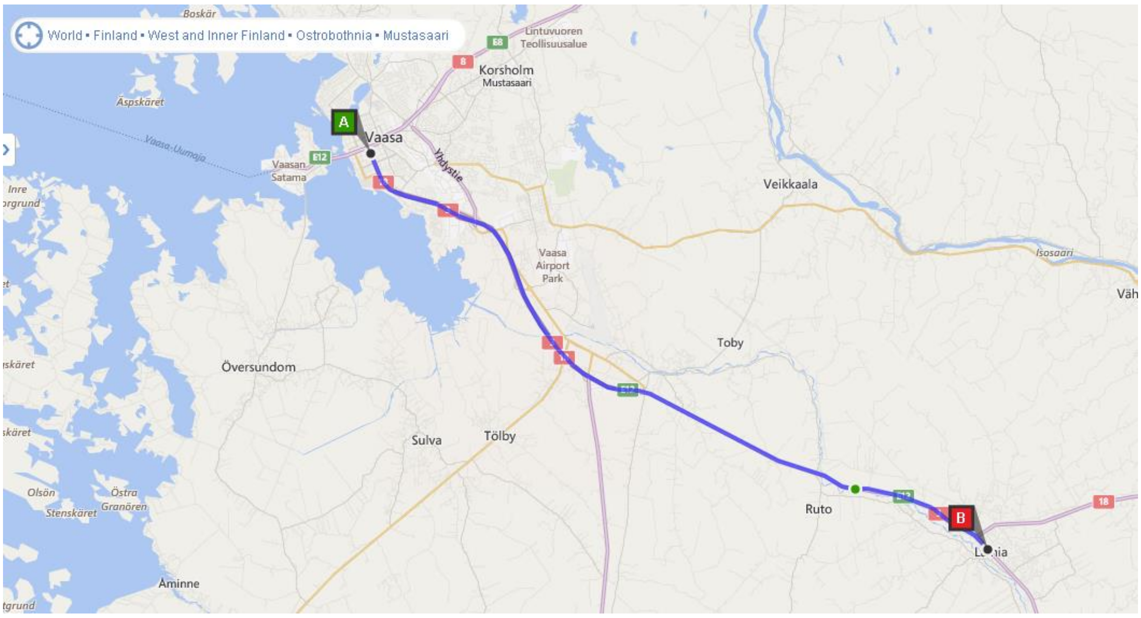

Figure 22. Route between Vaasa and Laihia town by Bing Maps (2014)

The trajectory involves 5 base stations placed across the highway E12, E3 and E18 that connect both municipalities. Hence, the mobile station moves through the trajectory specify in the next table.

Table 10. Mobile Speed trajectory

Trajectory	Distance (km)	Traverse Time	Ground Speed	Accum Time
1	0	0	0	00.00s
2	1.250092	37.46s	120.137021	37.46s
3	3.055677	1m31.58s	120.118318	2m09.04s
4	3.811759	1m54.24s	120.118441	4m03.28s
5	1.753245	52.53s	120.153843	4m55.81s
6	1.584706	47.50s	120.104057	5m43.31s
7	5.31619	2m39.31s	120.132354	8m22.62s
8	2.543393	1m16.25s	120.081529	9m38.87s
9	2.933088	1m27.88s	120.153816	11m06.75s

The mobile station moves at 120 km/h during 22.25 km between Vaasa Kauppatori to Laihia town in Finland.

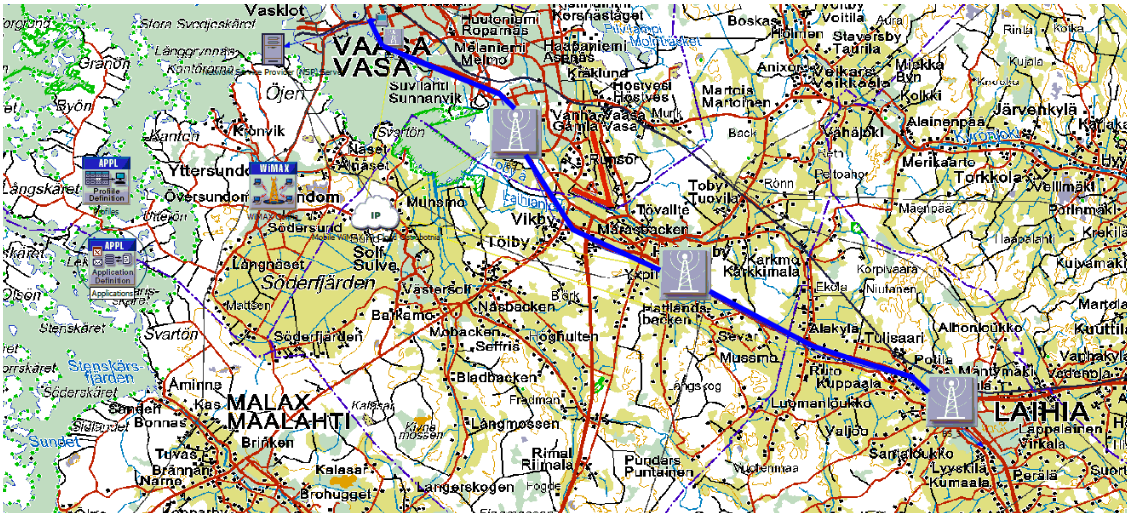

Figure 23. Scenario 2 – Mobile Station at vehicular speed (120 km/h)

4.6 Third scenario

This last scenario is bound to measure and evaluate the longest distance reachable by a MS and conclude the most efficient implementation. The distance between point A and point B is about 50 km, equivalent from Vaasa to area until Ylistaro/ Seinäjoki. The measurements involve three (3) cases within pedestrian and vehicular speed. The first and second case, test the performance in those 50km distance, while the last case compare the results obtained in the first two cases and conclude which is the most suitable and optimal network implementation in terms of distance.

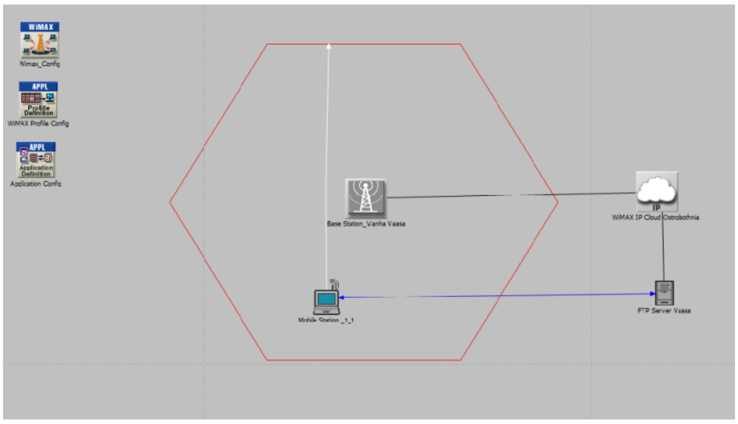

Figure 24. Scenario 3 – Single Base station analysis

5. TEST RESULTS AND ANALYSIS

5.1 Scenario 1– Results

This scenario analyzed the handover performance of WiMAX Technology when the mobile station (pedestrian user) moves alongside with the coverage area provided by three cells or base stations and when the handover process occurs. Thereby, the target of this scenario is to evaluate how the throughput and delay is affected during handoff process with a single user that supports WiMAX IEEE802.16e.

The global throughput result obtained in the following figures, indicates that the handover process has occurred smoothly and this has not affected the total data traffic, beyond the external interference and signal propagation obstacles encountered by MS.

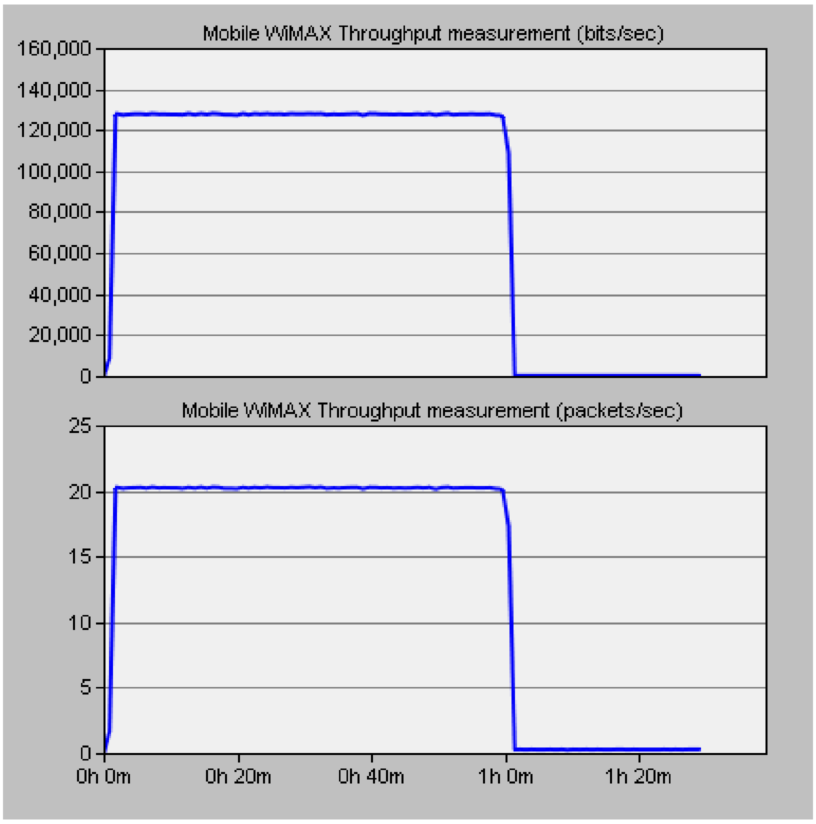

Figure 25. Global WiMAX Throughput

The figure above symbolize the global throughput sent from the WiMAX layer to higher layer in the whole WiMAX elements connected to the network designed.

As expected, the mobile station experienced a successful throughput rate during the simulation time, the result response to the short-distance between the mobile station and the BS_1, BS_2 and BS_0.

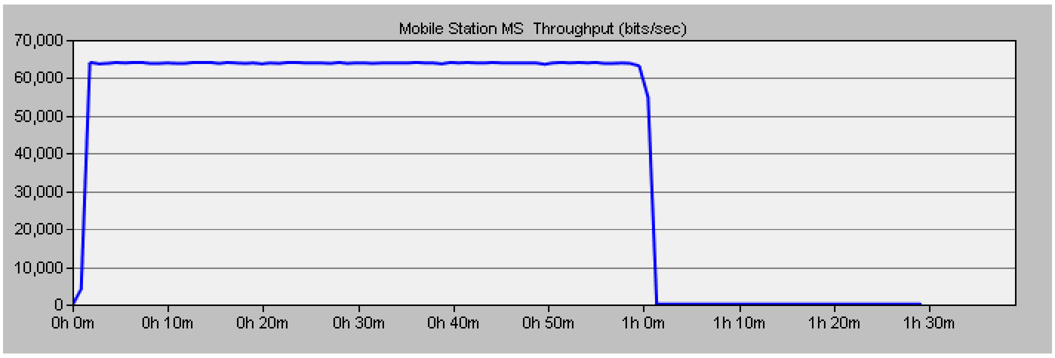

Figure 26. Mobile station throughput (bits/sec).

During the simulation study, the WiMAX PHY drop packet rate indicator was enabled to measure the mobile WiMAX network performance, since the initial movement until the last mile, in consequence, the figure below shows a successful performance, since the packet loss rate in downlink and uplink result is 0%.

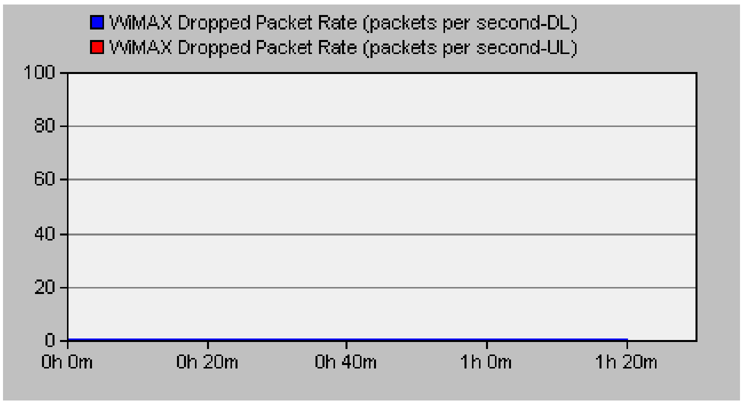

Figure 27. WiMAX Packet drop rate in DL and UL.

The following figure represents the average end-to-end delay of all the packets received by all the WiMAX MACs linked to the IP Cloud and forward to the higher layer.

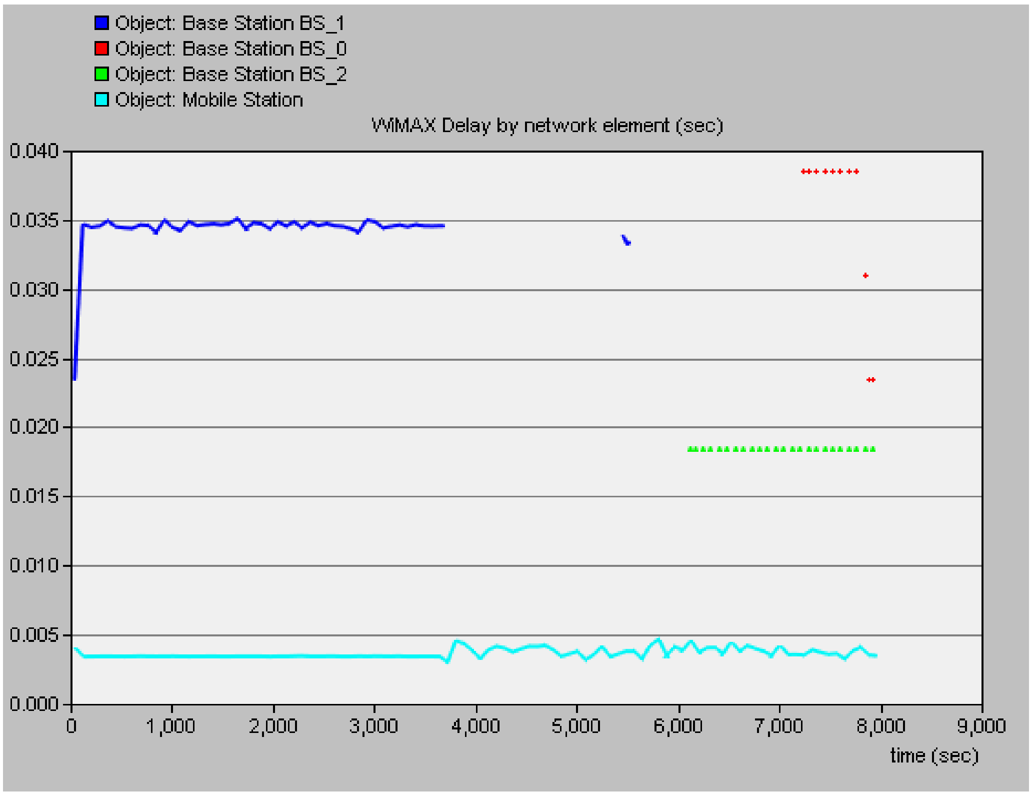

Figure 28. WiMAX Delay by network element

As the mobile station moves along the coverage area, the handover process is triggered along the route designed. Thereby, the delay experienced by every node varied in time.

As expected, since the coverage range defined to BS_1 and BS_2 is wider, the average delay result for these two networks elements is greater than the delay experienced by BS_0 which coverage is oriented to highway and open areas from Vaasa City center to Suvilahti area.

The delay parameter defined in this master thesis is address to measure the time when the mobile user attached and detached from every single BS, better known as handover process, by this reason, the minimum and maximum values result at every single base station remains as the average value.

The minimum, average and maximum number of delay experienced by all the elements connected to the WIMAX Network may be observed in the following table.

Table 11. Delay result experienced by objects (sec)

Rank	Object Name	Minimum	Average	Maximum
1	Base Station 1	0.023528	0.034334	0.03509
2	Base Station 2	0.023528	0.031028	0.038528
3	Base Station 0	0.018528	0.018528	0.018528
4	Mobile Station	0.003024	0.003564	0.004595
	Total	0.095934	0.096883	0.098058

To analyze in detail the handover delay experienced by the mobile station (MS), the following graph was printed out to see the accurate variation during the simulation time.

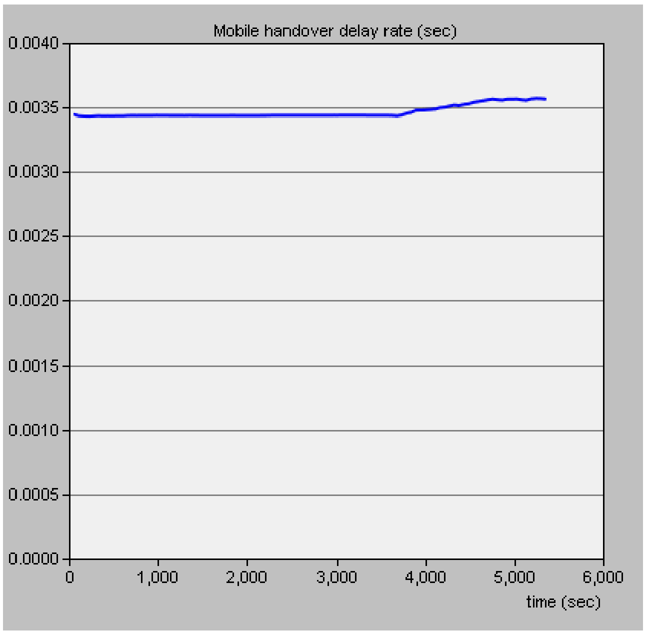

Figure 29. Mobile Station HO delay (sec)

Since the mobile trajectory is diverse at every single base station, the MS experienced the lowest delay during the first 60 minutes simulation time, whereas the distance from BS_1 and BS_2 is shorter unlike the coverage area provided by the BS_0 which network coverage is wider and oriented to highways and open areas. In spite this tiny HO delay variation, the HO delay result obtained meet optimal value specified by the WiMAX Networking Group which HO delay time must below 50 milliseconds.

Table 12. MS Handover delay variation

Object Name	Minimum	Average	Maximum
Mobile Station	0.003024	0.003564	0.004595

The last representation in this case belongs to the serving BS ID for the mobile station node.

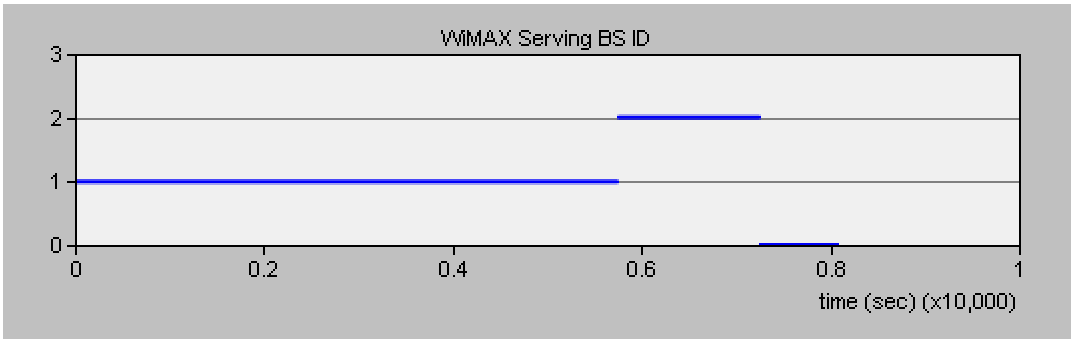

Figure 30. Mobile WiMAX Serving BS ID.

The blue signal represent the serving BS connected to the mobile user versus simulation time, so that, the previous figure demonstrate how the mobile station maintains its longest connection period with BS_1 and the shortest connection with BS_2 and BS_0 respectively. This result satisfies the mobile trajectory defined over this scenario.

5.2 Scenario 2 – Results

Since this scenario involved five base stations and the mobile station is moving at vehicular speed up to 120 km/h, the throughput rate is more affected unlike scenario 1 whereas the latency is shorter and the connection is more stable. The average throughput is shown in figure 31.

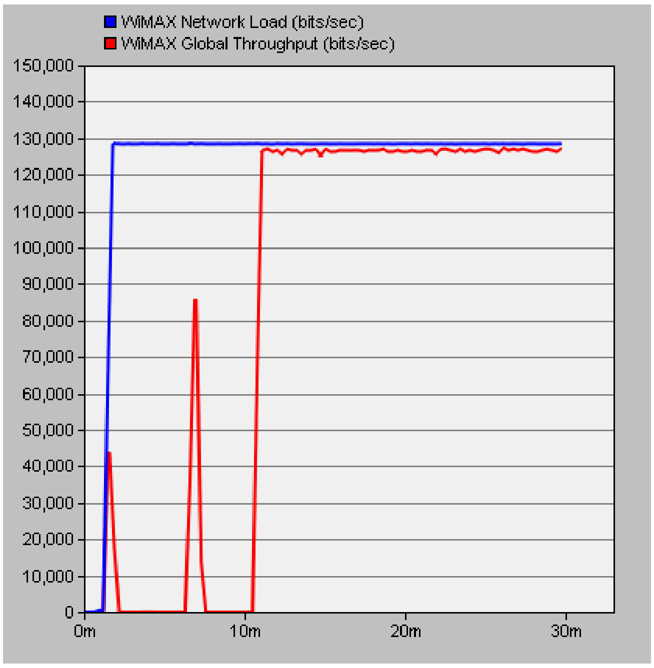

Figure 31. Global WiMAX Through versus Network Load.

As expected, the average throughput obtained upon the simulation of scenario 2 is lower compare to the average scenario 1.

In spite of the lower global throughput experienced in the network, the MS throughput result is very close to the MS throughput obtained in scenario 1.

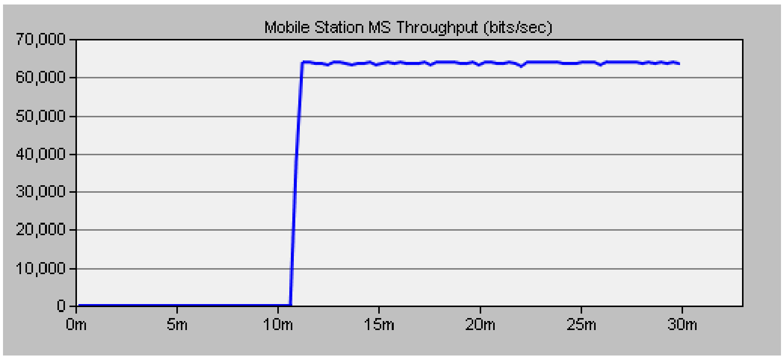

Figure 32. Scenario 2 – MS throughput (bits/second).

Yet, the mobile equipment experienced latency within the initial minutes in the simulation time done for 1800 seconds and this behavior response the WiMAX packet dropped rate presented in figure 33, whereas the BS_0 obtained the highest dropped rate with 3 packets dropped.

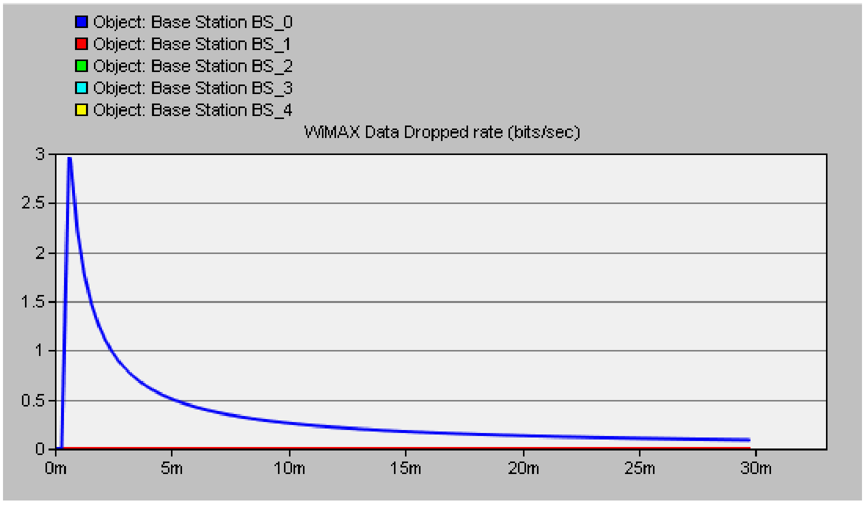

Figure 33. Scenario 2 – Packet dropped rate in bits per second.

The WiMAX overall delay result obtained in this scenario is plot in figure 34. As the number of base station increased, so does the overall delay and the HO delay experienced by the MS illustrated in the right side.

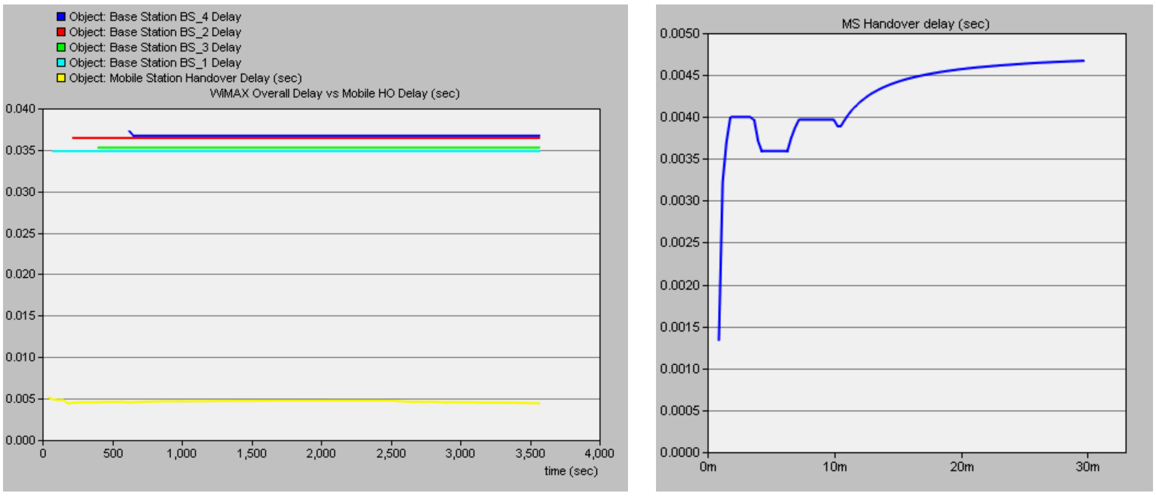

Figure 34. WiMAX network overall delay vs mobile HO delay.

Table 13 represents the delay result obtained by all the network elements connect to the WiMAX network proposed. As may be seen in the following table, both BS_4 and BS_2 experienced the highest average delay value with 36 milliseconds, followed by BS_3 and BS_1 with 35 milliseconds and 34 milliseconds respectively, which is roughly the same among all base stations.

The maximum HO delay obtained exceed the time lapse

Table 13. Delay Results by objects

Object Name	Minimum	Average	Maximum
BS_4	0.036002	0.036713	0.037424
BS_2	0.03644	0.03644	0.03644
BS_3	0.035276	0.035276	0.035276
BS_1	0.034843	0.034843	0.034843
MS_0	0.001244	0.004445	0.006606

Since the quality of the signal received by the MS is subject to interference, fading, degradation and noise, the adaptive modulation and coding (AMC) scheme was introduced in mobile WiMAX technology in order to mitigate these factors, and allow an efficient bandwidth usage between the BS and MS. Today, the bandwidth is the most valuable resource for the wireless provider; thereby, the TDD frame structure of mobile WiMAX is employed to carry the data in terms of data burst as has been defined and illustrated in chapter 2.

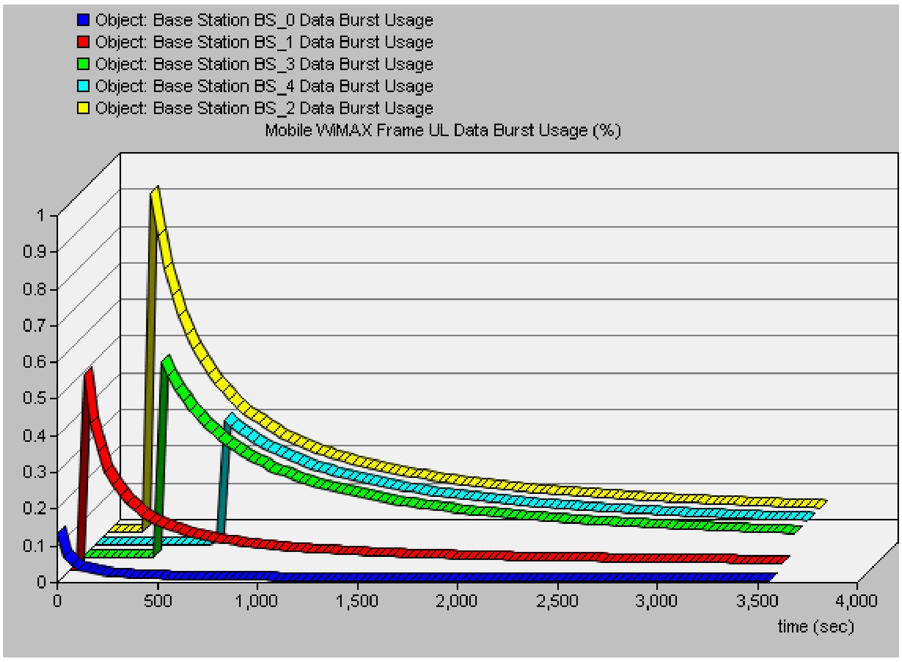

Figure 35. WiMAX Network Frame UL data burst usage (%)

The figure 35 represents the frame UL data burst usage, whereas the maximum data usage is reached by base station BS_2, BS_4 and BS_3 above 60% usage rate, while BS_1 and BS_0 experience less than 20% data usage rate.

In detail, The UL data burst usage results may be observed in the table below.

Table 14. Frame UL data burst usage values

Object Name	Minimum	Average	Maximum
BS_2	0	0.064334	6.4334
BS_4	0	0.06374	6.2478
BS_3	0	0.063642	6.3642
BS_1	0	0.015939	1.5939
BS_0	0	0.001322	0.1322

5.3 Scenario 3 – Results

The last scenario aims to evaluate the longest distance and optimum implementation reachable by the MS within the coverage area provided by a single cell, so the three different cases has been designed to analyzed the network performance and signal behavior.

- Case I: Mobility at pedestrian Speed (Av. 5km/ h) and a total distance of 47.64 km
- Case II : Mobility at vehicular speed (Above 90 km/h) and trajectory of 47.64 km
- Case III: Mobility at vehicular speed with a total coverage range of 10 km.

The simulation time applied in this case was 2,000 seconds.

5.3.1 Case I – Pedestrian Speed

Figure 36 represents the global throughput within pedestrian speed, as shown the average throughput is alike compare to the throughput result obtained in scenario 1 and scenario 2 respectively.

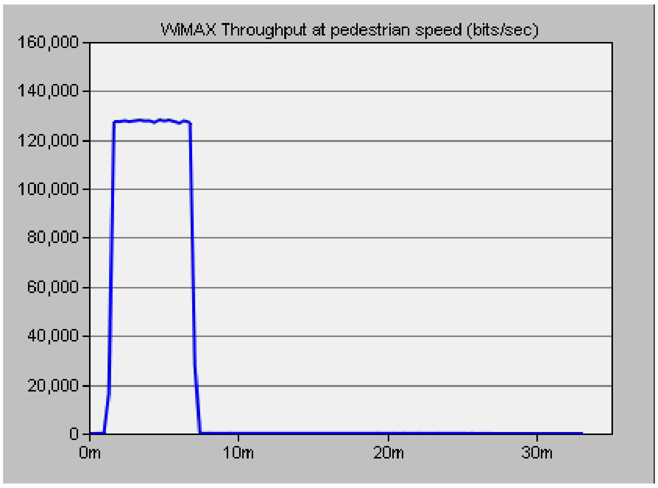

Figure 36. Global WiMAX throughput within pedestrian speed (10 km/h).

Figure 37 plots a comparison between the global the delay experienced by the single BS and the MS handover delay in seconds within pedestrian speed.

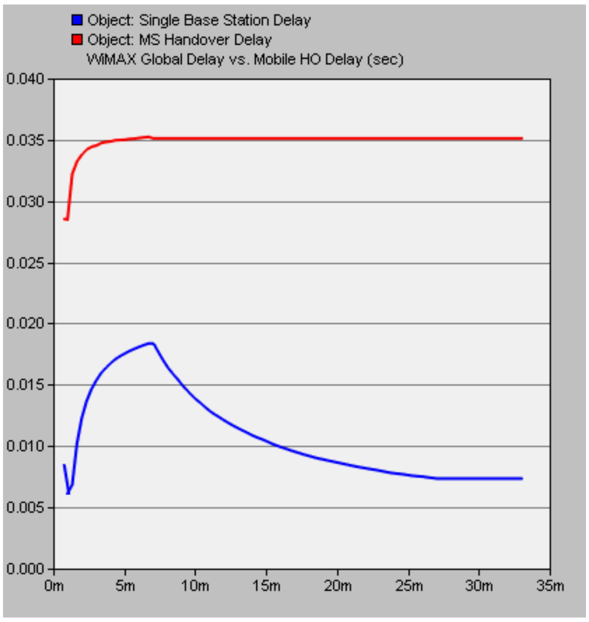

Figure 37. WiMAX global delay vs MS handover delay (sec)

Due the extend mobile trajectory, this case experienced a MS handover delay much higher than the single base station delay, whereas the maximum MS HO delay exceeds the global delay by 15 milliseconds.

5.3.2 Case 2 – Mobility at Vehicular speed

The result obtained in this scenario is very remarkable, in a wide coverage area as the distance between the BS and MS increased, the global throughput is affected dramatically within vehicular speed, and this result may be observed in figure 38.

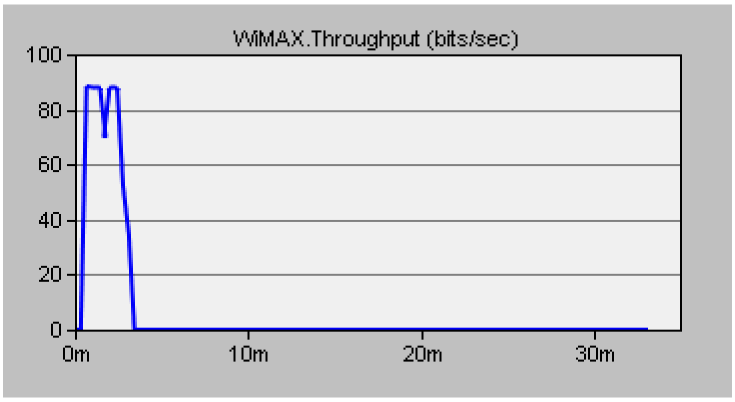

Figure 38. Global WiMAX throughput at vehicular speed (90 km/h).

The maximum throughput rate barely reached the 100 bits per second.

This second case shows similar result compare to the delay relation in previous scenarios 1 and scenario 2, whereas, the mobile HO delay is lower than the global HO delay by 25 milliseconds.

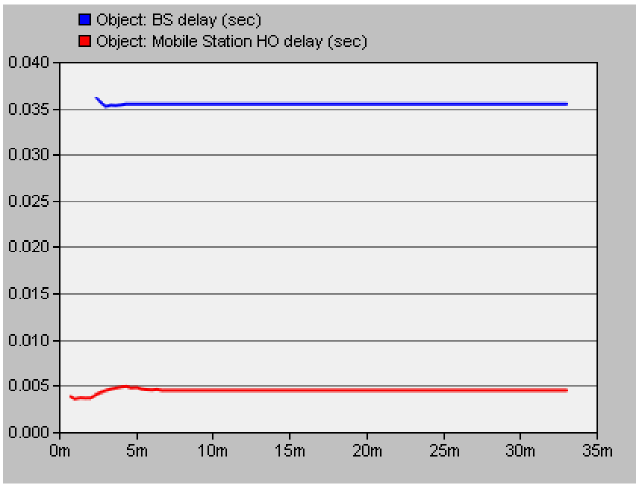

Figure 39. Global delay vs MS handover delay in seconds.

In both cases 1 and case 2, the mobile users reached successfully the total distance of 47.64 km proposed in this scenario but the throughput rate has a notable degradation over vehicular speed.

5.3.3 Case 3 – Mobility at vehicular speed comparison

This case was bound to evaluate which mobile network implementation and base station location may achieve the optimum performance in terms of mobility and network coverage. The network arrangement placed a new base station in the middle of the trajectory with a total distance of 10.56 km. This time the ground speed average was 89.98 km/h.

As a result, higher rates were experienced by the mobile station unlike the throughput result experienced in case 2. Then, the graphical representation is shown below

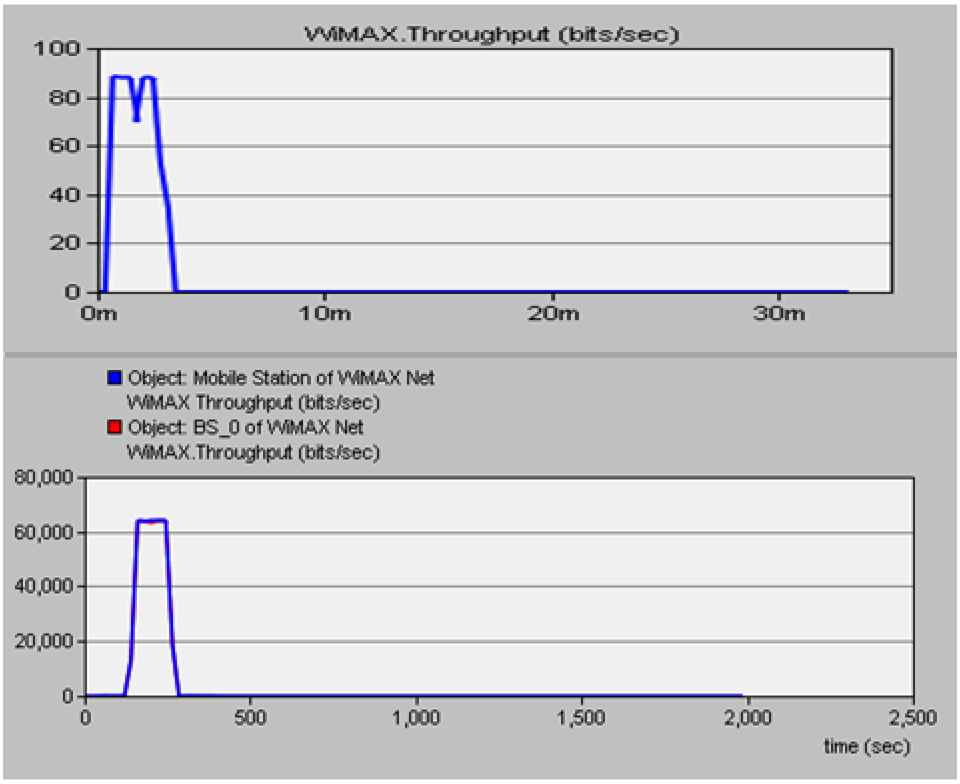

Figure 40. Case 2 v. case 3 Throughput comparison (bits/sec)

When thousands of cells are implemented and integrated within a mobile cluster, the distance between them are normally alike to provide an optimum network coverage, capacity and performance. To achieve this, the network coverage by one single base station tends to be smaller. In reality, an optimum coverage performance is achieved within 5 – 7 km range distance in rural areas and much less in urban area. This is approached by an efficient radio network planning and mobility management phase.

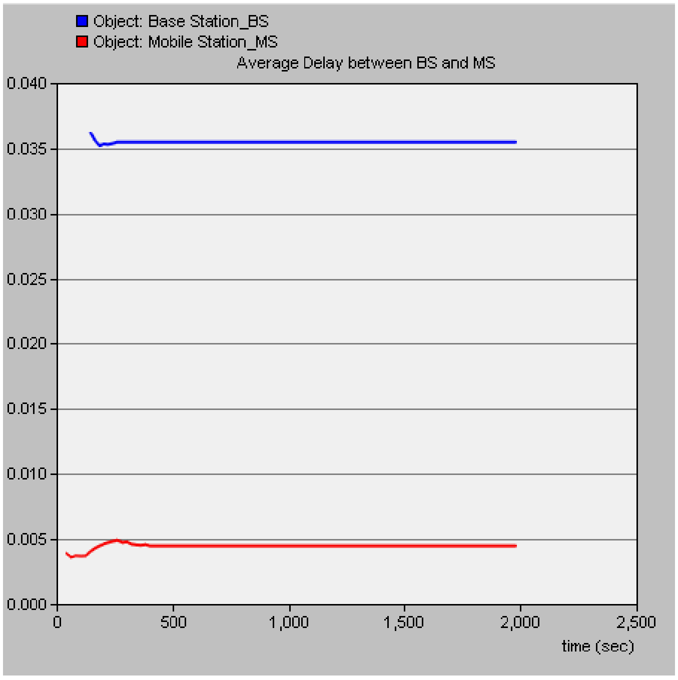

Figure 41. Average delay between BS and MS.

Again, the average delay experienced by every single element is alike to previous scenarios with a tiny difference between them.

The results has indicated that the average throughout and delay result are affected directly by the distance and mobility speed, in consequence, a high quality of service and quality of experience may be achieved if and only if, an efficient network plan and network implementation is accomplished.

6. CONCLUSIONS AND FUTURE WORK

Upon the orthogonal frequency division multiple access (OFDMA) and MIMO technology incorporation to the original WiMAX standard, wireless mobility and more efficient data rate are achieved under IEEE 802.16e-2005 standard.

This master thesis has analyzed the mobile performance of three scenarios deployed using OPNET simulator in terms of packet loss, call drop, average throughput, and handover delay. The key performance indicators (KPI) measured are today the most essential metrics employed by mobile operators, network and internet service provider aimed to increase the customer satisfaction and keep an optimum mobile network flow.

The average handover delay and network latency obtained in all scenarios presented, satisfied the mobile WiMAX forum specifications, from which the HO delay or latency should not exceed the 50ms time lapse to avoid call failures and packet drop.

While the throughput variation depends upon the distance and mobility speed, from the results obtained, the drastic throughput degradation in scenario 3 - case 2 is due high speed mobility above 90 km/h along with a large and wide coverage range deployed up 50 km provided by a single base station, nevertheless, a successful result was achieved in case 3 with the same WiMAX topology, but in this case the coverage range was adjusted to 10km, so here the average throughput overcame the expectations when this achieved similarities rates to scenario 1 and scenario 2.

The results obtained from simulation, indicated how the parameters evaluated are affected by the distance, number of station and mobility speed. For instance, as the mobile speed reduces, the throughput rate is raised proportionally. This behavior has been demonstrated in different cases presented in scenario 3. From the results, case 3 achieved successful rates within 10 km coverage range and ground vehicular speed average of 90 kmph. In consequence, the mobile WiMAX network performance is affected at vehicular speed mobility above 90 km/h when the coverage range exceeds 10 km distance.

The overall packet loss rate result from the simulation scenarios was less than 1%.

The first scenario is theoretically the most common wireless deployment in urban areas, however the WiMAX topology to be implemented and considered are based on wireless broadband provider target and customer needs, whether rural areas, urban areas or simply a specific region. For instance, few cells might be deploy in Lapland, north Finland to provide internet access to the local communities while South Finland requires more cells in order to mitigate external interference, path loss and noise.

In general, the networks parameters result obtained, indicates that the handover process has occurred in a smooth way and this has not affected the total network performance result.

A potential future work would include two case study approached, first to evaluate the mobile WiMAX and Wi-Fi technology integration in urban scenarios and the second study to analyze long-term evolution (LTE) technology and mobile WiMAX Networks integration.

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