REDUCTION OF HANDOVER DELAY IN WIMAX FOR HIGH MOBILITY

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ABSTRACT

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In emerging technologies, WiMAX is identified as a cheaper replacement to mobile and wireless technologies such as 3G, 4G or any other future generation technologies and can provide high-speed data transfer over long distances and at suitable Quality of Service (QoS) at high mobility. WiMAX requires support and capacity for high mobility to avoid the loss of quality of service. The goal of faster mobility can be achieved, but WiMAX needs the support of an effective handover mechanism to ensure continuous and without any interruption in data transfer. This thesis focusses to solve the handover problem in mobile WiMAX (IEEE 802.16e and IEEE802.16m) and to find and identify the factors which directly affect the handover process. There is a range of factors which can affect the mobility process in Mobile WiMAX. The acceptable handover delay is 50 ms as per IEEE WiMAX standards (Radio-Electronics.com, 2012). This study has identified that there is a total of 16 factors which have direct and indirect effect but after detailed simulation and analysis, it has been found out that only 7 factors could be used to improve handover delay in WiMAX and that's why the initial RIVERBED simulations tried to identify the extent of these factors which

directly affect the handover delay in WiMAX. The following parameters that are directly linked to the handover success are identified are as follows:

a) Link goes down faster

b) Scan iteration

c) Interleaving Interval

d) Timeout Parameter

e) Frame Duration

f) Client Timeout

g) Scan Duration

The simulation experiments on individual factors has identified that these factors result in a minimum handover delay at specific values which are called best performing values. When these best performing values of the 7 factors were applied to single WiMAX experiment, the improvement was identified, which showed that there have been better handover delay results due to the better-received signal strength, better average delay per Second and the throughput was drastically improved. There was further need to improve the handover decisions and therefor handover algorithm was used for this purpose. The handover algorithm used was a dual trigger algorithm which improved the handover delay, but resulted in packet loss and consequently resulted in retransmissions. To solve to problem of handover delay without downgrading the WiMAX signal, a new algorithm was suggested and tested which has shown results in lowering the handover delay and increasing the signal level. The handover improvement was done in stages and therefore there was a gradual improvement in handover delay in each individual stage. The overall problem

has been divided into stages considering that the solution is dependent on many factors. The development of the WiMAX model is the main issue in this research. Different types of scenarios were adopted on RIVERBED simulations to produce significant data for analysis and validation.

Key Words: WiMAX, Mobile Broadband, Handover Delay, Handover Algorithm.

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2G	Second Generation
3G	Third Generation
4G	Fourth Generation
AAS	Adaptive Antenna System
ACP	Automatic Cell Planning
AFP	Automatic Frequency Planning
AMC	Adaptive Modulation and Coding
BER	Bit Error Rate
BLER	Block Error Rate
BS	Base Station
CapEX	Capital Expenditure
CCI	Co-Channel Interference
CDMA	Code Division Multiple Access
CP	cyclic prefix
CSI	Channel State Information
DL	Downlink
DL FUSC	DL Fully Used Subcarriers

DL PUSC	DL Partially Used Subcarriers
DOCSIS	Data Over Cable Service Interface Specification
DSL	Digital Subscriber Line
EIRP	Effective Isotropic Radiated Power
EMC	Electromagnetic Compatibility
EVDO	Evolution-Data Optimized
FDD	Frequency Division Duplex
FD-TDMA	Frequency-Division Time-Division-Multiple-Access
GSM	Global System for Mobile Communications
HARQ	Hybrid Automatic Repeat Request
HC	Hill Climbing
HSDPA	High-Speed Downlink Packet Access
HSPA	High-Speed Packet Access
HSUPA	High-Speed Uplink Packet Access
ICI	Inter-Cell Interference
IEEE	Institute of Electrical and Electronics Engineers
IFFT	Inverse Fast Fourier Transform
ISI	Inter-Symbol Interference

KPI	Key Performance Indicators
LOS	Line-of-Sight
LTE	Long Term Evolution (4G)
MAC	Media Access Control
MIMO	Multiple in and multiple out
NLOS	Non-Line-of-Sight
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
OpEX	Operating Expenditure
PermBase	Permutation Base
PHY	Physical layer
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RF	Radio Frequency
RPD	Rapid Pipeline Development
RTP	Reception Test Point
SA	Simulated Annealing

SINR	Signal to Interference-plus-Noise Ratio
SNR	Signal to Noise Ratio
SOFDMA	Scalable OFDMA
TDD	Time Division Duplex
UL	Uplink
UMTS	Universal Mobile Telecommunications System
WCDMA	Wideband Code Division Multiple Access
WiMAX	Worldwide Interoperability for Microwave Access
Wi-Fi	Wireless Fidelity

CHAPTER 1: INTRODUCTION

WiMAX, which is also called as worldwide interoperability Microwave access. The WiMAX Standard IEEE 802.16 is accepted a standard for WiMAX networks. Discussing WiMAX mobility and performance the most important factor involving the performance of WiMAX network is handover delay time. As there is increasing demand for mobile services such as such, as Internet TV, video streaming, video conferencing, VoIP, etc. These applications, demand for stable and reliable mobile network which can provide efficient access to mobile services.

WiMAX and Wi-Fi are both based on wireless technology, which is a protocol based and they provide higher data rate to access the internet but that's the only similar thing between them. Wi-Fi is mainly set up for wireless connectivity on shorter distances, especially indoor and which is mainly used in homes and offices. There has been some work done to make it connected to city network, which requires lots of devices. The other most important difference between WiMAX and Wi-Fi is Wi-Fi works mostly on unlicensed band. While WiMAX works in the licensed band which is mainly 2.5MHZ.

This increasing demand is driving the development towards more stable, reliable next generation (NGN) wireless networks. These NGN network systems are expected to facilitate a large number of mobile applications where at the network level NGNs are able to provide high-speed broadband connection together with Quality of Service (QoS) to be able to share a bandwidth connection with multiple services for different requirements.

NGNs systems such as Mobile WiMAX, which promises to provide QoS which is required by these new mobile services and applications. Due to it's the efficiency of mobile WiMAX demand for WiMAX base networks is increasing, according to Maravedis 4G Counts Quarterly Report network, the number of subscribers has crossed 17.25 million at the end of March 2011.This report also suggests that it will increase at a very high rate.

As WiMAX is becoming in demand, but there are some limitations which have to be solved if WiMAX is supposed to provide the efficiency which WiMAX promises. These limitations provide key research challenges and one of research challenges is WiMAX Mobility management and which involves steps such as Location Management and Handover Management. When the connection is established and the user location management is used by the system to identify the user and then enables the connection with that user while Handover management helps the mobile user communication from one base station (BS) to next one. The handover management is very important for WiMAX signal performance especially the time where the mobile station disconnect from one BS and connect to next BS. This time is called handover delay and the minimal amount of this time would result in more efficient WiMAX signal.

The Aim of this research to create the most efficient WiMAX Network by reducing Handover delay to a minimum by identifying the mechanisms and handover algorithms which will reduce the handover delay, ensure the highest Quality of service (QoS) and Signal throughput. Which can make the WiMAX signal and the overall network performance more predictable. This research should make mobile WiMAX as an alternative to any Next-generation 4G network, which will make WiMAX cheapest and more reliable to implement and provide high data rates

1.1 Motivation

There is increased development in the mobile services Sector and lots of mobile applications are currently providing services which in the past few years were not even possible, but with the new demand and dependence on mobile services there has been an increased requirement to provide stable and cost-effective data network which makes research in this field very attractive and challenging. In order to start research in this field, the most important steps were to understand and investigate the standards, technologies and routing mechanisms to keep an eye on new changes in these Sectors. The topic of wireless technology and the mobility management has attracted many researchers to improve common impairments due to terrain effects and noise limitations. WiMAX offers infrastructure solutions with wideband, high mobility and high quality of service (QoS). When WiMAX mobility issues are resolved it has the capability to offer an entire package with affordable bandwidth wireless network, which can be used not only for Internet services but also for streaming multimedia applications.

WiMAX mobility and infrastructure, including learning to design, plan and integrate with other networks is very attractive subject to research. The use of RIVERBED simulation tool in this research makes it easier to deploy and to simulate large scale WiMAX communication network, which help in achieving the goal of reducing the handover delay and increasing the mobility in Mobile WiMAX in order to provide high bandwidth and higher quality of service at lower cost compared to other technologies.

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1.2 Research Questions

In this dissertation, the main research problem can be described as keeping a stable WiMAX network connection while moving at various speeds. The other research problem is to ensure higher QoS and lower packet loss while providing high mobility in WiMAX.

To make sure the aforementioned problems are solved properly, there is need to have proper classification and precise modelling of an existing solution to mobility. In the beginning, there is a need of well-investigated anthology of mobility issues and problems in WiMAX and which should contribute to detailed understanding of the Subject. Another Aim of this study would be studying WiMAX behaviour under different mobility conditions. The Third Aim would identify the limitations when it comes to WiMAX and its mobility and other associated problems so that the suitable solutions could be found. The fourth target or aim of this dissertation has been to apply different scenarios through alternative approaches.

In order to properly analyse the problem research questions were addressed and this Section states the aim of each of every specific question and these questions are considered to be the prospective contribution of this thesis. Each question would represent a contribution to the current state of research. While studying WIMAX the first two topics which needed to be investigated are WiMAX technology and its background while the other topic structure WiMAX Network system.

To complete this research it is very important to understand the capabilities of WiMAX including pros and cons of this technology. These topics will provide a basic understanding of the aims and objectives of this study and these are covered in chapter 2. As WiMAX is also termed is worldwide interoperability Microwave access research reveals that WiMAX is considered as the main alternative to 3G and even 4G networks due to its cheap implementation cost and higher bandwidth. The detailed understanding of different versions of WiMAX standards which were developed with time. The first WiMAX standard developed in 2001 which was termed IEEE 802.16.2001 and this standard has covered stationary connections only as the WiMAX was being accepted as an alternative to other broadband technologies which resulted in more research in field of WiMAX. Which resulted in the development of standards such as IEEE 802.16-2004 and later on with IEEE 802.16-2005 which is also termed as IEEE 802.16e and the latest WiMAX standard IEEE 802.16M and both these standards are providing promising solutions for wireless technologies and these standards made WiMAX as mobile technology.

The Research questions are as follows

1.2.1 Research Questions

Research Question 1

- What are the different types of handover delay that affect mobility in mobile WiMAX standards such as IEEE 802.16e and IEEE 802.16M.
- How to improve the handover delay in WiMAX for high mobility.

As there is a need of deeper understanding of how WiMAX works and how to develop a working WiMAX model and to understand the handover in detail and its types, it is very imperative to raise this question and to find a solution to it.

Research Question 2

- What are the WiMAX physical parameters including the effect of speed on mobile WiMAX.

- How do we optimize mobile WIMAX handover delay while reducing the negative effects optimization on bandwidth, delay and packet loss probability and Improve QoS.

In this study, there is a total of 6 main experiments with a number of sub-experiments which are detailed in Chapter 6. The aim is this research is to reduce the handover delay in WiMAX ensuring minimum handover times and maximum mobility. This research question helps in achieving the aim of reducing handover delay in WiMAX and understanding their effect. The research questions concentrate mainly on reducing handover delay in WiMAX. The Chapter 6 provides a detailed analysis of simulation experiments results on both WiMAX mobile standards IEEE 802.16e and IEEE 802.16m and which tries to provide a systematic and detailed answer to these questions where each experiment is a vehicle towards the goal of reducing handover delay in WiMAX and ensuring Mobile WiMAX with maximum mobility. In this study, there is a total of 6 main experiments with a number of sub experiments which are detailed in Chapter 6.

1.3 Objectives

The objectives of this research are:

- Investigate, review and understand handover problems as reflected in the literature and Capture, recognize and analyse the process of handover delay in WiMAX.
- Design the WiMAX simulation Model and Choose a simulation tool to run the simulation experiments
- Develop simulation scenarios to understand and resolve the problem of handover delay.
- Test the effect of WiMAX signal physical factors on Handover delay and Develop simulation scenarios to understand and resolve the problem of handover delay.
- Understand the effect of speed and other factors on handover delay in WiMAX

- Choose a Handover algorithm that is best for improving the handover decisions and Improve handover decision times.
- Develop analytical model for new handover algorithm
- Test the chosen handover algorithm on latest mobile standards, WiMAX (IEEE 802.16e) and WiMAX2 (IEEE802.16m)
- Analyse and Compare results from simulation, using latest mobile standards, WiMAX (IEEE 802.16e) and WiMAX2 (IEEE802.16m) on QoS parameters such Throughput, Packet loss, Packet delay and Jitter

1.4 Aims

The main aims of this study are

- Develop an understanding of handover problems in WiMAX.
- Develop Working WiMAX model for Simulation
- Improve handover delay in WiMAX by fine tuning WiMAX physical parameters without any negative effect on QoS from these changes.
- Choose or develop Handover algorithm to improve handover delay and QoS

The central goal of this research is to reduce the handover delay caused by moving mobile station at a certain speed and improve the mobility within the mobile WiMAX and suggest a stable alternative to the next-generation wireless technologies. This is tried and tested in chapter 6.

1.5 Knowledge Gap Contributions

It is very important to discover and to eradicate handover delay to minimal level in WiMAX but unfortunately not much research has been done in this field and due to that WiMAX capability as an alternative to its mobile competitors, has not been fully explored. The review of literature has pointed out the need for more research in the field of mobile WiMAX, especially in the field of handover delay in WiMAX. Studies such as (Sufyan, et al., 2017) and (Jiao, et al., Spring 2007) explained the importance of WiMAX and pointed out the challenges for WiMAX and emphasized on QoS requirement as the biggest challenge for WiMAX applications. The applications such as Video streaming is considered as the biggest challenge for Mobile WiMAX. Which is caused due to the handover delay and while another study (Talwalkar, et al., 2008) had identified packet loss, jitter and handover delay as basic limitations to handover improvement. While in a similar way (Xujie & X.L, 2010) investigated handover code and clearly identified mobility challenges which has to be fixed to achieve optimal performance. These studies pointed out clearly that to achieve better performance and to ensure high QoS in WiMAX, mobility issues need to be addressed to solve mobility problems in WiMAX. The handover delay has to be minimized to ensure better performance of WiMAX signals. Therefore, the following contributions are closing the knowledge gap as follows:

1. Investigated handover parameters at high mobility in standards such as IEEE 802.16e and IEEE 802.16M
2. Investigated speed effects of objects versus handover delay.
3. Find limitations of handover delay versus the high mobility effect.
4. Optimise the handover delay, bandwidth, and packet loss for better QoS

1.6 Critical Review

This thesis is smaller part in the research work happening and as WiMAX network is continually under development and WiMAX handover delay is research problem which is still ongoing, which will introduce more challenges as the technology gets recognized and becomes matured. The good points of this study are:

- This work is fully dedicated to improving handover delay in WiMAX, with the aim of improving mobility problems, while taking into consideration the signal factors effecting the handover delay
- The study is focused on improving the handover delay and to keep the other factors within the limits, which would result in making the signal performing better.
- The study suggests an algorithm which is more dependent on digital factors than on analogue factors which would make WiMAX performing better.

As WiMAX research is currently ongoing and the challenges will become more diverse as the technology gets implemented in the telecommunications industry and there are many factors in the proposed optimization of handover delay in WiMAX. Which could be more improved in order to make WiMAX a viable telecommunication technology and here are some of the limitations of this research thesis.

- As this study assumes the terrain effect to be minimal as the simulation assumes the line of sight between the base station to the mobile station. This study can be improved by studying the effect of the terrain using a new purposed handover algorithm.

- As mentioned in the study, the simulation experiments assumes all other WiMAX signal factors to be the standard, which leaves space for more study and these factors need to be tested to understand their effect on handover delay while using this new algorithm.

In this thesis, the efficiency of the handover in Mobile WiMAX network was tested and simulated. The study was mainly done using mobile WiMAX standards and suggested algorithm was implemented using RIVERBED simulation tool. The study tried to improve the handover delay by standardising signal parameters and implementing the new suggested handover algorithm to improve handover decisions. As the technology improves and telecommunication community is looking for a cheaper alternative for wireless broadband technology and with this in mind, The scenarios and problems will continue to exist until the researchers overcome these challenges.

1.7 Structure of the thesis

This thesis is subdivided into different chapters which discuss the main objective of this thesis. Where each chapter describes and analyses different aspects of the research and using a novel approach of simulation. The results of simulation scenarios are presented and analysed in its own chapter. While at the end there is a discussion of future work related to the field of handover optimization.

The detailed structure of the thesis is described as

Chapter 1 -Introduction

This chapter discusses the scope, aim and objective of the research in a detailed way. The study was positioned in the domain of WiMAX and handover delay in WiMAX and the research questions postulated, are focused in subsequent chapters which are together with the structure of the thesis.

Chapter 2 - WiMAX Technical Background and Overview

This chapter starts by discussing the technical background of the whole WiMAX technology, including the description and types of Handover in WiMAX and description of limitations within WiMAX technology. Another important part of this chapter is the previous work done in the field of WiMAX and Handover delay in WiMAX. This chapter helps in identifying the problems while creating a better WiMAX model. There is a detailed description of technical background on WiMAX technology and different WiMAX standards including mobile WiMAX and WiMAX-2.

This chapter would also describe different techniques used to improve the handover delay and various designs and handover algorithm used to improve the WiMAX signal by providing a comprehensive evaluation of previous work done and providing the user details about the need for more research in this area.

Chapter 3 - Literature Review

This chapter discusses the review of literature in WIMAX, while concentrating more on the work done in the field of handover delay in WIMAX. The literature review provides detailed analysis of a complete set of papers which is applied to WiMAX and Handover delay in WiMAX. The researcher reviews the articles which are regarding the use of WiMAX technologies as standard and studies the benefits of using WiMAX technology as a replacement for 3G and 4G technologies. Consequently, the review suggests that general guidelines are standard. In addition, it was also studied about the WiMAX technology as a model. The researchers classified the review into three different Sections: where the researcher studied WiMAX as a communication system and the researcher took the study of (Li, et al., 2010) where they provide a study of WiMAX standard 802.16e which provides deep insight into developing WiMAX model.

The literature about the mobility in WiMAX is researched. The researchers classified the mobility techniques and reviews the literature based on the classification. The pros and cons of each classification are examined. The researchers studied (Chang & Huang, 2007) which provides the details about mobility problems in WiMAX. The researcher also studied the literature about the handover delay in WiMAX, which is also main aim of this research. In this Section the researcher identifies the pros and cons of different handover delay methods. The study of (Pontes, et al., 2008) provides detailed insight into handover mechanisms which were the main inspiration for the study.

Finally, the researcher performs literature survey and the study confirms that there is no proper way defined and there has been no complete study done previously which is mainly directed at reducing handover delay in WiMAX.

Chapter 4 - Research Methodology

This chapter explains and describes the entire process carried out from initial stages of concept development to the final stages of simulation, results and analysis. This chapter describes and explains the process from basic sketch model to complete model of WiMAX. The Chapter also includes the evolutionary experimental approaches and includes detailed configuration of WiMAX model in RIVERBED simulator .

Chapter 5- A Novel Analytical Model Developed On WIMAX Handover Delay

As telecommunication systems and devices get advanced day by day. Providing support to these new devices, which enables them with an undistruped data transfer is the biggest challenge for the research and telecommunications community. The challenge became more complex when the factor of handover failures was introduced, which usually happens due lack of resources and limitation in coverage including the speed of mobile device. The handover schemes and models which are currently developed are not able to support the current complex scenarios. This thesis proposes a new approach to modify the process of handover decisions and to reduce the unnecessary handovers. This chapter discusses a numerical analysis of the proposed new algorithm. The results of this numerical analysis are also discussed in this chapter, which shows that the model performs better than existing models with reduced number of unnecessary packet loss.

Chapter 6-WiMAX Experiments, Parameters, Setup and Collected data

This chapter is one of the main building blocks of this thesis, which includes the discussion of different scenarios designed for experiments with a detailed discussion of parameters. This chapter also includes a detailed discussion of experiment setup and design. The other most important part of this chapter is collected-data and results. This chapter discusses the collected data and provide brief Analysis including the process of experimenting and finding the results of research questions by simulations.

Chapter 7-Results Comparison & QoS Analysis Between WiMAX and WiMAX-2

This chapter provides a complete analysis of Handover delay times between Analytical and RIVERBED Simulation results which includes results from both WiMAX and WiMAX-2 simulation experiments. This chapter also discusses their impact by providing complete performance analysis, including a description of each and individual QoS parameter. This chapter also provides verification and confirmation of results by comparing results with previous case study scenarios.

Chapter 8-Analysis, Discussion And Recommendations

This chapter would provide a complete summary of this thesis and discuss the empirical approach used within this thesis.

Chapter 9 -Conclusion and Future Work

This final chapter provides conclusions and justification of the new WiMAX model and the thesis summary includes the pros and cons of this thesis including future work which will be required to meet new research challenges.

CHAPTER 2: WIMAX TECHNICAL BACKGROUND AND OVERVIEW

WiMAX is termed as World Interoperability for Microwave Access. WiMAX is based on standard IEEE 802.16 which is standard for air-interface in microwave and millimetre-wave band. In other words, WiMAX is also known as Metropolitan Area Network (MAN). WiMAX has the capability to provide an effective interoperability broadband wireless access in a multi-vendor environment and it is considered an emerging technology which provides high-speed connectivity for the internet. WiMAX can be connected to the wired backbone and it can serve as Wireless extension enabling wireless broadband access. Which can provide up to 50 Km coverage and many countries in America and Europe are working on the development of this technology.

In 1999 IEEE 802 committee set up a working-group called 802.16 working-group to develop broadband wireless standards and associated functions. While based on IEEE 802.16 standard series WiMAX features can be defined as it provides stable wireless transmission in the area of 50 km providing speed up to 70 MB/s (IEEE 802.16e-2005 IEEE Standard for Local and Metropolitan Area Networks, 2006). In this thesis, we try to find techniques to deal with the problem of handover delay in the WiMAX and develop a new modified handover algorithm, together with physical signal modifications tested under KPIs such as average values of throughput, application throughput, completion time defined by the WiMAX Forum, an industry-led consortium promoting the WiMAX. The fairness index would show

how the resources and bandwidth were shared with subscribers and the delay results would show that it doesn't violate the QoS requirements.

The handover algorithm suggested in this research would be analysed in a controlled environment in simulation software called RIVERBED. Where this controlled environment has no variation in conditions such as building, walls etc and mobile devices have a connection between a base station to mobile station which should have a clear line of sight.

The choice to run the simulations for individual speed range, even though it has increased the amount of work involved, resulted to be very helpful and interesting results were identified. For starters, the controlled environment provides an intuitive way to see the behaviour of individual flows over time and the effect scheduling decisions have on them.

In summary, The new and modified algorithm was found to be a comprehensive and customizable, which resulted in high-throughput while still being able to ensure its QoS commitments and including lower handover delay times.

2.1 What is WiMAX Technology?

AS there was more advancement in a communication network. WiMAX has proven to be more and more realistic with strategic significance, moreover, when there is no global uniform standard has been set up for broadband wireless access. The main type of standard such as IEEE 802.16d supporting air interface which is used for the fixed broadband wireless access system.

Broadband Wireless Access Metropolitan Area Network (BWA-MAN) is alternatively called WiMAX. Which is based on IEEE 802.16 standard usually called as Wireless MAN.

2.2 Background of WiMAX

In 1990s broadband wireless access technology was rapidly developed. These technologies, which are usually represented as Local Multipoint Distribution System (LMDS) and Multichannel Multipoint Distribution Service (MMDS). These technologies have found its position and place in wireless technology market, which is mainly developed for commercial users such as small and medium network companies and urban commercial centres. (Andrews, et al., 2007) described that out of the expectation of everyone, the industry was slow in expanding further and which was due the lack and need of universal and uniform standard for broadband wireless systems.

A work-group was organized by IEEE in 1999, which was called 806.16 Workgroup, which was mainly specialized to work on a technical specification and try to provide a uniform global standard for broadband wireless access. Currently, IEEE 802.16 has two main standards such as the 802.16-2004, i.e., the 802.16d standard for fixed broadband wireless access, while 802.16e provide a standard providing support for mobile broadband wireless access. 802.16e was issued on October 1st,2004 and this standard describes the air interface between the user device and a base station with fixed access and defines PHY and MAC layer of the air interface. The most important features of the 802.16e standard are it supports mobility and this standard describes a system where there is support for both fixed and mobile. This standard works in a permitted frequency range below 6 GHz, which is suitable for providing mobility and supports the mobile user in moving phase.

The user capacity conditions of fixed wireless access which is specified by standard 802.16 are not affected. The Workgroup specifically, IEEE 802.16 Workgroup confirmed and established specifications of the standard, which is more directed to physical and MAC layer of wireless MAN. To establish a working network, IEEE 802.16 technology requires additional support from other components and to solve this problem WiMAX forum was created to help in regard to this components demand. In April 2001 WiMAX forum was officially established. In the startup phase, this organization was mainly set up to offer certification services specifically in broadband wireless access products which are based on IEEE standard 802.16 including ETSIHiperMAN standard and certified product was identified was a mark of "WiMAX Certified". Due to the development of mobile WiMAX standard 802.16e specially in technology, specification, Job and responsibility gradually extended and now not only it is working to create a complete certification system based on standard 802.16 including ETSI HiperMAN standard. Other than that it is also working on research in the area of broadband wireless access system, analysis, application modes and expansion of the market and due to that it has helped in promoting the development broadband access market.

There is a general understanding that IEEE 802.16 Workgroup is the main body of IEEE 802.16 for air interface specification of WiMAX. WiMAX forum is the main governing body and main pushing force behind this technology is industry chain, and it's important to mention that WiMAX is also called by IEEE 802.16 WiMax covering the standards IEEE 802.16 d/e.

2.3 IEEE 802.16 Standards

A normal user would generally opt for DSL, T1 or Cable-modem when he or she is in need for broadband network service, but in situations such as less populated areas, the network providers would not be willing to install the needed infrastructure such as optical fibre and cables due to the high cost of new equipment. The broadband technologies such as LMDS and MMDS has been suggested in past but due to the problem of not being able to provide uniform technical standard and the incompatible air interfaces, which was provided and used by different manufacturers, limited the progress in this industry and posed a biggest problem in the development of such technology. IEEE tried to solve this problem and created a Workgroup call IEEE 802.16 Workgroup in 1999. This Workgroup was only tasked with the development of broadband wireless access technology and later in December 2001, it issues its first standard IEEE 802.16-2001.

2.3.1 IEEE 802.16-2001

The development started by keeping in consideration LMDS compatibility with available systems. Due to that the IEEE standard IEEE 802.16-2001 defined the frequency ranges regulated at 10 -66 GHz and this standard provided network specifications for Metropolitan Area Network (WMAN). The standard IEEE 802.16-2001 was mainly suitable for open and clear areas due to its microwave signals in the frequency range 10-66 GHz, which have poor signal and lack of penetrability and signals could easily be affected by rain. Due to the conditions LOS approach is needed and adopted in the interaction between a base station (BS) and the subscriber station (SS) and while another requirement for setting up this system was that it needs a higher number of antenna installation.

2.3.2 IEEE 802.16a

In order to solve IEEE 802.16 limitations and enable it to operate in areas with buildings and structures such as a crowded city or metropolitan area. IEEE 802.16 Workgroup published and presented standard IEEE 802.16a in April 2003, where this new standard is an extension of IEEE 802.16-2001 and which functions in the frequency range of 2-11 GHz and these also include bands requiring and not requiring a license. In this new standard, the signal range was extended up to 50km and the frequency band used by this new standard has the ability to work in NLOS (non-line-of sight) and rain conditions. This new standard has also reduced the requirement of the antenna. While in addition to that, this new standard offers support for

Mesh topology and MAC offers a QoS guarantee supporting both voice and video messages. Due to these above features, IEEE 802.16a standard proved to be more competitive in the telecom market because this WiMAX sends out a wireless signal by fixed NLOS a Super WiFi Base station. The WiMAX network coverage is larger than WiFi including the transmission rate, which is very suitable for an ISP which may be used to create better Hot Spot wireless network access service.

2.3.3 IEEE 802.16-2004 (IEEE 802.16d)

As IEEE 802.16 a is modified version of IEEE 802.16-2001. Later in 2004 WiMAX Workgroup integrated IEEE 802.16-2001 and IEEE 802.16a standard and revised some of the features and published IEEE 802.16-2004 which is also called IEEE 802.16d. This standard defines more directly physical and MAC layers for frequency range 2-66 G and when compared to old IEEE 802.16 series, IEEE 802.15d proved to be more practical and relevant to current requirements.

2.3.4 IEEE 802.16-2005 (IEEE 802.16e)

In the beginning WiMAX was mainly considered as fixed network and the standard IEEE 802.16 was created to cater for fixed network. The continuing progress and advances in wireless communication and user demand for more mobility moved the progress towards wireless requirements and it was realized by adding mobility features. The mobility features guarantee bigger consumer market due to prospect of wireless broadband network. In order to support such features WiMAX Workgroup, presented IEEE 802.16e standard, which is based on IEEE 802.16-2004 and was aimed to support high-speed data transmission and while being able to move at higher speeds. Due to its mobility features IEEE 802.16e is considered as a main wireless broadband technology, which is able to compete 3G and 4G networks. This standard defined some functions which have a close co-relations with mobility features which includes handoff, sleep mode, saving energy, call search and improved safety, in addition to supporting mobile communication. In table 2.0.1 shows a comparison between standards.

Table 2.0.1 Comparison between 802.16 standards (Radio-Electronics.com, 2012)

WiMAX Signal Properties	IEEE 802.16 Standard for Fixed or Stationary Applications	IEEE 802.16a Standard for Fixed with Portable applications	IEEE 802.16e Standard for Full mobility Application
Spectrum	16-66 GHz	2-11 GHz	2-6 GHz
Channel Bandwidth	20,25, and 28 MHz	1.5 to 20 MHz	1.5 to 20 MHz with UL Sub Channels
Modulation	QPSK,16QAM,64 QAM	OFDM 256 sub carriers QPSK,16QAM,64 QAM	OFDM 256 sub carriers QPSK,16QAM,64 QAM
BIT Rate	32-134 Mbps(28 Mhz)	75 Mbps (20MHz)	15 Mbps (5 MHz)
Channel Conditions	LOS	Non-LOS	Non-LOS
Typical cell Radius	2-4 km	7-10 Km, max 50 Km	2-5 km

2.4 WiMAX Standard (IEEE 802.16M) WiMAX-2

The current requirements for mobile Internet, streaming and multimedia applications has motivated towards further development in wireless access in the last few years. WiMAX more specifically mobile WiMAX has moved the convergence of both mobile and fixed broadband networks with flexible network architecture and common wide-area radio-access technology. In January 2007 IEEE 802.16 Working Group developed a new update to its IEEE 802.16 standard, which was called as IEEE 802.16m also termed as WiMAX-2. IEEE 802.16m comes with an advanced air interface to meet the requirements of ITU-R/IMT-advanced for 4G systems and for next-generation mobile network operators. In WiMAX-2 the available bandwidth and multi- antenna mode decides the air to air data transfer rates supporting the data rates in excess of 1Gb/s. The higher data rates provide support to a wide range of multimedia applications, ensuring full backward compatibility with existing mobile WiMAX systems to preserve the investments and continuing to support first-generation of WiMAX products. The most distinctive plus points such as flexibility and extensibility of this physical and medium access layer protocol, which makes mobile WiMAX more attractive and more suitable for the realization of ubiquitous mobile Internet access. The WiMAX 2 or IEEE 802.16m is more suited for mixed deployments with old legacy mobile stations (MSs) and base stations (BSs) where backward compatibility is allowing error free upgrades to old deployments, while it will enable roaming and seamless connectivity across IMT-advanced and IMT-2000 systems through use of proper interworking functions.

2.4.1.1 IEEE 802.16M SYSTEM REQUIREMENTS

In field deployments using IEEE 802.16m the network operator can decide to disable the support for legacy systems while full backward compatibility and interoperability with reference system is required for most of the deployments.

The reference system is considered as a compliant with a subnet of IEEE 802.16e-2005 (IEEE Standard, 2009) features. The backward compatibility features ensure smooth migration from legacy to new systems without any significant impact. The requirements of WiMAX-2 are chosen to guarantee competitiveness and ensuring leading edge as compared to other available wireless techonologies. WiMAX-2 System requirements are evaluated and depend on methodology mentioned on Report ITU-R M.2135 (IEEE 802.16 Task Group m (TGm), 2009). In similar fashion WiMAX meets the service requirements for IMT-advanced system which is specified in the report, ITU-R M.1822 (M.1822:Framework for services supported by IMT, 2007) and at the same time evaluation scenarios and parameters which is configured for WiMAX-2 evaluation document are based on the evaluation of the reference system (WiMAX Forum, 2008) which is used to benchmark improvements.

2.4.2 PHYSICAL LAYER OF IEEE 802.16M.

As WiMAX-2 is in early stages of development and the enhancements which are being considered are for inclusion in future systems and that’s why it's still based on concepts and principles.

A. Flexibility enhancements to support heterogeneous users in IEEE 802.16m:

As the world is moving towards connected systems and the wireless systems are trying to cater to the needs of different users and that’s why there is always need of flexible designs. In situations where users are using low rate streaming applications and where the link reliability is more important than the data rate. While others users might be interested in achieving the maximum data rate even if it adds retransmission and which adds additional delay (Gozalvez, 2007). In addition to that the co-existence of different users is accomplished by relatively low control overhead. Due to that the frame format and subcarrier mapping schemes, the pilot structures are modified in WiMAX-2 (IEEE 802.16m) as compared to IEEE802.16e and in a similar way the frame format, mapping schemes and pilots are modified.

The downlink and uplink frames start with control information which is used to synchronize the data transmission. In any mobile station transmission is carried out in blocks which is configured from basic units called slots, where each slot can be considered as two-dimensional blocks. One block or dimension is time while the other dimension being frequency (Garber, 2008). The Partial Usage of Subchannels (PUSC) zone, which is required and which improves the diversity to spread out the effect of inter-cell interference. Every individual slot extends over the entire signal bandwidth, which results in each subchannel having same channel quality. WiMAX-2 uses PUSC to reduce the effect of inter-cell interference where subchannels are subdivided among the base stations so that adjacent base stations are not used in same subchannels and the main aim of using FUSC permutation scheme is similar to PUSC, mainly to improve diversity and to spread out the effect of inter-cell interference.

B. Advanced use of MIMO transmission in WiMAX-2

Multiple-Input Multiple-Output (MIMO) communication is commonly used by a number of wireless systems such IEEE 802.11n and IEEE 802.16e. As MIMO technology becoming more and more stable and in the same fashion its more widely used for wireless communication. The main aim of Next Generation WiMAX systems is to support the minimum up to 8 transmit antennas at one base station and 3 streams and space-time coding (Piggin, 2006). While some MIMO features of 802.16e, such as closed-loop MIMO has not been implemented in Mobile WiMAX but it is promised that it will be included in 802.16m based systems and more specifically closed-loop MIMO using the Channel Quality Information. In systems such as 802.11n and 802.16e standard, MIMO transmission is used to increase the data rate between the transmitter - receiver pair and reliability of the link. The exception from 802.16m and future 3GPP systems is that they will extend MIMO support to multiple user MIMO in more specific situations where the use of multiple antennas can improve the achievable data transmission rates within the network with given frequency resources. Theoretically the capacity region of the uplink and the downlink increases in general, when MIMO transmission is employed (Piggin, 2006).

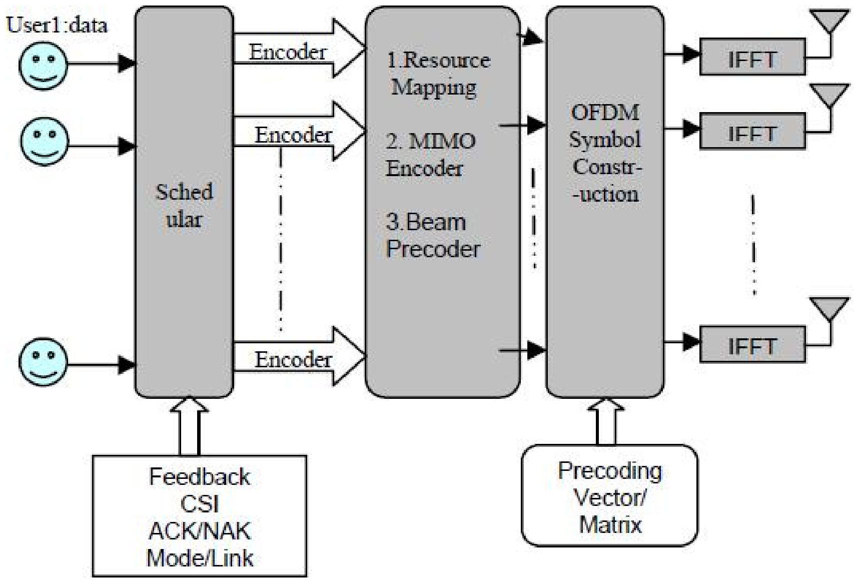

Figure 2.0.1 MIMO architecture for the downlink of 802.16m (WiMAX-2) (Rakesh, et al., 2010)

C. Resource allocation and multi-cell MIMO

Network planing needs very detailed frequency planing to accomplish a network with minimum outage probability and at the same time provide the minimum interference within users of neighbouring cells. To achieve this kind of network different parts of the frequency spectrum are typically assigned to neighbouring cells. In the current systems this frequency assignment is static and this can only be changed with manual re-configuration of the system. The frequencies are mostly reused by cells, which are sufficiently far away so the interface caused by transmission on the same frequencies is same enough to guarantee satisfactory signal to interference and Noise ratios. The frequent rise simplifies the design, but the handover process becomes more complicated for mobile stations.

D. Interoperability and coexistence.

To enable WiMAX-2 to support for legacy base station or mobile stations and legacy technologies such as LTE, the concept of time zone an integer number of continuing subframes is introduced. IEEE 802.16 standards, interoperability (Wang, et al., 2008) and WiMAX-2 (802.16m) network reference Model permits interoperability of IEEE 802.16m Layer 1 and Layer 2 with legacy 802.16 standards. As WiMAX networks are already deployed and that's made it very important to implement interoperability, then update entire network. While the benefit of implementing interoperability can be that 802.16 standard has different standards, providing specific functionalities in WiMAX network. The main goal of 802.16m is to enable co-existence of all functionalities.

Table 2.0.2 Features And System Requirements Of WiMAX Standards 802.16e And 802.16m (Rakesh, et al., 2010)

Requirement	**IEEE 802.16e**	**EEE802.16m**
Aggregate Data Rate	63 Mbps	100 Mbps for mobile stations, 1 Gbps for fixed
Operating Radio Frequency	2.3 GHz, 2.5-2.7 GHz, 3.5 GHz	< 6 GHz
Duplexing Schemes	TDD and FDD	TDD and FDD
MIMO support	up to 4 streams, no limit on antennas	4 or 8 streams, no limit on antennas
Coverage	10 km	3 km, 5-30 km and 30-100 km
Handover Interfrequency Interruption Time	35-50 ms	depending on scenario
Handover Intrafrequency	Not Specified	30 ms
Handover between 802.16 standards (for corresponding mobile station)	From 802.16e serving BS to 802.16e target BS	100 ms

2.4.3 Characteristics of WiMAX Physical Layer

The Frequency range of WiMAX is in the ranges from 2 to 66 GHz while channel bandwidth has the possibility of being adjusted within the range from 1.5-20 MHz, which provides the opportunity to fully utilize frequency spectrum in distributed channel bandwidth. WiMAX signals are scattered as macro cells, which had maximum coverage up to 50km. While channel bandwidth of 20 MHz will provide and support sharing data transmission rate up to 70Mbit/s where the maximum coverage in this situation will be 3-5 km. The system capacity can be expanded using multi-Sector technology and provide support for more than 60 business users and while thousands of home user having E1/T1 at the same time. The adoption of latest new technologies within WiMAX to ensure NLOS and LOS transmission. These technologies such as OFDM diversity when receiving or transmitting and adaptive modulation and these technologies have improved the efficiency of wireless transmissions in the cities. There are two kinds of wireless duplex multiple access, which is supported on a physical layer such as TDD/DMTA and FDD/TDMA, to ensure WiMAX is able to adopt telecom requirements in different regions. The physical layer also supports single carrier (SC), OFDM (256 points), and OFDMA (2048 points) and they are selected flexibly as needed. There might be changes in physical layer due to transmission channel performance. The physical layer parameters of modulation mode can be changed in order to provide better transmission quality.

2.5 Characteristics of WiMAX MAC Layer

WiMAX MAC layer has three sub-layers which are

a) Service Specific Convergence Sub-layer (CS) b) Common Part Sub-layer (CPS)

c) Privacy Sub-layer (PS).

2.5.1 Service Specific Convergence Sub-layer (CS)

The primary function CS is defined as that it is used to convert and map the data received from the external network by SAP to MAC SDU and later on transmit it to the SAP of MAC layer. The various external protocols are provided with a multiple CS specification by this protocol.

2.5.2 Common Part Sub-layer (CPS)

The core of MAC layer is CPS, which is providing the main function of system access, bandwidth allocation, connection establishment and connection maintenance. CPS receives data from multiple CS layers via MAC SAP, which classifies them into particular MAC connections and in the meantime, QoS controls are implemented to ensure data is transmitted and sent to the physical layer.

2.5.3 Privacy Sub-layer (PS)

PS provides basic function of authentication, key exchange and encryption/decryption processing. The study by (Andrews, et al., 2007) has shown MAC Layer and PHY Layer of WiMAX as described in figure 2.0.2

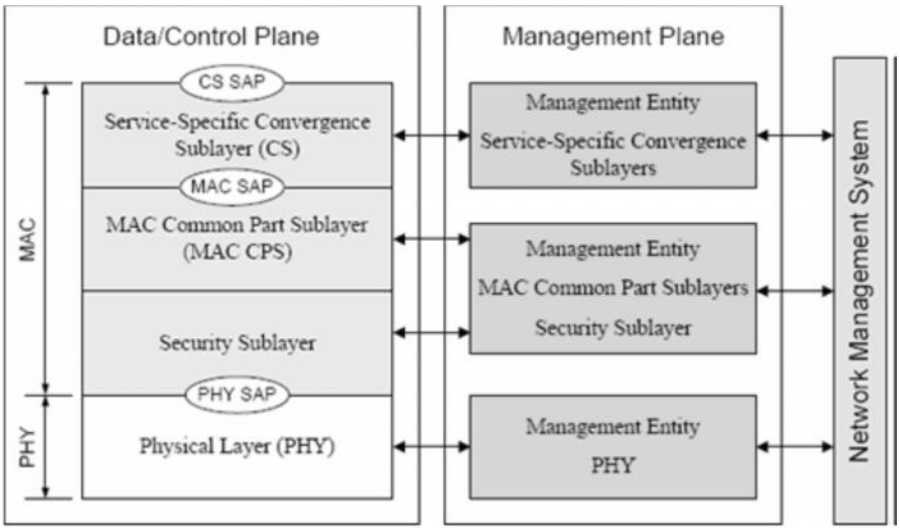

Figure 2.0.2 MAC Layer and PHY Layer of WiMAX (Andrews, et al., 2007)

2.6 Structure of WiMAX Network System

The main parts of WiMAX network have two basic units, the first one is core network and while the Second one is access network. The first basic unit of WiMAX network, the core is comprised of network system management, main router, AAA server or agency, User database and User equipment for the gateway, which enables connection to WiMAX users. The Second unit is access network, which includes a base station (BS), a subscriber station (SS) and mobile subscriber station (MS), which provides wireless access to WiMAX users. The below figure 2.0.3 (Andrews, et al., 2007) shows WiMAX Network architecture IP-Based.

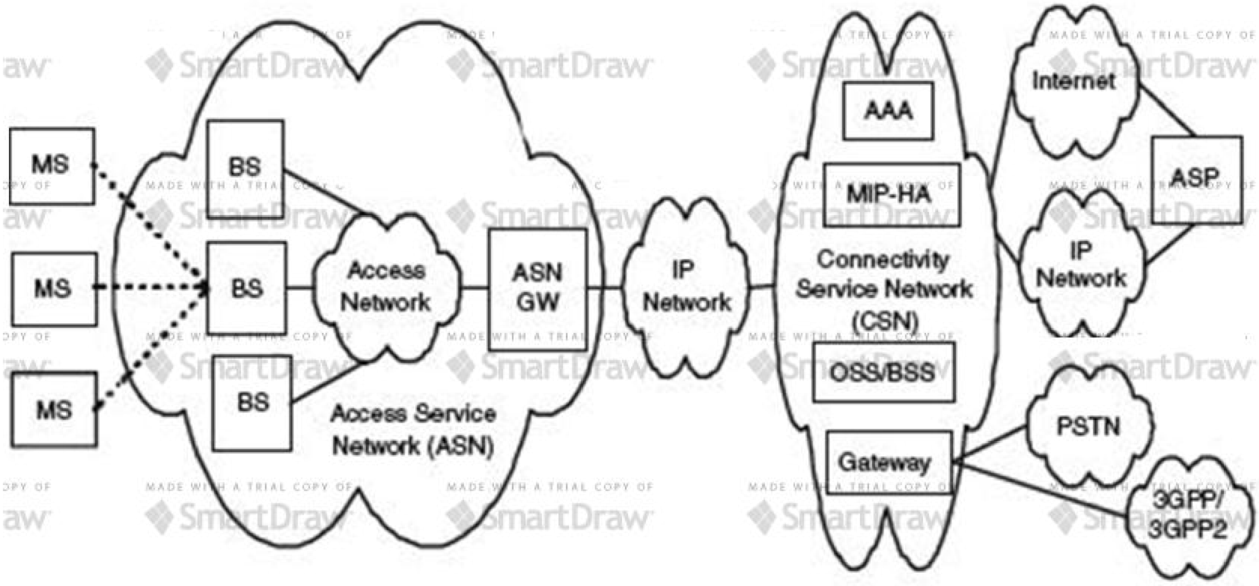

Figure 2.0.3 IP-Based WiMAX Network Architecture (Andrews, et al., 2007)

2.6.1 Core Network

The WiMAX main unit called core unit and which takes care of user Auth, roaming services, network admin also providing an interface to other networks. The system admin is utilized for many core functions such as monitoring and controlling all the base stations and subscriber stations in the network which it is monitoring. It also provides functions such as providing functions of inquiry and subscriber stations, including software download and system parameters configuration. WiMAX uses a traditional switching network to be connected to an IP network and in the same way, WiMAX provides the connection interface for IP network and base stations.

2.6.2 Access Network

The core network and subscriber stations are connected via base stations. There are different antennas in use by WiMAX such as Sector or beam antenna and umbrella antenna used to provide an arrangement and configuration of subchannels and upgrades to it expends the network on the requirements of users. The repeater connection is provided by type of base station called subscriber station to the equipment of user terminals. The antenna usually used by WiMAX is called beam antenna which is usually installed on the roof and the signal mode used is called dynamic adaptive modulation and which is used to make the communication between base station and the subscriber station. The mobile station MS which is the term mainly used to refer to the mobile WiMAX terminal and mobile devices responsible for ensuring wireless access for mobile WiMAX subscribers.

2.6.3 Base Station

The core network is connected to the base station via subscriber station to ensure strong connectivity. The base stations usually use Sector /beam antenna or umbrella antenna which has the capacity to provide adjustable arrangement and configuration of subchannels upgrades and ensure the network expending of the network base on the requirements of users.

2.6.4 User Terminal Equipment

User terminal equipment is connected by WiMAX with the use of, connection interface equipment to the base stations and also provides the connection interface between the user terminal and also access to terminal equipment, while user terminal equipment doesn't belong to WiMAX system

2.7 Main Technologies of WiMAX

2.7.1 MIMO

There has been continuing development of wireless technology and with this development, it sets tougher conditions for system capacity and efficiency frequency spectrum. There is continuing work underway to meet these requirements. MIMO (multiple input and multiple outputs) systems were invented at the time when was really needed. MIMO uses space-time coding (STC) its element array and that benefits in spectrum efficiency within the specific bandwidth and which makes MIMO one of the main technology for WiMAX, LTE, 802.11n and all other superior wireless technologies, usually called wireless communication systems for the future.

MIMO is the type of technology which uses multiple transmitting and receiving antennas and which is improved for each user according to QoS. When the comparison is done between MIMO technology and traditional single element system, MIMO provides a better amortization rate of the frequency spectrum, due to which it provides better data transmission with higher speed under limited bandwidth. Especially in systems such as WiMAX 802.16e system, uses MIMO and OFDMA to ensure and better coverage and doubles the WiMAX system capacity and including the cost of network establishment and maintenance are reduced and due to development in the field of mobile WiMAX has greatly improved.

2.7.2 OFDM

OFDM, which is also called The Orthogonal Frequency Division Multiplexing termed as a multi-carrier digital modulation technology. It can be found out that research on OFDM technology is traced in the middle of the 1960s. The OFDM concept has been under discussion for many years, but it was accepted in later years as a viable technology for bi-directional high-speed wireless communication, when development was done in the media industry in current years and later it was accepted and adopted by European Digital Television Standard (DVB-T) and Digital Audio Broadcasting (DAB) as standard. It is the main core technology for WLAN for networks such as ETSI HiperLAN/2 and IEEE802.11a and also broadband wireless access for standard IEEE 802.16. There is further development of chip technology for DSP CMOS and other technologies which are adopted by Fourier transform/inverse transform. There is been more concentration in the implementation of OFDM in mobile communications systems and it is expected that this technology will the main technology for 4^{th} and 5^{th} generation mobile communication systems.

In a wireless environment, OFDM is high-speed transmission technology, where most of the frequency response curves in wireless channel are not flat. What makes OFDM far more superior is the idea behind OFDM technology, which divides the fixed channel into many orthogonal subchannels in a frequency range. The subcarrier on each subchannel for modulation, where the subcarrier is transmitted in parallel. This makes non-flat channels with different frequency options and every subchannel is relatively flat and narrowband transmission is completed on subchannels with signal less than the corresponding bandwidth of the channel. In the same way interference level in signal waves will be eliminated, which is due to carriers on subchannels in OFDM are orthogonal to each other. Due to that the overlapped Freq spectrum reduces the interference between the subcarriers which improves the utilization rate of the frequency spectrum. Frequency-Division Multiplexing/ Frequency-Division Multiple Access (FDM/FDMA is usually an old technique, but the TDM/TDMA (Time-Division Multiplexing/ Time-Division Multiple Access) and CDM/CDMA of the greater frequency efficiency spectrum are the main Core which can turn to be the core transmission technology for wireless communication.

2.7.2.1 Advantages of OFDM

CDMA is old technology which is being replaced by OFDM in a new generation of core technology in wireless communication network systems and the main reason of this changes the features and advantages of OFDM and these are

(1) Higher frequency spectrum efficiency

It approaches the Nyquist limit theoretically with sub-carriers, which partly overlap the FFT processing. It effectively ensures the avoids the interference between the users using OFDM-based which establishes the orthogonality of different users in a particular area capacity.

(2) Good expandability of bandwidth

OFDM system can provide good expandability of bandwidth due to its ability to include many sub-carrier where OFDM system based on quantity of subcarriers used. Due to this feature its ability to realize bandwidth from few to hundreds of KHz to as large as hundreds of MHz. It can provide service of mobile broadband communication from 5MHz to maximum 20MHz above the support of OFDM system to bigger bandwidths.

(3) Anti-multipath-fading

Broadband transmission is transformed by OFDM into narrowband transmission on different sub-carriers and sub-carriers in the channel can be accepted as a horizontal fading channel which reduces the complexity of the received equalizer. In other words, the multipath equalization sharply increases complexity of the single carrier as there is increase of bandwidth for which broader bandwidth is hard to support

(4) Frequency spectrum resource for flexible allocation

The OFDM system use and select a suitable sub-carriers establishes a dynamic Frequency allocation where number resources, and it's also fully uses the frequency diversity which provides optimum system performance for multiuser diversity.

(5) Realization of MIMO

OFDM each channel subcarriers are accepted as a horizontal fading channel where additional complexity is created by the MIMO system and which is controlled in lower level and with the quantity of antenna presents a linear increase. Where the complexity of each single carrier within the MIMO system is in direct relation to the power of the product by multiplying the quantity if quantity of multi-paths and antennae which negatively affects the implementation of MIMO.

2.7.3 OFDMA

The OFDM multiple access systems subdivide the transmission bandwidth into a number of orthogonal sets which are without overlap, then allocate them to different users to ensure multiple access. The bandwidth resources are allocated as per user on demand, which ensures system resources easily optimized. It is ensured that there is no interference between users to achieve idea synchronization as different users occupy nonoverlapped subcarriers.

2.7.4 Sub-Channel OFDMA

The OFDMA system bandwidth is subdivided by subchannel OFDMA, where the subchannel carriers allocated to uses may occupy more than one subchannel. The subchannels are made of two types of OFDM subcarriers, one is called localized and the Second one is called distributed, where the localized would allocate successive subcarriers to a subchannel. The localized system would be able to select an optimum subchannel for transmission. In addition to that localized system also help in reducing the channel estimation where the frequency gain is small while the performance is relatively poor. The Frequency diversity gain is achieved by subcarriers when they are spread with distributed type and the complex channel estimation while scheduling is not applied in addition to that the anti deviation is poor

2.7.5 OFDMA Frequency Hopping

The Subcarriers of subchannel are allocated by OFDMA subchannels fixedly where an individual user takes over the allocated subcarrier set for the longest time. The entire residential area can be supported by such OFDMA system, but there are few problems. The channel changes for individual areas are based on the subcarrier resources taken by individual residential area necessarily interference which ends up in interference between different residential areas. This interference is avoided with coordination, which is required between neighbouring residential areas. This coordination will require additional support of signalling changing from the network layer. The architecture network is effected where frequency hopping is available. In this system subcarrier resources applied to user change in a rapid way. Where each time slot a user extracts from a subcarrier from all to occupy and various user's extra different subcarrier sets in the same time slot. The choice of the subcarriers are random independent then channel conditions which are different from the scheduling base sub-channel service. Subcarrier used by users have not very often had a conflict with one another which is regardless of any channel change when users hop from one subcarrier to another. Which creates a shorter cycle of scheduling in subchannel in OFDMA in a cycle of the frequency of hoping. In this way, the users orthogonal to each other inside a residential area which can utilize the diversity gain and coordination is unnecessary between the residential areas. The rapid frequency hoping to scatter the interference in time and frequency ranges even though the subcarrier might conflict. In other words, we can say the interference is converted to noise which results in a reduction in the harm of interference

2.8 Combination of MIMO and OFDMA

Mobile WiMAX 802.16 e system uses MIMO and OFDMA in a combined format which helps in improving the network coverage and even it redoubles the WiMAX system capacity. In addition to that the network construction and maintenance is minimized and which works on making WiMAX a viable network alternative and this helps in the development of mobile WiMAX. The applicability of MIMO technology to all wireless communication systems is the same. However, in WiMAX 802.16e system, there is the ideal combination of MIMO and OFDMA. As MIMO has antipathy fading capacity, but it cannot control selective fading of frequency and that is why other systems would adopt an equalization technique to solve the problem of frequency successfully.

The future generation of the mobile communication system will require higher frequency spectrum rate and where OFDMA has limited ability to improve the frequency spectrum utilization but when combined with MIMO the frequency spectrum is modified without the increase the bandwidth of the system. The combined use of this technology offers high data transmission but also higher speeds, reliability and stability of the system and in addition to that guard interval of OFDM has a powerful capacity of anti multipath interference. In this way it releases the seamless network coverage.

2.8.1 Network Coverage

The Transmission loss of WiMAX 802.16e is relatively high due to a higher frequency range, which is higher than other mobile communication systems and the biggest challenge to WiMAX is how to expand the network coverage. The network coverage is expanded and improved with the application of MIMO technology, which greatly enhances the network coverage. Especially in the diversity mode application of MIMO technology increases the radius in a residential area due to diversity gain. Additionally, when in multiplexing mode the coverage radius is increased due to diversity gain, which is obtained with the increase of speed and the edges of the residential area. While in adjustable switching mode the edges of the home area the diversity mode and coverage gain has the identical effect to diversity mode.

2.8.2 System Capacity

WiMAX standard 802.16e and WiMAX 802.16m system have a higher throughput rate with mobility which ensures that the user can access online services anytime. The Mobility features ensure the users are online while on the move. MIMO technology in multiplexing mode multiplies the system throughput, frequency spectrum and the peak speed for each individual user. The proportion of High-order modulation (HOM) is improved and increased when system throughput and frequency spectrum in diversity mode. Additionally, when in adjustable switching mode, the centre of urban area works in multiplexing mode and edges working in diversity mode, which in turn has improved system throughput and frequency spectrum falls between two modes. In a WiMAX system when OFDMA and MIMO technologies are applied provides improved frequency spectrum efficiency and to large extent provides higher broadband speed which has the ability to support high-quality mobile video television services.

2.8.3 Cost

The users who have higher requirements for system peak rate and throughput who are usually based in high-density urban areas, but the capacity is some situation is low in some situations due to the density of the area. When MIMO technology is adopted WiMAX capacity is improved up to 55% and 33 % for downstream and upstream respectively. In situations of restrictive capacity the quantity of base station lowered by 25% approx but when this is compared with multi-antenna technologies, MIMO provides benefits in capacity gain in high-density urban areas and due to that the cost of network construction or expansion is reduced. When we discuss the restrictive coverage MIMO technology increases the coverage radius up to 50 % and also increases the coverage area for single station up to 100% which result in 40 till 60 % base stations under certain coverage.

Implementation of MIMO technology in areas such as suburban and villages the coverages at maximum, which is reduction in the cost of network creation. In addition to that setup and maintenance costs are lower. The AAS antenna requires 4 timeless spaces, then the beam antenna which results in a smaller space. When the comparison is done with old antenna AAS requires a higher number of feeder lines and a wider range of transmission which in turn increases the work quantities. The size of AAS antenna is big, so it requires bigger equipment and higher wind resistance which is not acceptable in many areas with wind problem. In comparison, MIMO requires fewer antennas and a common while the AAS antenna is heavy, requiring ±45°dual-polarized antenna which is enough to support 2×2MIMO. Additionally, the lower conditions of installation space and usage capacity, it is easy to maintain and manage. Which reduces the cost.

2.9 Handover

Handover can be explained as it’s a process which helps and ensures a stable connection to the mobile station (MS) while it's on the move from an area of the one base station (BS) to another base station. While the BS which provides connection to MS is called to serve base station, which is updated when Mobile Station is Moving from the area of one BS to another BS. The new base station BS will provide services to MS when the handover is completed and that new BS is called target BS. Blow Sections will provide information and overview available in a different version of WiMAX standards with the support of full mobility.

2.9.1 Handover In IEEE 802.16E Standard

In the standard (Aquino Santos, 2014) three types handovers are identified. Hard Handover, Macro Diversity Handover (MDHO) and Fast Base Station Switching (FBSS). In WiMAX systems, Hard handover is obligatory while the other two types of handover are optional.

2.9.2 HARD HANDOVER

Hard handover can be described as a handover where MS establishes a connection with just one BS and all the connections with existing BS or serving BS is disconnected before a new connection is made to target BS and there is a limited time interval where MS has not connected to any BS. The handover process is started after predefined channel parameters such as signal power from neighbouring BS crosses the same parameters from serving BS from a neighbouring Base Station moves over the same parameters from the serving Base Station. This process is shown in Figure 2.0.4

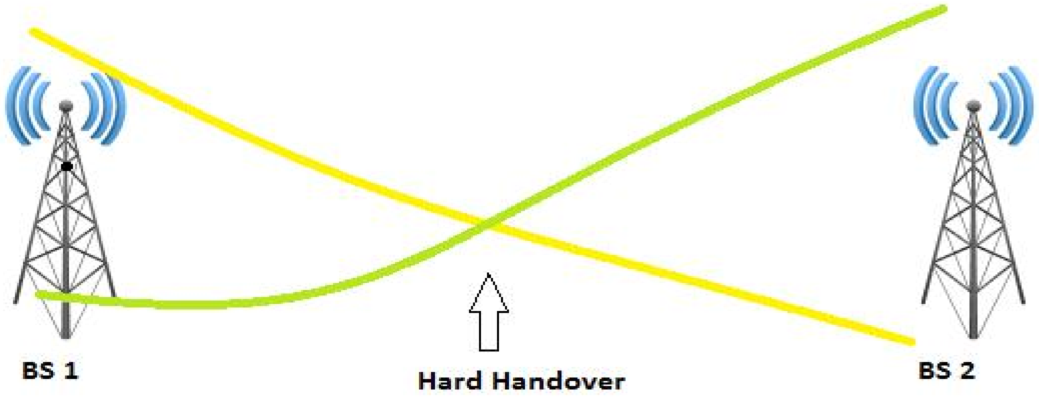

Figure 2.0.4 Hard Handover

The hard handover has limited complexity and very simple, but it results in higher packet loss (Ben-Mubarak, et al., 2009).

2.9.3 MACRO DIVERSITY HANDOVER

Microdiversity handover is abbreviated as MDHO and it is a type of handover supported by both MS and BS while in some publications which are mostly focused on UMTS and LTE (Ekström, et al., 2006) noted as active set, while in (Holma & Toskala, 2001) & (Lin, et al., 2004) it is maintained by the Mobile Stations and Base Stations. During the handover procedure, a diverse set is a list of Base Stations are involved. This set is maintained by Mobile Stations and Base Stations. This is updated via Medium Access Control management messages (Aquino Santos, 2014). The messages which are used for transmission are usually based on Carrier to Noise plus an Interface Ratio level of Base Stations where it depends on the two thresholds defined for additional in deletion of a BS to create diverse set. The diverse set includes addition and deletion of thresholds with additional downlink channels descriptor message (Aquino Santos, 2014). For each MS The diversity set values are defined which continuously monitor all BS stations and diversity set selects an anchofrom and diverse the anchor in BS is of Base stations from the diverse set. The Anchors are registered synchronized and authorized by MS and also MS performs the ranging and monitors a downlink channel of anchor BS for control information. The Mobile station ensures the communication and simultaneously communicates with anchor BS and all active BS stations in the diversity set as shown in figure 2.0.5

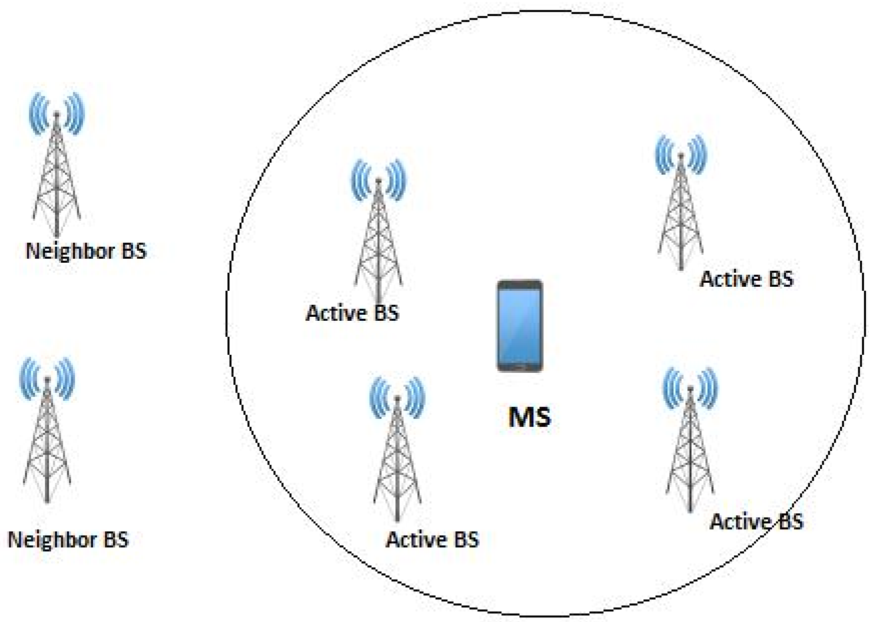

Figure 2.0.5 Macro Diversity Handover

The diversity combining can be done by Mobile Station when two or more Base Station transmits data in the downlink direction. In the downlink direction, two or more Base Stations transmit data to the Mobile Stations such that diversity combining can be done by the MS (Hottinen, et al., 2003). While in the uplink direction, Multi BSS receives the transmission of

MS and in that way, the selection of diversity information is performed (Yue, 2000). The base station, which is identified as neighbour BS which can also receive the communication with MS and other BS stations, but still the signal level received by the Mobile Station to the Base Station is not enough to add this Base Station to diversity set.

2.9.4 FAST BASE STATION SWITCHING

Fast base station switching (FBSS) closely resembles MDHO where the diversity set is established by Mobile Station and Base Station but in contrast to MDHO. The mobile station transmits with anchor Base Stations for every type of uplink and downlink traffic including the management messages. When a mobile station is connected one Base station the diversity set will only hold BS which is termed as anchor Base Stations, where anchor Base Station can be changed on the frame to frame basis which depends on the Base Station selection scheme. Which can be explained that each and every frame will be sent by different Base stations in diverse set and the anchor BS procedure for updating is based on the same principles as the diversity set update.

2.10 Handover in Standard IEEE 802.16J

The standard IEEE 802.16e explains a handover only between BS stations and it does not use the idea for RS (Relay Station) and the main objective of RS station and its implementations in WiMAX is the main objective of IEEE 802.16j standard which was released in June 2009. The RS stations can be defined as Base Station, which can be used to extend the coverage of a Base Station or to increase the capacity in a certain area (Wei, 2006). Two types of RS stations are defined one is called Fixed RS and the Second one is called Mobile RS. The Fixed RS is fixed install which is located at one location permanently whereas the mobile is designed to be installed in moving objects such as vehicles, buses and trains (Chou, et al., January 2006). The connection of RS station to the network is done via radio, which means there is no fixed or hard connection to the backbone and these systems relay from a capability point of view which can be distinguished as centralized and decentralized relaying (Hoymann & Klagges, 2007). There are different scenarios mentioned in (Lee, et al., 2006) where the handover is described as it should be differentiated according to serving Base Station, access station and target stations as shown in figure 2.0.6 . There are two types of handover which are distinguished as inter-Base Station handover and intra Base Station handover. Where the inter Base Station handover means the handover between the cells of different Base Station while the intra Base Station handover is called where Mobile Station performs a handover in the area of one Base Station. The connection to a network via RS station is called multihop communication where multi stands for the number of parts between as MD and its Serving BS

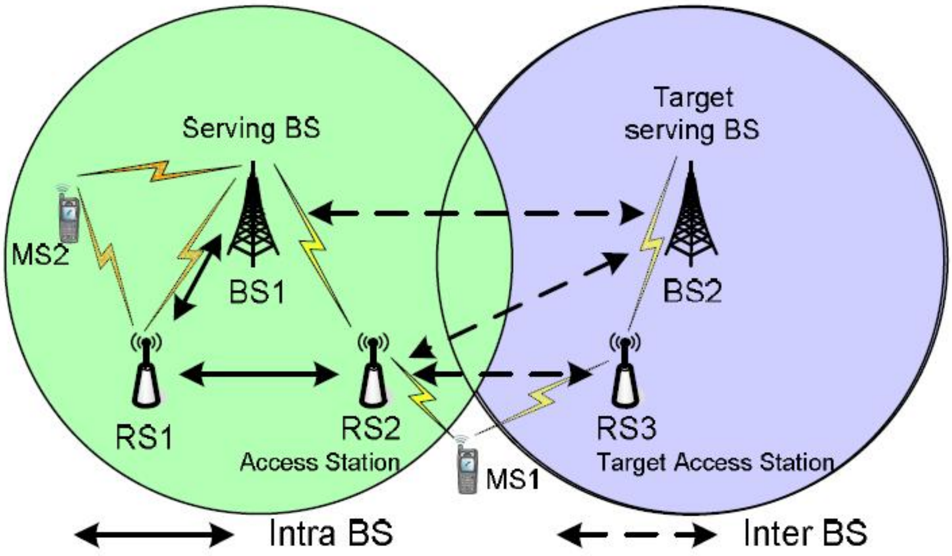

Figure 2.0.6 Inter-BS vs. intra BS handover (Bečvář, 2009)

2.10.1 Handover in Standard IEEE 802.16M

When consider the Standard IEEE 802.16m so we can clearly identify that this standard comes in the middle of the standardization process and there are several publications trying to define the requirements of the target system (Cudak, 2014). The methodology and for evaluation of simulation for proposed techniques (Srinivasan, et al., 2008) which system descriptions and a working version considered as a working version of the final standard (Lee & Ihm, March 2009) & (Srinivasan & Hamiti, 2009) are available. The main Aim of this version is to ensure an advanced air interface for operation in licensed bands. This standard should set up a system for performance enhancements which provide a needed support for future services which is specified IMT advanced Generally, the main aim of this version is to provide an advanced air interface for setup in licensed bands. The standard should configure a system with performance enhancements necessary to support future services and applications specified by IMT-Advanced. Where the standard IEEE 802.16m where the handover procedure is compatible with all old standards (Srinivasan & Hamiti, 2009). The handover procedure is improved, especially then handover time is reduced, which is also called handover latency or handover delay.

2.11 Handover In WiMAX

The main idea behind handover in WiMAX network is explained as (Aquino Santos, 2014)& (Zhang & Chen, 2007) where RS station implementation which leads to modification of the handover procedure as there is no wired connection between BS station and RS station. The decision for handover is based and should be based on the new metric, which considers specifies RS station. For examples such as enhancements relay path and access station, which is based on algorithms considering multiple QoS conditions (Li & Jin, 2009). Radio Resource Cost (RRC) (Mach & Bešťák, 2007)or Expected Link Throughput (ELT) (Shrestha, et al., 2007). The Idea of hybrid handover in multihop radio access network with RS stations which is addressed in (Ghassemian, et al., 2005). In this publication discusses and compares the reactive and proactive handover approach from an overhead point of view and higher end modifications of the handover procedure considering RS stations are presented in (Lee, et al., 2006), where this paper further introduces and describes the handover procedure for networks with RS stations where overhead is reduced in scanning . The scanning overhead reduction is done by joint transmission of scanning requests and reporting messages from all the MS stations and access stations.

CHAPTER 3: LITERATURE REVIEW

3.1 Introduction

WiMAX is expected to provide network coverage over large distances at high throughput conditions. The modified features in IEEE 802.16 standards, includes flexible sub-channel and MIMO systems which have upgraded WiMAX support up to 128 Mbps with a bandwidth of 20 MHz (Srinivasan, et al., 2008). The continuing demand for high-speed access, which is cost-effective, easy to deploy and provide high bandwidth even in the last mile. WiMAX is designed to ensure and provide broadband metropolitan area network and the biggest feature of WiMAX is it is able to provide service in low infrastructure areas with low maintenance cost. The main advantages of WiMAX technology include the ability to provide services in areas with poor infrastructure deployment and high scalability but with these advantages, there are some challenges which researchers trying to solve, to make WiMAX stable and more reliable broadband wireless network. This thesis is also an effort to solve the problem of handover delay in WiMAX. This chapter will discuss the previous work done in WiMAX, while concentrating more on the work done in the field of handover delay in WiMAX. Where literature review will provide detail analysis of a complete set of paper which is applied to WiMAX and Handover delay in WiMAX and this can be sub-divided as below

- WiMAX as Communication Network
- Mobility in WiMAX
- Handover Delay in WiMAX

3.2 WiMAX as Communication Network

WiMAX is also defined as Worldwide Interoperability for Microwave Access which was initially designed to provide a data rate of 30 to 40 Mbps which was later updated to 1Gbps for fixed stations. WiMAX is emerging technology which is considered as an alternative to Cable, DSL and 4G in Wireless Man form.

(Abichar, et al., 2006) Studied and discussed WiMAX technology and explained that a wireless network which include both business and private customers which upscale the network into a size of metropolitan. In addition to that it discussed the importance and ease of install in areas which have been destroyed in a natural disaster such as hurricane where all other communication systems has been destroyed. WiMAX network can be set up to ensure recovery missions are able to communicate including the use of WiMAX as a backup to the wired network. The main limitation in the study was that WiMAX was considered as a temporary solution while WiMAX can be implemented as permanent solution for mobile communication in a particular area.

An interesting study by (Shen, et al., 2007) which purposed four basic architecture integration for EPON and WiMAX. The study suggested that both of them are complementary. The integration process is described in such way where EPON is used as a backbone to interconnect multiple WiMAX base stations, which take benefit of high-capacity fibre communication and with mobile as non-line of sight (NLOS). In addition to that the study discussed the basic architecture and other relevant operational issues which in turn proposed the integrated architecture. They suggested that the design and operational issues using EPON and WiMAX provide promisable resize options which can reduce the overall design and operation cost considerably, while providing reliable cost-effective network. The limitation of this study is that, the studied integration architectures consider only the fundamental EPON and WiMAX systems. While there should be consideration for higher access bandwidth.

In a study conducted by (Teo, et al., 2007) defined a wireless standard, which introduced (OFDMA) Orthogonal frequency division access, which enabled broadband services to move an object at speed up to 120 kmph. This model made WiMAX network in close competition to wireless local area Networks and 3G networks on network area and data rate. In addition to that, it presented Mobile WiMAX standard, which was deployed and it helps in creating and supporting standards for Multihop relays in WiMAX network. As WiMAX was gaining interest many other people started thinking about WiMAX as an alternative and the interesting point of this study was creation of WiMAX model which brings a change in broadband technology which we have now.

In a study by (Khan & Ghauri, 2008) where they have defined how best WiMAX can be understood and defined. The study pointed out that we can make WiMAX more better once WiMAX model is developed and in this paper discusses in detail the model building process. The developed tool was used and tested in WiMAX under different conditions. The developed model was used in research conducted in different areas of WiMAX the standards such as IEEE and ETSI has been developed from this model. In November 2007 Mobile WiMAX was successfully implemented by ITU and later it became one of major international cellular wireless standard, which provided more cost-efficient data transfer than 3G. This study is limited due to it don’t include the components of the MAC layer and a complete end to end WiMAX system that could be built based on this model.

(Wang, et al., 2008) studied and provided very detailed insight on functionality of WiMAX at different conditions. These conditions are important for proper and efficient data transfer such as configuration channel conditions, which were discussed in this paper including detailed overview about how WiMAX evolved. The wireless industry has already started the evolutionary process toward more advanced mobile WiMAX systems. The evaluations include a project in the WiMAX Forum with minor revisions to the 802.16e specification and a project of the IEEE 802.16 working group for developing a more advanced 802.16M standard. This article highlights several key requirements and techniques of the ongoing mobile WiMAX evolution.

(Etemad, 2008) Described that WiMAX IEEE802.16M can enable low-cost mobile internet applications which can be access interface between mobile and wired interfaces. In addition to that the study defined that mobile WiMAX sums up, but OFDMA and advanced MIMO, which exceeds the capacity of existing networks and WiMAX as 4 generation mobile network solution. This study of Mobile WiMAX has defined the technology evolution roadmap for the next few years also discussed IEEE802.16M as next generation technology. The combination of mobility and the Internet enables new killer applications and low-cost service models, making such services available to a wide range of embedded retail devices, including consumer electronics are expected to bootstrap the global adoption of technology in the next few years.

In a paper published (Vaughan-Nichols, 2008) discussed mobile WiMAX IEEE 802.16M and describing WiMAX ability to do high-speed mobile communications and described it as a mobile solution which can support and compete with Cellular and Wifi and even technologies such as DSL and Cable. In addition to that the study described IEEE plan for making WiMAX standard called IEEE 802.16M, which offered data rate of 100 Mbps for mobile devices and 1 Gbps for fixed networks which were fully adopted in 2012. The limitation of this study is, that it didn’t discuss WiMAX QoS and mobility problems.

(Li, et al., 2010) the study discussed WiMAX standard 802.16M and 3GPP LTE-Advanced mobile data networks, which are evolving and targeting 4G wireless systems. In addition to that, the study defined the use of Multiple inputs and multiple output (MIMO) antenna which is playing a higher role in 4G conditions. According to this paper the application of MIMO is the most important improvement of 3G and 4G systems and which increases the conventional point to point link but also establishes downlink multiuser MIMO. The study also described that large number of MIMO techniques which have been especially developed for different links and a different number of channels. This study also provides a detailed description of MIMO techniques used in 802.16M and 3GPP LTE/LTE-Advanced and identified WiMAX as the future of wireless broadband. While this study also fails to discuss the mobility problems which is the biggest problem in mobile WiMAX.

(Ahmadi, 2010) Wrote detailed study of WiMAX standards and also presented the new standard IEEE 802.16M standard, which is also called WiMAX-2 and provided detailed top down approach and explained in detail the algorithmic descriptions together with explanation of principles of individual air-interface protocols and network components.

Another interesting study where (Aldmour , 2013) described the importance of WiMAX and LTE for future communications systems. The study pointed out future directions for wireless systems and in addition to that reviewed evolution of WiMAX and LTE. In further discussion the study identified that WiMAX is the only wireless technology which can serve the future communication needs and pointed out that the need of further research which is needed to solve the problems existing within WiMAX performance and QoS. The study is limited as it fails to suggest solution to WiMAX mobility problems

In similar way (V. Gawit & D. Ghuse, 2015) studied and discussed the rapid growth and need for Wireless broadband networks and mobility, which is needed for seamless communications. They discussed the possible solutions and studied the Security factors within mobile WiMAX. They also described issues related to Security and mechanisms for encryption and privacy management within WiMAX. In addition to that the study pointed out the importance and benefits of WiMAX and its use as commercial alternative to other next generation wireless networks.

An Interesting study by (Manzoor & Kansal, 2016) studied the effect of digital values in WiMAX specially the effect of BER. In addition to that this study puts forward the idea for using a code system to enhance WiMAX performance. This study points towards the use of better channel coding technique to enhance the performance of WiMAX to support broadband networks. As of now, this paper gives us an idea that which code should be applied to a WiMAX system for a required performance. From the results, discussion we come to the following conclusion that RS codes and BCH codes are a good competition to current popular LDPC codes and convolutional codes. The study is limited due to limitation of better channel coding technique where the performance of WiMAX system could be greatly improved which is our ultimate goal.

In a similar way (Lin, et al., 2016) conducted a study where he considered the resource allocation problem in the downlink broadcast of massive amounts of Relay-Aided Downlink Data Broadcast in LTE-Advanced or 802.16m WiMAX-Based Wireless Networks. Where the main objective was to identify a subset of mobile stations and to allocate an appropriate amount of resource to each of them. This study provides excellent direction for further research and in similar way lacks the spatial reuse and interference issue in addition to that other limitations include the carrier aggregation and call-admission control.

An interesting study by (Chakrabartty, et al., 2017) where WiMAX IEEE 802.16m is tested under concatenated coding technique for error correction and noise correction in order to reduce noise. The performance parameters in in term of Bit Error Rate (BER) with Signal to Noise Ratio (SNR) are done by considering concatenated coding over different channels with MATLAB simulations. The simulation results show better results for various modulation schemes, but the limitation of this study is the suggested modulation cannot be used in long distance wide band communications.

(Manoj, et al., 2018) studied relay selection algorithms on performance metrics for different mobile standards in WiMAX such as IEEE 802.16e Mobile WiMAX, IEEE 802.16j MMR WiMAX, IEEE 802.16m. The performance metrics which were investigated were SER and channel capacity. The study identified relay selection algorithms such as max_min and threshold based harmonic mean SNR algorithm. The limitation of this study is the lack of different power allocation techniques along with Section algorithm.

3.3 Mobility in WiMAX

Mobility or mobility management is one of the basic prerequisites for any large scale wireless network, whether it's 3G, GSM or UMTS network. The basic functionality of this network is to track the user's devices and allowing services such as calls, SMS and data transfer. Understanding the importance of this property and implementation of this feature in WiMAX has been the goal of many studies for many years. One such study (Agis, et al., 2004) described the WiMAX standard IEEE 802.16 as fast emerging broadband which is capable of data transfers in multiple of MBs with throughput which can support any kind of wired and wireless mobile operation. The same standard also describes its flexibility which supports both licensed and unlicensed bands. In addition to that the study described its scalability and explained that the mobile services are based on OFDMA (Orthogonal Frequency Multiplexing and Multiple Access) which a large group of network operators expected to deploy in systems in License Bands below 11 GHz but acceptance and deployment of mobile 802.16 depends on the development and adoption of open and extensible air -air structure. The study also described 806.16 architecture version and the WiMAX certification process. The set of ongoing activities outlined in this article, a PHY and MAC layer specification that unites the market behind a common set of standards, a flexible end-to-end network architecture which is coupled with a coherent service vision. An efficient certification process that enables interoperability, are key enablers for realizing the Mobile WiMAX. The study is limited as it failed to discuss the QoS problems in WiMAX due to handover delay.

To further describe the need and implementation of Mobile WiMAX (Chang, 2005) studied the mobile IP based wireless systems used in the Metropolitan Area and he describes the importance of mobility and explains its importance of mobility in Wireless broadband networks. The study also discussed the use of the WiMAX IEEE 802.16 standard for building metropolitan network and described the importance of mobility providing mobile broadband solution to consumers who are not satisfied with Wi-Fi and 3G networks. In additional to that the study mentioned complications and challenges to mobility in the metropolitan network and discussed the lack of wireless infrastructure to provide network services to fast moving users. The study proposed mobility management scheme which is based on micro-mobility of hierarchical integration. Where this scheme showed higher performance, fast and vertical handover at higher traffic load and based on that he describes how to make and design next-generation wireless networks. The study is limited due to lack of QoS issues in the proposed mobility management scheme.

The researchers started to work on handover schemes to make WiMAX more stable and in one such study (Huang, et al., 2007) studied the bandwidth reservation scheme for mobile WiMAX and discussed the different mechanisms to avoid connection dropping in cellular communications also discussed the handoff events which happen at a higher rate when on a

4G WiMAX network then older cellular networks. In addition to that, it suggests a self-adaptive bandwidth reservation scheme which uses probabilistic mobility and prediction to calculate the bandwidth required which is supposed to reduce the forced Handover. While discussing the simulation results which shows the performance and call blocking probability. The limitation of this study is the lack of feasibility in applying intelligent tools such as neural networks, fuzzy logic and genetic algorithms into the proposed scheme to further improve the accuracy of the motion prediction for the mobile station.

In an another study of handover mechanisms (Riato, et al., 2007) where the impact of Physical/Mac Layer algorithms on mobility in WiMAX systems are discussed and explained. The WiMAX standard 802.16 was developed for applications which require high QoS in networks where both low and high mobility users are active at the same time and MAC and Physical Layer Algorithms are needed to provide support for both low and high mobility users. Additionally, it discusses the impact of user mobility on design and performance on WiMAX base stations. The study also discusses the simulation results which provide an indication where the maximum cell load is achievable for multiple mobilities and QoS profiles. Schedulers analysis highlighted the significant performance gain AMC allows and the limited conditions under which it can be achieved. In particular, the gain has been proved to be achievable for delay tolerant services (NRTVR and BE) and for static/pedestrian users only which can also be considered the limitation within this study.

(Chang & Huang, 2007) Studied fast and Secure mobility in broadband Wireless networks and described the support of next-generation wireless networks for applications such as VOIP and Video calling and also described the mobility features of this network which allow mobile users to move freely. In addition to that also discussed the need for cross-layer design and cross function optimization which is needed to improve the delay in broadband wireless networks including the use of handover algorithms in MAC layers. The very important factor of fast key exchange and fast authentication, which helps in reduction of authentication time which is needed to network re-entry. It is desirable to compare the technology specific procedure with the technology independent procedure and find out the fundamental differences and this is where this study is a limited and a detailed performance analysis of these two procedures would be an interesting addition to this study.

While discussing integration a study by (Taaghol, et al., 2008) described the integration of WiMAX with 3GPP networks and explained the importance of developing solutions which can easily be integrated and deployed in the current infrastructure. Additionally, it explained the detailed procedures and architecture which is needed for the integration. The study also discussed the handover mechanisms which enable mobility between mobile WiMAX and other systems such as 3GPP, UTRAN or GERAN. It suggested a Novel handover mechanism where the mobile terminal doesn't need to support connection with both WiMAX and 3GPP at the same time. That’s why it has less severe RF coexistence problems which improve handover performance. It also provided a detailed overview of both WiMAX and 3GPP network setup and technologies used. The study is limited due lack of QoS analysis with Novel handover mechanism.

In the same way, another study by (Munasinghe & Jamalipour, 2009) discussed WiMAX and 3G integrated data networks which are tested for mobility management and performance evaluation. It purposed a network architecture for interworking heterogeneous all IP networks with detail analysis for its performance. This framework freely establishes any 3G system such as UMTS (Universal Mobile Telecommunication system) or CDMA 2000 systems to be internetworked with WiMAX for providing broadband wireless systems. In addition to that it discussed and universal coupling mediator which will enable two different systems to provide users with broadband data connection while achieving mobility. RIVERBED was used to evaluate and investigate the handover delay, packet loss, jitter and signalling cost. The study is limited in developing a common AAA framework and facilitating multiple network accessing.

(Ivan & Muquet, 2009) published a study reduced complexity feedback equalizers to provide high mobility support in WiMAX and also described the performance of WiMAX in the fast varying environment, which is optimal in normal static channels. The study described normal single tap OFDM equalized which cannot support at the normal speed of 60kmps and later they provide the study of WiMAX in context before emphasizing on decision feedback equalizers. Based on the results and analysis, it purposed new DF equalizer which uses sliding window which will provide a better tradeoff between complexity and performance. The study lacks in the impact of the channel estimation on the performance of that class of receivers.

(Balakrishnan, et al., 2010) The published and discussed mobile relay and group mobility within 4G WiMAX relay. The study described the relay which provided a very important feature for IMT-Advanced systems and provides descriptions of relay architecture which was defined by IEEE802.16m and 3GPP LTE. The relay is connected to the specific Base Station and that becomes a unit of the fixed access network. Additionally, it mainly points out and uses three different cases where mobile relays offer different setup options and proposes an advanced handover mechanism which provides relay based group mobility which is used for extending IEEE802.16m. The study described in detail the architecture of handover for mobile relay pointing out C-plane and U-plane which is required into support mobility of mobile stations. The study lacks in description and use of multihop relay, client relay, cooperative relay and mesh relay built upon 4G cellular network architecture. Mobile relay along with other relay enhancements are promising technologies for better network performance, broader applications and more satisfying mobile computing experience. The study lacks in future suggestions to further verify mobility conditions in WiMAX.

(Fernandes & Karmouch, 2012) Published & discussed the vertical mobility management in wireless networks. As Mobile data hungry application are forcing wireless network systems to improve handover services and devices. Additionally discussed a detailed overview of the mobility management setup for providing a seamless handover of mobile devices in mobile wireless networks. It provided a design rationale for particular architectures in detail and explaining their goals, assumptions and requirements and presented a new base setup which is called Context-Aware Mobility Management System (CAMMS) and which is a cross-layer and context-aware and interactive approach to providing a seamless handover of services and users. The study lacks in QoS analysis of CAMMS system for handover.

There was another study which was done by (Shalini & Sundararajan, 2013) where mobility problems were discussed and performance analysis done on the the group handover with group leader. In addition to that the study found the throughput and jitter affecting signal performance to be minimized while using go up mobility handover. In further discussion, it was identified that mobility management requires further attention from the researchers, which is also considered as a limitation of the study.

An interesting study done by (Sikhwal & Rathi, 2014) studied the vulnerabilities and Security issues within WIMAX and suggested possible measures to make WiMAX more Secure. In addition to that this study discussed the problems currently faced by mobile WiMAX and they pointed out that in addition to the problems of Security the problems of mobility has to be solved if WiMAX should be used as a next generation broadband network. The study lacks in providing comparison between WiMAX and WiMAX performance metrics. Which would result in better understanding of WiMAX.

In an interesting study by (Sikhwal & Rathi, 2014) where they studied the various vulnerabilities and Security attacks on WiMAX network at PHY layers. The attacks such as jamming on PHY layers. This study accepts that the recent changes and Security solutions in IEEE 802.16m has solved many issues , but some still exist and need to be considered carefully. This study suggests a Security solution which is better as compared to other solutions. WiMAX is still under development and need more research on its Security vulnerabilities. In the near future, when WiMAX achieves a maturity level, it would have a great opportunity to be a successful wireless communication technology. In addition to that this study described many Security issues in WiMAX , where there is no complete solution suggested for these problems and which can be considered as limitation within this study.

In a similar fashion study by (Fahoud & Lobiyal, 2016) considered and studied WiMAX handover performance . The study used QuelNet to do simulation and analysis and tested random mobile scenario and DEM scenario. The obtained results indicate that the performance of handover in terms of number of handover performed and packets dropped is affected by the load of managing messages, mobility model of the moving nodes and the variation of terrain data. Depending on this analysis, we see that handover is effected by the mobility pattern and terrain variation. The study is limited due limited consideration of delay, jitter and packets dropped to support real-time applications.

(A. Hamada , et al., 2016) Proposed interworking model and proposed model integrates LTE, WiMAX and WLAN by using IMS compatible architecture for real time session negotiations for seamless service provisioning. This study also presented SIP and MIP-SIP handover mechanisms and compared as potential mobility solutions for this architecture. This study expresses limitation in solving issues concerning authentication and authorization for IMS networks including other handover mechanisms which needs to be applied to achieve seamless mobility support to mobile users for real time applications.

In a similar way to find a solution for mobility issues (Gilani, et al., 2017) studied The emergence of the SDN/NFV for solving the mobility issues in the traditional WLAN and WiMAX-2. The study proposed an integrated mobility management scheme which considers both seamless handover and load balancing. The study shows the process for creation of LAP, assign LAP and make the migration of LAP according to a real-time decision algorithm that was executed at the SDN controller. While the study is very interesting but limited in the mobility management scheme needed for a power saving module, and location awareness.

3.4 Handover delay in WiMAX

Handover delay is one biggest hurdle in the WiMAX path to achieve its deserved place in wireless network systems in a paper published by (Roy, et al., 2006) described the QoS integration model for Wireless Lan and WiMAX. The study purposed mechanisms which supports best connected (ABC) quality of service (QoS) for applications which are connected to heterogeneous networks and these networks consists of IEE802.11e WLAN and IEEE 802.16d, IEEE 802.16M for WiMAX access networks. While the network equipment is configured for both setups WLAN and WiMAX, which provides access configurations. It also purposed that network will provide a generic virtual link which is placed above WLAN and WMAN Mac layers. This choice of network is dynamic and based on QoS parameters like Throughput packet loss and delay. The study lacks in providing suggestions for improvement in QoS in WiMAX.

(Chen, et al., 2007) studied Cross-Layer Fast Handover Scheme for mobile WiMAX and discussed the WiMAX standard IEEE 802.16e 2005. The study explained why it can bring wireless broadband to a new level which can support nomadism. The study also discussed the effect of delay due to handover within mobile WiMAX and real-time continuity sessions for application which is due to Layer 2 scanning /ranging and also due to re-entry procedure, which causes delay of hundreds of milliSeconds which exceeded the requirement for real-time services. Additionally, it described the way which incorporates information from different OSI layers to speed up the Layer 2 handover. The study lacks in providing solutions to delay which is caused by Layer 2 scanning /ranging.

In a similar way another study by (Pontes, et al., 2008) discussed the handover management in WLAN and Mobile WiMAX. Additionally, it started efforts done by researchers to improve the wireless technology and also emphasized that handover management is still one of the major challenges which are needed to be solved in order to achieve seamless integration. In addition to that, the study also presented IEEE 802.21 as one of the new emerging standards which are targeted at providing the basic structure for media independent handover. While the limitations in this study is the lack of MIH support of Multihop heterogeneous networks.

(Jo & Cho, 2008) discussed cross-layer vertical handover in this paper he discusses the inter-networking of mobile WiMAX and 3G networks which is needed to provide seamless wireless connectivity on a wide area. This paper proposes a cross-layer optimization, vertical handover between WiMAX and 3G. Which mainly due to L2 (layer 2) and L3 (Layer 3) messages due to signalling for vertical handover, which is analysed and processed to optimize the handover procedure. The Detailed simulation discussed in this paper shows proposed scheme increases the efficiency of vertical handover in between WiMAX and 3G networks

In the same way, handover was defined as the main problem by (Yang, et al., 2008) published on vertical media independent handover decision algorithm between Wi-Fi and WiMAX networks. The study also discussed hybrid network designed with combination of Wi-Fi and WiMAX networks, which provided high data rate, but the biggest challenge in making such network work in providing optimized handover decisions. The QoS can be improved by using handover scheme called the terminal handover decision in mobile device, which should be equipped with multiple radio interfaces. IEEE 802.21 tries to provide background for the MIH (media independent Handover) and MIH supports seamless handover in Hybrid networks. The simulation results pointed out that the suggested algorithm resulted in lower handover times and better mobility. The study is limited in performance measurement of the vertical handover decision algorithm and solid mathematical modelling in the integration of UMTS, Wi-Fi and WiMAX heterogeneous network environment.

(Song,, et al., 2011) discussed effective Mechanisms in Heterogeneous networks and explained that the next-generation wireless networks will be able to coordinate and integrate different communications systems. The study explains the biggest problem in providing a handover mechanism. These mechanisms provide link level triggers which provide information that enables handover decisions. Additionally, it proposed a predictive handover framework which utilizes neighbour network information which generates link decisions triggers. These handover mechanisms appropriately finish before the current link goes down. The required handover time is given neighbour network conditions which predicts link triggering and handover start time, which is determined dynamically to reduce the handover cost. The analysis described showed that this method increased handover performance. This research lacks in performance evaluation of the analysis by using network simulation tools, such as OPNET or NS-2.

In relation to handover schemes (HAO, et al., 2009) described and studied a velocity adaptive handover scheme using mobile WiMAX systems based on IEEE 802.16e. Additionally, the study explains that in order to have a stable mobile WiMAX network, the handover schemes should be created, designed and adopted and hard handover is compulsory. As data communication should be paused during handover that’s why handover delay causes severe degradation in performance while the existing draft standard is considered as only received signal strength while triggering handover initiation. To solve these limitations and in addition to that, it proposes a velocity adaptive handover scheme which adopts dynamic handover threshold according to different velocity and simulation results which validate the efficiency of the proposed mechanism. The study is limited in QoS analysis of the suggested handover scheme.

(Lu & Ma, 2009) proposed and presented a study on location awareness and fast handover for mobile WiMAX. As WiMAX is wireless network considered for broadband wireless communication. The mobility support which can handle the handover for connectivity of services is required and needed. The entire process which has the scanning process selects the suitable neighbour base station which targets base stations and network re-entry process to establish the new connections to target stations. Additionally, it proposed a refined handover scheme which included the scanning re-entry, which is supposed to lower the interruption of data transmission in the handover. This scanning scheme is also called location-based scanning, which is called early transport CID update and this reduces latency within the connection established by earlier transport CID. The simulation results showed the proposed scheme has significantly reduced data transmission delay. The QoS provisioning for real-time traffic during handovers is considered as limitation of this study.

To provide seamless handover and ensure mobility (Khan, et al., 2009) published and provided a detailed study of handover between WiMAX and UMTS. It discussed challenges in providing seamless services to end users moving from one network to another and explains how critical it has become. In addition to that, it discussed intersystem handover which can be a solution to maintain the continuation of an ongoing session and IP management and to resolve this issue both application layer and network layer should be the point of focus and proposed a method which uses both IMS and MIP at the same time to achieve seamless handover. The study lacks in handover analysis to verify the performance improvements.

(Neves, et al., 2009) Published a study where it discusses and explaines media independent handover framework. They explained the changing and-and wide range of overlapping radio access and also explained in future all mobile devices would be multiple access devices and discussed the need for media independent handover mechanisms to support these mobile devices. Additionally, the study presents a handover mechanism which is based on a media independent scheme to ensure seamless mobility in the heterogeneous environment. The proposed media independent handover framework (eMIHF) extends IEEE802.21 by provisioning, implementation of QoS resources in target radio technology during the handover phase. Network simulation with NS-2 provides and seamless mobility with low delay. The study lacks in considering the speed of mobile device and QoS analysis at different speeds.

In the same way to provide efficient handover WiMAX needs to ensure mobility (Ray, et al., 2010) studied handover in mobile WiMAX and published and discussed next-generation wireless networks for the metropolitan area and using WiMAX as core technology based on IEEE 802.16 standards is considered an evolving fourth-generation technology. The introduction of mobility management in WiMAX IEEE802.16e has enabled WiMAX in competition to existing network technologies available. While better mobility framework mainly depends on achieving seamless handover irrespective of any deployed scenarios. As an IEEE defined new model Mobile WiMAX (IEEE 802.16e) with mac-layer handover management framework with upper layers full-fledged Mobility is not very far to achieve. Additionally, it focused on potential handover related research issues.

(Ashoka, et al., 2011) also studied handover delay and discussed the rapid development in WiMAX due to its ability of Mobile WiMAX to serve large coverage areas per base stations which is the reason for this technology being popular. This ability to serve large areas is also drawback because it supports more mobile stations and these mobile stations would require efficient handover scheme. As Mobile WiMAX currently has a long delay which contributes to communication delays in WiMAX. Additionally the study tried to solve this problem by analysing the performance of standardized handover schemes such as mobile IP and ASN based network mobility (ABNM). The results showed ABNM is more efficient than others and the study pointed out that there is a need for more work in the area of Mobile WiMAX handover delay to enable full capacity of Mobile WiMAX. The research is limited in providing history-based selection of BS and network-based handover to reduce the scanning time and the handover delay in mobile WiMAX.

In similar way another important study was done (Kaur & Kaur, 2013) where mobile WiMAX standard 802.16e is tested and analysed. The analysis done in this study show the probability of successful handover when the mobile station is moving at high speed in addition to the this study discussed and compared the techniques such as forward error correction (FEC) and identified the effect of speed on handover delay and suggested towards the need for more research to improve the handover delay times. The study is limited in providing the use of queues to provide the best performance at higher speed in order to achieve minimum data loss.

Another important study done by (Yadav, et al., 2014) discussed and identified the importance of WiMAX as one of next generation communication technology and also pointed towards the fact of enhancing the capability of Mobile WiMAX standard 802.16e. In addition to that this study discussed the Mobile WiMAX roaming services in metropolitan and regional network in order to support real time mobile services while moving at higher speeds. In addition to that this study discusses a performance analysis of the mobile WiMAX handover at different speeds and identified, handover delay as a problem which needs to be saolved to ensure full mobility in WiMAX networks.

In similar way another study by (Sridevi, et al., 2014) discusses Mobile WiMAX as broadband solution which could support both fixed and mobile networks and discusses in detail the architecture. In addition to that it discusses the promising features of mobile WiMAX in terms of bandwidth, coverage and cost of implementation and maintenance while also analysed the critical areas which is far away from the base station, where the signal is overloading from two different base stations and suggested methods of handover improvement in these areas. This study is limited in Security related issues and also QoS management of the proposed protocol.

In similar way another study by (Mayoof, et al., 2015) discussing the rejection of ongoing connection and identified it as a very serious problem affecting the QoS. In addition to that the impact on performance was studied, which is caused during the handover process within WiMAX. The study pointed out effect of failed handovers which results in retransmission and which in turn results in loss of QoS. The study pointed towards a very important factor in solving the problems handover delay which is the basic foundation to ensure better mobility and higher QoS. The study discusses the need of further research in order to solve the problems handover delay in WiMAX. Which will ensure higher quality of service (QoS) and enable WiMAX as next generation broadband communication network. The limitation in this research study the examination of the WiMAX connection to other wireless networks by considering shorter handover interruption time in which it believes to affect the performance of packet handling while transformation.

In similar type of study (Aldmour, 2013) comparing LTE with WiMAX wireless technologies. The study reviewed the evolution of two technologies such as LTE, WiMAX and WiMAX-2. The study points towards the Integration of WiMAX to LTE and enables its companies to serve their specialized segments with private networks while at the same time offering them the public service. The study is limited due to lack of performance analysis between WiMAX-2 and LTE.

(Abdulhussein, et al., 2015) studied the performance of the handoff process in Mobile WIMAX network. Using OPNET simulator simulation was done and the study showed that the designed WIMAX module used category Rtps is better than module that use UGS and Ertps techniques in terms of Voice over IP (VoIP) rate. In this case handover needs less time to move to the other BS, which was because of the variety of packet data size where it's observed effect can be clarified with increasing data traffic.

In similar fashion (Sufyan, et al., 2017) studied the comparison between WiMAX and WiMAX Release 2(IEEE 802.16m). This study also discusses the properties of IEEE 802.16m such as bandwidth efficiency, lower latency and QoS enhancements, increased capacity for downlink and uplink VoIP, and multi-carrier support and increased Sector/site throughput both at the uplink and downlink data transport modes. While the limitation to this study is the need of enhanced QoS analysis, particularly by implementing the handover schemes of WiMAX 2 at MAC layer.

3.5 Limitation or Gap in Knowledge

The literature review discusses the previous work done in WIMAX, while concentrating more on the work done in the field of handover delay in WIMAX. The literature review provides detailed analysis of a complete set of papers which is applied to WiMAX and Handover delay in WiMAX in latest WiMAX standards IEEE 802.16e and IEEE 802.16m.

(Wang, et al., 2008) and (Balakrishnan, et al., 2010) The researcher reviews the articles which are regarding the use of WiMAX technologies as standard and studies the benefits of using WiMAX IEEE 802.16e and IEEE 802.16m technology as a replacement for 3G and 4G technologies.

Consequently, the review suggests that general guidelines are standard. The researchers classified the review into three different Sections, where the researcher studied WiMAX as a communication system and the researcher took the study of (Li, et al., 2010) Where the study provides insight into WiMAX standards IEEE 802.16e and IEEE 802.16m and also provides complete study into developing a WiMAX model.

The literature about the mobility in WiMAX is researched. The researchers classified the mobility techniques and review the literature based on the classification. The pros and cons of each classification are examined. The researchers studied (Chang & Huang, 2007) which provides the details about mobility problems in WiMAX. The researcher also studies the literature about the handover delay in WiMAX, which is also main aim of this research. In this Section the researcher identifies different handover delay problems. The study of (Pontes, et al., 2008) provides detailed insight handover mechanisms which were the main inspiration for the study while (Lin, et al., 2016) compare LTE and WiMAX and recommended further study in to handover delay.

Finally, the researcher performed a literature survey, including on the latest standards IEEE 802.16e and IEEE 802.16m. The study confirms that there is no properly well defined and complete study, which is mainly directed at reducing handover delay in WiMAX. As many previous studies pointed toward need of more research in the field of handover delay in WiMAX in order to make WiMAX as next generation broadband wireless network with higher Quality of Service.

3.6 Conclusion

The researcher reviews the articles which are regarding the use of WiMAX technologies as standard and studies the benefits of using WiMAX IEEE 802.16e and IEEE 802.16m technology as a replacement for 3G and 4G technologies The literature review also discusses the previous work done in WIMAX, while concentrating more on the work done in the field of handover delay in WIMAX. The literature review provides detailed analysis of a complete set of papers which are applicable to WiMAX and Handover delay in WiMAX in latest standards IEEE 802.16e and IEEE 802.16m for example (Wang, et al., 2008) and (Balakrishnan, et al., 2010). The literature survey done by researcher, including on the latest standards IEEE 802.16e and IEEE 802.16m confirms that there is no proper way defined and there has been no complete study which is mainly directed at reducing handover delay in WiMAX. As many previous studies pointed toward need of more research in the field of handover delay in WiMAX in order to make WiMAX as next generation broadband wireless network with higher Quality of Service.

CHAPTER 4: RESEARCH METHODOLOGY

This chapter describes the procedures, processes and research methodologies which are used in this research. This chapter also provides a description about process model which is adopted and used to design the suggested network model. The chapter also discusses the entire process from a single idea up to complete network model and the methodology undertaken to do different experiments and the choice of simulation tools. The WiMAX network modelling process which is focussed on providing efficient Mobile WiMAX signal with the lowest amount of handover delay and highest QoS. The entire process is subdivided into the following different stages

4.1 Concept Development

Methods in Research, Paradigms, Design and Approaches

In order to understand the nature of research (Hussey & Hussey, 1997) pointed out the need to understand the term paradigm which refers to development of a scientific process based on the principles comprehension and their surroundings which is based on comprehension.

In this research the theory of concept development is used to achieve a number of objectives and aims. Concept development is used in achieving objectives such as

- Investigate, review and understand handover problems.
- Design the WiMAX simulation Model and choice of simulation tool

The concept development is used to achieve above objectives by literature review to create an understanding of WiMAX and Handover delay and creating a WiMAX simulation model and finding suitable simulation tools.

4.1.1 Justification of Paradigm

This justification of paradigm was explained by (Hussey & Hussey, 1997) in detail and they described that there is two research paradigms one which is labelled as positivist and Second phenomenological. The positivist paradigm which finds out the facts of the phenomena and it also avoids a human emotional state, whereas phenomenological paradigm deals with human thought . The paradigm has been explained as Objectivist,scientific , experimentalist and traditionalist which, according to the paradigm is subjectivist in a humanistic and interpretive way.

There has been a classification of paradigm into positivist, interpretivist and critical paradigms (McMurray, 2006). There is a more detailed classification of paradigm which turns into a positivism critical theory and realism (Guba & Lincoln, 1994) . The concept of justification of paradigm is used in achieving the below objectives.

- Develop simulation scenarios to understand and resolve the problem of handover delay.
- Test the effect of WiMAX signal physical factors on Handover delay and Develop simulation scenarios to understand and resolve the problem of handover delay.

This concept is used to develop understanding of the WiMAX handover delay problem, create simulation scenarios and develop a foundation for experiments by understanding the effect of physical factors on WiMAX signal.

4.1.2 Positivism

Being an external researcher, the positivistic paradigm for ontological assumptions of positivistic paradigm. Which is to consider the world from a more objective perspective as the world is being perceived. The existence of reality is differentiated from the observer (McMurray, 2006). Which can be differentiated by natural laws, which can be free from generalisations and the knowledge it holds is important and significant which can be based on observation of external reality. The assumptions for epistemology is more about the study of knowledge and when we discuss the knowledge as what is known to be the positive belief is considered and that is the only phenomena which can be observed and quantified as the real knowledge. The true nature of reality is only uncovered by scientific principles. The use of scientific principles can uncover the real side of reality (Perry, et al., 1997). The researchers usually consider oneself as objective, distant, non-interactive, value and bias-free (McMurray, 2006). The part of the research process is the researchers who are not even part of the research process, but the results in finding that value freedom and theory free (Guba & Lincoln, 1994). While some don't agree with this idea that the knowledge does not value freedom as knowledge, which is a mechanism of self-preservation (Habermas, J, 1970). The main process and goal of methodologies are doing surveys and experiments in order to confirm and disconfirm the hypotheses. Which some researchers accept the methodology used should be objective, especially determining the qualities of the real world (McMurray, 2006).

The theory of positivism helps in achieving the objectives which require to be free from generalisations and the results of these objectives are based purely on reality based on scientific principles.

- Understand the effect of speed and other factors on handover delay in WiMAX
- Choose a Handover algorithm that is best for improving the handover decisions Improve handover decision times.
- Develop analytical model for the new handover algorithm

4.1.3 Constructivism

Constructivism is considered as same as interpretivism paradigm, but the ontological perspective is that there are many realities which are subject to different social interactions (McMurray, 2006). The researchers have personal values, beliefs and attitudes due to epistemology stand and which may be biased when the research is performed where it is subjected to their own understandings (McMurray, 2006). The researcher is also called passionate participant where to overcome the problem of personal bias the researcher should continuously agree with the findings (Guba & Lincoln, 1994). Constructivism is not suitable for any research where there is any connection or correlations about personal or human emotions and thoughts. The data which has been triangulated from different sources and methods to enhance the dependability and reliability of data (Lincoln & Guba, 1985). This theory is used to achieve below objectives

- Test the chosen handover algorithm on latest mobile standards, WiMAX (IEEE 802.16e) and WiMAX2 (IEEE802.16m)
- Analyse and Compare results from simulation, using latest mobile standards, WiMAX (IEEE 802.16e) and WiMAX2 (IEEE802.16m) on QoS parameters such Throughput, Packet loss, Packet delay and Jitter.

As constructivism is considered as same as interpretivism paradigm, but the ontological perspective is that there are many realities which are subject to different social interactions (McMurray, 2006). Above objectives are achieved without involving personal emotions and data is confirmed and verified with different sources to enhance the dependability and reliability of data.

4.1.4 Critical Theory

The critical paradigm and critical theory are synonymous and this theory describes the understanding of the ontological element which was similar to both the positivist and the interpretivist paradigm. The critical theory paradigm is synonymous with the critical paradigm (McMurray, 2006). While the people who are called critical theorists who still believe in reality, but as the reality is subjective and it's views are based on values. The researcher intent is mainly focuses on epistemological aspects where it tries to convince their subjects as to what makes practical sense rather than accepting them on their views (McMurray, 2006). When discussing the issues of methodology, the objectivity has no meaning. While the objectivity is considered as myth and data is subject to researcher subjective interpretation, but this myth is removed by "enlarging insights through action" (Neuman, 2006). In many situations, the Research methodologies are longitudinal such as ethnography where is historical research on organisational structures and processes (Healy & Perry, 2000).

4.1.5 Realism

The paradigm which depends on realism perspective on an ontology element which believes the "real external world is only imperfectly and probabilistically apprehensible" (Guba & Lincoln, 1994). There are a number of realists who accept that there is an actual difference between the real world and various views which is relative to time and space (Riege, 2003). The realism or in other word realism paradigm permits both qualitative and qualitative data collection methods which allow in-depth interviewing ,Focus groups, instrumental care research, survey and structural equation modelling (Perry & Healy, 2000).

4.2 Research Design

The goal of the research is classified into three different parts which are exploratory, descriptive and explanatory (Hart, 1998). In order to find out unknown, the exploratory research was done to resolve an issue which were unknown and has few or no studies at all of the reference (Sekaran, 2000). There are questions such as "how", "what", "when". In such case "where" is asked mostly in exploratory research (Zikmund, 2000). The process of research is usually based and depend on case studies and observation of historical analysis in the form of quantitative or qualitative data (Hussey & Hussey, 1997). Application of this approach is wide which allows gathering information. This research uses this paradigm which helps in quantifying both qualitative and quantitative data, which is very important in this research.

4.3 Data Collection Method

This research uses computer simulation tools as a method of gathering data, where the logic is used as a method to ensure correct model development. Usually, the researchers are interested in the goal called target (Zeigler, 1984). The main idea behind creating the model is to create a target which is simpler to study than the original target. We hope that a conclusions which have been identified in this study and model that will be applied to the target are sufficiently similar. Even though we are keeping the model simple due to our modelling capabilities and the model will be simpler than the target. In the real world, the target is always a dynamic which is changing due to factors such as time and its surrounding environment. The model structure should be also dynamic which is able to cope with these additional factors of the environment. A model can be represented as mathematical equation, A logical statement or computer program and this needs to be examined over time to develop the model over time. There are different ways in which this can be done and one way of achieving this is making use of the analytical method. As model becomes more and more complex, the specification becomes nonlinear such as analytical reasoning which is very hard. In most cases in telecommunications simulation uses only method. The simulation usually means running the model ahead through time and identifying the results.

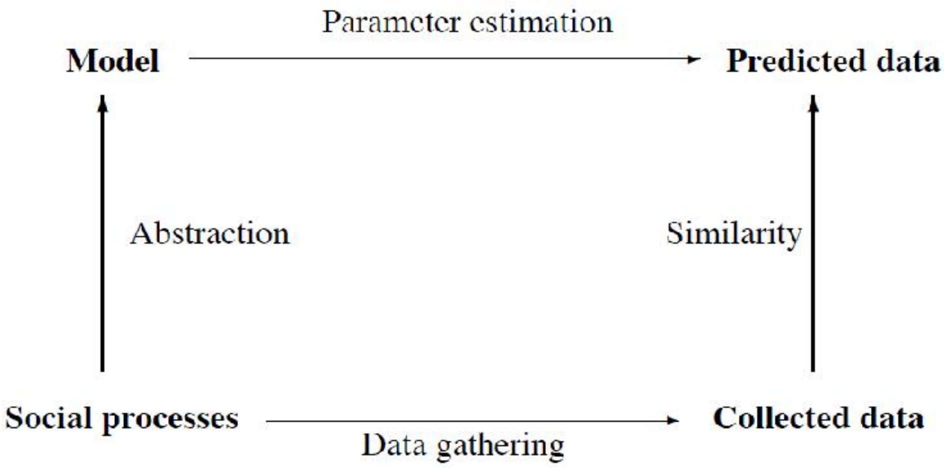

Figure 4.0.1 The logic of statistical modelling as a method (Gilbert, 1993)

4.4 The Simulation logic

When we implement the statistical model, there is very clear understanding about the relationship between model and target as per figure 4.0.2. Where it identifies that the researcher develops a model and it is passed through obstacles from the presumed process towards the target. However, the equations will include some parameters and its magnitude is determined while in the process of estimating the equations.

It is important when the researcher is in the process of developing the model, there will be some data collected in this process and with this data researcher will perform the estimation. This estimation and analysis usually have two steps. The first step would be where the researcher asks questions such as whether the model creates predictions and if they have any similarity to the data which have been collected and the 2nd would be where the researcher has to calculate the magnitude of the parameters under question.

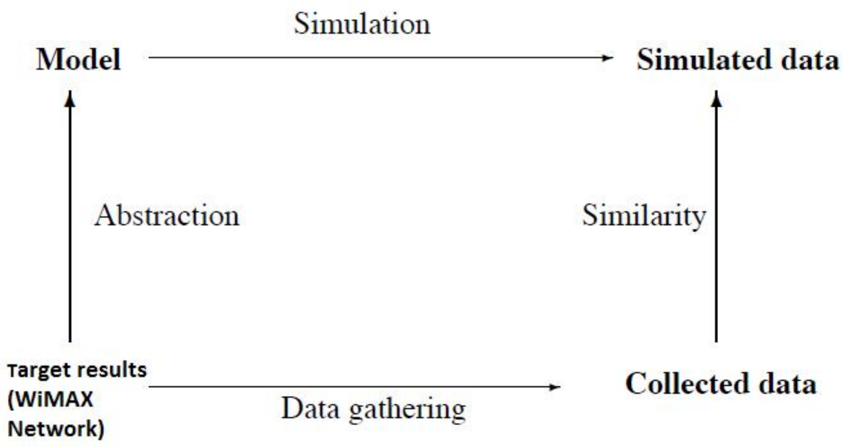

Figure 4.0.2 The logic of simulation as a method in the WiMAX Research

4.4.1 The stages of simulation-based research

Keeping the logic of simulation and basic ideas about simulation in mind. The research is the step needed using the simulation, especially in a network environment where simulation tools are used to test the different parameters. Whether there is specific set of goals and aim which need to be resolved. The steps involved are very simple and obvious and sometimes not simple to carry out and while some steps require less attention, but it is very important to complete the entire cycle. This most important factor is to ensure they are correctly implemented and would require verification or debugging step. The situations where there are complex setups involved it is difficult to remove all the bugs.

The next step would be validation which would ensure the behaviour of the model, which does follow the behaviour of the target system. All models will be a simplification and sometimes big simplification of the target mode and the most confusing and difficult step is, where we need to decide what needs to be left out and what needs to be included. The more parameters are kept out or kept as standard the higher the conceptual leap between the conclusion drawn from the model and their understandings in relation to the target. So the more parameters are included in a simulation which is measured then assumed. Which, in turn, will affect the validity of the conclusions which are obtained. Usually, it is expected that the model which has a minimum number of assumptions, which are applied generally as possible to many different situations. There is always a temptation for researchers to create a model which is more detailed than the research requires. Which increases the work needed such as the labour of data collection, which adds a substantial amount of data which will add more complexity. This would mean that it would be very hard to draw conclusions from the research.

4.5 Building the Actual Model

When the modelling task is completed and the model has been identified, but up till now its only conceptional model and the next important step is writing a special computer program or using available simulation packages and tickets which have been developed to help in the creation of simulations. There are many different points of view regarding how to proceed with this step. Some researchers opt for easier to use package which is created for this particular purpose, but some would like to write own program specifically created for this research which would be the ideal situation. The biggest problem with such solutions would be the time and the skills needed to write such a program. While some packages might provide limited graphics facility and display of output variables. These packages have been used and debugged by previous subsequent users. Here are some features in any simulation package which will make it suitable for being used in this WiMAX handover delay research. These features needed can be described as below.

a) The programming language used should be structured and allow for incremental updates. Which helps in the specification details of the program as the problem is later understood better. Therefore, it is important the programmer can easily move between coding, testing and changing the code. Examples of such languages are Java, Visual Basic, Python or Ruby

b) The programming code should be able to cope with rapid changes in coding and there should be easy and rapid debugging as simulations generate lots of data, therefore, it's very important to ensure there is easy processing of this data.

c) Any simulation tool or program if written should be able to run sensitive analysis and this requires the tool or program to be also efficient.

d) The language used to write the simulation program or tool used should be used previously in similar types of research and the researcher community should be aware of this simulation tool or the language

4.6 The Choice of Simulation Tool or Package

When we look at the evolution of scheduling solutions proposed and used, there is clear pattern visible which shows two parallel views. One view will be leaning towards simplicity and speed while the other one will favour more elaborate alternatives with higher execution time and complexity. Simulations are the only way which helps to compare schedulers which are simple in design and consider a few factors to more elaborate techniques which consider a higher number of variables with higher complexity. There are a number of choices available to perform mobile WiMAX simulation in the market. In the beginning most of the research community used MATLAB to simulate the portions of WiMAX implementation and due to its limitations. Later researchers had to write their own MAC/PHY implementation for end to end simulation tool like NS-2 and RIVERBED. The biggest problem with this implementation in the beginning, but they were not publicly available which forced the researchers to replicate similar conditions for fair and unbiased comparisons of results. In the recent past, commercial and open source solutions started to become available for researcher community. The choice of a simulation tool for this research where the aim is to improve WiMAX handover delay. Below are some of simulation and modelling tools which were reviewed in order to choose the best tool possible, which is suitable for designing, testing and analysis of WiMAX network in question. Below were few simulation tools which were under consideration for this research.

4.6.1 MATLABS / SIMULINK

MATLAB/SIMULINK is developed by the MathWorks, which is based on numerical computing. The name MATLAB stands for matrix laboratory and MATLAB was originally written to provide easy access to matrix software developed by the LINPACK and EISPACK projects, which together represent the state-of-the-art in software for matrix computation.

MATLAB allows matrix control with a scheme of functions, execution of algorithms, creating user combines, and interfacing with programs written in other languages. MATLAB is mainly for numerical count, while an individual toolbox uses the Mu PAD significant engine, which allows access to significant computing capabilities. MATLABS is Model-Based design used for embedded systems Simulink, adds graphical multi-field simulation (MATLAB®/Simulink®., 2017).

MATLAB is considered a performance oriented language more targeted on technical computing, which integrates computation, visualization, and programming in an easy-to-use environment more suitable for problems and solutions which are expressed in familiar mathematical notation (MATLAB®/Simulink®., 2017).

Typical uses include:

- Math and computation
- Algorithm development
- Modelling, simulation, and prototyping
- Data analysis, exploration, and visualization
- Scientific and engineering graphics
- Application development, including Graphical User Interface building

The interactive system provided by MATLAB where the basic data element is an array that does not require dimensioning which allows one to solve computing problems. In university environments, it is the standard instructional tool for introductory and advanced courses in mathematics, engineering, and science. In industry, MATLAB is the tool of choice for high-productivity research, development, and analysis. The Model-Based scheme allows for better efficiency by Using a common design process area across project teams (Pillay & Krishnan, 1988).

- Linking designs directly to specifications.
- Refining algorithms over multi-domain simulation.
- Generating embedded software code ·
- Generating documentation.
- Designs to deploy systems across multiple processors and hardware targets.

The application-specific solutions called toolboxes are most important features of MATLAB and tool Toolboxes are comprehensive collections of MATLAB functions (M-files) that extend the MATLAB environment to solve particular classes of problems.

The MATLAB system consists of five main parts:

- **The Language**

  The MATLAB language is a combination of high level flow control statements, functions, data structures also input/output programming features which allow both programming in order to solve complex problems.

- **The Working Environment.**

  The environment where the MATLAB programmer uses a set of tools while writing code for MATLAB which includes the facilities for managing the variables and exporting data. It also includes tools for developing, managing, debugging, and profiling M-files, MATLAB's applications.

- **Handle Graphics**

  Handle Graphics is a MATLAB graphics system which includes high level commands for two-dimensional and three-dimensional data visualization, image processing, animation, and presentation graphics.

- **Mathematical Function Library.**

  This built in library has a vast collection of computational algorithms ranging from elementary functions like sum, sine, cosine, and complex arithmetic, to more sophisticated functions like matrix inverse, matrix eigenvalues, Bessel functions, and fast Fourier transforms.

- **Application Program Interface (API).**

This API is used to write C and Fortran applications which allow interaction with MATLAB and It includes facilities for calling routines from MATLAB (dynamic linking), calling MATLAB as a computational engine, and for reading and writing MAT-files.

4.6.2 Test-Beds

A Test-Bed more specifically, WiMAX Test-Bed is a real environment to test WiMAX applications in a real environment at a neutral site. There are different types of Test-Beds available such as

- ORBIT (Open-Access Research Testbed for Next-Generation Wireless Networks) Test-Bed.
- Assert (Advanced wireless Environment Research Testbed)

ORBIT (Open-Access Research Testbed for Next-Generation Wireless Networks):

ORBIT was first funded in 2003 under the Network Research Testbeds (NRT) program (CNS-0335244) and subsequently under a follow-on grants CNS-0725053, CNS-0958483 and CNS-1513110. ORBIT is a two-tier wireless network emulator/field trial designed to achieve reproducible experimentation, while also supporting realistic evaluation of protocols and applications (ORBIT, 2009). ORBIT based on Radio Grid Testbed, which uses a 20x20 two-dimensional grid of programmable radio nodes, which can be interconnected into specified topologies with reproducible wireless channel models and after validation of application concepts it allows users to move the experiments to the OUTDOOR ORBIT network, which provides a configurable mix of both high-speed cellular networks (WiMAX, LTE). The 802.11 wireless access in a real-world setting. The Latest ORBIT versions include a number of SANDBOX networks used for debugging controlled experiments.

In Oct 2005 ORBIT radio grid was first released and still is widely used community resource for the evaluation of emerging wireless network architectures and protocols. Examples of specific experiments that have been run on the ORBIT testbed include multi-radio spectrum coordination, cognitive radio networks, diagnose WiFi networks, cellular/WiFi multi-homing, vehicular and ad hoc network routing, storage-aware/delay tolerant networks, mobile content delivery, location-aware protocols, inter-layer wireless Security, future Internet architecture, cloud computing and mobile.

Assert (Advanced wireless Environment Research Testbed):

Assert was designed in collaboration with Crane Wireless Monitoring Solutions and funded by the US Department of Defence, Defence Microelectronics Activity (DMEA). Due to its small footprint, it emulates mobility and link degradation in a repeatable manner inside a room (Ertin, et al., 2006) . In Assert front-end computers control all the experiments and topology modifications are done through keyboard and mouse which reduces the time taken than physically changing the topology in existing over-the-air wireless networking testbeds. Due to the immunity of the interference from other devices in the laboratory and the environment. It creates the possibility for experimenters to inject noise or the desired interference into the system, and understand its impact on the system being studied. Assert allows the researcher to scale to higher number of nodes. Furthermore, while an RF emulator does all the calculations in a central location for all nodes, which makes a decentralized solution. Assert makes it is possible to conduct experiments in licensed bands like the cellular service band without interfering with the services offered by the owners of these licensed bands. Assert sophisticated custom hardware and easy-to-use control software has many valuable features that allow it to reduce the cost of testing wireless networking protocols at scale.

4.6.3 QualNet

QualNet® is a simulation tool which is used for planning, testing and training, which simulates the behaviour of the real communication network. This simulation tool can simulate, develop and manage the network in the entire lifecycle. QualNet provides a complete structure for designing, creating and animating Network situations using any protocols and analysing their performance. QualNet is using graphical and visualization tools, which can be used to set up any kind of terrain network connections and mobility patterns of the network. QualNet has graphical analyser which displays hundreds of metrics. QualNet can be installed on any platform such as Windows and Linux Operating systems including 32 and 64 bit operating systems

4.6.3.1 Mobile WiMAX Simulation in Qualnet

As in research community the most desirable simulation tool is from the open source community which is considered as more reliable but due to lack of reliable open source tools for mobile WiMAX scheduling simulations, Only commercial alternatives are considered for this kind of simulation and research work. Qualnet's Advanced. Wireless Model (Qualnet, 2008) has provided research flexibility where the research licence can run on a licence server on campus and QualNet clients can run off campus with features such as

• OFDMA PHY this feature makes a very realistic simulation of mobile WiMAX, that would require multiple access both on downlink and uplink.

• MAC messaging, ranging, bandwidth request/allocation, handover, sleep mode, paging,

Power control.

• Adaptive modulation and coding (AMC) which would allow BS and subscribers to change in their modulation according to radio link conditions.

• Mobility support, This feature would allow scenarios under mobility conditions. This provides a great advantage and helps over the NS-2 based module available from NDSL which allowed testing under stationary conditions only.

• QualNet also provide support for all five service classes (UGS, ertPS, rtPS, nrtPS, BE) specified in the standard.

• QualNet also provides basic admission control via a token bucket mechanism which is an important in conditions where some of the proposed algorithms operate in conjunction with admission control.

4.6.3.2 Limitations of QualNet Simulator

There is a number of limitations specifically when keeping in consideration the research done in this thesis and generally based on WiMAX, where Qualnet's simulation software has more serious limitations and some of the important features which are not implemented or partially implemented which should be considered in regards to this research.

a) QualNet traffic has no authentication, nor it has traffic encryption. In addition to that, when we don't have authentication can imply also not even having MAC authentication messages while in network entry or during handoff process, which has a direct impact on the throughput which is obtained as additional overhead introduced when encryption over the air is enabled.

b**)** QualNet 's Packet header is not implemented with compression, which should not directly impact the behaviour of the certain scheduler and against another. While it is a consideration when keeping an eye on throughput.

c) QualNet implemented WFQ scheduler, which does not consider priorities among connections which are within the same scheduling service.

d) Qualnet's uplink bandwidth scheduler which is not implemented as an API and at the same time the downlink scheduler is configured to use well-defined API which is able to perform scheduling tasks such an adding packets to queues, setting and retrieving current priorities of the queues and adding changes to modify the behaviour of the scheduler.The uplink direction which is implemented in a serval files which has a hundred lines of code with no documentation. When we write the schedulers for both uplink and downlink would then imply working not on three but on six schedulers which is not applicable in this current research.

e) In QualNet the application of QoS parameters are not configurable and these can only be determined on the basis of the configured application. When we look at the recent release of Qualnet the values of CBR and VBR map and correspond to their QoS parameters, for example, a CBR application which is configured to send 18 bytes per packet in every Second would map QoS parameters as below.

maxSustainedRate = 1024 bps (128 bytes/Second * 8 bits/byte)

minReservedRate = 1024 bps

maxLatency = 1000000000 (1000 ms)

toleratedJitter = 0 (0 ms)

The parameters looks very convenient whereas the service flow parameters are automatically configured, but the problem is the number of applications which can be simulated and voice over IP application is mapped partially using A Voice over IP application which is using a G.711 codec and requirement for that is at least 64 kbps which is before overhead is mapped to parameters below

maxSustainedRate = 800 bps

minReservedRate = 800 bps

maxLatency = 100000000 (100 ms)

toleratedJitter = 100000 (0.1 ms)

In this example, we can see that such flow would not be able to carry the voice over IP traffic as a result, it would create considerable uplink delay and packets drop specially ertPS or UGS service flows that rely on pre-allocated bandwidth to deliver their data are used. When we are not using UGS or ertPS for voice traffic. That would have a very negative impact on latency which could not be guaranteed and the traffic would be competing with throughput intensive applications. In addition to that, another reason for limiting the scope of simulation is to downlink the configured QoS parameters which could not be used for uplink VoIP traffic without the rework which could be either on the map t service flow properly or implement a way to configure the QoS parameters independently from the application. There are other important applications such as FTP and HTTP which would also suffer from the same limitation, where the FTP and HTTP applications, for example, do not map to any QoS parameters and there is no way to manually configure these services where it would not be possible which would not be implemented in current implementations to configure HTTP in a service class different from BE

4.6.3.3 Qualnet's WiMAX Scheduler

All current scheduler software, including the ones mentioned in this research comes from same basic root scheduler class which defines and configures the same basic member functions which all scheduler come implemented and must implement such as scheduler initialization, add and remove queues and insert/dequeue packets from to/from a specific queue. It is implementation dependent where additional data structures and variables are used to keep track of counters weights rations and flags which will be required. When we are discussing Qualnet's WiMAX downlink scheduler which is called the MacDot16Bs structure contains a pointer to a structure of scheduler type initialized as part of instantiations of WiMAX MAC and all the required member functions which will create/delete queues and insert/retrieve packets to/from the queues are accessed from there.

There are a number of queues in the schedule and each one is corresponding to WiMAX CID. Where each queue is having the dynamic array which stores the packets which are needed to be scheduled, where each queue then has a dynamic array which stores the packets that need to be scheduled and every time new downlink WiMAX connection is established a temp queue is created to store packets which are sent to that connection with new queue added to store packets which are sent to that connection where new queue we added to the scheduler. Once queue is set up and defined the packets from the temporary are moved over and any subsequent packets arriving for that connection will be enqueued using the insert member function. Later it is up to the scheduler to decide what queues need to serve on each scheduling cycle and call the retrieve functions to do so.

The WFQ algorithm which Qualnet implements is from WfqScheduler class which is derived from the FQScheduler class. This class exists to provide some common functions to other weight based schedulers and the reason for that is to only specify the insert and retrieve member functions needed to be implemented. The process of scheduling a downlink subframe can be described as in every 5ms a new MAC frame supposed to be built so as the function is called to reset the previous downlink and uplink allocations. What happens first is called Uplink allocations which are in order to determine the size of uplink mas and number of slots which will be left to build and downlink map and data allocations. In situations where the schedule DISubframe function is called the data, the scheduler will be checked which are to determine if there any queues requiring the service. The queues when in high priority scheduling service are only kept empty and the next will be served. This process will continue until there are no empty slots available and until all queues are served. The DL subframe building process is not linear and everytime slots are allocated to as check to ensure that the capacity of subframe will not exceed when mapping overhead is added. IF these checks are failed the frame would consider as full and the last packet, which is supposed to be added to subframe is left on the schedule. Once the contacts of DL subframe which has been defined as MAC which is including the UL and DL maps and they include the downlink data bus and passed to the PHY layer for transmission and this process will keep on repeating in subsequent scheduling cycle.

4.6.4 The Network Simulator - NS-2

Network simulator, which is mostly called as NS2. This tool is configured mostly as an event-driven simulation tool, which has proved and tested useful in studying the dynamic nature of communication networks. NS-2 has the ability to simulate both wired and wireless networks in every function and protocol such as routing, algorithms, TCP and UDP can be done in NS-2. Generally, NS-2 provides users with a way to specify network protocols, and simulating their respective behaviours and with its flexibility and module nature, The NS-2 gained much appreciation in the network research community from the time it was developed in 1989. There have been few revisions which have marked the growing maturity of the which is owed to the University of California and Cornell University who developed the network simulator. NS-2 is actually based on the foundation developed since 1995 with the Defence Advanced Research Agency (DAPRA) who developed NS through the Virtual InterNetwork Testbed (VINT) project and at the moment the National Science Foundation (NSF) has started working in development and still there are researchers and developers in the development community are working on further development of a detailed list of NS-2 codes which has been contributed by the research community (Chung & Claypool, 2008) . As mentioned NS-2 is a simulator which is the event-driven and open source used mainly in research areas of computer networks, MANET, WSNs. In NS-2 Computer network is modelled and designed and analysis is done while users can make changes to the simulator to fulfil analysis needs and it supports almost all the protocols available today. NS-2 is open source software. Unlike most of the commercial simulators which are based on GUI NS-2 mainly works with scripts and commands for network parameters and simulation output is mainly traced files which document each and every event in the simulation

4.6.4.1 Basic Architecture of NS-2

NS-2 is configured to take input as an executable command as an input argument and the name of simulating scripting file is Tcl. The users when setting up simulation inputs Tcl script which is used as an input argument to NS. In the majority of cases, the trace file is created and which will be used to plot graph and or to create animation. NS-2 uses two basic programming languages which are C++ together with Object-oriented Tool Command Language (OTcl). Where The C++ defines the internal mechanism which in other terms is called backend for simulation objects and OTcl configures and setups the simulation by assembling and configuring the objects including scheduling discrete events. Both front-end and backend are mapped using TclCL with objects called handles. In OTcl domain a handle acts as frontend objects where it sometimes defines its own procedure and variable to facilitate the interaction. Procedures and variables in the domain which are called the instance procedures. The basic requirement for working with NS-2 is having knowledge of C++ and OTcl languages. Before starting work with NS-2 it is suggested to learn the details of C++ and brief tutorial of Tcl and OTcl (Schildt, 2002). A number of built-in C++ objects are used by NS-2 that’s why it's advisable to use C++objects when configuring and setting up the simulation. When the simulation is completed, the NS-2 output is either in the form of test-based on animation results. To understand and interpret the results in any form of graphically and interactively, there are tools used such as NAM (Network Animator) and XGraph are used. Using these tools helps the researcher to extract a relevant subset of text-based data and convert it to understand format to ensure easy analysis.

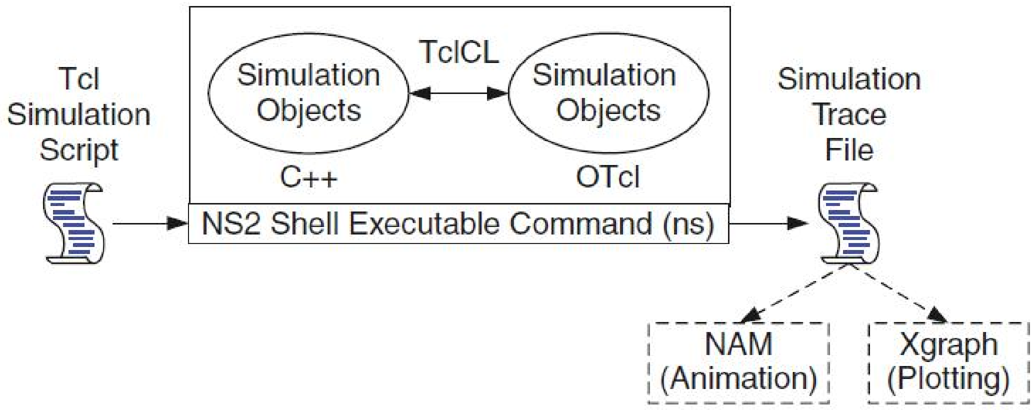

Figure 4.0.3 Basic Architecture of NS (Teerawat & Ekram , 2009)

4.6.4.2 NS-2 Scheduler

As we are aware that scheduler keeps the chain of events and simulations. When Simulation is running it moves along the chain and starts one event after another as there is one chain of events in the simulation that's why there would be one scheduler object in a simulation. That's why scheduler objects are also called as a scheduler. NS-2 supports four types of schedulers (Fall & Varadhan, 2007)

a) List Scheduler

b) Heap Scheduler

c) Calendar Scheduler

d) Real-Time Scheduler

4.6.4.3 NS-2 Simulator

The root classes which ensures the entire simulation are OTcl and C++. As we have mentioned previously that scheduler has one object, in the same way, there can be only one simulator object in the entire simulation which in general terms is also called Simulator during the entire simulation. The simulator is comprised of two key components called Simulation object and information storing objects. The main or key components in a simulation object which drive entire simulation are the Simulation objects and they drive the simulation from the Network configuration phase and will also be used in simulation phase. While the information storing objects usually contain information which is supposed to share between several objects. The example of such a situation would be when NS-2 needs to know all the created nodes and which links in order to develop a routing table. The information storing objects are created via a number of instprocs, which is done in Network configuration phase. In Simulation phase the information accessed from objects via information storing objects in a process called instvarns_ (simulation instance) which is a reference to the simulator.

4.6.4.4 Limitation of NS-2 Simulator

As we are aware that model is a simplified representation of real-world systems, which is mainly done for experimentation, Boundaries, rules and sometimes there are deficiencies which are developed or identified. The most troubling deficiency which all researchers and developers face is the high processing power and memory capacity which is needed when network size is increased. The limitation is faced by most of the simulation tools, but NS-2 also have more technical limitation which is described below

TCP one-way

- The lack of a dynamic window advertisement
- Segments and ACK calculations are in the packets
- No SYN/FIN connection establishment/teardown.
- TCP one-way, ECN (Explicit Congestion Notification)

- The sender doesn't check if the receiver is ECN compliant

TCP two-way (full TCP)

- No dynamic window advertisement,
- No 2MSL-wait or persist states
- No urgent data or RESET segments

The biggest limitation in NS-2 is the lack of a GUI built in the package and there are few open source scripts which are trying to fill in the gaps, but they result in reduced functionality as the tool is not designed with built-in option. The limitation of graphical analysis tool makes it hard to simulate more complex network

4.6.5 RIVERBED (OPNET):

RIVERBED modeller is a simulation product from RIVERBED Techonologies Inc. The technology, which RIVERBED uses for this tool is hierarchical in structure. RIVERBED is divided into a three-layer model mechanism which is comprised of Process Model, Node Model and Network Model. This tool has multiple suites of protocols and technologies such as VoIP, TCP, MPLS, etc. The strongest feature of RIVERBED is its statistical and analysis modules, which help the modeller in collecting the performance statistical data in every network layer and generate graphical reports. Within the RIVERBED WiMAX module which is a specialized model which specially designed to support IEEE 802.16-2004 and IEEE 802.16e-2005 standards. Another important feature of this tool is, which can be used to evaluate custom scheduling algorithms for WiMAX base and subscriber stations. Optimizing application performance by creating and enabling WiMAX QoS policies and predicting network performance of difference MAC and PHY layer profiles. RIVERBED provides an environment to model, simulate and evaluate performance for all kinds of wired and wireless networks and distributed systems. This tool can be installed and configured at many different operating systems such as Windows 2000, XP, Linux and Solaris platforms. The graphics tool which is included in the package provides help in scenarios, model conception and data collection and data analysis. RIVERBED simulation consists of projects, including setting of scenarios where the project is created using project editor, which is also known as a central interface for RIVERBED and the functionalities are available and accessible from the editor and including to that it gives an access to other editors which propose functions which include node, process model creation, building packets formats and creating filters and parameters. The additional functions which RIVERBED provides to the user which are included High-Level Architecture (HLA) module which ensures communication between different simulators. As RIVERBED provides hierarchical modelling which is done within the modelling environment by defining a network as a combination of sub-models showing and representing sub-networks or nodes. As modelling is done in modelling environment which is made of three domains and the first one is called network domain which defines communication network topology to simulate while the 2nd domain is called node domain where the node domain instantiates the nodes which are defined within network domain such as units connected to the network which can send and receive data. The 3rd one is processed domain which describes every module which is configurable/programmable by the user which execute process and tasks. The analysis and visualization of results are done through analysis tool and filter editor. The analysis tool combines and manipulates the data which is displayed a series of simulation graphs. The raw results can be seen in the project editor. The modelling modularity of RIVERBED is an asset to model critical infrastructures which provides a user an ability to define different models to specific infrastructure and simulate its performance. The parameters which can also be a specific model action which might happen within the infrastructure which is distinguished by process model

4.6.5.1 RIVERBED Key System Features

RIVERBED is very big software tool which has extensive design and RIVERBED toolset is very extensive, which in addition to its network support for general network modelling helps in providing support for the any type of network simulations. RIVERBED has lots of features and capabilities. Below are some of features and capabilities which are important to current research.

Object orientation. RIVERBED design and configuration consists of objects. These objects come with modifiable sets of attributes which belong to classes. These classes provide certain characteristics. Each and every new class including their definition are supported in order to addresse the system as wide as possible and to provide the scope of system as detailed as possible. In some situations, classes can also be derived from classes which are specialized, which provide more detail support for specific target applications.

• **Specialized in communication networks and information systems**.

There are many constructs which are provided in RIVERBED and these are mainly related to communication and information processing. These provide very high leverage for modelling of networks and distributed systems.

• **Hierarchical models**. The model in RIVERBED is hierarchical and naturally paralleling to the structure of real communication networks.

• **Graphical specification**. The features of GUI integration have changed the simulation world and RIVERBED has made it possible for models to be configured via graphical editors. These graphical editors help and provide a detailed mapping of the modelled system which is used for the RIVERBED model specification.

• **Flexibility to develop detailed custom models**. The ability of RIVERBED to provide a flexible high-level programming language which has extensive support for communication systems. RIVERBED ensures and allows realistic modelling which includes all communication protocols algorithms and transmission technologies.

• **Automatic generation of simulations**. RIVERBED uses C programming language as the base language for the model specifications. They are automatically created and compiled into executable, efficient, discrete-event simulations using this language. The advanced simulation and configuration techniques ensures and minimizes the compilation requirements.

• **Application-specific statistics.** When RIVERBED simulations are running, the performance statistical analysis tools help in collecting this data and show it understandable graphical format.

• **Integrated post-simulation analysis tools**. The RIVERBED analysis tool does the Performance evaluation and trade-off analysis, which requires large volumes of simulation results to be interpreted. RIVERBED comes built-in with an advanced tool for graphical presentation and processing of simulation output.

• **Interactive analysis**. The RIVERBED will automatically incorporate support for analysis via a sophisticated interactive “debugger”.

• **Animation**. The RIVERBED is configured with animation tools and which will help in automatically creating and generating animations of the modelled system at various levels. The animations automatically include animation of statistics as they change over time which provide extensive support for developing new applications.

• **Application program interface (API)**. RIVERBED comes with a built-in programmatic interface which provides an alternative to graphical specification. RIVERBED models researcher can open data files which may be specified and modified via a programmatic interface. This feature is very useful for automatic generation of models which allow RIVERBED to be tightly integrated with other tools.

4.6.5.2 RIVERBED Architecture

The RIVERBED environment provides development environments, which gives the user ability to do modelling and performance analysis of any communication network and distributed systems. RIVERBED also provides a number of tools which focuses on particular aspects of the modelling process. The RIVERBED modular can be subdivided into three major categories during modelling and simulation. These steps includes

a) Specification, b) Data Collection c) Simulation and analysis

These three phases and process are performed in the stepwise process, which will run in a cycle. There are two parts of specification one is termed an initial specification and the Second one is respecification.

4.6.5.3 Model Specification

Model specification is assigned for developing a representation of the system that is to be further studied. RIVERBED understands and supports the concept of model reuse as most models are based and depends on lower level models developed in advance and stored for model reuse in model libraries. Finally, all models are based on the basic concepts and initial building blocks supplied by the RIVERBED environment.

4.6.5.4 Specification Editors

RIVERBED comes with a number of tools which supports the model specification. These tools which are sometimes called editors help in capturing the characteristics of modelled system’s behaviour. As RIVERBED is based on sets of editors which help and address different aspects of a model and these features enable it to address diverse issues which are faced in networks and distributed systems. Intuitive interface which is presented to the model developer and these editors which break down the required modelling information in a manner which is parallel to the structure of the actual networked system. The model specification which is performed within the Project environment or editor depends on the elements which are specified in the node editor. The researchers use the models which are defined in process editor while the other editors are used to define the various data models which are typically tables of values and which is later accessed by processor node level.

This entire structure can be described as below.

• **Project Editor:** This is an important tool which helps in developing the network models. The models, especially the network models, are made up of node models and subnets. This editor has the basic simulation and analysis features.

• **Node Editor:** Node editors help in developing node models. Where the node models are objects in a network and these node models are composed of modules with process models.

• **Process Editor:** This tool helps in developing process models and where as the Process models stabilize module behaviour and also reference parameter models.

• **Link Model Editor**: Create, edit, and view link models

• **Packet Format Editor**: The packet editor develops packet format models. These packet formats are to ensure the structure and order of information stored in a packet.

• **ICI Editor**: The ICI editor creates, edits, and view interface control information (ICI) formats. They are also used to communicate, control information between processes.

• **Antenna Pattern Editor**: this editor creates, edit, and view antenna patterns for transmitters and receivers.

• **Modulation Curve Editor**: this editor Creates, edit, and view modulation curves for transmitters.

• **PDF Editor**: The PDF Editors Create, edit, and view probability density functions (PDFs). They are used to control the events such as a number of packet generation which is in the source module.

The RIVERBED uses the graphics, features and specification of models when possible and that's why the specification model of editors, presents a GUI interface in which users use to configure objects representing the model components and structure. Every editor has specific object sets and operations, which help in modelling tasks such as the project editor which makes use of node and link objects and node editors provide the processors,queues transmitter and receivers. The Process editors which are usually based on states and transitions.

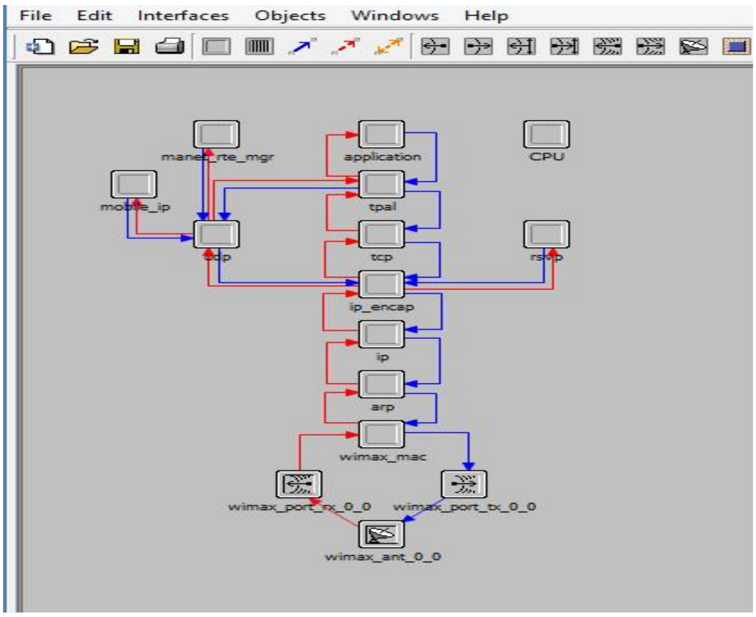

Figure 4.0.4 RIVERBED Node Editor

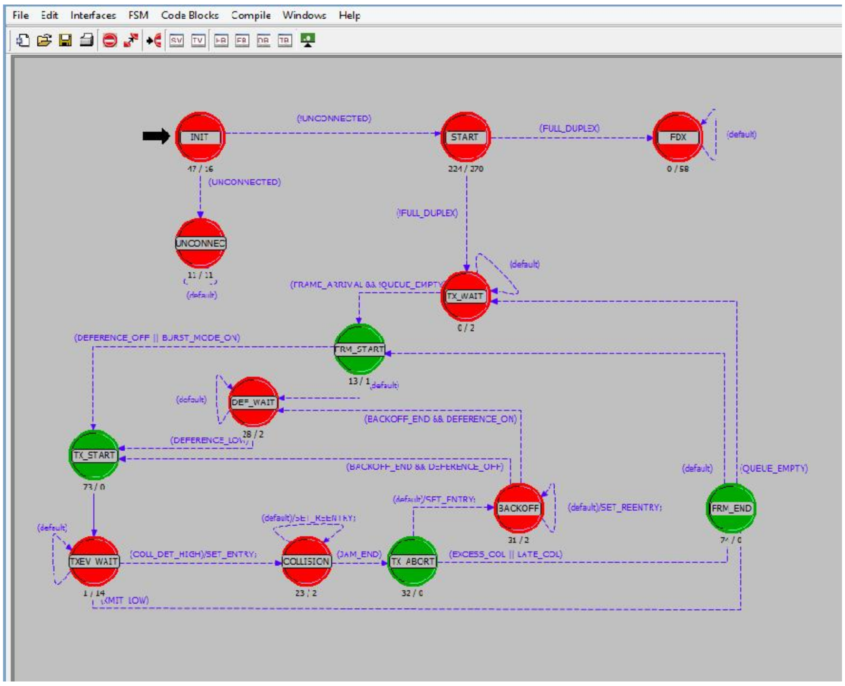

Figure 4.0.5 RIVERBED Process Editor

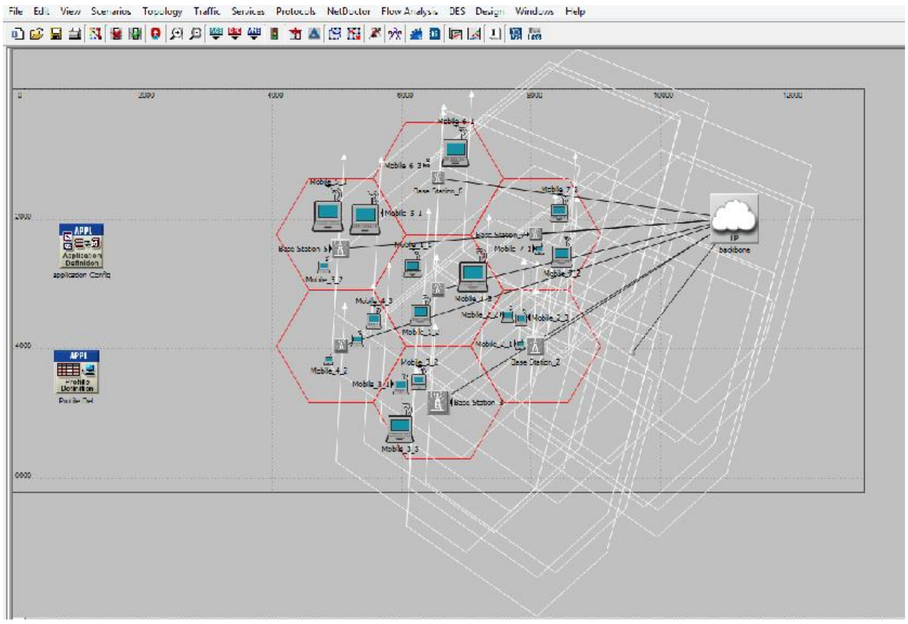

Figure 4.0.6 RIVERBED Project Editor

4.6.5.5 Modelling Domains

The modelling domain of RIVERBED includes The Network, Node, and Process modelling as they all span in the hierarchical level of the model

4.6.5.6 Network Domain

The definition of topology in any communication is very important and this task is done within a simulation framework inside Network Domain. The entities which are sometimes called nodes and these nodes have specific properties and capabilities which are defined by designing the model. The development of node models is done in the node editor which is done in a single large network model. In some situations, there are many nodes in the same model. When there a need for distinguishing node models, especially when they are sharing the same model, the term node instance is used to refer to an individual node, but when a node is used in relation to network domain it assumed as a node instance other than node model.

There are multiple numbers of node model in network model and RIVERBED does not apply any specific restrictions on the types of nodes which can be deployed in a communication network. Modelers use an open approach where modellers develop own library of node models which can be used as building blocks and also there is no limitation of a number of models or node instances in any network model. There are no restrictions from RIVERBED regarding the types of nodes which can be deployed in any communication network and RIVERBED adopts an open policy where modellers have the option to develop new models or use the library as building blocks for network model. Including to that, there is no limitation on the number of node instances of network models, whereas a project editor provides an overview of network model development.

There are wide options available with the choice of location on the world and elements of wide area network including to provide an intuitive environment for deploying the components of network model. The features provide an idea of distance which helps in the calculation of communication delays which can happen due to distance. The fixed communication node is used as a building block and as a basic object when building network models. This fixed node can be assigned arbitrary locations, but it's important that during the simulation the location of the fixed node should not be changed. In addition to fixed nodes RIVERBED Radio versions also allow the users to add mobile and satellite nodes and these nodes can also be defined with trajectories which specify their positions as a function of time for throughout the simulation in the same way satellite nodes are assigned predefined orbits and their motions.

The simulations have also options to involve all types of nodes and these nodes need the ability to communicate with other nodes to be able to function in the network model. There are a number of types of communication link architecture which has the ability to provide interconnection to nodes which communicate with each other. RIVERBED has the ability to provide unidirectional, bidirectional and Point to point links which help in connecting the nodes in pairs with bus line which allow the broadcast of communication for a large set of fixed nodes.

4.6.5.7 **Node Domain**

The modelling of communication devices is done with the help of Node Domain which can be set up and interconnected at the network level. In RIVERBED such a device is called nodes and in real world they are termed as different types of computing and communication equipment for example router, bridges, workstations, terminals, mainframe computers, file servers, fast packet switches, satellites and etc. Node Editors are used to develop Node models which are displayed in terms of smaller building blocks called modules. There are few modules which provide a capability which can substantially predefined and can configure through a set of built-in parameters. Their parameters include a number of transmitters and receivers which allow the nodes to be attached to Com links in the network domain. There are other modules which are called processors and queues which provide the option of their programmable due to their high nature of their programmability and their behaviour of a self-assigned process model.

The process model is developed using the process editor. A process model usually consists of a number of models of different types. The interaction between modules has supported by three types of connections such as packet streams, statistic wires and logical associations. The formatted messages which are called packets allowed by packet streams are conveyed from one module to another. The statistic wires convey simple and numeric signals or control information between modules which are usually used when one module which needs to investigate the performance or condition of another. The binding is identified between modules to help of logical associations and in the meantime, these bindings are allowed only in between transmitters and receivers which shows that they should be used as a unit when attaching the one to link in Network Domain and within the Node Editor. A device depends on specific stack of protocols which can be modelled while creating a processor object for each layer of that particular stack which help in defining packet streams between neighbouring layers

4.6.5.8 **Process Domain**

The user programmable elements such as Node domain, queue and process modules are the key building blocks of communication nodes. The tasks which are done by these modules are named as processes and each process can be similar in many ways to a running a software program which includes the set of guidelines and maintains state memory. The Process model defines processes in RIVERBED and they are defined in Process Editor. The relationship within process model and process are similar to the relationship between a program and individual session of the program running the task. Within the Project, Editor nodes are created and instances of nodes models are defined in node editor while each process which executes in a queue, processor is an instance of the particular process model. The concept of process groups are supported in RIVERBED process modelling paradigm. While process group consists of multiple processes which execute within particular processor or queue. The simulation starts with each module having only one process and that process is called root process. This root process can later create a new process which can, in turn, create more. When one process creates another one that process is termed as a parent while the new process is called a child.When the process is created during simulation they are called dynamic process.

As we are aware RIVERBED has no limit on a number of the process which may be created in a particular processor or queue. These processes may be created and destroyed, which is usually based on changeable conditions which are analysed within the logic of the executing process. This type of paradigm is a formal framework for modelling many systems and network structures. Especially when the multitasking operating system where the room process represents the main operating system itself and they dynamically created processes which correspond to a new task and multi-context protocols where root process represents a new task. When we discuss multitask protocols where the root is represented by session manager where each session is requested, is modelled by creating a new process and where only one process should be executed at any particular situation. When the process is running through new instructions which are part of the process model is termed as executing a process where the process begins executing it is termed as being invoked. The process which is in executed stage can also invoke another process in its group to cause it being executed. When this accrue the invoking process is temporarily halted until its processing for its current invocation is completed. When the invoke process is blocked the invoking process resumes its processing where it was halted this process mimics the procedure call in C programming language.

4.7 The Selected Simulation tool for Current Research

After reviewing the four best simulation tools such as Test-Beds, QuelNet, NS-2 and RIVERBED and considering scenarios within this research. It was identified that Test bed provides more realistic results, but the cost of simulation using test-bed will be very high and can used in future for further verification of results. Keeping limitation of cost in mind RIVERBED simulation tool is chosen for this research due to its advantages, some of which are described below.

The biggest advantage of RIVERBED modeller and the reason it was selected as a simulation tool for this research was because RIVERBED modeller supports a number of models and the RIVERBED modeller empowers a user interface to develop several networks. NS-2 is better simulation tool, but the biggest disadvantage with NS-2 is the complexity of its behaviour and it includes lots of coding part and while RIVERBED does not have this problem. Another important factor which invites the user of RIVERBED to use its drag and drop feature. This approach makes the simulation process very simple by choosing the needed objects from the object palette which is available in RIVERBED object library and the configuration of objects are provided in a very easy format. RIVERBED supports multiple model setups over the wireless network to configure the communication.

The required setup for a network and its simulation can be done with help of dragging and droping and the required objects palette which is later configured as per research scenario. The model for simulation includes the functions such as creating the network needed, ensuring the consistency of the model, simulation running and results estimation. Which does not depend on the type of network which needs to be created and steps followed in creating any kind of network are universal and which is the reason behind RIVERBED being considered for this research study

4.8 Verification and validation

When the simulation is in a stage where it is running stable, the next step in this process is ensuring the simulation is doing what one expects (Balci, 1994) . It is easy to make errors while using a complicated computer program and get results with mistakes, which is rather than a consequence of the mode and the process of identifying and ensuring the program performs what it was planned for and this is known as verification.

When we look at simulations, the problems with verification are usually compounded with a fact that number of simulations comprise of random number created which shows every simulation run in separate fashion and its distribution of results which might be predicted by the theory. That's why it is important that ensure error-free simulation which can be done with debugging the simulation carefully. Which is done with a set of test cases and in cases of extreme situations the results are very predictable. Most usually it is practical to set up and identify test cases and run the simulation in comparison with them and every time a major change is made more errors are introduced and to make this process easier it is advisable to have a system which automatically runs the test site and note the outputs while highlighting the differences between the previous run and new one. This can be kind of control system to ensure everything is running in order.

However, abstract models are not clear in which the data cannot be validated and issue with these models are artificial societies where the goal is either deliberately remote from the simulation or don’t exist at all. Once one researcher chooses a model which is considered to be valid at least for the particular experiment and parameter values for simulation experiment has been run, the researcher wants to consider the sensitivity of the analysis. Regardless of any reasons when we introduce change in the simulation will have to be tested a number of times in order to identify the behaviour in a number of conditions. The results of the simulation are needed to be expressed as distributions or means with confidence intervals. When a random element is included in the simulation, there is need to be further tested and analysed using initial statistical methods which have been created for existing experimental research.

4.9 Conclusion

In this chapter, the entire process, including the research philosophy, design, simulations and methods is undertaken to achieve the aim and objectives of the research studied. There is also discussion of techniques which are implemented while using the design techniques and the process of data collection is implemented and discussed. The details of actual processes and steps used in this research are discussed in subsequent chapters. In the next chapters and subSections, the response to the research question is discussed and analysed. The knowledge and steps identified in this chapter will create the basis for subsequent chapters.

CHAPTER 5: A NOVEL ANALYTICAL MODEL DEVELOPED ON WIMAX HANDOVER DELAY

5.1 Introduction

Telecommunication systems and devices get advanced day by day and to support these new devices and provide them with an undistrupted data transfer is the biggest challenge for the research and telecommunications community. The challenge has become more complex due to the factor of handover failures, which usually happens due to lack of resources and limitation in coverage including the speed of mobile device. The handover schemes and models which are currently developed are not able to support the existing complex scenarios. This thesis proposes a new approach to modify the process of handover decisions and to reduce the unnecessary handovers. The new model is based on new handover algorithm conditions. The numerical results show that the proposed new algorithm performs better than existing with reduced number of unnecessary packet loss which are due forced handovers. Even with better performance and QoS results there is still need of an operational model for operational spaces.

5.2 The Proposed Approach

This thesis proposes a novel handover algorithm for high mobility environments, where the knowledge of network availability, coverage and strength of failing link is main factors which play a role in handover decisions. In this way, the proposed model and new proposed algorithm decides the time where the mobile station needs to start the handover process. In order to reduce the number of unwanted handovers the proposed algorithm determines the required time while assuming the mobile user is moving at a specific speed.

Here are the conditions of algorithms for Network Model

SNR (Signal to Noise Ratio) Calculation:

Signal measurement is the main factor and it is the power received from the base station at the mobile station (Lee & Choi, 2007)

1) $P_r[mW] = P_{tBS1} G_{tBS1} G_r \,/\, PL(d)L$ (Lee & Choi, 2007)

While the power received from the base station is

2) $Pr\,[mW] = P_{tBS1} G_{tBS1} G_r \,/\, PL(D-d)L$ (Lee & Choi, 2007)

In the equation 1 and 2 P_{tBS1}, G_{tBS1} and G_{tBS2} are the transmitted power and the gain in transmittion from BS1 and BS2. While PL(d)L and PL(D - d)L is path loss.

3) $\text{Pr}\,[dBm] = 10\log(P_r\,[mW])$

$$= P_{tBS1} + G_{tBS1} + G_r - PL(d) - L.$$ (Lee & Choi, 2007)

4) $P_r[dBm] = 10\log(P_r[mW])$

$$= P_{tBS2} + G_{tBS2} + G_r - PL(D-d) - L.$$ (Lee & Choi, 2007)

Here its assumed that transmitted power in all base stations are equal. while the autocorrection of shadow fading is

5) $E[u(d_1)u(d_2)] = E[v(d_1)v(d_2)]$

$$= \sigma_s^2 \exp(-|d_1 - d_2|/d_0),$$ (Gudmundson,, 1991)

Where σ_s^2 is usually between 3 dB and 10 dB and d_o determines the correlation decay with distance. The threshold id defined by averaging the received signals in the proposed handover algorithm

5.3 The Proposed Handover Algorithm Model

The new suggested algorithm combines a number of mechanisms which help in improving handover delay times. The main feature of this new algorithm is that it does not depend on the free capacity conditions which ensures that unnecessary handovers are avoided due which used to happen in older algorithms

$SNR_{maxDT} - SNR_{DS} \geq H1$ & $BER_{avg} \geq E_b/No$ **Proposed Handover Algorithm**

Scanning Stage:

In this process the base station, which is serving the mobile station provides the PHY layer parameters to base stations and its connected mobile stations and while scanning level reaches its optimal threshold it sends MOB_SCN-REQ message to serving base station which starts the scanning process. The mobile stations use these values to calculate the QoS of neighbouring base stations and send MOB_MSHO-REQ message to target base station for receiving base station.

Handover Stage:

The handover initiation and decision can be started by both mobile stations and base stations and the new handover algorithm suggested where new triggering mechanism based on BER and E_b/ No vales which are more stable and less prone to be effect of other factors.

$SNR_{maxDT} - SNR_{DS} \geq H1$ & $BER_{avg} \geq E_b/No$ (**New Suggested Algorithm**)

Where

BER_{avg} is Average Bit Error Rate

E_b/N_0 energy per bit to noise power spectral density ratio

While figure 5.0.1 shows the flow chart of new handover algorithm

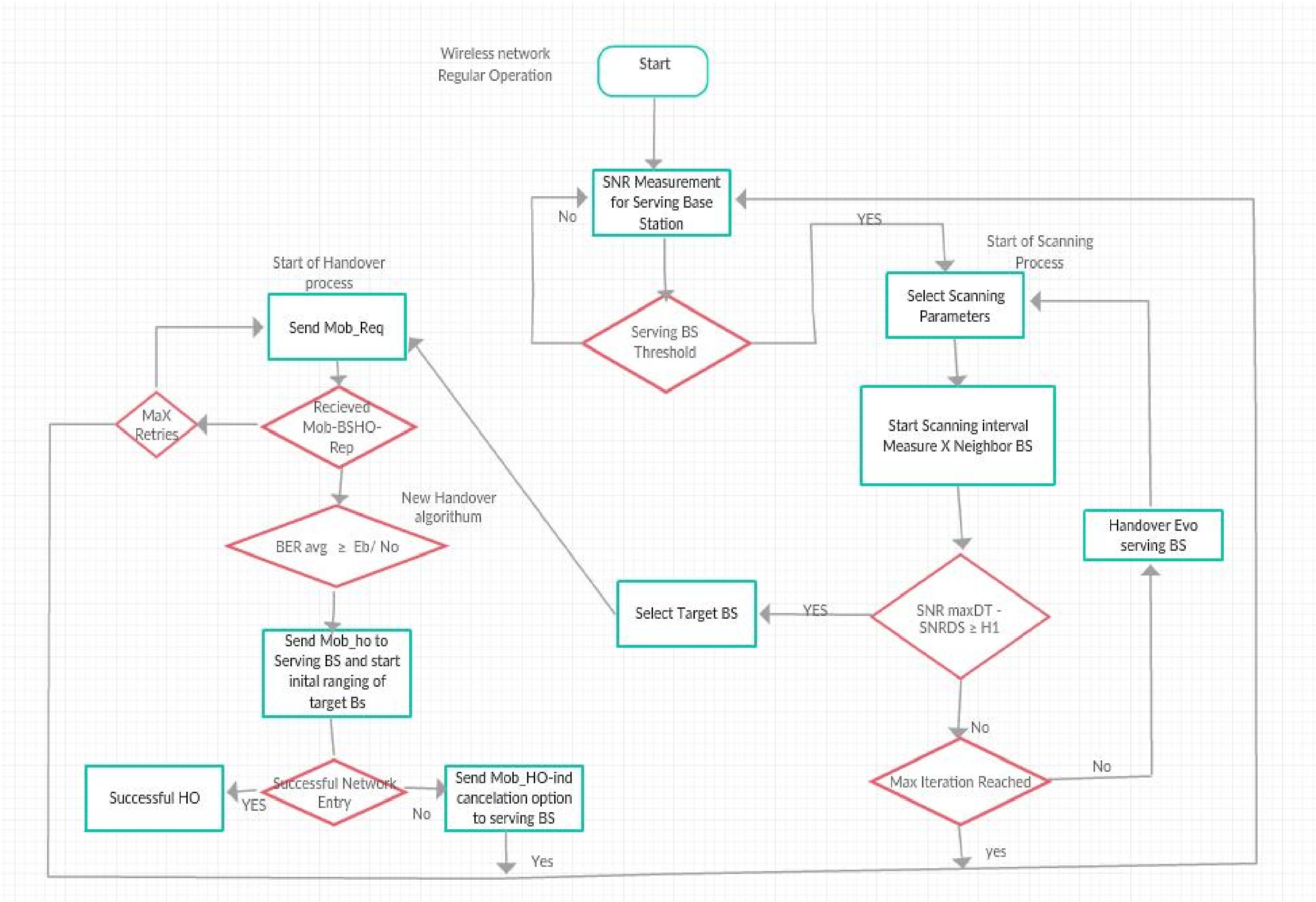

Figure 5.0.1 Schematic Data Flow Diagram for New Handover Algorithm suggested by Researcher

5.4 Performance Evaluation

The effectiveness and accuracy of new suggested analytical model and purposed new handover algorithm to improve handover delay in WiMAX is shown and presented by numerical results. The proposed model is tested using the discrete event simulation (DES). Where DES uses stochastic processes for mobile devices, where incoming and outgoing mobile devices are random, discrete og event driven. When one event is in process the other one is generated. The results derived from this simulation are within 5% to 95 % confidence level (Kirsal , et al., 2015). C++ language was used to configure the scenario. The numerical calculations mainly focuses on performance related parameters such as handover delay, QoS.

5.4.1 Key Parameters

The system parameters are defined, which are based on relevant literature (Al-Rousan, et al., 2011). A base station is configured with a Media Access Control address which is corresponding to its name. In (Al-Rousan, et al., 2011) the OFDMA frame and its sub carriers are kept 512 kbps and 5 ms respectively. While the mobile station down link flow is kept at 64 kbps. While other parameters are configured as per the tables below.

Table 5.0.1 Scanning parameters (Al-Rousan, et al., 2011)

Scanning Threshold (dB)	35 dB
Scan Duration (N) (Frames)	3 N
Interleaving Interval (P) (Frames)	255 P
Scan Iteration (T)	5 T
Maximum Scan Request Retransmissions	8

Table 5.0.2 Handover parameters (Al-Rousan, et al., 2011)

Handover Threshold Hysteresis (dB)	6.0 dB
MS Handover Retransmission Timer (ms)	30 ms
Maximum Handover Request Retransmissions	6 T
Multitarget Handover Threshold Hysterias (dB)	0,0
Maximum Handover Attempts per BS	3

5.4.2 Adjusted Parameters

The system parameters are configured with adjusted parameters where the Base station is configured with a Media Access Control address which is corresponding to its name. The OFDMA frame and its sub carriers are kept 256 and 3 ms respectively. While the mobile station downlink flow is kept at 128 kbps and other parameters are configured as per the tables below.

Table 5.0.3 Adjusted Scanning parameters By Researcher

Scanning Threshold (dB)	30 dB
Scan Duration (N) (Frames)	2 N
Interleaving Interval (P) (Frames)	230 P
Scan Iteration (T)	3 T
Maximum Scan Request Retransmissions	5

Table 5.0.4 Adjusted Handover parameters By Researcher

Handover Threshold Hysteresis (dB)	3.0 dB
MS Handover Retransmission Timer (ms)	20 ms
Maximum Handover Request Retransmissions	3 T
Multitarget Handover Threshold Hysterias (dB)	0,2
Maximum Handover Attempts per BS	2

Table 5.0.5 Adjusted OFDM Parameters By Researcher

OFDMA frame	256 kbps
Subcarriers	3 ms
Downlink flow	128 kbps

5.4.3 Results

The proposed analytical model results are achieved by numerical calculations shown in the table 5.0.6 and they show the effectiveness of the model providing lower handover delay and better signal performance. The values such as data packets dropped are close to none which shows that according the numerical calculations, there is next to none retransmissions and in addition to that the SNR values have improved which shows the strength of signal in the last mile of network coverage has more capability for data transmission. In similar fashion the values of BLER and Load shows more stable values without sudden changes.

Table 5.0.6 Analytical Model Numerical Results

Handover Delay (s)	DataPackets Dropped(s)	Load(bits/s)	Downlink (BLER)	Downlink (SNR)
0.011	1500	7000	2×10^{-6}	12
0.010	1000	10000	1×10^{-6}	14
0.009	500	11000	0.8×10^{-6}	15
0.008	100	11000	0.6×10^{-6}	17

5.5 Conclusion

The proposed analytical model and new proposed handover algorithm under high mobility conditions results in handover delay values which is very promising. The handover analysis is an important issue, especially when WiMAX is used as an alternative wireless broadband technology. In chapter 6 the model together with a new handover algorithm is tested by using a simulation tool RIVERBED and later in chapter 7 comparative analysis of results are done between numerically calculated results and RIVERBED simulation results. The performance of this handover algorithm is estimated using numerical calculations in this chapter. The suggested model results from numerical calculations show that while in ideal conditions this model would result in lower handover delay and better signal performance and WiMAX mobility is drastically improved. In a similar way the new suggested model shows the considerable reduction in the number packets dropped, which shows that the number of unnecessary handovers were reduced by WiMAX system showing a more free capacity for additional client stations.

CHAPTER 6: WiMAX SIMULATION EXPERIMENTS, PARAMETERS SETUP, COLLECTED, DATA AND RESULTS

This chapter shows the knowledge behind the exploration of handover delay in WiMAX. The usability and accessibility are defined at the end of simulation and development process, due to which the modification is usually done at the end of the process. The main objective and heart of this thesis are covered in this chapter where we explore and identify the components of the entire WiMAX and ensure the handover delay is reduced. This complete process is covered in this chapter. In addition, based on simulation experiments the usability features are included and data is collected in an understandable format.

6.1 Idea Development

The idea development is a very crucial stage where all the studies have included previous research work done in WiMAX, especially in the field of handover delay is put into a workable format. The reason behind this step being considered as crucial step is because all previous theoretical work done previously creates a mental model in the researcher's mind where researcher under the shortcomings of previous work done try to create its one understanding and from there an idea develops and with this idea come also expectations and with these expectations is converted into an actual workable model.

The concept of development of the idea is considered as part of meaning design where new ideas are developed, including the structure and concepts are developed. The transparency introduced due to the information age, which has given everyone many ideas and given the world, many new ideas which have changed or changing our lives day by day. Paradoxically, very few ideas end up as business reality and which are communicated at the initial stage as recognize, thematize and draft. The idea development ensures and makes ideas visible, while problem and goal specification enable a thematic classification. Usually, in the idea development phase.

Preliminary sketch modelling

The simulating process needed a virtual model. This is a model where all ideas and research process kick-started. The literature review identified basic structure, including the shortcomings within the WiMAX network. To make this research focused the design features and parameters were chosen to ensure the research is on target for basic aim which is reducing the Handover delay in WiMAX. Once the concept was clear, the basic network design needs to be identified and this does not need any specific software tool. Due to the aim of creating a structure which will serve as a foundation. For this, a sketch model was created which took considerable time and the final sketch model can be seen in the figure 6.0.1. The actual modelling process started with the basic design of simulation which consisted of a number of sketches and these sketches provided a foundation and also provided a very simple and powerful starting point for future planning and before implementing into modelling software.

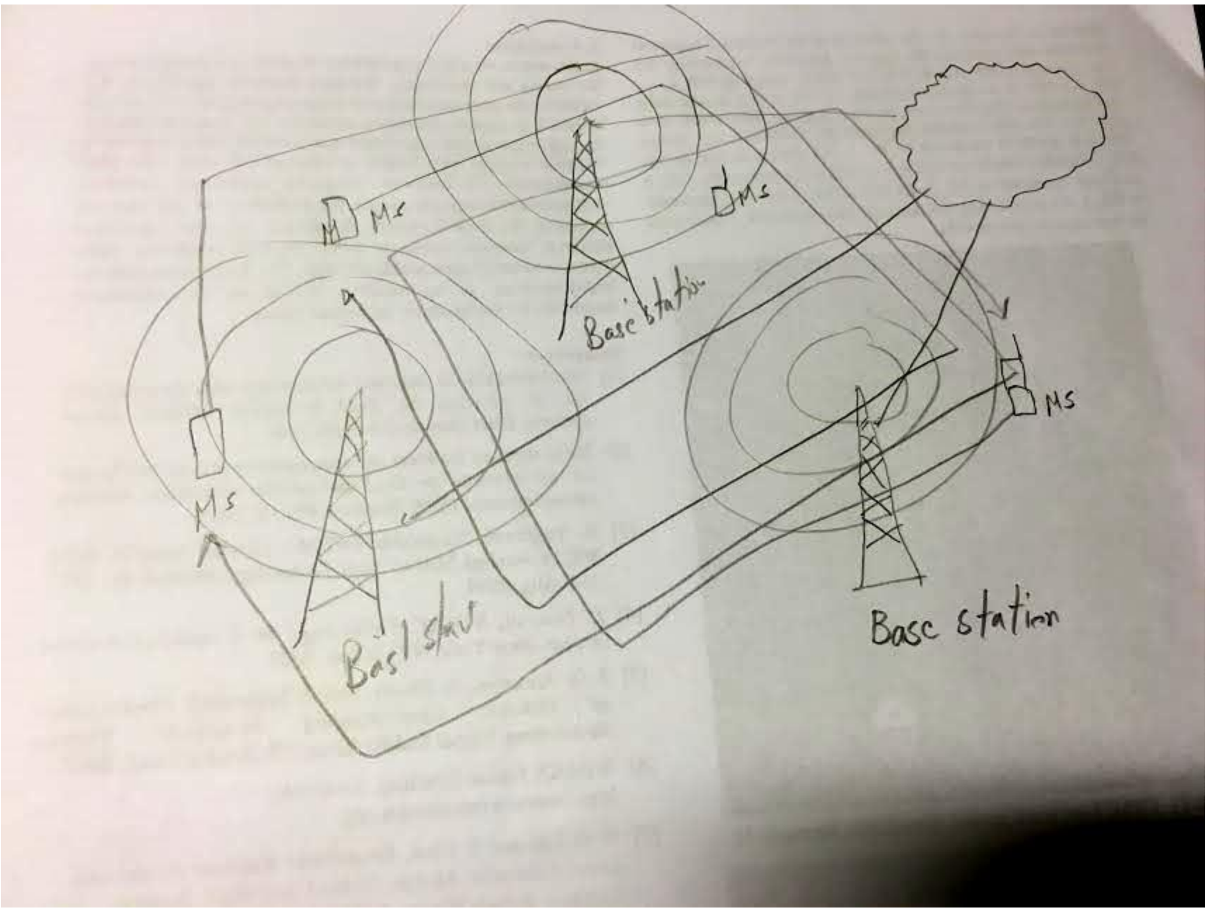

Figure 6.0.1 Preliminary sketch of initial WiMAX Network

The simulation tool was chosen to be RIVERBED and later on, this sketch model was converted to working model with simulation software.

6.2 Software Model for RIVERBED Simulation

The process of software modelling started after the basic sketch model of the network was ready. As RIVERBED was chosen as a simulation tool for this research due to the number of benefits it provides such as an analysis tool and ease of designing a network model with graphical interface and a number of ready-made built-in objects available to use. Even with the ease of use WiMAX is not simple and it requires an understanding of all expects of the tool which including programming scripts for modified simulation. I completed a crash course on this tool and later identified that RIVERBED 17.5 version was best suited to continue and proceed with this research. RIVERBED 17.5 version provides a WiMAX model which is suited to the current WiMAX model and ease of programming individual structure in very detailed manner and one other point which was interesting as the version 17.5 used limited simulation size. The simulation tool RIVERBED is used to translate the sketch WiMAX model to real software model and once this model was converted to software model its ready to test all the parameters in different simulated conditions. The use of RIVERBED 17.5 Software as a simulation tool helps in an expedient way to design and simulate while reducing the need for actual WiMAX network equipment. This software package helps in creating a complete WiMAX network without the need of any external hardware which reduces development time and cost. This Software package provides high precision analysis to help in analysis and development. Once the basic design has been sketched with a paper during sketch modelling and later this model is implemented in software for simulation and further designing. The Sketch model is converted into a RIVERBED software model. The WiMAX software model which is translated to RIVERBED has three subnets which are wireless subnet, cloud subnet and wired or server services subnet. The figure 6.0.2 shows the wireless subnet. The wireless subnet has 27 mobile WiMAX clients these mobile clients or mobile stations are mobile and they are moving with specific speed as per the simulation scenario and these mobile stations move in a specific trajectory which is circular in nature. The mobile station's move between the seven WiMAX zones which is supported by seven base stations. These base stations provide WiMAX signal to the mobile station which moves around from area one mobile WiMAX base station to another and here where the important handover takes place and the aim of this research is to reduce the handover delay to a minimum as possible.

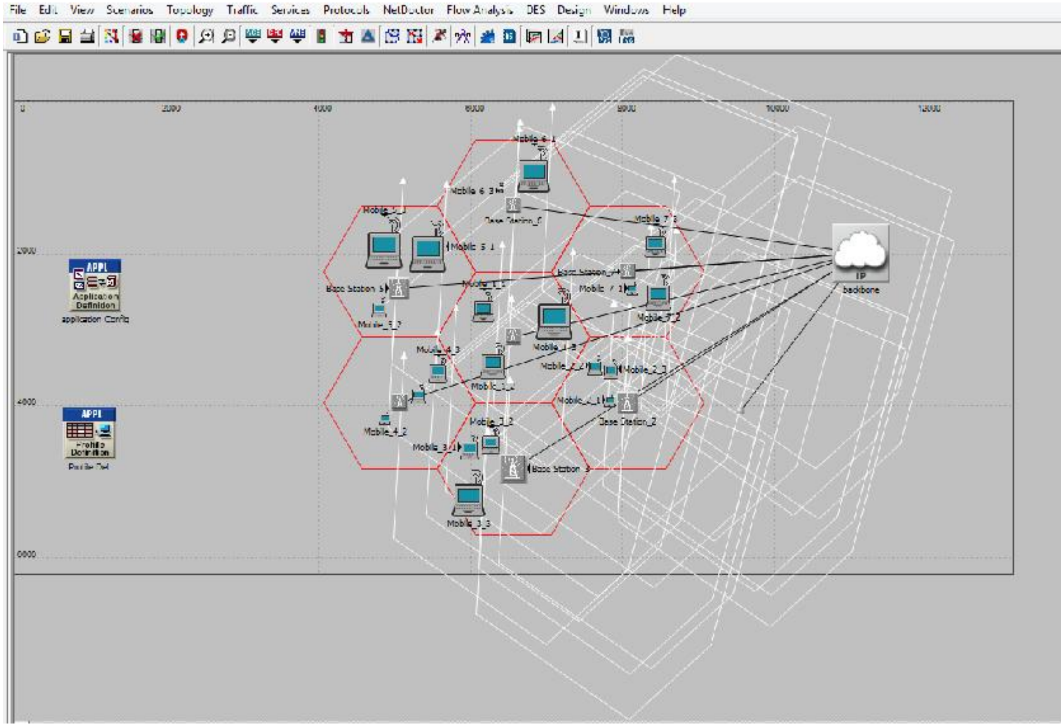

Figure 6.0.2 Preliminary RIVERBED WiMAX Wireless subnet Design

Figure 6.0.3 describes the cloud subnet of WiMAX network designed to be used in the simulation for this research, which consists of two separate network subnets which are connected to each other with a cloud internet connection which is a gigabit network line. This connection can be considered as a backbone connection which enables mobile devices in WiMAX mobile subnet to access the services from the servers in a wired network subnet as the mobile devices are moving at different trajectory with specific speed accessing the network services. This creates continues data download and upload and puts a lot load on the entire network.

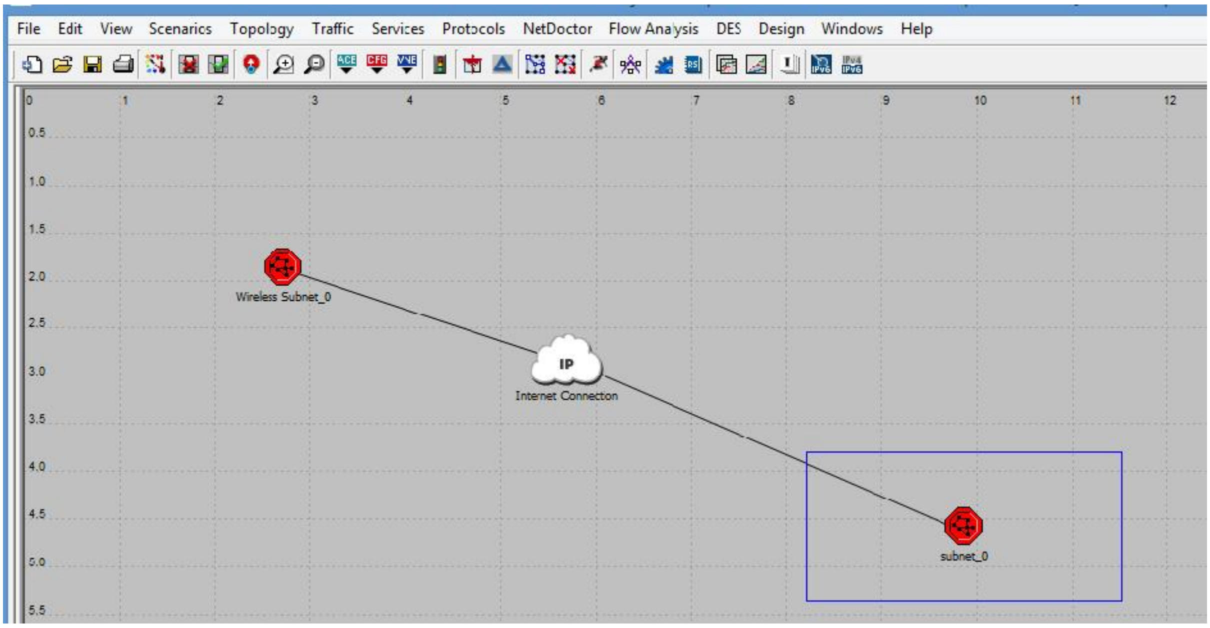

Figure 6.0.3 Preliminary RIVERBED WiMAX network joining to the wired network

The next subnet is very important part of WiMAX network due the reason all the network services are hosted shown by figure 6.0.4 that shows the wired subnet. This subnet can be considered similar to the datacenter where different application servers are located and providing services to mobile clients which are connected to network via a WiMAX signal. Mobile devices are moving at specific speed in a specific direction around the entire WiMAX network, moving from one base station to another and undergoing handover while exchanging from one base station to another station. In the figure 6.0.4 also consist of different network devices which makes it able to communicate. The network starts with a router which is connected to a firewall which ensures only authenticated data is being transferred and it also ensures the communication with the internet. The firewall is connected to internal subnet and this internet subnet has three user workstations. This is used to ensure the network is configured correctly and there are few clients devices, including three servers configured which are providing different services such as VoIP, Video streaming server and an Internet server. These services are accessed via WiMAX network by mobile devices while on the move.

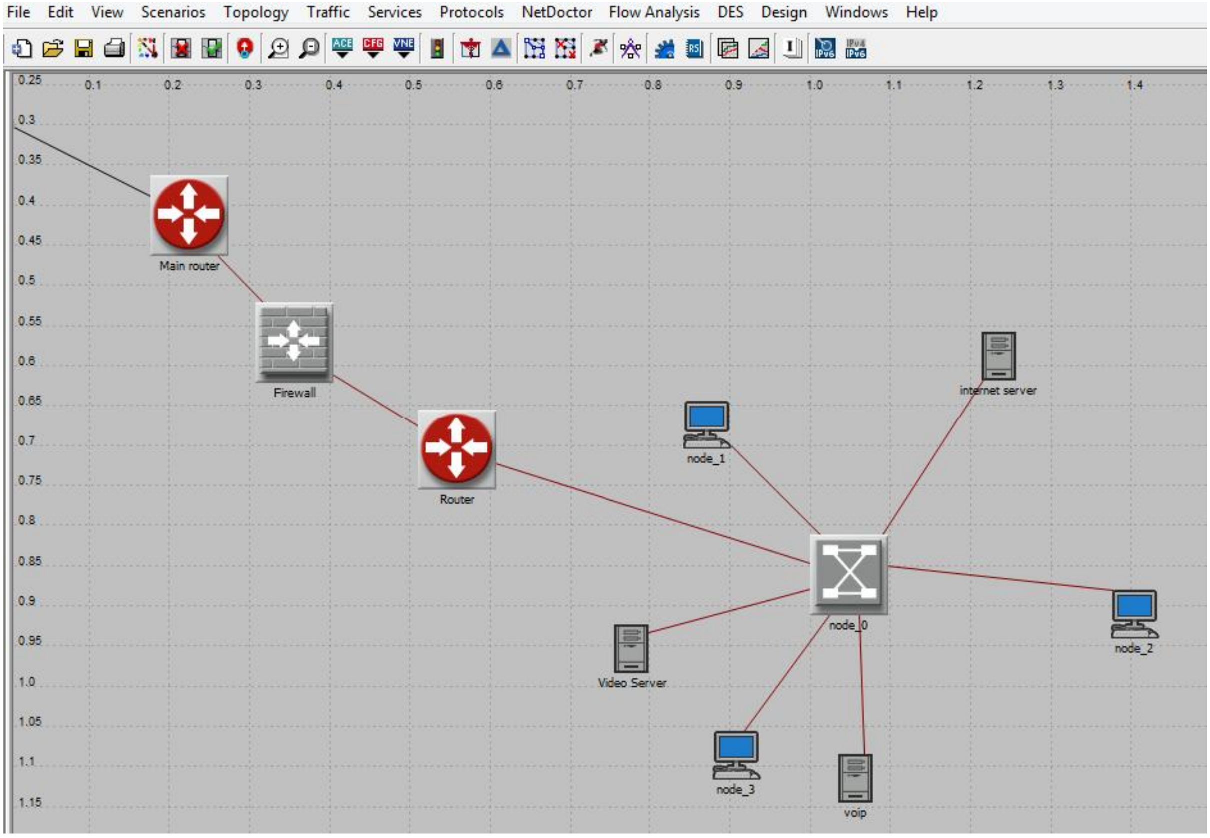

Figure 6.0.4 Wired Subnet of RIVERBED network model

6.2.1 Parameters Setup in the Simulation

Once the basic model is configured which means simulation is ready to be tested now comes the important step simulation configuration. The advanced parameters need to be set up and which changes the behaviour of simulation each and everytime change is done with the parameter setup. In this research for finding ways to reduce handover delay in WiMAX the communication happen between mobile stations and the base station and all signal modifications is supposed to happen with modification of parameters.

6.2.1.1 Base Station Parameters

The base station parameters configure and modify the behaviour of the base station. Figure 6.0.5 shows the parameters/attributes of the base station where it can be seen all the modification which can be done to modify the behaviour of simulation and more precisely behaviour of WiMAX signals originating from this base station.

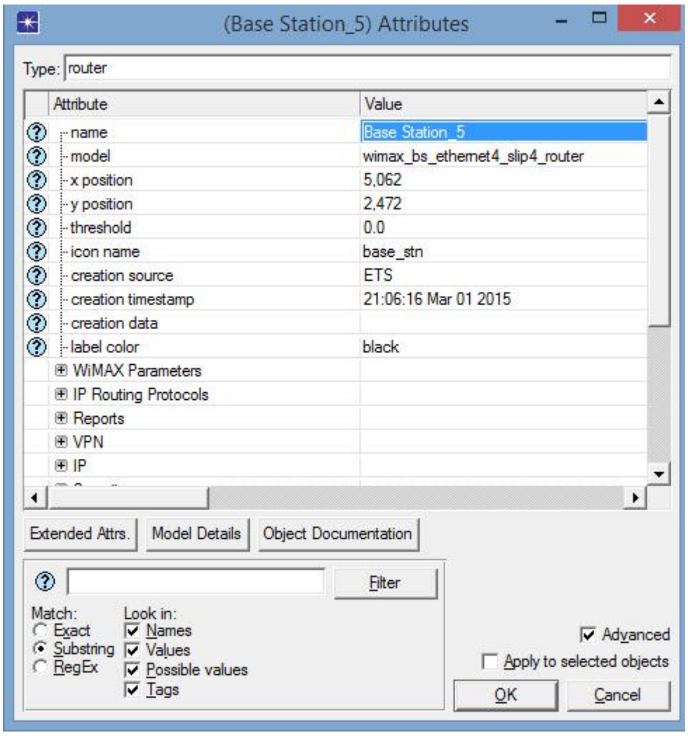

Figure 6.0.5 ***Base station Physical parameters***

In RIVERBED the researcher has the ability to apply the modification to only one base station or to apply this modification to all base stations with a single click. The researcher can modify the factors such as WiMAX parameters such as the detailed behaviour of WiMAX signal, Routing protocols, VPV etc. The values are modified and these effects the entire device behaviour. Whereas figure 6.0.6 shows the detail chip structure of the base station.

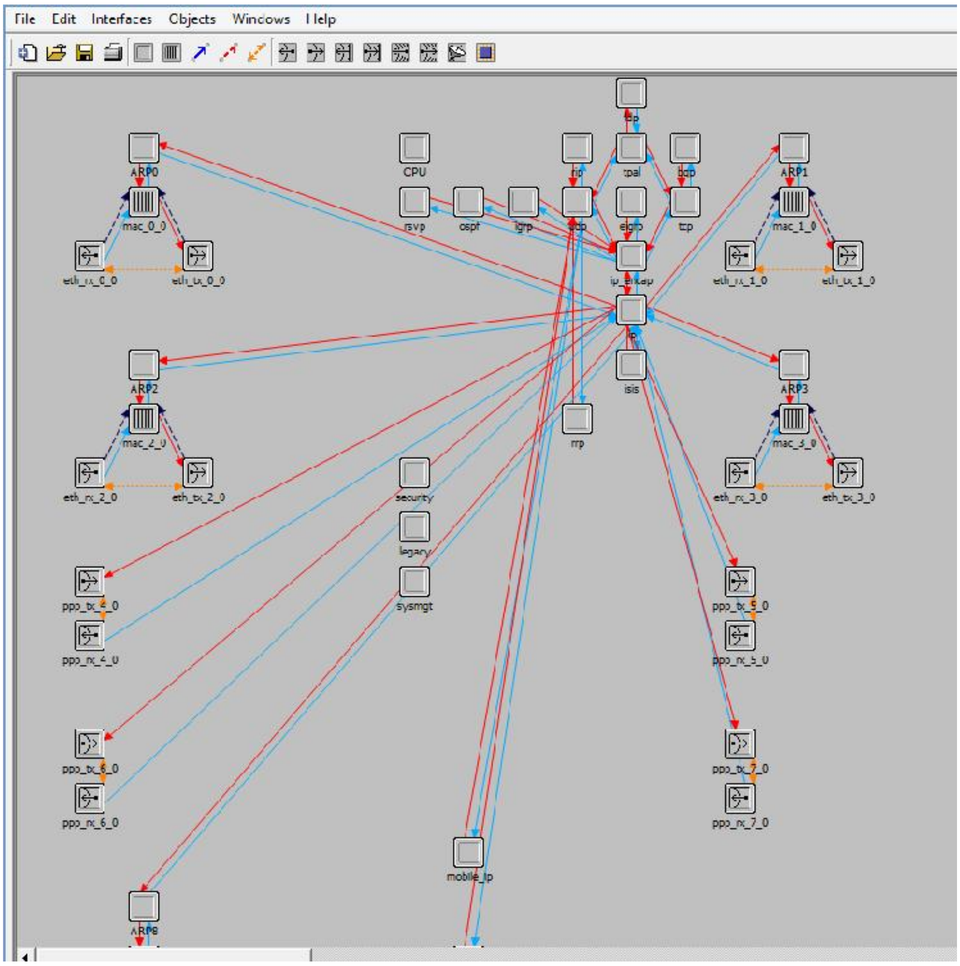

Figure 6.0.6 Base station chip structure

RIVERBED allows modification to chip structure and allow for modification inner workings of a base station including application new algorithms and writing a complete program to modify the behaviour of the base station to suit the simulation requirements. Figure 6.0.7 shows detailed logical parameters which can be modified by writing simple code to change the behaviour of the individual chip.

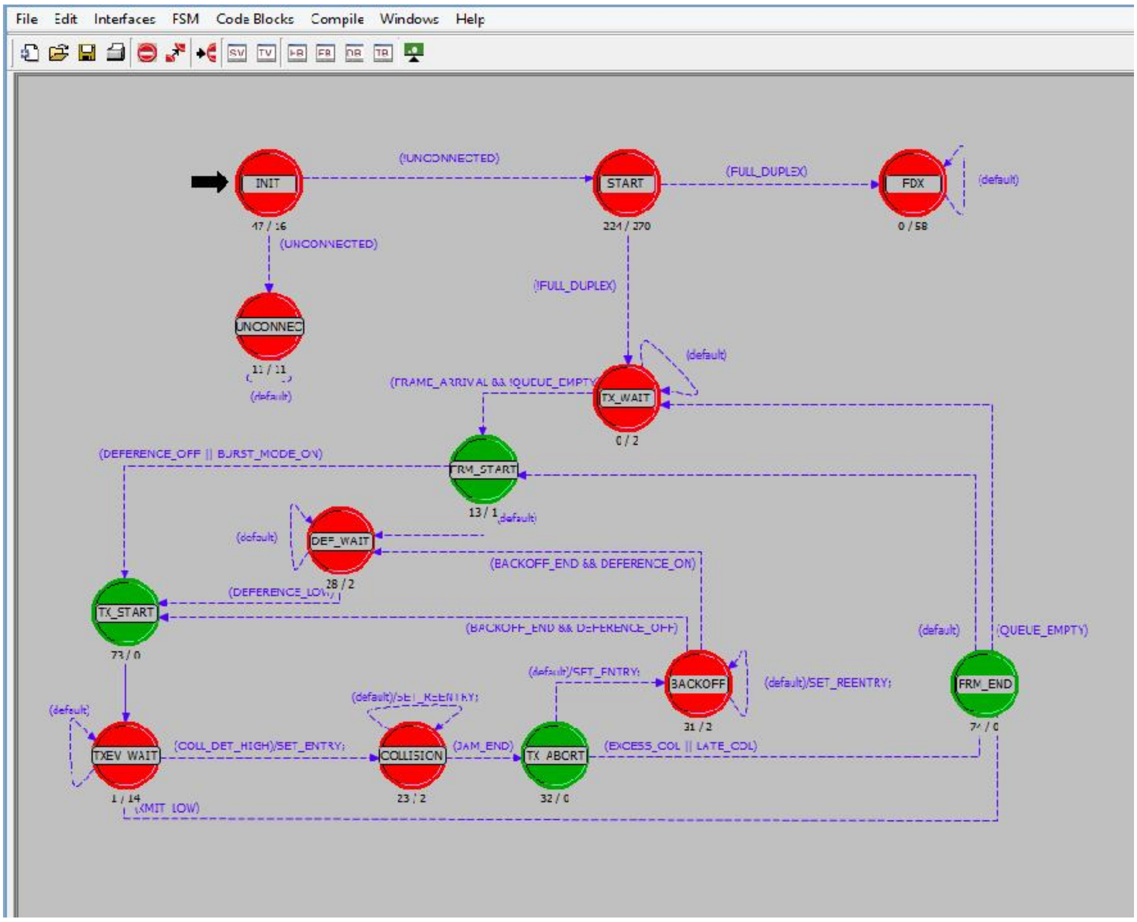

Figure 6.0.7 Base station Logical parameters.

6.2.1.2 Mobile Station Parameters

The mobile station is another important unit in the simulation experiments. As the aim of this research is to improve the handover delay in WiMAX signal while the mobile device is on the move at a specific speed.

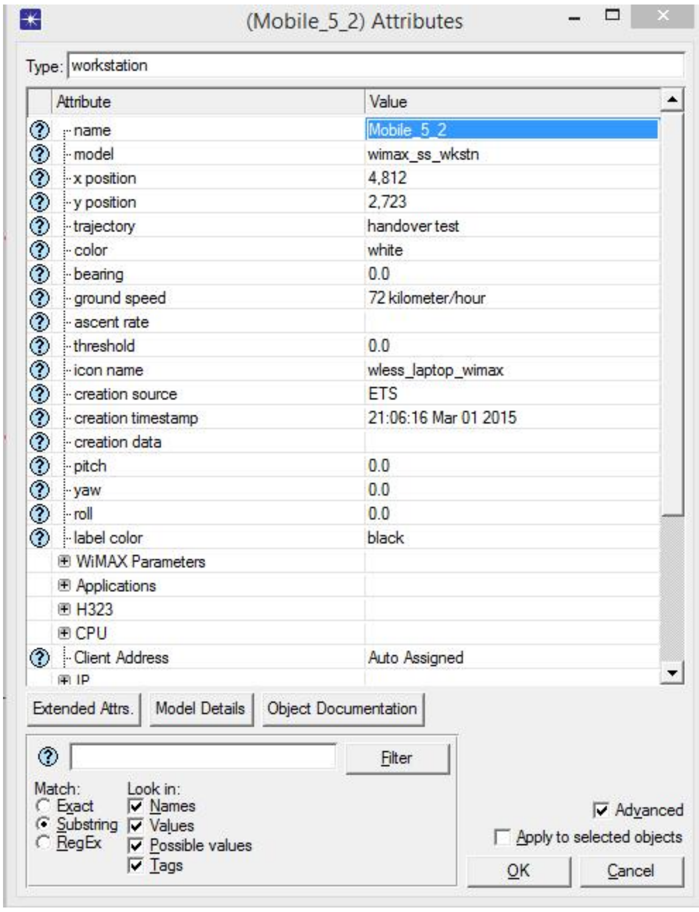

Figure 6.0.8 Mobile station Physical parameters

Figure 6.0.8 shows the physical parameters setup which can be further configured as per requirement. These parameters can totally modify the behaviour of mobile WiMAX wireless station or device. The parameters which can be configured are, for example, WiMAX Parameters, Application Setup etc.

This most important setup which configures the behaviour of Mobile station is the application setup within mobile station. This research uses a higher data rate to ensure the bandwidth is used is at max. Which will help in getting more accurate handover delay data and also help in the modification of handover delay, which is the main aim of this study. RIVERBED also helps in mobile station chip designs as seen in figure 6.0.9. The chip design can be modified by writing additional code where the behaviour of individual chip is modified.

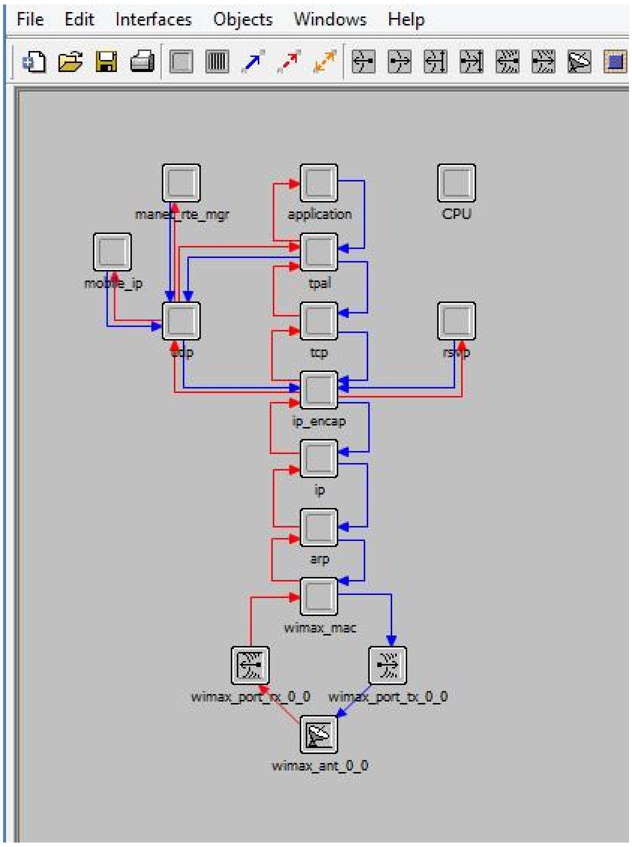

Figure 6.0.9 Mobile station chip design

The logical design, setup gives a detailed understanding of the logical setup of the mobile station and when the logical needs to be changed or modified especially when a particular algorithm is applied to the mobile station. The algorithm is applied to the logical design of the mobile station, which totally changes the behaviour of the device.

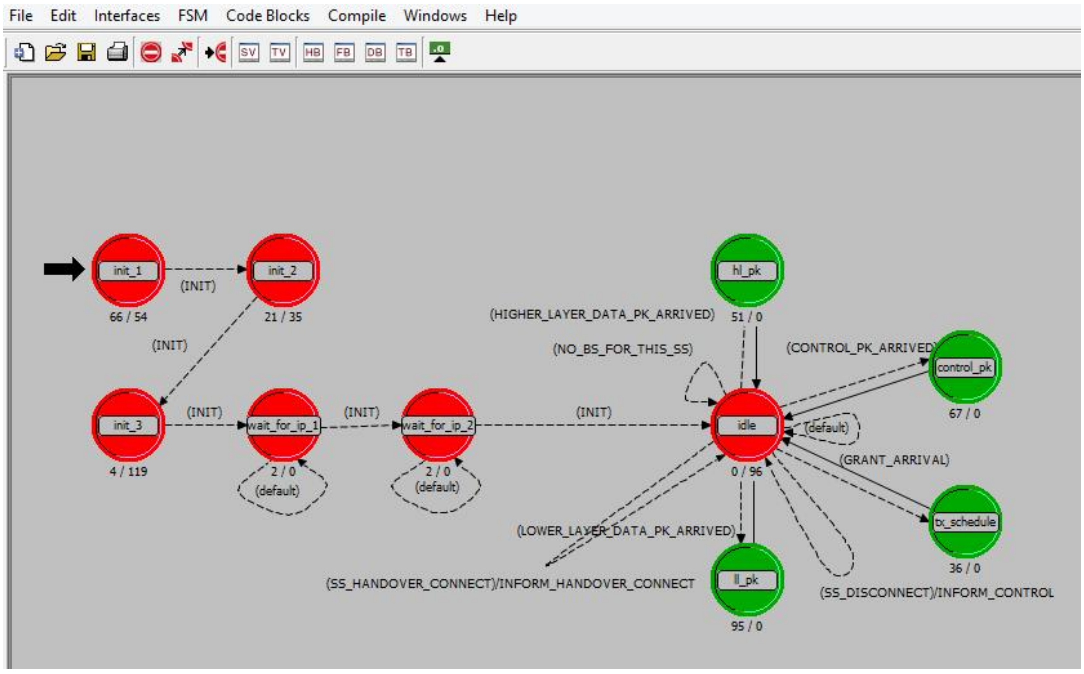

Figure 6.0.10 Mobile station Logical design

6.3 Handover Delay Improvement Experiments on Mobile WiMAX Standard IEEE 802.16e

In the beginning WiMAX was mainly considered as fixed network and the standard IEEE 802.16 was created to cater for fixed network, but with continued progress and advances in wireless communication and user demand moved the progress towards wireless requirements and it was realized by the adding mobility features which would be able to guarantee bigger consumer market due to prospect of wireless broadband network. In order to support such a features WiMAX Workgroup, presented IEEE 802.16e standard, which is based on IEEE 802.16-2004 which was aimed to support high-speed data transmission and while being able to move at higher speeds. Due to mobility features IEEE 802.16e, it is being considered as a main wireless broadband technology which is able to compete 3G. This standard defines some functions which have close co-relations with mobility features which includes handoff, sleep mode, saving energy, call search and improved safety. In addition to supporting mobile communication. As We are trying to improve Handover in Mobile WiMAX the next 5 Experiment and sub Experiments are done on WiMAX Standard IEEE 802.16e.

6.4 Experiment No 1

Once the model setup is completed and WiMAX model functions as per the standards, then process modification handover delay starts. The first step in the process is to reduce or minimize the effect of physical factors. The physical factors include the effects of terrain, effects of wind and effects of Speed etc. To be able to identify the factors affecting and then modify handover delay, it's very important to isolate the handover from other factors to study in detail the handover phenomena. The factors such as effect of terrain, effects of wind can be totally removed with the help of RIVERBED simulation tools, but the effect of speed cannot be nullified or totally removed, which is due to handover delay comes into effect only when the mobile device is moving at a certain speed between one base station to another base station.

The experiment is repeated a number of times at different speeds and simulation is configured where each and every time the mobile device is moving at different speeds and simulation is tested at speeds of 20,40,60,80,100,120,160,180 Kmph.

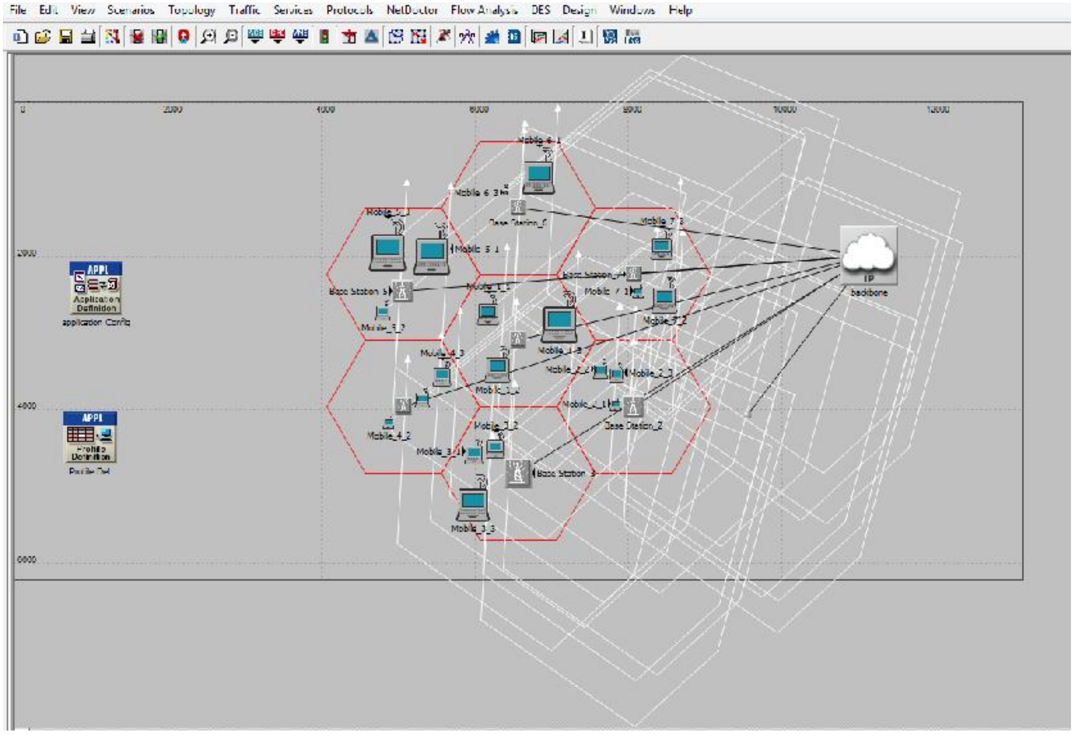

Figure 6.0.11 Mobile stations moving in specific trajectory

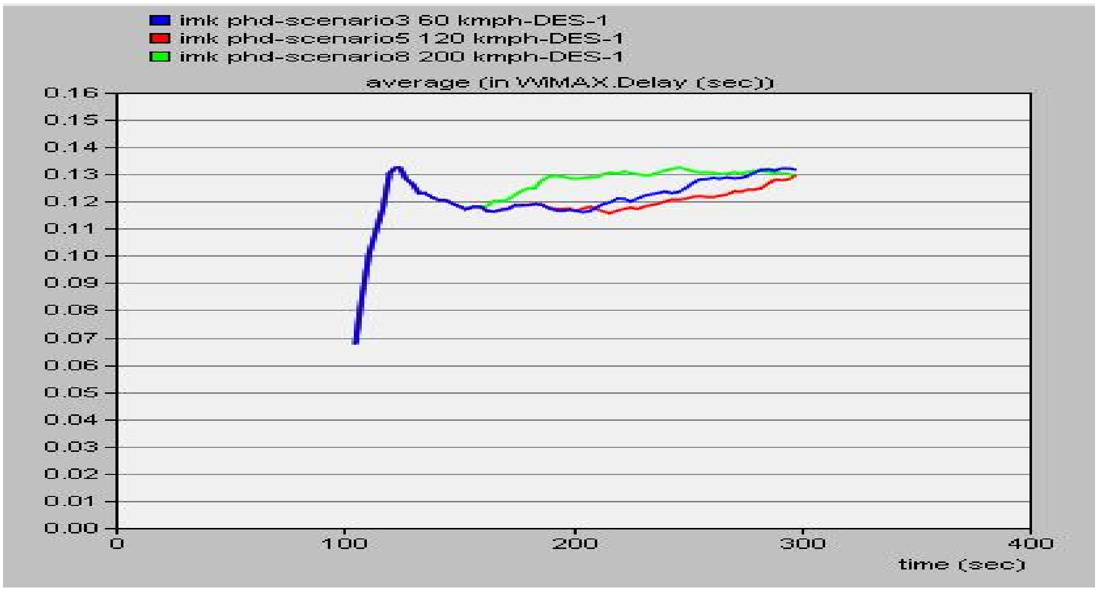

Figure 6.0.12 Handover Delay While Moving at different Speeds

When the experiment is tested a number of times at different speeds the outcome is very clear as shown in the figure 6.0.12 which taken from RIVERBED 17.5 results module. In this figure, it can be clearly seen that there is a minimum handover delay when the mobile device is moving at 60 kmph. The same can be seen from the table 6.0.1, where it can be seen clearly that handover delay values are lower at while moving at speed 60 Kmph.

Table 6.0.1 Simulation Results When Moving At Different Speed

Mobile Device Speed (km/h)	Handover delay (Sec)	Load (Bits/Sec)	Throughput(Packets /Sec)
60	0.13	700,000	500-750
120	0.135	705,000	550-600
200	0.14	800,000	550-600

While studying detail results which is shown in the table 6.0.1. In the table we can see when the mobile station is moving at a speed of 200 Kmph the throughput (Packets/Sec) is between 550-600, while the Load (Bits/Sec) 800,000 at the same time the handover delay is 0.14 Sec and when the mobile station is moving with a speed of 120 Kmph the load is 705,000 bits/Sec and throughput is between 550-600 Packets/Sec and where the handover delay is 0.135 Sec. When the mobile station is moving at 60 kmph the handover delay is 0.13 Sec at the same time the throughput is 500-750 packets/Sec and load is 700,000 bits/Sec, which shows that when the mobile station is moving at the average speed of 60 kmph without the effect of other physical factors will provide lowest handover delay.

6.4.1 Conclusion of Experiment 1

As the results of the experiment show that when we remove all the factors which can effect handover and only monitor the speed of the mobile station. It is clearly evident that when the mobile station is moving at the speed of 60 kmph, the handover delay will be at the minimum. These results create a basic building block for the current study where the goal is to minimize the handover delay in WiMAX signals while the mobile station is moving at a particular speed. The conclusion of this experiment is that when the mobile device is moving at 60 kmph would result in a minimum handover delay and for that reason, the speed in the next experiments would be kept constant at 60 kmph.

6.5 Experiment No 2

This experiment mainly tries to identify the signal parameters which influence handover delay in WiMAX and as per WiMAX forum that standard delay is 50 ms In the previous experiment, we identified that the mobile station speed of 60 kmph would cause minimum handover delay when we keep all other factors standard or totally remove their effect. The simulation model used in this experiment is same as the one used in the previous experiment and some parameters will be kept constant to keep the simulation process simple.

6.5.1 Objective Of This Experiment

The Aim of the experiment is to identify the factors which directly effect the handover delay in mobile WiMAX and also identify when these factors would result in a minimum handover delay which would help us standardize these factors in order to reduce handover delay in WiMAX.

6.5.2 Constant Parameters

In order to simplify the simulation process in this experiment and the complex nature of the handoff process in mobile WiMAX would make it very hard to execute this experiment and that’s why some of the values are kept constant throughout the next few experiments which are related to configuration of Base stations specifically Coverage area, transmission power, operating frequency and effect of terrain. This would make it easier to adjust other parameters in order to identify which factors affect the handover process and also achieves lower handover delay time. The WiMAX Model is used same in each sub-experiments where the number is Base station and their location and the mobile station and movement direction are kept same in the entire process. The rate of transmission or bit rate is also kept constant which is 1.4 Mbps. In literature, it was identified that in order to send a MPED-1 file a data transmission bit rate is required (11172-1:1993, 1993). The packet size and duration time are also kept constant at a rate of 166 bytes and 15 ms respectively.

6.5.3 The Effect of Factors On WiMAX Handover Delay

The objective of these experiments are that we need to identify which factors have a direct effect on handover delay in WiMAX and which factors have no effect at all below is a list of parameters which are tested in different sub-experiments. The previous studies (Khan, et al., 2012) identified 16 factors which could have an effect on handover delay in WiMAX networks. The identified factors are below

a) Link going down factor (Lgd_factor)
b) Scan iteration
c) Interleaving Interval
d) Timeout Parameter
e) Frame_duration
f) Lost_dlmap_interval
g) Client_timeout
h) Lost_ulmap_interval
i) Ranging_backoff_start
j) MaxRADelay
k) MinDelayBetweenRA

l) Queue_length

m) T44_timeout

n) MinRtrAdvInterval

o) MaxRtrAdvInterval

p) Scan_duration

a) Link going down Factor

The Link going down factor is considered important parameters in WiMAX, where it determines the sensitivity of detecting a falling link. This factor is set and configured to create a Link Going Down effect and this effect is generated when the received signal power is less than factor RXThresh and then trigger is generated which starts the scanning process for neighbouring Base Stations. When for the particular coverage area, at the edge, RXThresh value establishes the limit of a particular area which means that outside of that area the data packet will be discarded. The higher the value of link going down the trigger is generated more sooner.

In order to test the link down factor, the LGD values are configured as per show in the figure 6.0.13. This factor is set up a base station level, which is inside the scanning parameters and Link Going Down factor is changed every time while other values are kept constant or kept standard.

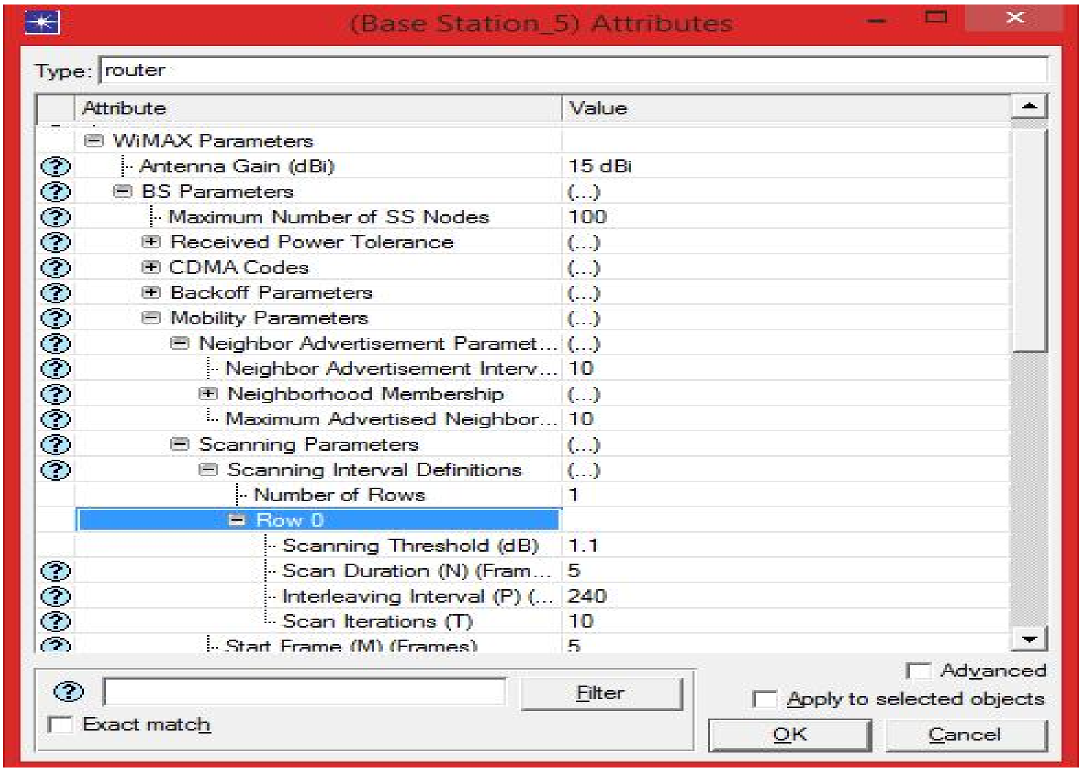

Figure 6.0.13 Link Going down factor Setup in RIVERBED

When the simulation is repeated a number of times we get the results for Link Going Down Factor effect on handover delay in WiMAX. The Figure 6.0.14 shows that when the mobile station is moving at the speed of 60 kmph the handover delay is at a minimum when link going down factor is at 1 and 1.3.

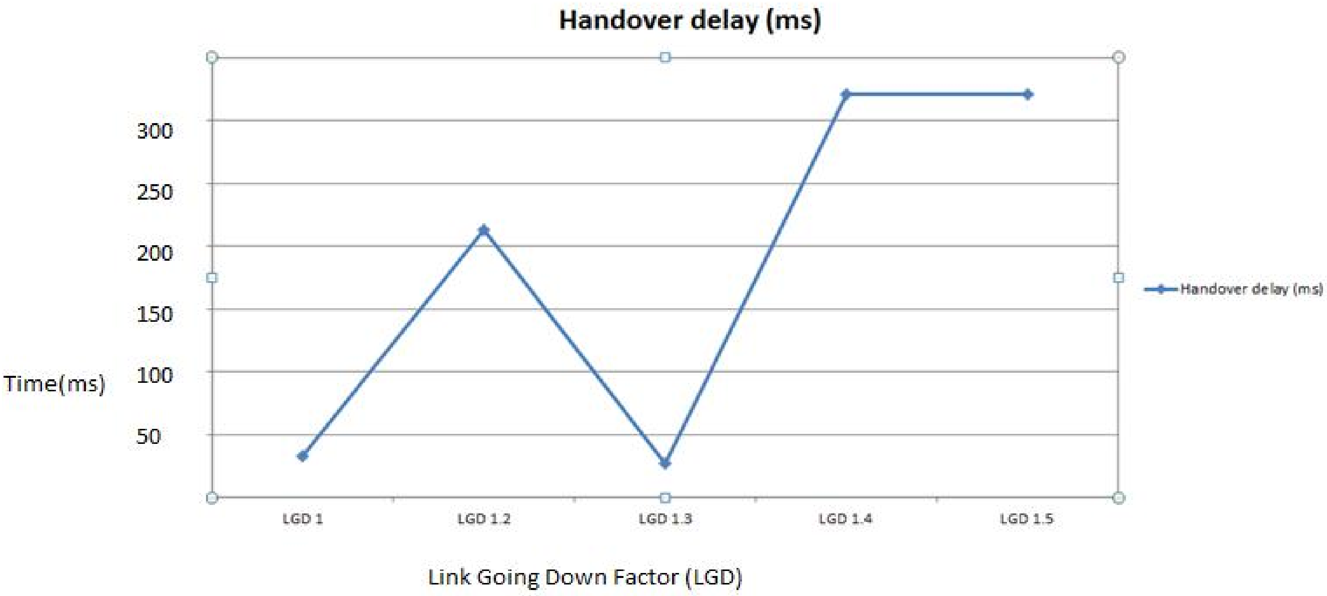

Figure 6.0.14 Effect of Link Going Down Factor on Handover Delay

The table 6.0.2 shows that if the LGD value is kept either at 1 or at 1.3 the signal broadcast will show the minimum handover delay while if the value is set up more than 1.3 the handover delay moves to the highest point. The results also identify when link going down factor is at 1 and 1.3 both provide a similar handover delay which is 0.015 Sec and at the same time the load and throughput is 400500 bits/Sec and 400 packets/Sec respectively

Table 6.0.2 Simulation Results of Link Going Down Factor

Link going Down Factor Value	Handover delay (Sec)	Load (Bits/Sec)	Throughput(Packets/ Sec)
1	0.015	400,500	400
1.2	0.020	400,000	360
1.3	0.015	400,500	400
1.4	0.020	400,000	350
1.5	0.020	400,000	340

The results also identify that when higher the LGD factor value the sooner the trigger is generated

b) Scan iteration

The Scan Iteration can be defined as it is the number of iterating scanning interval done by the mobile station. Which in other terms means that how many times the mobile station will complete the scanning procedure. To do a simulation using this attribute all other factors are kept standard, while the Scan iteration value is changed for each simulation and this value is configured at the base station level as seen in the figure 6.0.15.

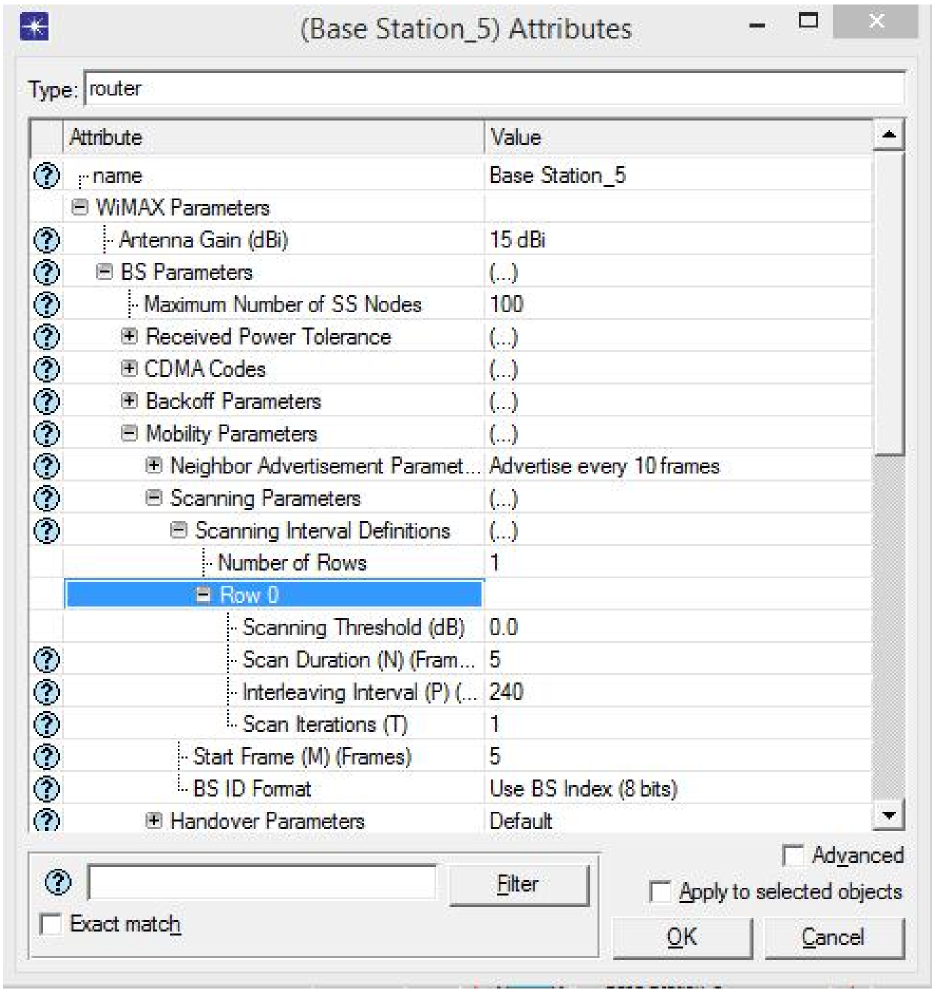

Figure 6.0.15 Configuring Scan Iteration Value for Simulation

The simulation is repeated many times while keeping everything else constant and only changing the value of Scan Iteration for each and every time. The only simulation is completed and the simulation results show a trend where the higher the value of scan interaction the higher will be a handover delay as shown in the figure 6.0.16.

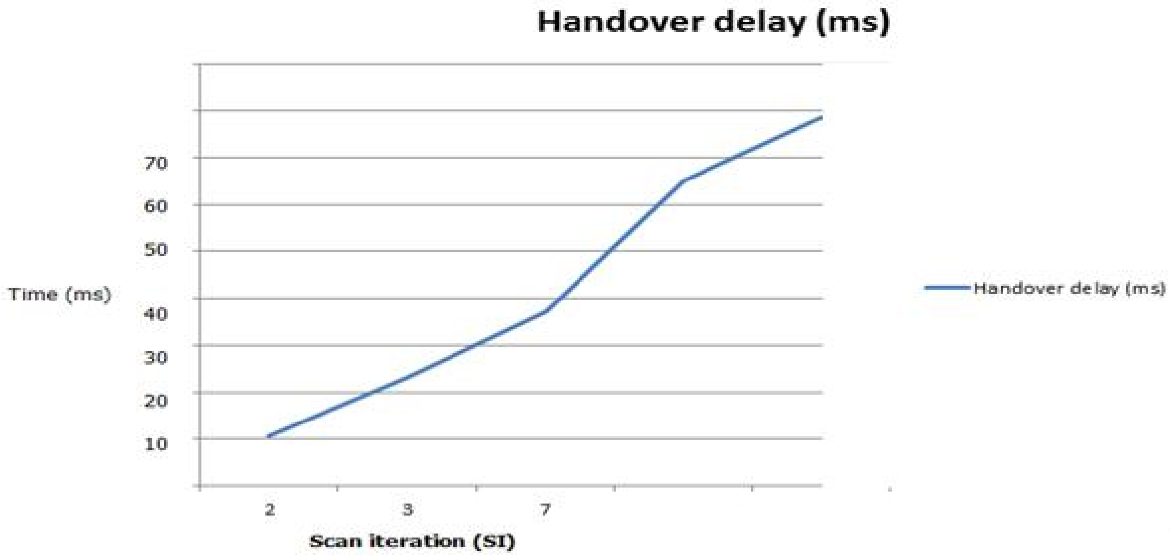

Figure 6.0.16 Effect of Scan Iteration on Handover Delay

The simulation results point towards that a higher the level of scan interaction will be resulting in higher handover delay time. Which clearly shows that in order to keep a handover delay low. We have to keep SI factor at a lower level.

Table 6.0.3 Effect of Scan iteration on handover delay, Load and Throughput

Scan iteration Factor Value	Handover delay (Sec)	Load (Bits/Sec)	Throughput(Packets/Sec)
2	0.021	425,000	420
3	0.023	401,000	400
7	0.025	420,000	350
8	0.029	400,000	300

The Simulation results in table 6.0.3 show that at when scan iteration value is kept at 2 the WiMAX will have a minimum delay and other values such load is a 425000 and throughput are 420 packets/Sec.

c) Interleaving Interval

The Interleaving interval is WiMAX parameter which can be defined as it is the time duration between the normal operation and scanning periods of the mobile station in frames. In other words, it can be also explained as it is the time duration between scanning period and normal frames in the mobile station. In order to simulate and test this factor in RIVERBED simulation, it should be setup and configured at the base station level and simulation is done changing the value for each simulation and every time.

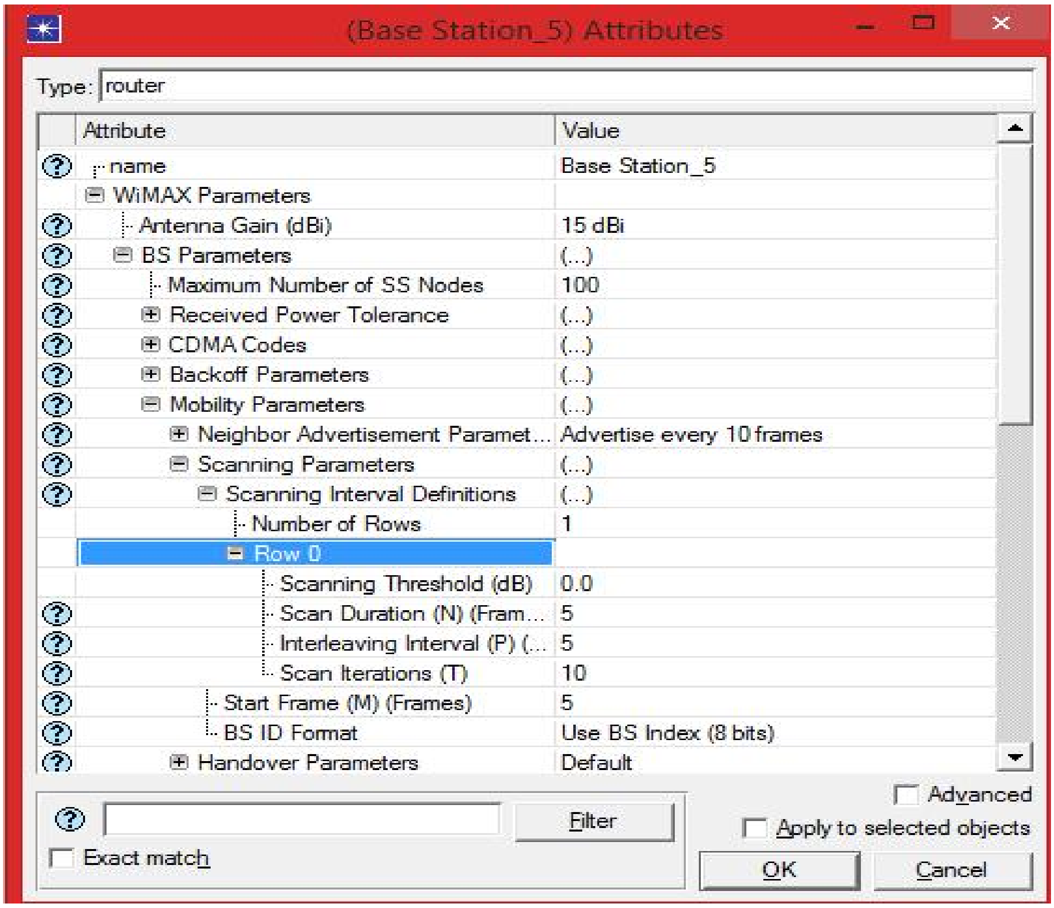

Figure 6.0.17 Configuring Interleaving Interval Value for Simulation

When the simulation was configured all changes were done at the base station level and while changing Interleaving interval values for each simulation all other parameters were kept constant and standard. When the simulation was completed a number of times, the simulation results show that there is the very limited effect of interleaving interval handover delay and when the value increases more than 20ms and handover delay increases and higher rate.

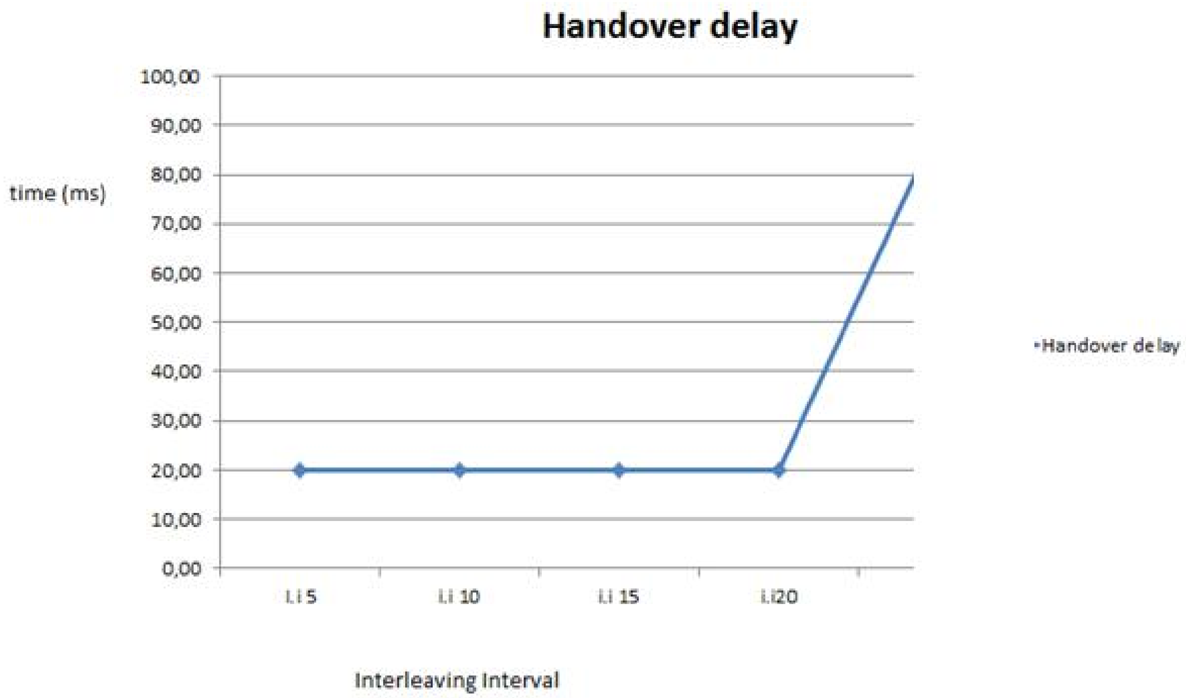

Figure 6.0.18 Effect of Interleaving Interval on Handover Delay

As We see in the figure 6.0.18, if we set up the value less than or equal to twenty frames it will affect the hands-off time with a small variation which means that from startup to 20 ms Interleaving Interval there is no direct effect on handover delay while when we increase the value to more than twenty frames will result in longer handoff times. When looking at detail results shown in table 6.0.4. In the table we can see that from the value of 5 till 20 there is no change in any values which means there no direct effect of interleaving interval on handover delay load and throughput, but when we cross the Interleaving Interval value of 20 the handover delay starts increasing this also effect on other values are also same.

Table 6.0.4 Effect of Interleaving interval on Handover Delay, Load and Throughput

Interleaving Factor Value	Handover delay (Sec)	Load (Bits/Sec)	Throughput(Packets/Sec)
5	0.020	400,000	340
10	0.020	400,000	340
15	0.020	400,000	340
20	0.020	400,000	340
25	0.027	440,000	300

d) Timeout Parameter

The Timeout Parameter can be defined as it is the timeout value for a Mobile station, which is searching for DL-MAP message. Which in other words means the mobile station needs to find a DL-MAP message within a specific time interval. In simple terms, the Timeout parameter can be defined as it is the time needed for a mobile station to receive downlink map message. When configuring the simulation to test the effect of Timeout parameter this value is configured at the base station level. This step is repeated each and every time the simulation is repeated as shown in the figure 6.0.19. Only the values of Timeout parameter are changed while the values other parameters are kept the standard and using the same model which was designed and configured initially.

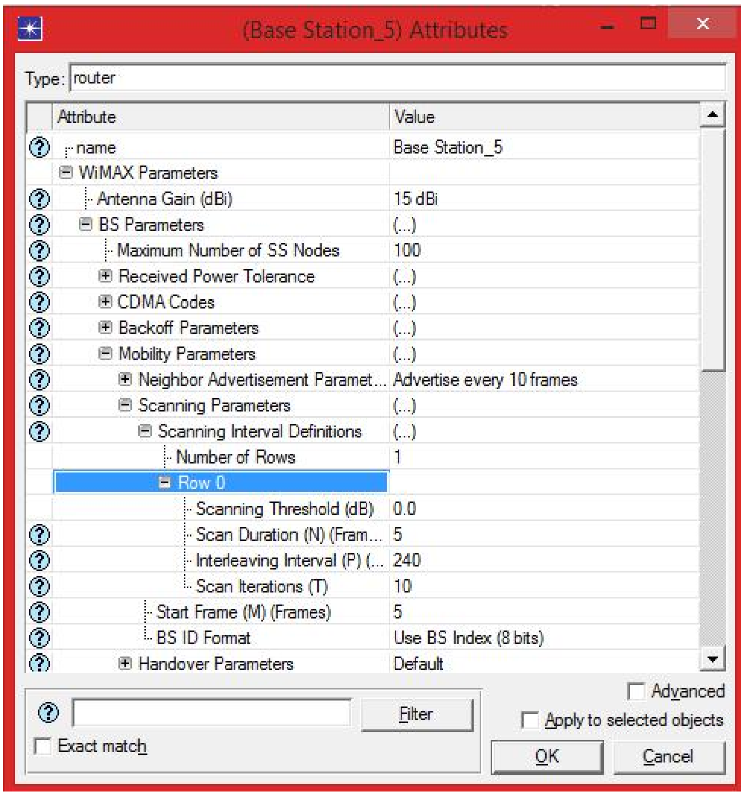

Figure 6.0.19 Configuring Timeout Parameter Value for Simulation

This value can also be set up at the base station level and when simulating this network this parameter will also be configured at base station attributes. After a number of runs, the simulation results show the trend that the handoff time is same. The figure 6.0.20 shows that when when timeout value is between 5 to 20 ms, there is no effect on handover delay time. However, once we increase value one by one and after 20 ms it increases the handoff time rapidly. Which means that any timeout parameter value which is set between 1 till 20 will provide minimum handover delay. When we look at the figure 6.0.20 and we can make a comparison and see the effects timeout parameter on handover delay.

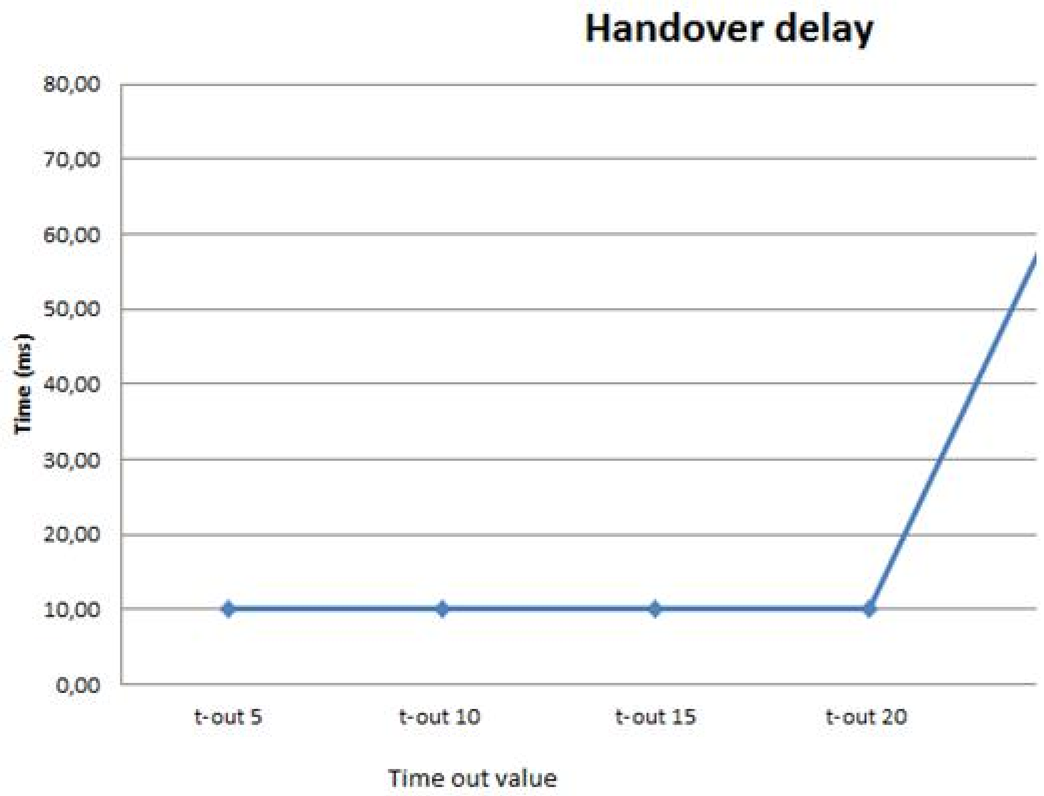

Figure 6.0.20 Effect of Timeout Parameter on Handover Delay

The simulation results in the table 6.0.5 show a particular trend where the handover time remains same between 5 to 20 ms, and there is a drastic increase in handover delay time after the timeout value gets higher than 20ms. When we also take into consideration the values of load and throughput we can identify that when the timeout parameter value is between 5 to 15 ms the handover delay time is 0.022ms and throughput value is 360 packets/Second, and when the timeout parameter value is at 20ms the handover delay time is 0.022ms but at this value of throughput which is 370 packets/Second. Therefore, it can be identified when timeout parameter is kept at 20 ms the overall performance of WiMAX signal is far better providing lower handover delay time better load and throughput values.

Table 6.0.5 Effect of Timeout Parameter on Handover Delay, Load and Throughput

Timeout Parameter	Handover delay (Sec)	Load (Bits/Sec)	Throughput(Packets/Sec)
5	0.022	420,000	360
10	0.022	420,000	360
15	0.022	420,000	360
20	0.022	420,000	370
25	0.030	400,000	320

e) Frame_duration

Frame duration can be defined as the length or size of a frame. The simulation is configured in the same way as other simulation keeping the speed of mobile devices 60 kmph. When Simulation was repeated the number of times it was identified that frame_duration show an effect on handover delay and any change in frame_duration show effect on the value of handover delay time. It can be seen from the table 6.0.6 that only when frame_duration is kept at 15 will result in minimum handover delay time of 0.020 Sec while at other values it results higher handover delay.

Table 6.0.6 Effect of Frame_duration on Handover Delay,Load and Throughput

Frame_duration	Handover delay (Sec)	Load (Bits/Sec)	Throughput(Packets/Sec)
5	0.040	420,000	340
10	0.040	420,000	350
15	0.020	420,000	370
20	0.045	420,000	350
25	0.050	450,000	350

f) Lost_dlmap_interval

The Lost DL-MAP can be defined as the interval which defines the timeout value for the last reception DL-MAP Message in the mobile station. In other words, it would mean that when the new DL-MAP message does not arrive at the MS within this time period the sync between Mobile Station and Base Station will be interrupted. Once Simulation was repeated the number of times we identified that the lower values of Lost_dlamp_interval would increase or result in a longer handover delay which can be seen from table 6.0.7. We have identified even it has lower handover delay time of 0.14 ms but the effect of this value is not very stable due to unstable throughput values and that’s why cannot be used to further modify the handover delay in WiMAX

Table 6.0.7 Effect of Lost_dlmap_interval on Handover Delay,Load and Throughput

Lost_dlmap_interval	Handover delay (Sec)	Load (Bits/Sec)	Throughput(Packets/Sec)
5	0.140	420,000	300
10	0.130	420,000	300
15	0.040	420,000	320
20	0.040	420,000	350
25	0.040	450,000	350

g) Client_timeout

Client_timeout can be described as the value which detects the range out of the mobile station. This value is not efficient when the mobile station is moving in the large network coverage area. Even taking note of this reality, the simulation results show the direct effect on handover delay times when the simulation is repeated. The simulation results can be seen in table 6.0.8 and It can be identified from that table that when Client_timeout is at 6ms would result in lower handover delay time of 0.014 ms and throughput of 350 Packets/Sec. Which points towards the fact that this value has a direct effect on handover delay time and which can used for further modification of handover delay time in WiMAX.

Table 6.0.8 Effect of Client_timeout on Handover Delay, Load and Throughput

Client_timeout	Handover delay (Sec)	Load (Bits/Sec)	Throughput(Packets/Sec)
6	0.140	420,000	350
10	0.160	420,000	200
15	0.150	420,000	220
20	0.150	420,000	300
25	0.160	450,000	250

h) Lost_ulmap_interval

The Lost_ulmap_interval has similar characteristics as Client_timeout but it is used for UL-MAP message. The parameter is configured in the same simulation model and keeping other parameters as standard. The result of the simulation is shown in Table 6.0.9, where we can see that with lower value Lost_ulmap_interval the handover delay is higher and its show bit lower handover delay at 15 ms, but another signal values are not promising which points out that this parameter cannot be used for further modification or improvement of handover delay time.

Table 6.0.9 Effect of Lost_ulmap_interval on Handover Delay,Load and Throughput

Lost_ulmap_interval	Handover delay (Sec)	Load (Bits/Sec)	Throughput(Packets/Sec)
5	0.140	410,000	300
10	0.130	400,000	300
15	0.045	420,000	320
20	0.043	430,000	350
25	0.042	450,000	350

i) Ranging_backoff_start

This parameter is important during the training phase of handoff and it's also used in the same phase, where it defines the size for the first backup window. The effect of this parameter is tested with configuring and running the simulation with WiMAX test model.

Once the simulation is repeated the number of times the results can be seen in the table 6.0.10 which shows that the handoff time for a window size of 2 to 5 slots, but when we there is an increase in the slot size to more than 5 handoff time is increased, respectively. However, it also shows that a slot size of 1 also causes longer handoff time. Therefore, we have used 3 slots as a backup window size for initial ranging and due to its inconsistent nature and its effect on handover this parameter cannot be used as a foundation for further modifying the handover delay in WiMAX

Table 6.0.10 Effect of Ranging_backoff_start on Handover Delay,Load and Throughput

Ranging_backoff_start	Handoverdelay(Sec)	Load Bits/Sec)	Throughput(Packets/Sec)
1	0.060	310,000	300
2	0.035	400,000	400
5	0.035	400,000	400
6	0.045	400,000	400
7	0.085	320,000	320
9	0.085	330,000	355

j) MaxRADelay

MaxRADelay can be defined as it is WiMAX parameter which defines or decides the maximum handover delay for sending a reply message to an RS. This parameter is configured on an existing WiMAX model while keeping the other parameters standard so we can monitor the effect of this parameter on handover delay. The simulation results as seen from the table 6.0.11 shows that a value less than or equal to 6 ms achieves the lower handover delay time, but as an effect of this parameter is more unpredictable and that's why it cannot be used for optimizing handover delay.

Table 6.0.11 Effect of MaxRADelay on Handover Delay,Load and Throughput

MaxRADelay	Handoverdelay(Sec)	Load Bits/Sec)	Throughput(Packets/Sec)
1	0.040	430,000	400
2	0.035	420,000	400
5	0.045	420,000	400
6	0.045	400,000	400
7	0.085	320,000	320
9	0.095	330,000	355

k) MinDelayBetweenRA

This parameter defines the override default value for minimum interval time which is between two conSecutive RAs and the Simulation was done to understand its effect on handover delay in WiMAX. The results in table 6.0.12 show that the value of 10 gives best handover delay time, but the values of Load and throughput show that it has also some negative effect on overall WiMAX signal performance.

Table 6.0.12 Effect of MinDelayBetweenRA on Handover Delay,Load and Throughput

MinDelayBetweenRA	Handoverdelay(Sec)	Load Bits/Sec)	Throughput(Packets/Sec)
1	0.050	330,000	300
5	0.035	360,000	320
10	0.030	420,000	400
20	0.045	350,000	350
30	0.048	320,000	320
50	0.060	330,000	355

l) Queue_length

The WiMAX parameter Queue_length can be defined as the parameter which used during the data transmission from Mobile station and it also defines the length of the buffer for a sending packet. The simulation is configured using the same model where the data rate for packet size 2 is used for simulation. The results are shown in the table 6.0.13 where we can clearly identify that the value of 2 shows better results, but same as other values this parameter also does not have a stabilizing effect on handover delay due to which this parameter cannot be used for further modifying handover delay in WiMAX.

Table 6.0.13 Effect of Queue_length on Handover Delay,Load and Throughput

Queue_length	Handoverdelay(Sec)	Load Bits/Sec)	Throughput(Packets/Sec)
1	0.050	310,000	300
2	0.035	360,000	420
4	0.040	410,000	200
6	0.045	370,000	350

m) T44_timeout

T44_timeout is WiMAX parameter which defines the timeout value for a successful scanning request which is during the scanning phase. The simulation was done in the same way the previous experiments where other values are kept constant while just keeping changing the values of this parameter and after a number of simulation the results show that these values show some effect when the value is kept more the 5ms is as shown in the table 6.0.14

Table 6.0.14 Effect of T44_timeouton Handover Delay, Load and Throughput

T44_timeout	Handover delay(Sec)	Load Bits/Sec)	Throughput(Packets/Sec)
1	Nil	Nil	Nil
5	0.055	360,000	420
10	0.040	410,000	300
15	0.045	370,000	250

The analysis of the simulation results shows this value needs to be more than 5 ms Where at 10 ms it provides better results.

n) MinRtrAdvInterval

MinRtrAdvInterval is the WiMAX signal parameter where it is considered as a most important parameter for ND module which defines the interval between conSecutive RAs. The simulation carried out on this parameter described its effect to be minimal in improving the handover delay in WiMAX. The results from the simulation is shown in the table 6.0.15

Table 6.0.15 Effect of MinRtrAdvInterval Handover Delay, Load and Throughput

MinRtrAdvInterval	Handover delay(Sec)	Load Bits/Sec)	Throughput(Packets/Sec)
1	0.060	400.000	425
5	0.055	360,000	420
10	0.060	410,000	300
15	0.065	370,000	250

The results show that when there is a large interval value result in longer handoff time. We have identified that the best result comes with the interval period of zero or lower that why this parameter does not show the direct effect on handover delay in WiMAX

o) MaxRtrAdvInterval

The Performace of this parameter is similar to the one used for the previous WiMAX parameter. When simulation is done with this parameter show bit different results and the simulation results shows that the signal will perform better when this value is kept at 10ms.

Which is the standard value and this way this parameter does not show the direct effect on WiMAX handover delay.

Table 6.0.16 Effect of MinRtrAdvInterval Handover Delay,Load and Throughput

MaxRtrAdvInterval	Handoverdelay(Sec)	Load Bits/Sec)	Throughput(Packets/Sec)
5	0.055	360,000	420
10	0.039	410,000	300
15	0.045	370,000	250

P) Scan_duration

The Scan_duration is also an important WiMAX signal parameter of WiMAX module, where Scan duration defines the length of the scanning period in frames and study (Khan, et al., 2012) says that to ensure successful scan long scan duration time is suggested. This parameter was tested by using the same model and keeping other values as standard the simulation results in table 6.0.17 show that when this value is kept at 5ms would result in better signal results with lower handover delay at higher throughput. On the other hand, short duration time for scanning also produces moderate elapsed time. We have found the best value can influence handover delay and that’s why the effect of this parameter should be further tested.

Table 6.0.17 Effect of Scan Duration on Handover Delay,Load and Throughput

Scan_Duration	Handover delay (Sec)	Load (Bits/Sec)	Throughput(Packets/Sec)
2	0.025	400,000	320
3	0.025	401,000	400
5	0.021	420,000	450
8	0.029	425,000	300

6.5.4 Experiment 2 Conclusion

The Experiment number 2 where we tried to identify the effect of physical factors on WiMAX handover delay as the previous study done by (Khan, et al., 2012) identified 16 factors which showed direct and indirect effect and study by (Khan, et al., 2012) identifies only 4 factors which show the direct effect on handover delay . As the aim of this experiment was to further identify those factors which directly affect the handover delay in WiMAX. The Simulations were carried out on all these factors. These 16 factors show a variety of results where some had very minute effect while few factors directly control the handover delay. After simulation, we identified that there are 7 factors out of 16 that have a direct effect on handover delay in WiMAX signals and a change in these factors would directly result in either increase or decrease in handover delay in WiMAX. These 7 factors are

a) Link Going Down Factor

b) Scan Iteration

c) Interleaving Interval

d) Timeout Parameter

e) Frame Duration

f) Client Timeout

g) Scan Duration

As these factors were identified, we also identified in our simulations that these factors perform better when they are kept at a particular value and WiMAX signal show minimum handover delay times. The table 6.0.18 shows that when these values are kept as same as in table 6.0.18 would result in lower handover delay times in simulation. Which shows that these factors have an effect on handover delay, while the remaining 9 factors don't show any effect.

Table 6.0.18 Showing the Values where these factors have the higher mobility and lower handover delay time.

Factors	Value for Which WiMAX Shows best Mobility Results
Link going down factor	1.3
Scan iteration	5
Interleaving Interval	20
Timeout Parameter	20
Frame Duration	15
Client Timeout	6
Scan Duration	5

These results show clear indication that WiMAX signal performs better with better mobility if these factors are stabilized at values where they show low Handover delay time . This creates the foundation for the next experiment.

6.6 Experiment No 3

The results identified in experiments 2 showed that after individual simulation each parameter demonstrated some indirect or direct effect on handover delay in WiMAX when these parameters were tested while keeping other parameters as standard. When the simulation was done on all 16 parameters only 7 parameters showed a direct influence on handover delay and also showed interesting results on values such as load and throughput. These results paved the way for further experiments and testing in order to further understand the effect of these 7 parameters on Handover Delay.

This experiment will try to help us understand and demonstrate combine effect of these 7 parameters on handover delay when best performing values of these 7 factors as shown in table 6.0.19 are applied to the WiMAX simulation model. The table 6.19 shows those values at which these factors showed minimum Handover Delay times from previous experiment. The simulation is configured keeping configuring these values at Base station in WiMAX simulations. These are configured at base station attributes as seen in the figure 6.0.21. This simulation was done only to understand the combined effect of these parameters when they are applied to WiMAX simulation model and also to identify how they will effect the handover delay times when applied together with the adjusted values. When the simulation was completed a number of times and after results analysis the handover delay results from the simulation as shown in the figure 6.0.22. The results analysis shows that handover delay is stable at 35 ms which is an improvement from the acceptable standard, which is 50 ms and in the same way the throughput results can be seen in the figure 6.0.23.

Table 6.0.19 Adjusted Values for the Experiment

Factors	**Value for Which WiMAX Shows best Mobility Results**
Link going down factor	1.3
Scan iteration	5
Interleaving Interval	20
Timeout Parameter	20
Frame Duration	15
Client Timeout	6
Scan Duration	5

The Handover delay results analysis shows that there is a steady increase in throughput up to it become stable in value which is close to 35,000 bits per Second with a handover delay of 0.0035 Sec. The most important aspect of these results is that the improvement is stable without any abrupt changes.

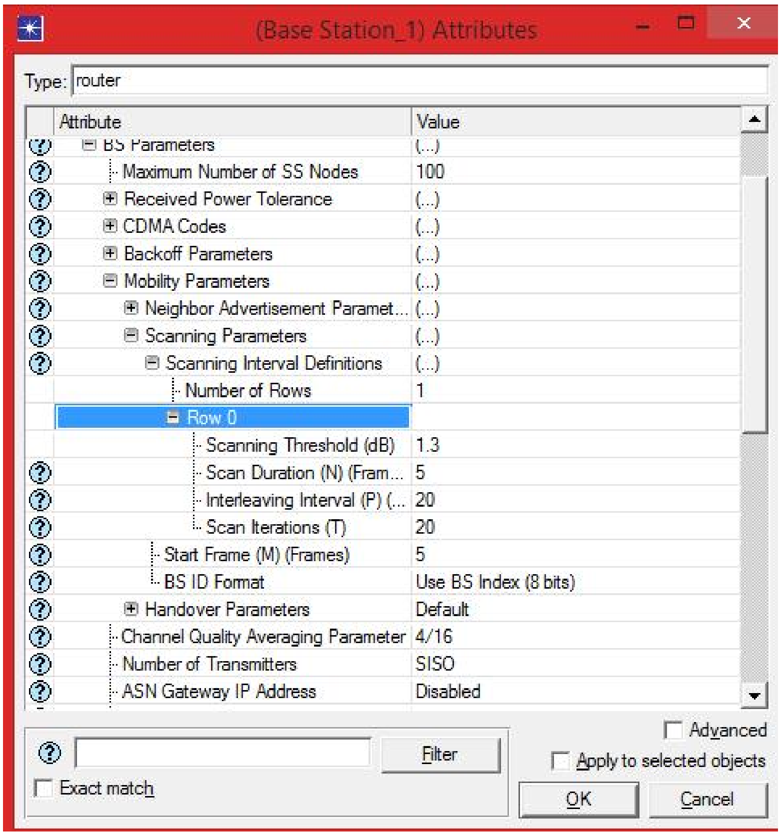

Figure 6.0.21 Simulation Configuration at Base station

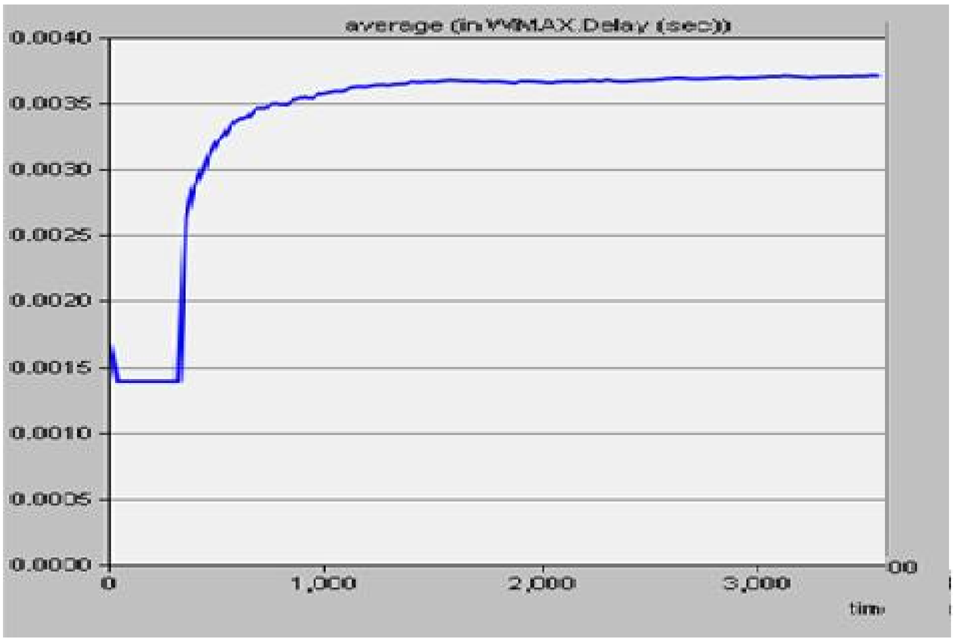

Figure 6.0.22 Combined Parameters Handover Delay vs Time (Sec)

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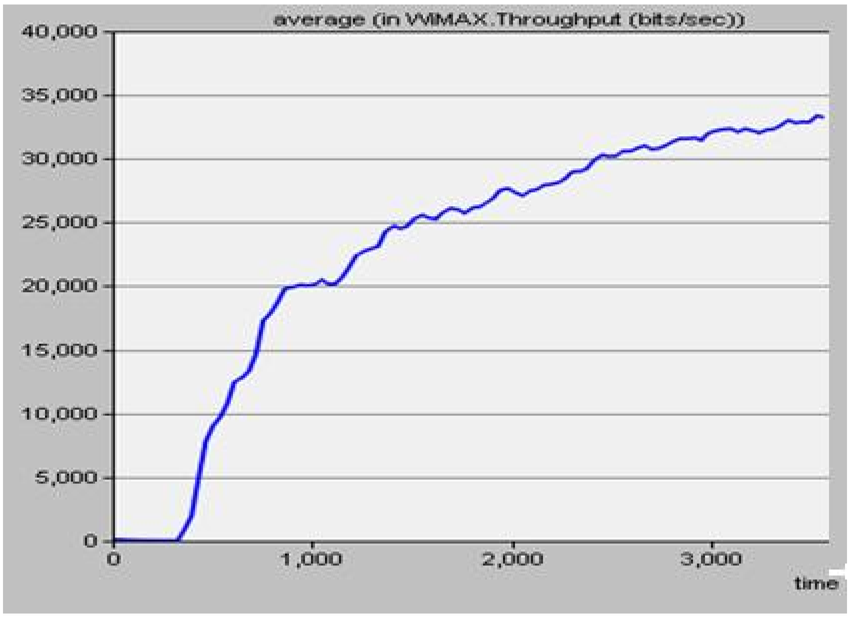

Figure 6.0.23 Combined Parameters Throughput vs Time (Sec)

6.6.1 Experiment 3 Conclusion

In this simulation experiment, the main aim was to find ways of reducing the handover delay to a level where the effect of handover delay in WiMAX signal transmission becomes lower. This simulation experiment tries to analyse the factors which are expected to control handover delay in WiMAX and shows promising results in reducing the handover delay. In the previous simulation experiment, we have tested the effect of these physical factors individually on WiMAX handover delay and identified that they have a specific effect on handover delay in WiMAX, for example, the link going down factor is kept either 1 or 1.3 and Scan iteration at 5 will result in lower handover delay. In a similar way Interleaving interval is kept between 5 till 20 and Timeout parameter acts the same way when it's kept between 5 till 20 will cause minimum handover. In addition to these 4 factors which previous studies have mentioned, we have identified 3 more factors which have a direct effect on handover delay such as when Scan Duration is kept at 5 ms, frame duration is 15ms and Client Timeout is 6 would result in lower handover delay times. As the aim of this simulation experiment to identify to what extent these factors would affect the handover delay when they are applied together at one WiMAX model. In order to achieve maximum mobility and limited handover delay. The results identified that there is improvement in handover delay time and handover delay was reduced to 35 ms which is far below from the standard of 50ms accepted for WiMAX as standard, but it still didn't minimize the effect the handover delay to a level expected from this study.

6.7 Experiment No 4 (Handover imporvement Using Dual Trigger Algorithm)

As the previous experiment reduced the handover delay in WiMAX but reduction of handover delay is still not enough that why there is further improvement needed and that's why when we tried to understand the process of handover delay. We identified Handover delay also depends on a number of factors such as signal strengths by the Mobile Station (MS), target base stations (BS) and handover can also be forced to happen, which is due to network traffic load channel fading, etc.. In order to further improve the handover delay in WiMAX, we need help from handover algorithms which can help in handover decisions by using factors such as noise ratio (SNR) and signal straight indicators (RSSI). There are two main types of handover algorithms (Lee & Choi, 2007). These two types of handover algorithms can be described as.

a) The first type of handover algorithms where handover decisions are mainly based on the received signal strength of the receiver base station to new target base station

b) The Second type of algorithms are where handover is based on relative signal strength and the threshold.

As our experiment need a choice of an algorithm which needs to be helpful in improving handover decisions and the scanning parameters. The algorithm which has been implemented and chosen in this simulation experiment, combines the existing handover algorithms and is based on both types of algorithms called a hybrid Handover Algorithm used for simulation

6.7.1 Handover Algorithm used for Simulation

The algorithm which is chosen in this simulation experiment which should help in improving handover decisions. The simulation algorithm proved very successful in previous studies, where only 4 physical factors were considered for Handover improvement (Al-Rousan, et al., 2011) the algorithm used is called Dual Trigger Handover Algorithm. The experiment 4 will use 7 factors which were identified in previous experiments and apply Dual Trigger Handover Algorithm to analyse handover delay time improvement. Dual Trigger Handover Algorithm prevents a Mobile Station from starting handover when the Base Station has no free Capacity. Which is also the negative side of this capacity condition, where the Base Station has to force one Mobile Station to start the handover before it accepts new Mobile Station. This algorithm can be subdivided by its function into two processes. a) Scanning b) Handover

Dual Trigger Handover Algorithm is Mathematically defined as Follows.

$SNR_{maxDT} - SNR_{DS} \geq H1$ AND $C_{EF} \geq H_2 \times C\ max$, (Lee & Choi, 2007)

Where SNRDS is downlink SNR for serving BS

CEF estimated free capacity

Cmax the maximum free capacity

H1 and H2 are first and 2nd Handover

a) Scanning Process: The scanning process starts with a MOB_NBR-ADV message which is used by BS to send PHY Layer parameters to Neighbouring Base Stations and Mobile Stations. The Mobile Station starts scanning process when approaches its threshold by sending MOB_SCN-REQ later than Mobile Station starts measuring the signal strength by using the parameters to decide the QoS level and send message to the Recipient Base Station for Handover

b) **Handover Process :**The handover process starts which is decided by the mobile station and base stations, while algorithm provides a triggering system and this triggering system is calculated with SNR and Free Capacity estimation.

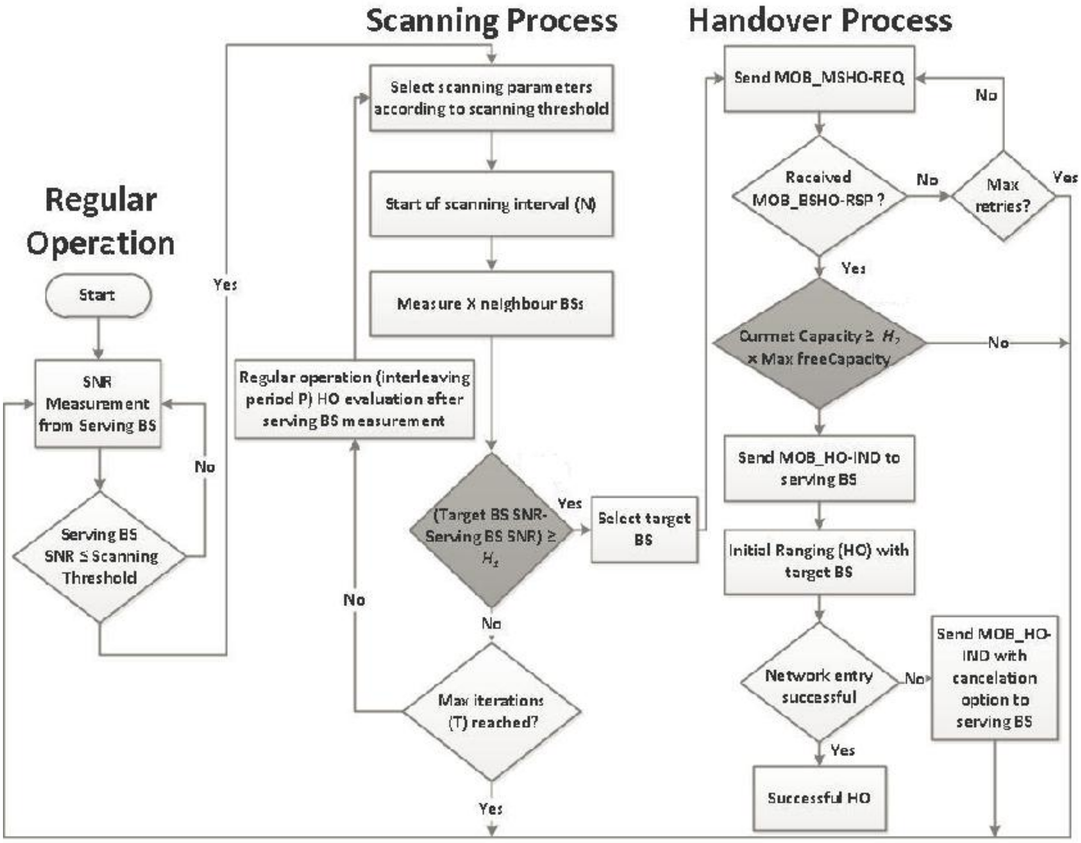

Figure 6.0.24 : Schematic Diagram for Dual Trigger Handover Algorithm (Al-Rousan, et al., 2011)

6.7.2 Simulation Configuration

In this simulation experiment same WiMAX model is used which consists of 7 cells having multiple base stations and mobile stations which are moving at 60 kmph, the speed we identified from previous experiments. To test the effect of Dual trigger algorithm on WiMAX model used in this research the parameter is configured as per standard, including the factors which are identified from the previous experiments which as also kept as standard as shown in table 6.0.20. In This RIVERBED simulation experiment, the Base Station are given MAC address and similarly Base Station ID, for example, BS=I where I = 1,2,3…OFDMA = 512 frames with 5 ms duration with BS station traffic rate of 64 Kbps. In this simulation experiment where we want to resolve efficiency problems such as handover delay, this simulation will use dual trigger algorithm which in turn supposed to result in lower handover delay times due to better handover decisions which in turns increase mobility.

Table 6.0.20 Adjusted Values for the Experiment

Factors	Value for Which WiMAX Shows best Mobility Results
Link going down factor	1.3
Scan iteration	5
Interleaving Interval	20
Timeout Parameter	20
Frame Duration	15
Client Timeout	6
Scan Duration	5

This dual trigger algorithm is programmed in RIVERBED Simulation including other factors which are also kept the standard.

Table 6.0.21 Standard WiMAX Signal values (Al-Rousan, et al., 2011)

Chosen Values Value (s)					
System bandwidth (MHz)	1.25	2.5	5	10	20
Sampling frequency (Fs, MHz)	1.42	2.85	5.71	11.43	22.86
Sample time (1/Fs, ns)	700	350	175	88	44
FFT size (NFFT)	128	256	512	1,024	2,048
Subcarrier frequency spacing			11.160 kHz		
Useful symbol time (Tb=1/f)			89.6 μs		
Guard time (Tg=Tb/8)			11.2 μs		
Symbol time (Ts=Tb+Tg)			100.8 μs		

Table 6.0.22 Standard WiMAX Signal values Adjusted By Researcher

Chosen Values Value (s)					
System bandwidth (MHz)	1.20	2.3	4	7	21
Sampling frequency (Fs, MHz)	1.12	2.70	3.71	8.43	18.86
Sample time (1/Fs, ns)	600	300	100	50	22
FFT size (NFFT)	80	126	256	1,000	1,048
Subcarrier frequency spacing			11.100 kHz		
Useful symbol time (Tb=1/f)			80.6 µs		
Guard time (Tg=Tb/8)			13.2 µs		
Symbol time (Ts=Tb+Tg)			120.8 µs		

6.7.3 Experiment 4 RIVERBED Simulation Results

The simulation results after completing the simulation experiments show that there is an improvement in handover delay and the handover delay has been improved as seen from the figure 6.0.25. Which shows the handover delay is between 0.019 till 0.030 Sec which is an improvement from previous experimental results of 0.035 Sec handover delay.

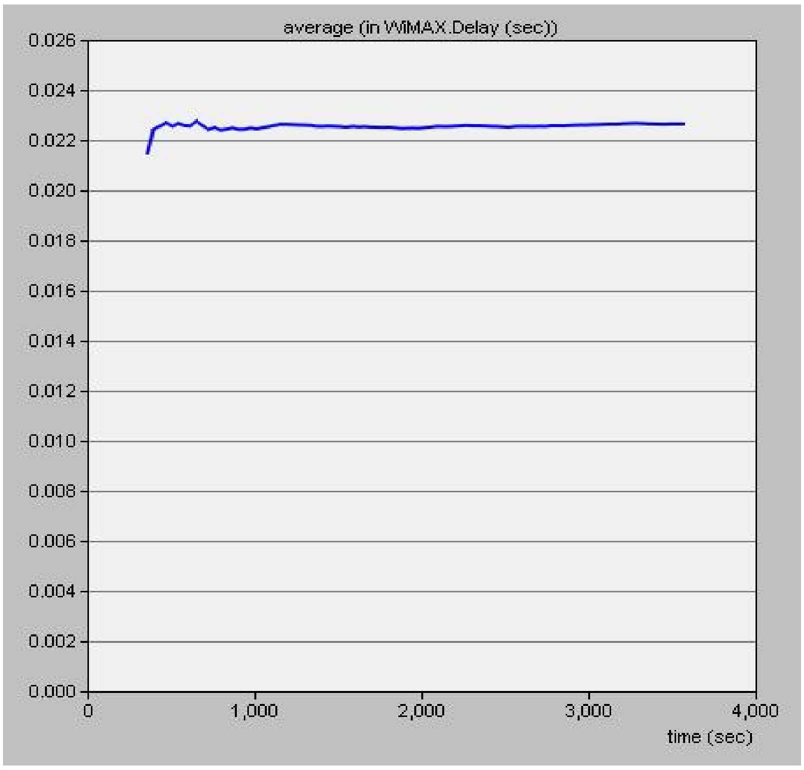

Figure 6.0.25 Average Delay Vs Time

When we look at throughput data and analyse it, we identify that there has been also improvement in throughput and it has more stable value as shown in the figure 6.0.26. We can also see in there is also considerable peak in the data packets dropped which creates a negative effect on overall WiMAX signal performance

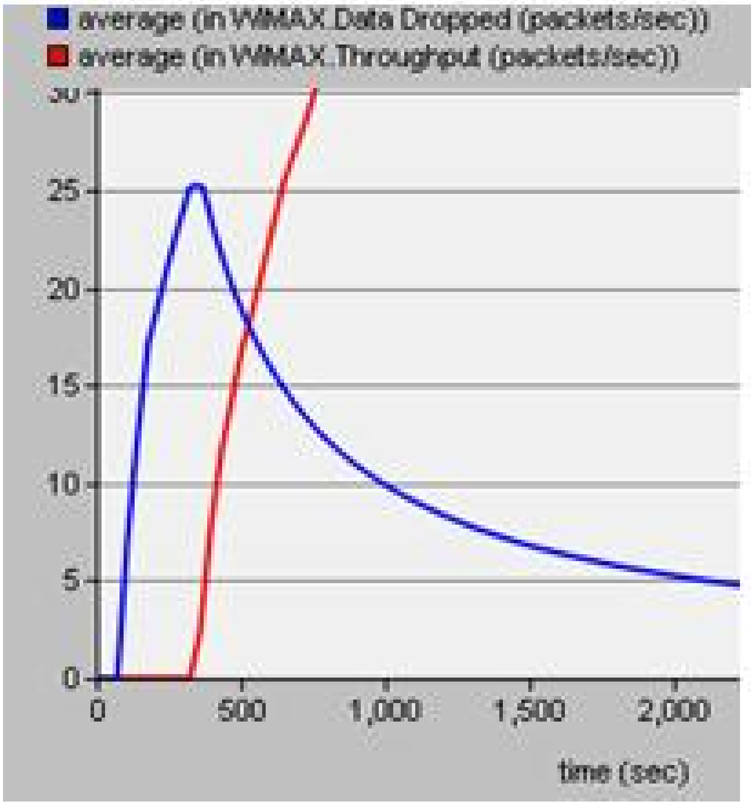

Figure 6.0.26 Average Data Dropped Vs Average Throughput

Now we can see from the above figures that handover delay of WiMAX signal has been improved, but with this improvement of handover delay, there is also a considerable increase in packet loss which is also confirmed by the figure 6.0.26. In the figure 6.0.26, we can see that with time there has been a considerable gap between data packets received and packets lost which identify the problem of packet loss which forces retransmission which in turn show bad signal performance and low QoS value. The results show that there is improvement resulting a stable WiMAX signal which explains the algorithm is making the signal perform better. We can also identify from the results that the base station is requesting packet retransmission and this is considered as the negative effect of using this algorithm which creating packet loss and request of retransmissions which is due to capacity condition of Dual trigger algorithm. We can see the value of SNR is unstable value and dual trigger algorithm is depended on SNR for making handover decisions.

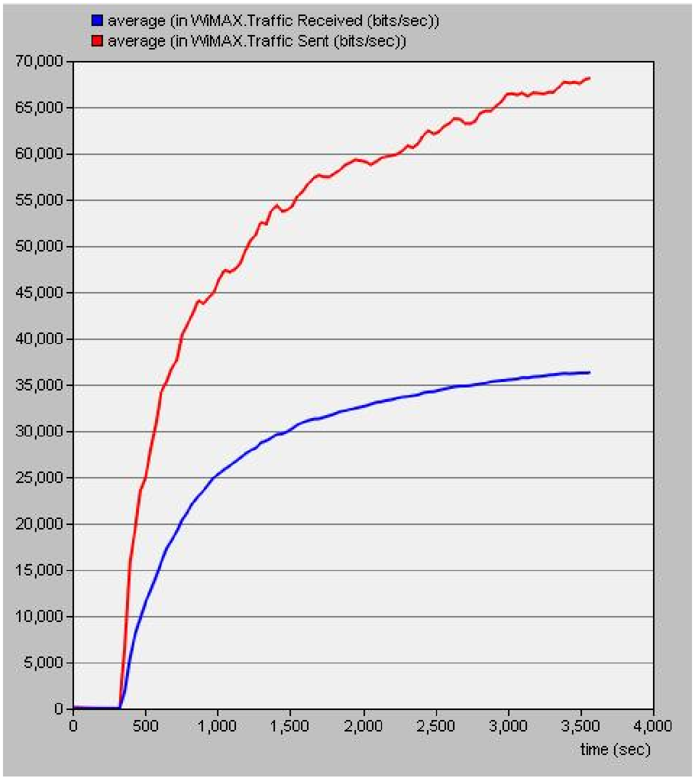

Figure 6.0.27 Average Received Traffic Vs Average Sent Traffic

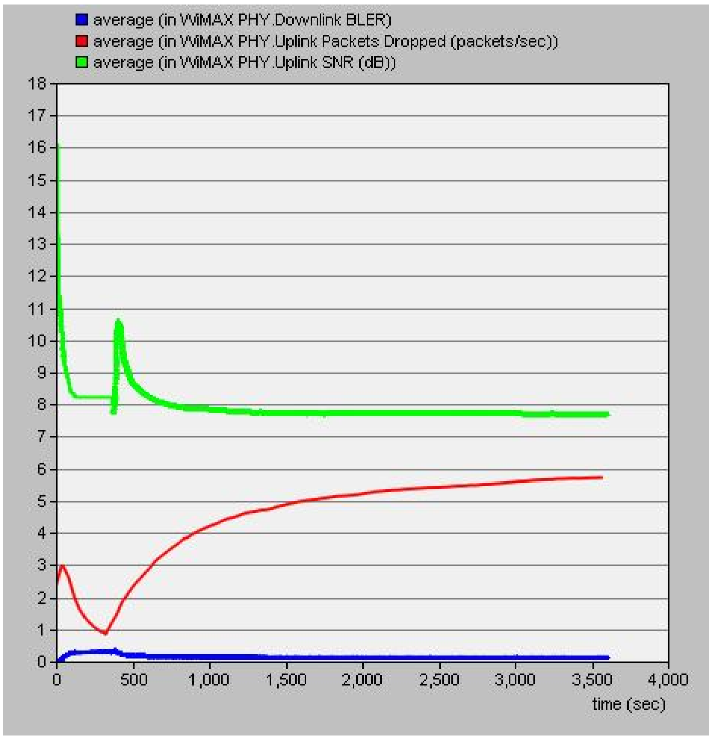

Figure 6.0.28 Average Downlink (BLER) Vs Average SNR (dB) Vs Uplink Packets Dropped

The same factors can be identified that when there is an increase in throughput there also increases in data dropped as seen from table 6.0.23. As we can see from the results that the dual trigger algorithm is making the handover delay lower and we can also see the handover delay lower up to 0.019 Sec which result in better throughput values, but when there is increase in throughput values there is increased number of packet loss and the gap between the packets sent and received increases to considerable value and that is due to a dual trigger algorithm which depends on SNR values and Free capacity conditions

Table 6.0.23 Handover delay Vs Packets dropped and throughput

Average handover Delay (Sec)	Average Data dropped (packets per Sec)	Average Throughput (Packets Per Sec)
0.019	15	40
0.020	25	33
0.021	20	27
0.022	15	25
0.023	10	10

SNR_{maxDT} - $SNR_{DS} \geq H1$ AND $C_{EF} \geq H_2$ x C max, (Lee & Choi, 2007).

Where SNRDS is downlink SNR for serving BS

CEF estimated free capacity

Cmax the maximum free capacity

H1 and H2 is first and 2nd Handover

As the results from table 6.0.23 point out that when there is an increase in throughput values which results in lower handover delay time. The results also point out that there is also increased in the number of handovers as the number of handovers increases the base station has no free capacity. In that situation another mobile station sends a request to base station for new handover and while the in base station due to capacity conditions forces a handover of the mobile station to create space for a new mobile station which results in double handover and also double packet loss which need to be retransmitted. Due to this negative effect dual trigger, the algorithm fails to perform under full capacity conditions.

6.7.4 Experiment 4 Conclusion:

In this simulation experiment, RIVERBED modular was used on WiMAX network, which was modified by adjusting the parameters to a level where WiMAX network resulted in a lower handover delay time and with this experiment we implemented Dual trigger algorithm to establish how the handover algorithm would improve handover decisions which should result in lower the handover delay in WiMAX. The simulation results identified that there was an improvement with the handover delay and WiMAX signal performed better, but there was also a higher rate of packet loss, even throughput value was improved. The SNR calculation had improved the triggering of handover, which in turn provided more stable WiMAX signal, but the problem with packet loss posed a negative effect on the overall performance of this algorithm for reducing handover delay in WiMAX and the main cause was the capacity condition which created more handovers then needed which in turn ended in retransmissions and packet loss.

6.8 Experiment No 5 (Handover Improvement Using new Suggested Handover Algorithm By Researcher)

We have identified from our previous experiment using Dual Trigger Algorithm that it performed in reducing the handover delay, but the handover decisions are made in dual trigger algorithm by capacity conditions which ended up forced handovers and packet loss. Based on this information we have modified the dual trigger algorithm and modified it so the negative effect of capacity conditions are removed.

6.8.1 The new Suggested Handover Algorithm By Researcher

The new suggest algorithm is an advanced form of the hybrid handover algorithm, where there is no capacity conditions. In this new algorithm, the handover conditions are based on using the bit error rate (BER) as the main parameter instead of the signal level. Where in new algorithm the handover will start when the BER is greater than energy per bit to noise power spectral density ratio

$SNR_{maxDT} - SNR_{DS} \geq H1$ AND $BER_{avg} \geq E_b/No$ (New Handover Algorithm suggested)

Where BER_{avg} is Average Bit Error Rate

E_b/N_0 energy per bit to noise power spectral density ratio

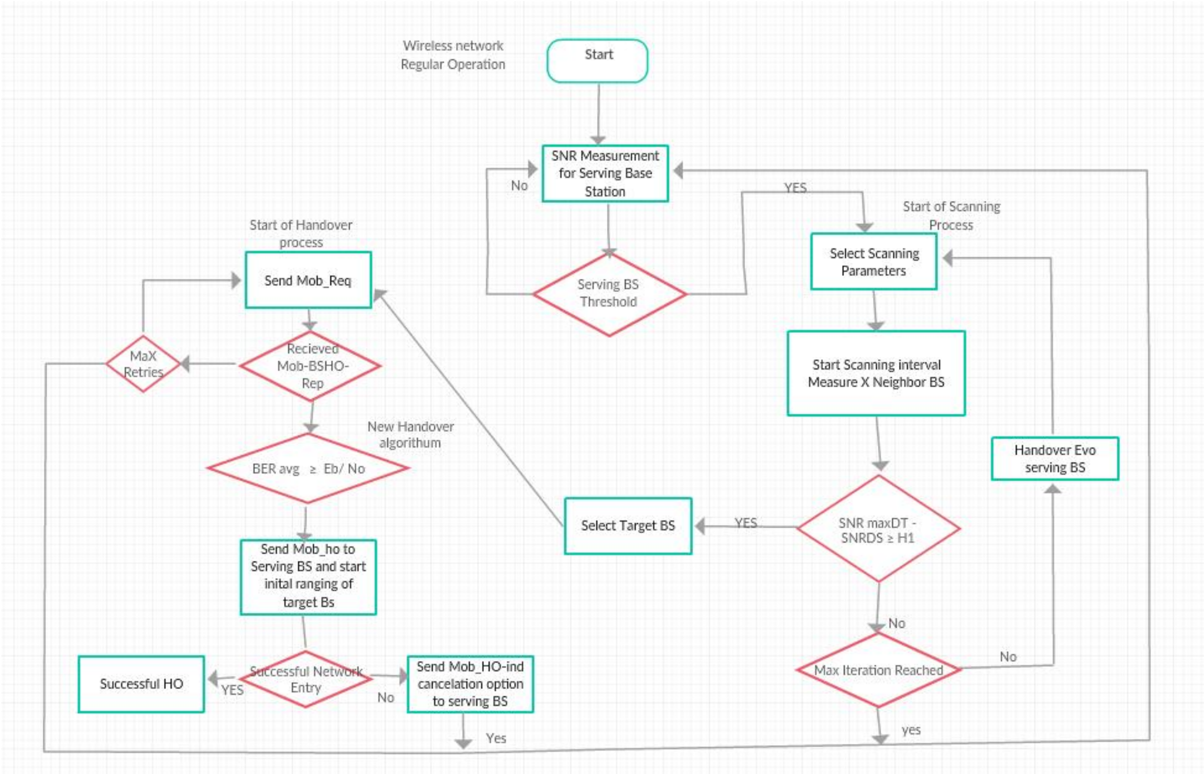

Figure 6.0.29 Schematic Diagram for New Handover Algorithm Suggested by Researcher

6.8.2 Experiment 5 RIVERBED Simulation Results

The algorithm was applied to the same model which was developed for this research. To test the effect of new algorithms on WiMAX model used in this research the parameter is configured as per standard, including the factors which are identified from the previous experiments which were also kept Standard.

In This RIVERBED simulation experiment, the Base Station is given MAC address and a similarly Base Station ID, for example, BS=I where I = 1,2,3…

OFDMA = 512 frames with 5 ms duration with BS station traffic rate of 64 Kbps.

Table 6.0.24 Adjusted Values for the Experiment

Factors	**Value for Which WiMAX Shows best Mobility Results**
Link going down factor	1.3
Scan iteration	5
Interleaving Interval	20
Timeout Parameter	20
Frame Duration	15
Client Timeout	6
Scan Duration	5

Table 6.0.25 Adjusted Standard Wimax Signal values By Researcher

Chosen Values Value (s)					
System bandwidth (MHz)	1.20	2.3	4	7	21
Sampling frequency (Fs, MHz)	1.12	2.70	3.71	8.43	18.86
Sample time (1/Fs, ns)	600	300	100	50	22
FFT size (NFFT)	80	126	256	1,000	1,048
Subcarrier frequency spacing			11.100 kHz		
Useful symbol time (Tb=1/f)			80.6 μs		
Guard time (Tg=Tb/8)			13.2 μs		

Symbol time (Ts=Tb+Tg)	120.8 µs

In this simulation experiment where we want to resolve efficiency problems such as handover delay and this simulation will test new modified algorithm which is supposed to solve the pack loss problem which in turn is would result in lower handover delay times and increase mobility. This new modified algorithm is programmed in RIVERBED Simulation including other factors which are also have been kept the standard as previous experiments. Now, this algorithm was configured in RIVERBED simulator and changing the criteria both at mobile stations and base stations which was repeated a number of times. The simulation results in even lower handover delay, which is stable throughout the simulation which points towards the stability of the signal as we see from the figure 6.0.29. The signal initially starts with a lower handover delay which increases close to 0.024 Sec while after some time the handover delay goes down and stays and becomes stable close to 0.017Sec.

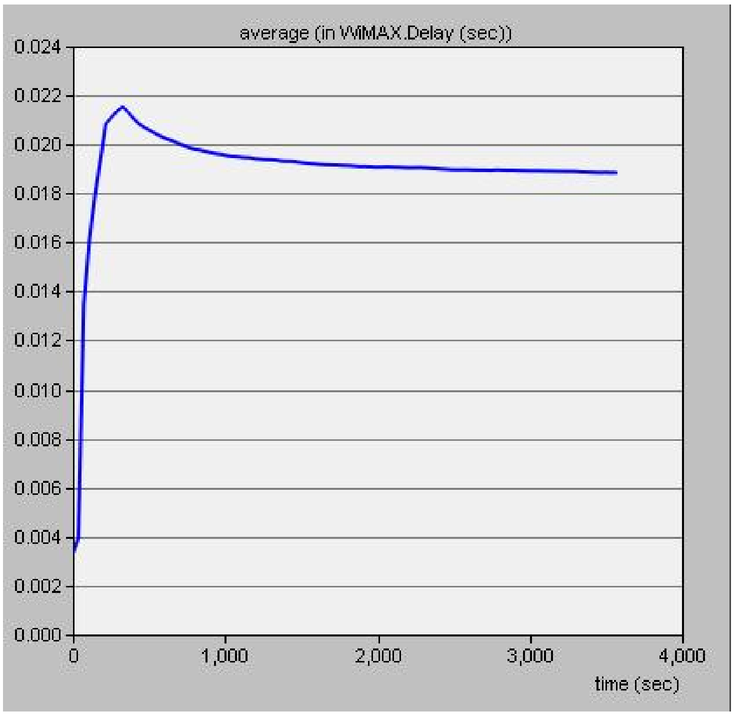

Figure 6.0.30 Showing Handover Delay

At the same time, the simulation results of average Handover delay and the value has been stabilized between 0.017 and 0.020, which is quite interesting improvement and as seen from the figure 6.0.30. There is low packet loss, even when the load on the WiMAX network is significantly increased. Which is a very significant improvement.

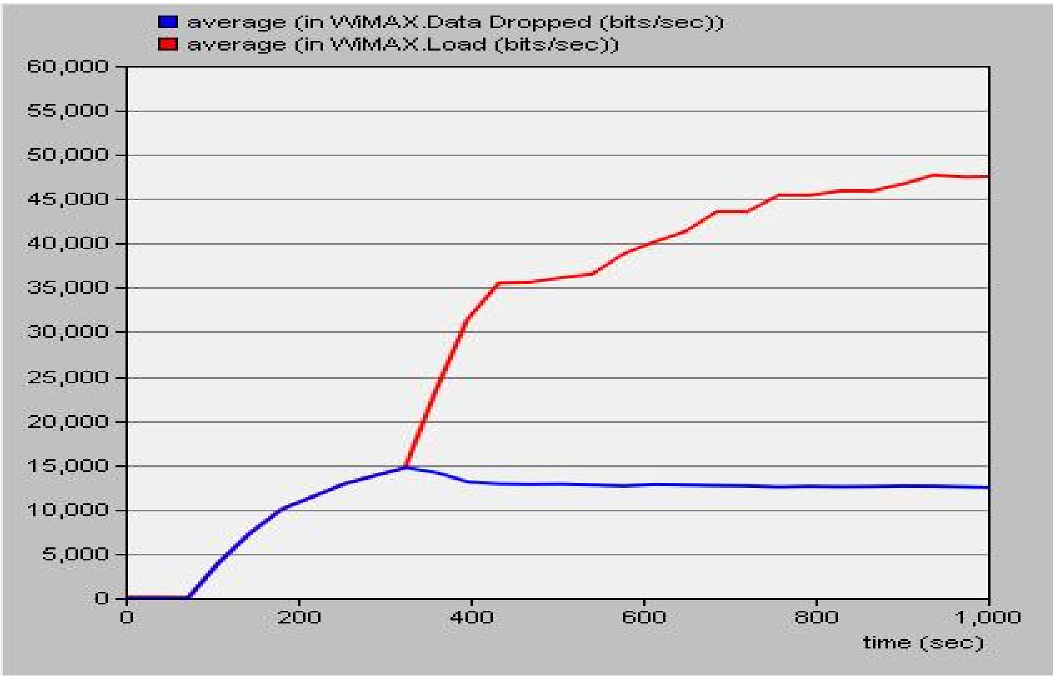

Figure 6.0.31 Showing the comparison between Data dropped Vs WiMAX Load

That shows not even the WiMAX handover delay has been improved also the signal performance has been improved. In the same way, The improvement is seen from the figure 6.0.30. As the new algorithm, the handover decisions depend on BLER Value which is very stable and that's why there is a stable handover from one base station to another.

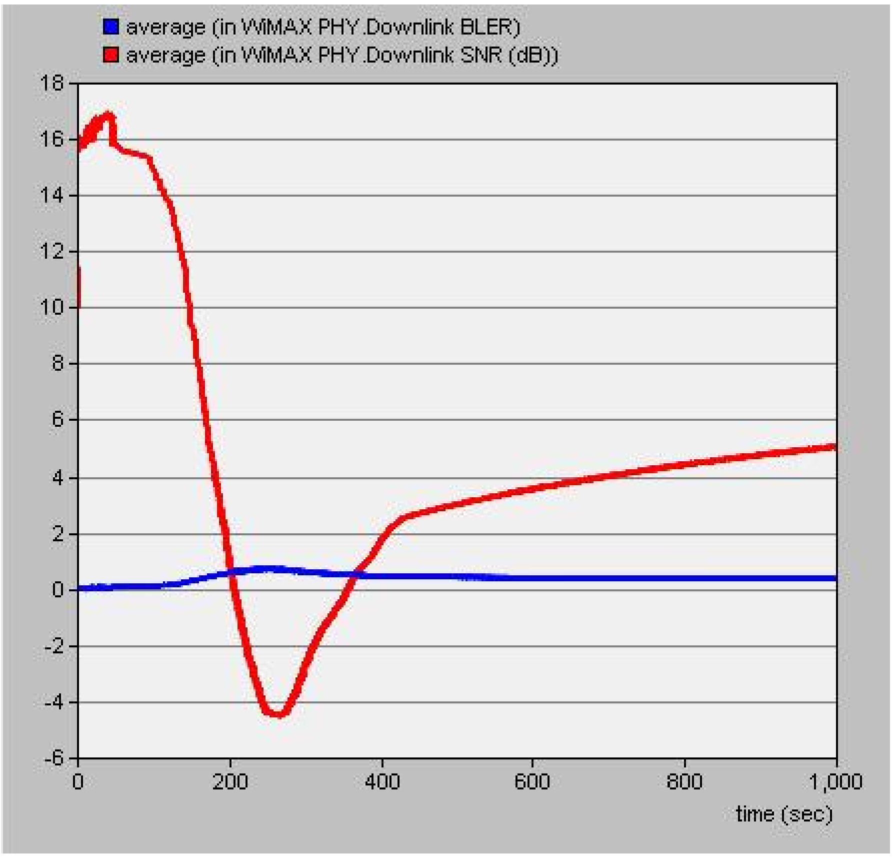

Figure 6.0.32 Showing the comparison between Values of BLER Vs SNR

Figure 6.0.31 shows a very interesting pattern where it describes the SNR values are unstable while BLER values show a very stable patterning and it describes the effectivity of the new modified algorithm. This is a very interesting improvement where it shows that when a the load increases, there is a reduction in packets dropped. This mainly due to effective handover, which is considerable improvement which is also shown in the table 6.0.26.

Table 6.0.26 Showing the results and signal improvement using modified algorithm

Handover Delay (s)	DataPackets Dropped(s)	Load(bits/s)	Downlink (BLER)	Downlink (SNR)	Throughput Packets/Sec	Packet-loss/Seconds	Jitter (s)	Packet Delay (s)
0.020	7000	7000	$2 X 10^{-6}$	12	300	27	0.05	0.09
0.019	3000	10000	$1 X 10^{-6}$	14	350	20	0.05	0.07
0.018	2000	11000	$0.8 X 10^{-6}$	15	400	15	0.02	0.04
0.017	1000	11000	$0.6 X 10^{-6}$	16	450	10	0.01	0.02

6.8.3 Experiment 5 Conclusion

In this simulation experiment, the new handover algorithm was tested, which is modified form of hybrid algorithm. The biggest problem in dual trigger algorithm was which was tested in experiment 4 was the packet loss which was due to retransmissions caused by forced handover to make space for new handover. This new algorithm has resolved this issue which has removed the problem of packet loss and including the handover delay, which is now at a stable rate of 0.017 Sec and is far better than standard handover delay in WiMAX.

6.9 Experiment 6 Handover Delay Improvement Experiments on Mobile WiMAX Standard WiMAX-2 (IEEE 802.16m)

The current requirements for mobile Internet, mobile streaming and multimedia applications have motivated towards further development in wireless access in the last few years. WiMAX more specifically mobile WiMAX has moved the convergence of both mobile and fixed broadband networks with a common wide-area radio-access technology with flexible network architecture. IEEE 802.16 Working Group in January 2007 developed a new update in IEEE

802.16 standard, which is called as IEEE 802.16m (WiMAX-2). WiMAX-2 is an advanced air interface to meet the requirements of ITU-R/IMT-advanced for 4G systems and for next-generation mobile network operators.

We have identified from our previous experiment that new handover algorithm performed very well in reducing handover delay on WiMAX standard IEEE802.16e. Now the new suggested algorithm applied to improve the handover decisions in WiMAX-2 (IEEE 802.16m)

6.9.1 Simulation Setup Using The new Suggested Handover Algorithm on WiMAX-2

The new Suggested Algorithm

In the new suggest algorithm the handover will start when the BER is greater than energy per bit to noise power spectral density ratio

$SNR_{maxDT} - SNR_{DS} \geq H1$ AND $BER_{avg} \geq E_b/No$ (**New Suggested Handover Algorithm**)

Where BER_{avg} is Average Bit Error Rate E_b/N_0 energy per bit to noise power spectral density ratio.

The algorithm was applied to the same model which was developed for this research and for this current experiment the WiMAX standard is IEEE 802.16m. To test the effect of new algorithms on WiMAX model used in this research. The parameter is configured as per standard, including the factors which are identified from the previous experiments, are kept as standard in this experiment.

Table 6.0.27 Adjusted Values for the Experiment

Factors	Value for Which WiMAX Shows best Mobility Results
Link going down factor	1.3
Scan iteration	5
Interleaving Interval	20
Timeout Parameter	20
Frame Duration	15
Client Timeout	6
Scan Duration	5

Table 6.0.28 Standard Wimax Signal values Adjusted by Researcher

Chosen Values Value (s)					
System bandwidth (MHz)	1.20	2.3	4	7	21
Sampling frequency (Fs, MHz)	1.12	2.70	3.71	8.43	18.86
Sample time (1/Fs, ns)	600	300	100	50	22
FFT size (NFFT)	80	126	256	1,000	1,048
Subcarrier frequency spacing			11.100 kHz		

Useful symbol time (Tb=1/f)	80.6 μs
Guard time (Tg=Tb/8)	13.2 μs
Symbol time (Ts=Tb+Tg)	120.8 μs

In This RIVERBED simulation experiment, the Base Station are given MAC address, and similarly Base Station ID, for example, BS=I where I = 1,2,3… and OFDMA = 512 frames with 5 ms duration with BS station traffic rate of 64 Kbps

6.9.2 Results from Simulation

In this simulation experiment aims to identify the performance of the new suggested handover algorithm on WiMAX-2. In previous experiment this algorithm performed well and reduced the handover delay using WiMAX standard IEEE 802.16e and in this experiment the new algorithm is tested to WiMAX standard IEEE 802.16m in similar network conditions. The objective of resolving the efficiency problems such as handover delay. This simulation will test new modified algorithm which is supposed to solve the packet-loss problem which in turn is supposed to result in lower handover delay times and increase mobility. This new modified algorithm is programmed in RIVERBED Simulation including other factors which are also kept standard. Now, this algorithm was configured in RIVERBED simulator and modifying the experiment and changing the criteria both at mobile stations and base stations. The simulation results in table 6.0.29 shows the performance of the new handover algorithm. As expected, the new handover algorithm performed in similar fashion or even better with new WiMAX standard IEEE 802.16m resulting in lower handover delay and this handover delay is stable throughout the simulation which shows the stability of the signal. The signal initially starts with a lower handover delay which increases close to 0.020 Sec while after some time the handover delay goes down and stays and becomes stable close to 0.015Sec.

Table 6.0.29 Showing the results and signal improvement using modified algorithm

Handover Delay (s)	DataPackets Dropped(s)	Load(bits/s)	Downlink (BLER)	Downlink (SNR)	Throughput Packets/Sec	Packet-loss/Seconds	Jitter (s)	Packet Delay (s)
0.020	6000	7000	1×10^{-6}	11	300	27	0.05	0.09
0.018	2000	10000	1×10^{-6}	12	350	20	0.03	0.06
0.016	1000	11000	0.8×10^{-6}	15	450	15	0.01	0.03
0.015	900	11000	0.6×10^{-6}	17	550	8	0.001	0.01

6.10 Conclusion

The objective of these simulation experiments and research is to reduce the handover delay in Mobile WiMAX (IEEE 802.16e & IEEE 802.16m). The process started with developing WiMAX model and understand the previous work done in this regard. In the first experiment it was identified that when mobile device move at 60 Kmph has minimum effect on handover delay and that's why keep 60 Kmph as standard in reminder of experiments. In the Experiment number 2 where we tried to identify the effect of physical factors on WiMAX handover delay as the previous study done by (Khan, et al., 2012) identified 16 factors which showed direct and indirect effect. A study by (Al-Rousan, et al., 2011) identified 4 factors which showed direct and indirect effect on handover delay . As the aim of this experiment 2 was to further identify those factors which directly affect the handover delay in WiMAX. The Simulations were carried out on all these factors. These 16 factors show a variety of results where some had very minute effect while few factors directly control the handover delay. After simulation, we identified that there are 7 factors out of 16 that have a direct effect on handover delay in WiMAX signals and a change in these factors would directly result in either increase or decrease in handover delay in WiMAX. These 7 factors are

a) Link Going Down Factor

b) Scan Iteration

c) Interleaving Interval

d) Timeout Parameter

e) Frame Duration

f) Client Timeout

g) Scan Duration

As these factors were identified, we also identified in our simulations that these factors perform better when they are kept at a particular value and WiMAX signal show minimum handover delay times. These seven Factors have an effect on handover delay, while the remaining 9 factors don't show any effect. The Table 6.0.30 shows the best performing values where these factors would result in lower handover delay times and WiMAX signal performs better with better mobility if these factors are stabilized at the values shown in Table 6.0.30.

Table 6.0.30 Best Performing Values for Physical Factors

Factors	Value for Which WiMAX Shows best Mobility Results
Link going down factor	1.3
Scan iteration	5
Interleaving Interval	20
Timeout Parameter	20
Frame Duration	15
Client Timeout	6
Scan Duration	5

The Experiment 3 tried to combine the individual effect of these 7 factors and apply them to a single model. As the aim of this simulation experiment 3 was to identify how these factors would affect the handover delay when they are applied together at one WiMAX model. In order to achieve maximum mobility and limited handover delay the individual results were combined And applied in a single simulation experiment. The results identified the improvement in handover delay time and handover delay was reduced to 35 ms which is far below from the standard of 50ms accepted for WiMAX as standard, but it still didn't minimize the effect the handover delay to a level expected from this study. The next experiment 4 implemented Dual trigger algorithm to establish how the handover algorithm would improve handover decisions which should result in lower the handover delay in WiMAX. The simulation results identified that there was an improvement with the handover delay and WiMAX signal performed better, but there was also a higher rate of packet loss, even throughput value was improved. The SNR calculation had improved the triggering of handover, which in turn provided more stable WiMAX signal, but the problem with packet loss posed a negative effect on the overall performance of this algorithm for reducing handover delay in WiMAX. The main cause was the capacity condition which created more handovers then needed, which in turn ended in retransmissions and packet loss. In this simulation experiment 5, the new handover algorithm was tested, which is modified form of hybrid algorithm. The biggest problem in dual trigger algorithm was the packet loss which was due to retransmissions caused by forced handover to make space for new handover. This new algorithm has resolved this issue which has removed the problem of packet loss and including to that the handover delay is at a stable rate of 0.018 Sec which is far better than standard handover delay in WiMAX. The Last Experiment or experiment 6 was to test the new algorithm on WiMAX latest mobile standard IEEE 802.16m and see the performance and after simulation and results analysis, it was interesting to note the new algorithm perform better in WiMAX-2 (IEEE 802.16m) resulting in minimum handover delay of 0.015s. The results point out that the new handover algorithm performs better and results in a lower handover delay in both mobile WiMAX standards IEEE 802.16e and WiMAX-2 (IEEE 802.16m).

CHAPTER 7: RESULTS COMPARISON & QoS ANALYSIS BETWEEN WIMAX & WiMAX-2

In this Chapter we analyse the results which give us an overview and understanding between the analytical model numerically calculated results to the results achieved by simulation during the simulation experiments in previous chapters which includes results from both WiMAX standards IEEE 802.16e & IEEE 802.16m.

7.1 Handover Performance Results Comparison & Justification

In this Section the values such as handover delay, Load and SNR results from RIVERBED simulation experiments which includes the results from IEEE 802.16e & IEEE 802.16m are compared with the next column of the same value/Parameter from Analytical model results. In the table 7.0.1 we can see the detailed comparison. The first value which compares the handover delay from RIVERBED simulations (IEEE 802.16e & IEEE 802.16m) and handover delay from Analytical Model and we can see the handover delay in numerically calculated results are lower than the values from RIVERBED simulations but overall they show the same trend during a specific time interval. The same can be seen in the vales of data packets dropped, where RIVERBED simulation results show higher values than Analytical model results, while the values of load are same in both RIVERBED simulated results and Analytical model and the same can be seen in BLER values in which also similar while SNR values also show a same trend.

Now when looking at the table the first value which is compared to the handover delay from RIVERBED simulations and the handover delay from Analytical Model and here we can see the handover delay in numerically calculated are lower than the values from RIVERBED simulations but overall they show the same trend during a specific time interval.

Table 7.0.1 Simulation Results Vs Analytical Model Results

Simulation Method	Handover-Delay (Seconds)	Data-Packets Dropped/Seconds	Load(bits/s)	Downlink (BLER) X10^{-6}	Downlink (SNR)
Analytical Model	0.011	1500	7000	2 X 10^{-6}	12
	0.010	1000	10000	1 X 10^{-6}	14
	0.009	500	11000	0.8 X 10^{-6}	15
	0.008	100	11000	0.6 X 10^{-6}	17
RIVERBED Simulation Results WiMAX Standard IEEE 802.16 e	0.020	7000	7000	2 X 10^{-6}	12
	0.019	3000	10000	1 X 10^{-6}	14
	0.018	2000	11000	0.8 X 10^{-6}	15
	0.017	1000	11000	0.6 X 10^{-6}	16
RIVERBED Simulation Results WiMAX Standard IEEE 802.16m	0.020	6000	7000	1 X 10^{-6}	11
	0.018	2000	10000	1 X 10^{-6}	12
	0.016	1000	11000	0.8 X 10^{-6}	15
	0.015	900	11000	0.6 X 10^{-6}	17

The same can be seen in the values of data packets dropped, where RIVERBED simulation results show higher values than Analytical model results while the values of load are same in both RIVERBED simulated results and Analytical model and the same can be seen in BLER values which is also similar while SNR values show a similar trend. There is another important factor we can identify with the results is that WiMAX mobile standard IEEE 802.16m performed better the IEEE 802.16e. The improved handover performance points out important fact that the WiMAX-2 has been designed better and is the future of WiMAX which will soon replace the existing WiMAX standards such IEEE 802.16e .

As Analytical model results are purely calculated numerically, using the respective formulas as that's why some of the factors show lower or better results than RIVERBED simulation. The main reason behind for the better results from an Analytical model is due to the effect of some unknown factors which are not calculated in the numerical calculation of Analytical model. In other words, we can say that the Analytical model calculates all factors and parameters while in RIVERBED may not be close to reality as it assumes or fixes the values for simplicity of calculations. That's why we can say that the analytical model show results in ideal situations without the negative effect of some unknown factors while RIVERBED simulation mimic the real time environment results. While comparing both results it is identified the both Analytical model and RIVERBED simulation show similar trend which mean the new handover algorithm has a positive effect in reducing handover delay and improving performance of WiMAX signal, which in turn result in better mobility.

The New Suggested handover algorithm showed similar trends in improving handover delay and QoS performance in Analytical Model which numerically calculated and in similar fashion in simulation experiments done on both WiMAX standards IEEE 802.16e and IEEE 802.16m. The results analysis of IEEE 802.16m simulation experiments showed better or improved performance, then IEEE 802.16e. The improved handover performance, such as lower handover delay times and better QoS values such as Throughput, Packet Loss, Packet Delay and Jitter points out the important fact that the WiMAX-2 has been designed better and is the future of WiMAX, which will soon replace the existing WiMAX standards such IEEE 802.16e**.** We can also assume from the both simulation results which includes the results from WiMAX and WiMAX-2 simulation and Analytical model results that the effect of the New Handover algorithm is universal in improving the handover delay time and QoS

7.2 QoS Performance Analysis

QoS provisioning encompasses providing Quality of Service to the end user in terms of several generic parameters (Talwalkar & Ilyas, 2008). The perceived quality of service can be quantitatively measured in terms of several parameters such as

a) Throughput

b) Packet Loss

c) Packet Delay

d) Jitter

We conducted a different set of simulations and the aim of each experiment was to enure high mobility and lower handover delay times. The Table 7.0.2 shows QoS parameter comparison such as throughput, Packet loss, jitter and Packet delay results of simulation experiments between WiMAX standards IEEE 802.16e and IEEE 802.16m. The QoS parameter results analysis from the Table 7.0.2 show that the new handover algorithm is performing on both standards in similar fashion and improving Hanover delay and resulting in better QoS values.

Table 7.0.2 QoS Parameters Simulation Results Comparison for IEEE 802.16e & IEEE 802.16m

Simulation (WiMAX Standard)	Handover-Delay (Seconds)	Throughput Packets/Sec	Packet-loss/Seconds	Jitter (Sec)	Packet Delay (Sec)
IEEE 802.16e	0.020	300	27	0.05	0.09
	0.019	350	20	0.05	0.07
	0.018	400	15	0.02	0.04
	0.017	450	10	0.01	0.02
IEEE 802.16m	0.020	300	27	0.05	0.09
	0.018	350	20	0.03	0.06
	0.016	450	15	0.01	0.03
	0.015	550	8	0.001	0.01

7.2.1 Throughput

Throughput is an amount of data rate (Packets per Second) which is generated by the application and the Equation below show the calculation of throughput.

$$\text{Throughput TP} = \Sigma\ \text{PacketSize}_i \ / \ \text{PacketArrival}_n - \text{PacketStart}_0$$ (IEEE 802.16-2004, 2004)

As a measure of the date rate is called Throughput, which is usually generated by the application as described by the equation above which shows the calculation for throughput

TP, where PacketSizei is the packet size of the earth packet reaching the destination, PacketStarto is the time when the first packet left the source and PacketArrivaln is the time when the last packet arrived. So in another way we can say that Throughput is the number of packets effectively transferred on a network, in other words, throughput is data transfer rate that is delivered to all terminals in a network.

Table 7.0.3 QoS Parameter Thoughput Simulation Results Comparison for IEEE 802.16e & IEEE 802.16m

Simulation (WiMAX Standard)	Handover-Delay (Seconds)	Throughput Packets/Sec
IEEE 802.16e	0.020	300
	0.019	350
	0.018	400
	0.017	450
IEEE 802.16m	0.020	300
	0.018	350
	0.016	450
	0.015	550

When we analyse Throughput results from the table 7.0.3 we can easily identify the similar trend such as at lower handover delay there is higher throughput which shows that the new handover algorithm is performing in a similar fashion on both WiMAX standards IEEE 802.16e and IEEE802.16m resulting lower handover delay and higher throughput. In addition to that we can also identify from Table 7.0.3 that at WiMAX Standard IEEE 802.16e the lowest handover times is 0.017 Seconds, resulting in throughput of 450 packets per Second and while in comparison to that the WiMAX-2 (IEEE 802.16m) results in lower handover delay time of 0.015 Seconds with higher throughput of 550 packets per Second.

7.2.2 Packet Loss

The quality of the application is determined by Packet loss and packet loss is usually caused by data corruption or errors in a bad wireless network when the channel becomes overloaded.

Packet Loss = Σ LostPacketSize$_i$ / Σ PacketSize$_j$ X 100 (IEEE 802.16e-2005 IEEE Standard for Local and Metropolitan Area Networks, 2006)

The Equation above to calculate packet loss and It is the sum of all the packets that do not reach the destination over the sum of the packets that leave the destination.

When we analyse QoS Simulation results from the table 7.0.4 we can easily identify that at lower handover delay and higher throughput has lower Packet Loss and this points towards that the new handover algorithm is performing in a similar fashion on both WiMAX standards IEEE 802.16e and IEEE802.16m. The resulting lower handover delay and higher throughput and lower Packet loss resulting in better WiMAX Signal. In addition to that we can also identify from table 7.0.4 that at WiMAX Standard IEEE 802.16e the lowest handover times is 0.017 Seconds, resulting in throughput of 450 packets per Second resulting in packet loss of 10 Packets/Second and while in comparison to that the WiMAX-2 (IEEE 802.16m) results in lower handover delay time of 0.015 Seconds with higher throughput of 550 packets per Second including the packs of 8 packets per Second. Which shows that WiMAX-2 is performing better with new algorithm resulting in better signal performance.

Table 7.0.4 QoS Parameter Packet Loss Simulation Results Comparison for IEEE 802.16e & IEEE 802.16m

Simulation (WiMAX Standard)	Handover-Delay (Seconds)	Packet-loss/Seconds
IEEE 802.16e	0.020	27
	0.019	20
	0.018	15
	0.017	10
IEEE 802.16m	0.020	27
	0.018	20
	0.016	15
	0.015	8

7.2.3 Jitter

Jitter, which is also called Delay variation and is observed as end-to-end delay variation between conSecutive packets. In other words Jitter is the variation in delay introduced by the components along the communication path. Jitter is commonly used as an indicator of consistency and stability of the performance of the network and the QoS the network offers.

$\text{AverageJitter} = \Sigma(\text{PacketArrival}_{i+1} - \text{PacketStart}_{i+1}) - (\text{PacketArrival}_i - \text{PacketStart}_i) / n\text{-}1$ (Talwalkar & Ilyas, 2008)

The Equation above shows the steps for calculation of average jitter. It is the average of the absolute difference in the time it took for successive packets to reach the destination.

Table 7.0.5 QoS Parameter Jitter Simulation Results Comparison for IEEE 802.16e & IEEE 802.16m

Simulation (WiMAX Standard)	Handover-Delay (Seconds)	Jitter (Sec)
IEEE 802.16e	0.020	0.05
	0.019	0.05
	0.018	0.02
	0.017	0.01
IEEE 802.16m	0.020	0.05
	0.018	0.03
	0.016	0.01
	0.015	0.001

The QoS results analysis from the table 7.0.5 points out that new handover algorithm shows better QoS performance in simulation by resulting lower Jitter value at the same time, resulting lower handover delay, higher throughput and lower Packet Loss on both WiMAX standards IEEE 802.16e and IEEE802.16m resulting lower handover delay resulting in better WiMAX Signal. In addition to that we can also identify that at WiMAX Standard IEEE 802.16e the lowest handover times is 0.017 Seconds, resulting in Jitter value of 0.01 Second and while in comparison to that the WiMAX-2 (IEEE 802.16m) results in lower handover delay time of 0.015 Seconds with lowest jitter of 0.001Seconds.Which shows that WiMAX-2 is performing better with new algorithm resulting in better signal performance.

7.2.4 Packet Delay

Packets Delay can be defined as it is the time taken by data packets to transverse from the source to destination. The reasons or sources of Packet Delay can be sub-divided in to categorize into the source-processing delay, propagation delay, network delay and destination processing delay

$Delay = \Sigma_i \ PacketsArrival_i - PacketStart_i \ / \ n$ (Talwalkar & Ilyas, 2008)

The Equation above describes the calculation for Average Delay, where PacketArrivali is the time when the packet “i” reaches the destination and PacketStarti is the time when the packet “i" leaves the source. “n” is the total number of packets. The Packets Delay results from Table 7.0.6 shows the lowest Packets Delay of 0.02 in WiMAX standard IEEE 802.15e. While in WiMAX standard IEEE 802.16m the packet delay is 0.01. These results points out that new handover algorithm shows better QoS performance in simulation by resulting lower Packets Delay at the same time, resulting lower handover delay, higher throughput, lower Packet Loss and Jitter on both WiMAX standards IEEE 802.16e and IEEE802.16m resulting better WiMAX Signal QoS performance. In addition to that we can also identify from the previous table 7.0.2 that at WiMAX Standard IEEE 802.16e the lowest handover times is 0.017 Seconds, resulting in Packets Delay value of 0.02 Second and while in comparison to that the WiMAX-2 (IEEE 802.16m) results in lower handover delay time of 0.015 Seconds with lowest Packets Delay of 0.01Seconds. Which shows that WiMAX-2 is performing better with new algorithm resulting in better signal performance.

Table 7.0.6 QoS Parameter Packet Delay Simulation Results Comparison for IEEE 802.16e & IEEE 802.16m

Simulation (WiMAX Standard)	Handover-Delay (Seconds)	Packet Delay (Sec)
IEEE 802.16e	0.020	0.09
	0.019	0.07
	0.018	0.04
	0.017	0.02
IEEE 802.16m	0.020	0.09
	0.018	0.06
	0.016	0.03
	0.015	0.01

7.3 Validation & Verification of Analytical & Simulation Results Carried on WiMAX (IEEE 802.16e) and WiMAX-2 (IEEE 802.16m)

The Simulation results analysis suggests considerable improvement on handover delay in both WiMAX Standards IEEE 802.16e & IEEE 802.16m and The results indicate that the new algorithm and other physical improvements have optimized the handover delay to considerably lower level. In this Section we try to validate and verify the simulation and analytical results with existing WiMAX test-bed and case study scenarios including the Comparison with WiMAX standards from IEEE.

7.3.1 Analytical & Simulation Results Validation and Comparison for WiMAX Standards IEEE 802.16e

Analytical and Simulation results suggest a considerable improvement, which is visible in the table 7.0.7 and it shows an overview of handover delay results as compared to work done previously in different case studies done in WiMAX Standard IEEE 802.16e. The work done by (Pardi, et al., 2011) which focuses on mobile and wireless transmission technology based on IEEE 802.16e and this study used the NCTUns 6.0 simulator and resulting in handover delay time 0.12 . Which is due to Mobile Station speed which influenced the handover duration time from serving base station to target base station and The study pointed out that when speed increases handover time will also increase. When we compare this study results with analytical and simulation results from this thesis where speed was kept standard 60 kmph resulted in Handover delay 0.017 Seconds from simulation while the Analytical model result show handover delay of 0.008 Seconds.

Table 7.0.7 Analytical & Simulation Results Comparison with WiMAX Case Studies in WiMAX Standard IEEE 802.16e

WiMAX (IEEE 802.16e) Case Study	Handover-Delay (Seconds)
RIVERBED Simulation Results from Researcher (Current thesis)	0.017
(Pardi, et al., 2011)	0.12
(Easwaramoorthy & Sundararajan, 2013)	0.5093
Analytical Model from Researcher (Current thesis)	0.008

In Similar way, when we compare the same results with another study (Easwaramoorthy & Sundararajan, 2013) where the WiMAX network and QoS parameters are tested for military applications. In This study the group handover scheme in WiMAX networks with VoIP application is implemented for the troop of soldiers in the military environment in the WiMAX network. This study resulted in handover delay time of 0.5093 Seconds and now when we compare this with handover times of Analytical and simulation results from thesis points towards considerable lower handover delay times due to improved WiMAX model and new handover algorithm.

7.3.2 Simulation Results Validation and Comparison for WiMAX-2 Standard

When we analyse the WiMAX handover results from table 7.0.8 and which provides an overview handover delay time from this this thesis including work done previously on WiMAX-2.

Table 7.0.8 Analytical & Simulation Results Comparison with WiMAX Case Studies in WiMAX Standard IEEE 802.16m

WiMAX (IEEE 802.16m) Case Study	Handover-Delay (Seconds)
RIVERBED Simulation Results from Researcher (Current thesis)	0.015
(Cudak, 2014)	0.06
(Saha & Chakraborty, 2013)	0.03
Analytical Model from Researcher (Current thesis)	0.008

The study (Cudak, 2014) which studied the IEEE 802.16m System Ra standard handover and the study resulted in a handover delay of 0.06 Seconds ,which is lower as compared to previous standards due to IEEE 802.16m improved resource management. In a similar way (Saha & Chakraborty, 2013) studied performance analysis of service classes for IEEE 802.16m QoS Optimization . This study identifies that a better MIMO solution requires better MIMO solution efficiency. Now when we compare handover delay results of (Cudak, 2014) which is 0.06 and (Saha & Chakraborty, 2013) handover delay time which is 0.03 to Analytical and Simulation results of this thesis. Which is 0.008 and 0.015 respectively and that is considerably lower and points and confirms the improvement done in this thesis with improved WiMAX model and new handover algorithm.

7.4 Conclusion

In this chapter results analysis is done in very detail fashion and results comparison is done between Analytical and Simulation results which includes the results from Simulation done with WiMAX (IEEE 802.16e) and WiMAX-2 (IEEE 802.16m). The results analysis shows that there is a similar trend in reduction of handover delay times where the Analytical model results show handover delay time of 0.008 Seconds while the simulation handover delay time are 0.018 Seconds and 0.015 Seconds for WiMAX and WiMAX-2 respectively. As Analytical model show results in ideal situations without the negative effect of some unknown factors while the Simulation results mimic the real time environment That's why Analytical model handover delay time is lower than Simulation results. The QoS performance analysis, which includes the values of Throughput, Packet loss, Packet Delay and Jitter confirms the similar trend of handover delay time and network signal improvement within WiMAX and WiMAX-2 which confirms the considerable improvement done due to improved WiMAX Model and Handover delay algorithms suggested in this thesis.

The Handover results were compared with previous case studies such as for WiMAX (IEEE 802.16e) the results were compared with (Easwaramoorthy & Sundararajan, 2013) and (Pardi, et al., 2011) and for WiMAX-2 (Cudak, 2014) and (Saha & Chakraborty, 2013) and its confirmed after results Comparison from these previous studies. The Analytical and Simulation results of this thesis, which is 0.008 and 0.015 respectively, which is considerably lower and points and confirms the improvement done in this thesis with improved WiMAX model and new handover algorithm

CHAPTER 8: RESEARCH ANALYSIS, DISCUSSION AND RECOMMENDATIONS

This chapter discusses the novel approach adopted to design the WiMAX network model for practical scenarios and the benefits which are proposed in the framework of this thesis. At start of the research details of WiMAX technologies are investigated and explained, including the previous work done in the field of WiMAX more specifically the handover delay problem in WiMAX. Which is the time taken to establish a connection when a mobile station is moving at a certain speed from one base station to another base station. Which helps in understanding the concept of WiMAX technologies and the benefits WiMAX brings to telecommunication community. While the limitation in mobile WiMAX technology is handover delay and the first step includes an understanding of the WiMAX model and previous work done in regards to solving handover delay problem. The next phase in this research was to determine the process of developing WiMAX model which needed to be tested and including to that we needed to investigate the choice of simulation tool which can be considered as the stage 1 of this research work.

Next, we started simulations and investigated the effect of speed on handover delay to identify a speed where WiMAX under standard conditions show lower handover delay time. Later we investigated the effect of varying parameters on WiMAX handover delay and this is considered as stage two where we identified the effect of speed and physical parameters affecting at a handover delay time in WiMAX. Finally, in stage 3 we built a WiMAX network employing that results of stage 2 in order to further modify and improve the handover delay time, which resulted in lower handover delay time but there was further need of improvement. The Improvement was implemented by using handover Algorithm to improve handover decisions and for this purpose dual trigger handover Algorithm was implemented . The effect of dual trigger algorithm was simulated which improved the signal and reduced the handover delay time but the negative effect of capacity condition used in Dual trigger algorithm for handover decisions created forced handovers which in turn ended up in packet-loss due to retrasmission of data resulting in lower QoS performance. Finally a modified algorithm was created and tested which showed improved results and showed better handover delay times in simulations which included both WiMAX and WiMAX-2. At the end, we build a network model employing the standard approach which widely presented in literature in order to compare the results in simplified problem formulation. The structure of this chapter is as follows.

8.1 Thesis summary and Structure

This thesis is separated into 9 chapters which discuss the main objective of this thesis. Where each chapter describes and analyses different aspects of the research and using a novel approach of simulation. The results of simulation scenarios are presented and analysed in its own chapter.While at the end there is a discussion of future work related to the field of handover optimization. The detailed structure of the thesis is as follows

Chapter 1 -Introduction

This chapter discusses the scope, aim and objective of the research in a detailed way. The study was positioned in the domain of WiMAX and handover delay in WiMAX and the research questions postulated, are focused in subsequent chapters which are together with the structure of the thesis.

Chapter 2 - WiMAX Technical Background and Overview

This chapter starts by discussing the technical background of the whole WiMAX technology, including the description and types of Handover in WiMAX and description of limitations within WiMAX technology. Another important part of this chapter is the previous work done in the field of WiMAX and Handover delay in WiMAX. This chapter helps in identifying the problems while creating a better WiMAX model. There is a detailed description of technical background on WiMAX technology and different WiMAX standards including mobile WiMAX and WiMAX-2.

This chapter would also describe different techniques used to improve the handover delay and various designs and handover algorithm used to improve the WiMAX signal by providing a comprehensive evaluation of previous work done and providing the user details about the need for more research in this area.

Chapter 3 - Literature Review

This chapter discusses the review of literature in WIMAX, while concentrating more on the work done in the field of handover delay in WIMAX. The literature review provides detailed analysis of a complete set of papers which is applied to WiMAX and Handover delay in WiMAX. The researcher reviews the articles which are regarding the use of WiMAX technologies as standard and studies the benefits of using WiMAX technology as a replacement for 3G and 4G technologies. Consequently, the review suggests that general guidelines are standard. In addition, it was also studied about the WiMAX technology as a model. The researchers classified the review into three different Sections: where the researcher studied WiMAX as a communication system and the researcher took the study of (Li, et al., 2010) where they provide a study of WiMAX standard 802.16e which provides deep insight into developing WiMAX model.

The literature about the mobility in WiMAX is researched. The researchers classified the mobility techniques and reviews the literature based on the classification. The pros and cons of each classification are examined. The researchers studied (Chang & Huang, 2007) which provides the details about mobility problems in WiMAX. The researcher also studied the literature about the handover delay in WiMAX, which is also main aim of this research. In this Section the researcher identifies the pros and cons of different handover delay methods. The study of (Pontes, et al., 2008) provides detailed insight into handover mechanisms which were the main inspiration for the study.

Finally, the researcher performs literature survey and the study confirms that there is no proper way defined and there has been no complete study done previously which is mainly directed at reducing handover delay in WiMAX.

Chapter 4 - Research Methodology

This chapter explains and describes the entire process carried out from initial stages of concept development to the final stages of simulation, results and analysis. This chapter describes and explains the process from basic sketch model to complete model of WiMAX. The Chapter also includes the evolutionary experimental approaches and includes detailed configuration of WiMAX model in RIVERBED simulator .

Chapter 5- A Novel Analytical Model Developed On WIMAX Handover Delay

As telecommunication systems and devices get advanced day by day. Providing support to these new devices, which enables them with an undistruped data transfer is the biggest challenge for the research and telecommunications community. The challenge became more complex when the factor of handover failures was introduced, which usually happens due lack of resources and limitation in coverage including the speed of mobile device. The handover schemes and models which are currently developed are not able to support the current complex scenarios. This thesis proposes a new approach to modify the process of handover decisions and to reduce the unnecessary handovers. This chapter discusses a numerical analysis of the proposed new algorithm. The results of this numerical analysis are also discussed in this chapter, which shows that the model performs better than existing models with reduced number of unnecessary packet loss.

Chapter 6-WiMAX Experiments, Parameters, Setup and Collected data

This chapter is one of the main building blocks of this thesis, which includes the discussion of different scenarios designed for experiments with a detailed discussion of parameters. This chapter also includes a detailed discussion of experiment setup and design. The other most important part of this chapter is collected-data and results. This chapter discusses the collected data and provide brief Analysis including the process of experimenting and finding the results of research questions by simulations.

Chapter 7-Results Comparison & QoS Analysis Between WiMAX and WiMAX-2

This chapter provides a complete analysis of Handover delay times between Analytical and RIVERBED Simulation results which includes results from both WiMAX and WiMAX-2 simulation experiments. This chapter also discusses their impact by providing complete performance analysis, including a description of each and individual QoS parameter. This chapter also provides verification and confirmation of results by comparing results with previous case study scenarios.

Chapter 8-Analysis, Discussion And Recommendations

This chapter would provide a complete summary of this thesis and discuss the empirical approach used within this thesis.

Chapter 9 -Conclusion and Future Work

This final chapter provides conclusions and justification of the new WiMAX model and the thesis summary includes the pros and cons of this thesis including future work which will be required to meet new research challenges.

8.2 Discussion

In the introductory chapter of this dissertation, two questions were presented in order to address the thesis statement. This Section provides the answers to the proposed research questions.

8.2.1 WiMAX As Communication Network

The literature for the WiMAX as communication network is reviewed and the researchers studied a number of articles regarding WiMAX and its use as a communication network. These articles were investigated provided a picture WiMAX being used as core network and they also provided insight into the benefits of WiMAX. The research describes that WiMAX has great potential which provides higher bandwidth. To provide further understanding about WiMAX standards and Handover delay in WiMAX, Thus the research question 1 is framed and answered through research.

Research Question 1

- What are the different types of handover delay that affect mobility in mobile WiMAX standards such as IEEE 802.16e and IEEE 802.16M.
- How to improve the handover delay in WiMAX for high mobility

8.2.1.1 WiMAX background and Structure

WiMAX is also termed as worldwide interoperability Microwave access and the research reveals that WiMAX is considered as the main alternative to 3G and even 4G networks due to its cheap implementation cost and higher bandwidth which makes it ideal for providing wireless broadband data and voice network services. Chapter 2 of this thesis provides and discusses the different versions of WiMAX standards which were developed with time and as the first WiMAX standard developed in 2001 which was termed as IEEE 802.16.2001 and this standard only covered only stationary connections as the WiMAX was being accepted as an alternative to other broadband technologies. Which result in more research in field of WiMAX, which saw the development of standards such as IEEE 802.16-2004 and later with IEEE 802.16-2005 which is also termed as IEEE 802.16e and latest addition to WiMAX standard is WiMAX-2 IEEE 802.16m which made WiMAX as a next 5G mobile technology. In Chapter 2 also there is a detailed description of the WiMAX network system which includes a physical layer, and Mac layer, while the structure can be subdivided into Core Network, Access Network, Base station, and the User terminal. The main parts of WiMAX network have two basic units, the first one is core network and while the Second one is access network. The first basic unit of WiMAX network, the core is comprised of network management system, router and AAA server or agency, your database and user gateway equipment. Which provide a network connection to WiMAX users. The Second unit is access network, which includes a base station (BS), a subscriber station (SS) and mobile subscriber station (MS), which provides wireless support to WiMAX users

8.2.2 Handover In WiMAX

Discussed in Chapter 2 the handover can be explained as it’s a process which helps and ensures a continuous connection to the mobile station (MS) while it's on the move from an area of one base station (BS) to another base station. While the BS which provides connection to MS is called to serve base station, which is updated when MS is Moving from the area of one BS to another BS. The new base station BS will provide services to MS when the handover is completed and that new BS is called target BS. The study done in this research identified different kinds of handover these types of handover defined in this standard (Aquino Santos, 2014) Hard Handover, Macro Diversity Handover (MDHO) and

Fast Base Station Switching (FBSS). In WiMAX systems, Hard handover is mandatory Other two types of handover are optional

8.2.2.1 HARD HANDOVER

Hard handover can be described as a handover where Mobile Station communicates with just one Base Station and all the connections with the existing Base Station or serving Base Station is disconnected before a new connection is made with the target Base Station and there is a short time interval where Mobile Station has not connected any Base Station. The handover process is started after predefined channel parameter such as signal strength from neighbouring Base Station crosses the same parameters from serving Base Station signal strength) from a neighbouring Base Station exceeds the same parameters from the serving BS.

8.2.2.2 MACRO DIVERSITY HANDOVER

Microdiversity handover is abbreviated as MDHO and it is type of handover supported by both MS and BS while in some publications which are mostly focused on UMTS and LTE (Ekström, et al., 2006) noted as active set (Holma & Toskala, 2001) (Lin, et al., 2004) is maintained by the MS and BSs.

During handover procedure, a diversity set is a list of Base Stations are involved.This set is maintained by Mobile Station and Base stations.This is updated via MAC (Medium Access Control) management messages (Aquino Santos, 2014). The messages which are used for transmission are usually based on CINR (Carrier to Noise plus Interface Ratio) level of BS stations where it depends on the two thresholds defined for additional and deletion of a BS to create diversity set. The addition and deletion of threshold (Aquino Santos, 2014) and these threshold values are broadcasted in DCD which is downlink channel descriptor message (Aquino Santos, 2014). For each MS The diversity set values are defined which continuously monitor all Base stations and diversity set selects an anchor Base Station and usually, the anchor in Base Station is one of Base stations form the diversity set. The Anchors are registered synchronized and authorized by Mobile Station and also Mobile Station performs the ranging and monitors a downlink channel of anchor Base Station for control information. The Mobile station ensures the communication and simultaneously communicates with anchor Base Station.

8.2.2.3 FAST BASE STATION SWITCHING

Fast base station switching (FBSS) closely resembles MDHO where the diversity set is maintained by Mobile Station and Base Station but in contrast to MDHO, the mobile station only communicates with anchor BS for every type of uplink and downlink traffic including the management messages. When Mobile station is connected one Base station the diversity set will only hold BS which is termed as anchor BS, where anchor BS can be changed on the frame to frame basis which depends on BS selection scheme. Which can be explained that each and every frame will be sent via different BS in diversity set and the anchor BS procedure for updating is based on same principles as the diversity set update.

In This study, we studied previous work done and identified that The main principle behind handover in WiMAX network is described e.g (Aquino Santos, 2014) (Zhang & Chen, 2007) where RS station implementation which leads to modification of handover procedure as there is no wired connection between BS station and RS station.The decision for handover is based and should be based on the new metric which considers specifies RS station For example such as modification is a relay path and access station which is based on algorithms considering multiple QoS parameters (Li & Jin, 2009). Radio Resource Cost (RRC) (Mach & Bešťák, 2007)o r Expected Link Throughput (ELT) (Shrestha, et al., 2007) .

The Idea and concept of hybrid handover in multihop radio access network with RS stations which is addressed in (Ghassemian, et al., 2005). In this publication discusses and compares the reactive and proactive handover approach from overhead point of view and higher end modifications of handover procedure considering RS stations are presented in (Lee, et al., 2006) , where this paper further introduces and describes the handover procedure for networks with RS stations where scanning overhead is reduced. The scanning overhead reduction is achieved by joint transmission of scanning requests and reporting messages from all the MS stations and access stations. As the study identified from literature review that ,the biggest drawback with Mobile WiMAX is the higher handover times which results in handover delay due to reconnection to new base station as studied done by (Teo, et al., 2007) clearly defines that. The interesting aspect was developing a WiMAX model which brings change in broadband technology . To achieve that the handover delay problem has to be fixed as with high handover delay problem the real-time and streaming video application will not be supported in WiMAX.

8.2.3 WiMAX Simulations

In this research a detailed study was done on the choice of a simulation tool for simulation experiments in this research study, which is in Section 3 chapter 4 of this thesis. Due to a number of benefits using RIVERBED as a simulation tool, RIVERBED was selected as a tool used for simulation experiments with the aim of reducing the handover delay in WiMAX. RIVERBED or RIVERBED modeller is a simulation product from RIVERBED Techonologies Inc. The technology, which RIVERBED uses for this tool is hierarchical in structure. RIVERBED has a three-layer model mechanism which is comprised of Process Model, Node Model and Network Model. This tool supports a broad suite of protocols and technologies such as VoIP, TCP, MPLS, etc. The strongest feature of RIVERBED is its statistical and analysis modules, which help the modeller in collecting the performance statistical data in every network layer and generate graphical reports. The RIVERBED WiMAX model, which is a specialized model designed to support IEEE 802.16-2004 and IEEE 802.16e-2005 and IEEE 802.16m standards. The other important feature of this tool is that it can be used to evaluate custom scheduling algorithms for WiMAX base and subscriber stations, application performance optimization by leveraging WiMAX QoS policies and predicting network performance of difference MAC and PHY layer profiles. RIVERBED provides an environment to model, simulate and evaluate performance for all kinds of network and distributed systems. This tool can be installed and configured in many different operating systems such as Windows 2000, XP, Linux and Solaris platforms. The graphics tool which is included in the package provides help in scenarios, model conception and data collection and data analysis.

In This study there are a total of 6 main experiments with a number of sub-experiments which is detailed in Chapter 6. This aim as the goal is this research is to reduce the handover delay in WiMAX to ensure minimum handover times and maximum mobility. Below are the research questions which help in achieving the aim of reducing handover delay in WiMAX.

Research Question 2

- What are the WiMAX physical parameters including the effect of speed on mobile WiMAX.
- How do we optimize mobile WIMAX handover delay while reducing the negative effects optimization on bandwidth,delay and packet loss probability and Improve QoS

The answer to this question in detail is explained in chapter 6, where number of experiments are illustrated. The first experiment results show that when we remove all the factors which can affect handover delay and only monitor the speed of the mobile station. The results of Experiment 1 clearly show that when the mobile station is moving at the speed of 60 kmph, the handover delay will be at the minimum. These results create a basic building block for the current study where the goal is to minimize the handover delay in WiMAX signals while the mobile station is moving at a particular speed. The conclusion of this experiment was that when the mobile device is moving at 60 kmph would result in a minimum handover delay and for that reason the speed has a direct effect on handover delay in WiMAX and one other point we can understand from this experiment is the higher the speed, higher would be a handover delay in WiMAX. The research question points to the need to need to identify the physical factors and identify the ones which have a direct effect on handover delay. After studying number papers on WiMAX we identified there are 16 factors which can effect on handover delay and WiMAX signal a study, for example, a study (Khan, et al., 2012) identified 16 factors which could have an effect on handover delay in WiMAX networks Once all factors were identified the Experiment number 2 in chapter 6 describes the details of 16 sub-experiments where this experiment mainly tries to identify the physical signal parameters which directly influence handover delay in WiMAX . As per WiMAX forum the standard delay is 50 ms. In the previous experiment, we identified that the mobile station speed of 60 kmph would cause minimum handover delay when we keep all other factors standard or totally remove their effect. The simulation model used in this experiment is same as the one used in the previous experiment and some parameters will be kept constant to keep the simulation process simple.

The Experiment number 2 where we tried to identify the effect of physical factors on WiMAX handover delay as the previous study done by (Khan, et al., 2012) identified 16 factors which shows direct and indirect effect. As the aim of this experiment was to further identify the physical factors which directly affect the handover delay in WiMAX. The Simulations were carried out on all these factors. These 16 factors show a variety of results where some had very minute effect while few factors directly control the handover delay.

After simulation, we identified that there are 7 factors out of 16 have a direct effect on handover delay in WiMAX signals and a change in these factors would directly result in either increase or decrease in handover delay in WiMAX. These 7 factors are below

Table 8.0.1 Showing the Values where these factors have the lowest mobility

Factors	Value for Which WiMAX Shows best Mobility Results
Link going down factor	1.3
Scan iteration	5
Interleaving Interval	20
Timeout Parameter	20
Frame Duration	15
Client Timeout	6
Scan Duration	5

As these factors were identified, we also identified in our simulations that these factors perform better when they are standardised at values showed in table 8.0.1 and they resulted in a lower handover delay in simulation.

8.2.4 The use of Algorithm to improve handover decisions

We needed to improve the handover decisions as the results shown by the experiment 3 described in chapter 6 show that even when using the combined best values of the parameters didn't show the improvement which was expected and still there was a handover delay of 35 ms which was mainly due to poor handover decisions. As our experiment need a choice of a handover algorithm which needs to be helpful in improving handover decisions. The algorithm which has been used and chosen in this simulation experiment is a combination of existing handover algorithms and which is based on both types of algorithms. That's why it is also called a hybrid which is based on initiated MS and Initiated BS. Dual trigger handover algorithm was used.

Mathematically, this can be defined as Follows.

SNR_{maxDT} - $SNR_{DS} \geq H1$ AND $C_{EF} \geq H_2 \times$ C max, (Lee & Choi, 2007)

Where SNRDS is downlink SNR for serving BS

CEF estimated free capacity

Cmax the maximum free capacity

H1 and H2 is first and 2nd Handover

In this experiment, RIVERBED modular was employed at WiMAX network, which was standardized and adjusted these parameters to a level where WiMAX network had a lower handover delay before implementing Dual trigger algorithm to identify how the handover algorithm will improve the handover in WiMAX. This Simulation results identified that there was an improvement with the handover and WiMAX signal performed better, but there was also increased in a number of packet loss while throughput was improved . The SNR calculation helped in the triggering of handover, which in turn provided more stable WiMAX signal, but the problem with packet loss posed a negative effect on the overall performance of this algorithm for reducing handover delay in WiMAX and the main cause was the capacity condition which created more handovers then needed which in turn ended in retransmissions and packet loss. This study has identified that once the WiMAX signal is improved by using physical factors and also using a dual trigger algorithm that it performed in reducing the handover delay, but the handover decisions are made in dual trigger algorithm by capacity conditions which ended up in forced handovers and packet loss. Based on this information we have modified the dual trigger algorithm and modified it so the negative effect of capacity conditions are removed.

8.2.4.1 The new Suggested Algorithm

The new suggest algorithm is modified form of dual trigger algorithm where the implementation of an adaptive mechanism for optimizing thresholds for the handover hysteresis values. In this new algorithm, the handover conditions are based on using the bit error rate (BER) as the main parameter instead of the signal level.

As the new algorithm is modified version of dual trigger algorithm where in the new algorithm the handover will start when the BER is greater than energy per bit to noise power spectral density ratio

$SNR_{maxDT} - SNR_{DS} \geq H1$ AND $BER_{avg} \geq E_b/No$ (handover Algorithm by Researcher)

Where

BER_{avg} is Average Bit Error Rate

E_b/N_0 energy per bit to noise power spectral density ratio

In Chapter 6 Experiment 5 describes in detail the experimental setup and simulation procedure. In this simulation experiment, the new handover algorithm was tested. The biggest problem in dual trigger algorithm was the packet loss which was due to retransmissions caused by forced handover to make space for new handover. This new algorithm has resolved this issue which has removed the problem of packet loss and including to that the handover delay is at a stable rate of 0.018 Sec which is far better than standard handover delay in WiMAX.

CHAPTER 9: CONCLUSIONS AND FUTURE WORK

9.1 CONCLUSIONS

The main condition for establishing and planning a cost-effective network is designing such a network which will increase the financial return on the investment and for any network provider which aims to increase financial return would like improve quality of service (QoS) at lower cost. That would ensure that the network users have an enhanced coverage level and increased bandwidth for streaming applications at lower cost and increasing the network capacity, which will reduce network cost and also reduce holes within the network topology. Mobile WiMAX delivers all these features to network planners and that's why WiMAX has enjoyed the interest from many network planners, but the problem of handover delay has prevented network planners to effectively use WiMAX as an alternative to other broadband technologies.

Historically the handover problem was solved by manual techniques and due to impractical approach followed by network providers. The network developers have included the wireless access and therefore these techniques have become impractical. As the technologies providing wireless access have become more accessible, which resulted in higher the number of subscribers and online services worldwide, but this has resulted in increase complexity of network planning to ensure network providers can keep their quality of service (QoS) in Mobile WiMAX and thus therefor has been more emphasis made to solve the handover delay problem and to make mobile WiMAX more efficient and most importantly feasible network.

The optimization process done in this research included the experiments, parameters setup, collected data and results in order to improve WiMAX mobility with lower handover delay times and higher quality of service (QOS) and better network plans. During the optimization process the key performance indicators were used to evaluate the system performance and to provide the final solution with minimum handover delay at higher QoS levels. There were six main experiments conducted with a number of sub experiments in this research. Experiment 1 the effect of speed on handover delay was identified, as higher the speed results in higher handover delay. As this study wanted to improve the basic parameters of the signal to ensure minimum handover delay. This experimentally identified that a speed of 60 kmph will result in a minimum handover delay at given boundary conditions. The Experiment 2 tired to identify the physical factors which effect the handover delay and there are 16 factors which can effect handover delay in WiMAX, but after the simulation experiment and results analysis, showed only seven factors have a direct effect on handover delay. These seven factors resulted in a lower handover handover delay, when they were kept at specific values which is called as best performing values. The Experiment 3 combines the results of the seven factors and keep the other factors fixed to get the best handover delay results. The experiment resulted in improving the handover delay, but not to the level expected from this study. Experiment 4 tried to improve the handover decisions by using a dual trigger handover algorithm which resulted in a lower handover delay, but resulted in more packet loss which was due to the forced handovers to make space for new client stations. Which also resulted in packet loss and retransmission that resulted in poor performance of WiMAX signal. Experiment 5 tried to improve the problem that was identified in experiment 4 and therefore suggested a novel handover algorithm where the results from experiment were promising with lower handover delay and better WiMAX signal performance. Experiment 6 tested the new handover algorithm on WiMAX-2 (IEEE

802.16m) and the results show a similar trend of handover delay time improvement as in WiMAX (IEEE 802.16e). The work done in this thesis has drastically improved the handover delay at high QoS and mobility but still there are more challenges. As many organizations are providing WiMAX for smart cities, it becomes paramount to keep improving the handover delay to cope very high mobility demand to serve all media and internet application.

9.2 FUTURE WORK

WiMAX network is continually under development and WiMAX handover delay is an ongoing research problem, which will introduce more challenges as the technology gets recognized and become matured. These challenges will become more diverse as the technology gets integrated into the telecommunications industry and there are several factors in the proposed optimization of handover delay in WiMAX, which could be further improved and complemented in order to make WiMAX a viable telecommunication technology.

- As this study keeps all assuming the terrain effect to be minimal as the simulation assumes the line of sight between the base station to the mobile station and this study can be improved by studying the effect of terrain using a new proposed handover algorithm.
- As mentioned in the study, the simulation experiments assume all other WiMAX signal factors to be the standard, which leaves space for more study and these factors need to be tested to understand their effect on handover delay while using this new algorithm.
- This study is done while setting up WiMAX experiment using RIVERBED and keep the effect of physical factors such as the wind, interference from other mobile device signals to the null. To further improve WiMAX handover delay, more study is needed

to understand the effect of these factors on handover delay while using new suggest handover algorithm.,

- This study is based on WiMAX experiments using RIVERBED simulation and there is need to run the same experiments on real-time WiMAX hardware and WiMAX Test-Beds, which is needed to test the WiMAX model and handover delay algorithm in order to test its performance on real times situations using WiMAX hardware and applications.

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APPENDIX. RESEARCH PUBLICATIONS

- Khan, I. and Yousef, S. *Substantial Reduction of Handover Delay for Optimum Mobility in WiMAX*. International Journal of Engineering and Technology, 6 (7). pp. 203-216. ISSN 2049-3444
- Khan I., Yousef S. (2016) Using Dual Trigger Handover Algorithm to Improve WiMAX Handover Delay. In: Jahankhani H. et al. (eds) Global Security, Safety and Sustainability - The Security Challenges of the Connected World. ICGS3 2017. Communications in Computer and Information Science, vol 630. Springer, Cham