Deanship of Graduate Studies
Al-Quds University

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Mahmoud Saleh Obaid

M.Sc. Thesis

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Master of Electronics and Computer Engineering

Thesis Approval

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Jerusalem-Palestine

1434-2013

Declaration:

I certify that this thesis submitted for the degree of Master, is the result of my own research, except where otherwise acknowledged, and that this study (or any part of the same) has not been submitted for a higher degree to any other university or institution.

Signed: ……………

Mahmoud Saleh Obaid

Date: …………….

Acknowledgments

First, I would like to thank almighty ALLAH for finally finishing the writing of this thesis for my Master’s degree in Electronic and Computer Engineering, despite all the difficulties and the unstable situation in Palestine as a result of the Israeli occupation and travel restrictions.

I would like to express my deepest gratitude to my supervisor Dr. Samer Bali for his valuable suggestions and comments; this work could not have been completed without his inspiring guidance.

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Abstract

The world has become a very fast technology consumer in the last decade. In particular, the broadband access technology has a great influence on the telecommunication industry. Therefore, broadband in general and especially WiMAX (Worldwide Interoperability for Microwave Access) has become the trend for all researchers to enhance the communication media, eliminate the obstacles of the Wi-Fi and 3G broadband, and reduce the cost and time rate of satellite broadband. WiMAX can make high speed wireless broadband internet services available to larger areas and it can provide a wireless connectivity range for up to 30 miles (or 50 kilometers), which is much greater than a typical Wi-Fi or DSL. It can also be interconnected with existing Wi-Fi networks.

The main goal of this work is to determine the parameters that have the greatest impact on the handoff process. Simulation experiments will be conducted that some of the parameters do not influence the handoff times at all. However, changing some of other factors, even slightly, has direct consequences. For example, link Going Down-factor, which determines the sensitivity of detecting a failing link, is considered a significant impact in the results.

We find the link going down-factor is the most important factor of the WiMAX module that influences handoff and the best value we got is **1.4**, the scan iteration is **two** iteration, inter leaving interval is **4** frames, while the time-to-searching the DL-Map is set to **5ms**.

The handoff latency, throughput and end-to-end delay are measured and the parameters of the simulator are adjusted, in order to achieve the best possible handoff times, comparing the results with the objectives set by the WiMAX Forum. The WiMAX Forum [3] says that the Mobile WiMAX supports mobility up to 72 km/h and the handoff should take less than 50ms. The results of this study show that there are some parameters which could be enhanced to reduce handoff time since it is still below the 50 ms limit up to 28 m/s (100 km/h).

Keywords: Handoff, WiMAX, 802.16.e, Mobility

الملخص:

لقد اصبح العالم في العقد الاخير مستهلك سريع للتكنولوجيا ، وخصوصا على مستوى تكنولوجيا الاتصالات ، ولما كانت تكنولوجيا النطاق العريض لديها التاثير الاكبر على صناعة الاتصالات السلكية واللاسلكية ، وعليه فان النطاق العريض وبشكل خاص ما يعرف "واي ماكسWiMAX" اصبح مقصد جميع الباحثين والعاميلن على تحسين وسائل الاتصال ، وازالة جميع المعيقات التي تواجه الواي ماكس والجيل الثالث للنطاقات العريضة ، كما يسعون لتخفيض تكلفة زمن "عملية الانتقال (Handoff) " للنطاق العريض.

يستطيع "واي ماكس" تقديم خدمات الانترنت بسرعات عالية ويمكن توفيرها لاماكن واسعة وعلى مسافات عالية يمكن ان تغطي مسافات هوائية تصل الى 30 ميل (50 كيلومتر) وهي مسافة اكبر بكثير من المسافة التي يغطيها "واي فاي(Wi-Fi)" التقليدي او"دي اس الDSL" ، كما انه يمكن استغلال وجود هذه الخيارات من خلال عمل توافق وترابط ما بين شبكات "واي فاي" المتوفرة والموجودة وربطها مع شبكات "واي ماكس".

ان الهدف الرئيسي التي نسعى له من خلال دراستنا في هذه الرسالة والتي ستكون محور حديثنا ونتائجنا هو تحديد المتغيرات والعوامل التي سيكون لها الاثر الاكبر على "عملية الانتقال"، ومدى اهمية هذه العوامل على التقليل من الوقت اللازم ل "عملية الانتقال" لتكون في افضل حالاتها ، وبناء على النتائج التي حصلنا عليها ، استطعنا تحديد مدى اهمية كل عامل من هذه العوامل بناء على القيمة التي يجب ان يكون عليها واستخلصنا ان بعض هذه العوامل والتغيير في قيمها لا يعكس اي تاثير على "عملية الانتقال" اطلاقا ، ولكن على صعيد اخر وجدنا ان بعض التغييرات في قيم عوامل اخرى حتى ولو بشكل طفيف كان لها اثار كبير، واستطعنا على سبيل المثال تحديد عامل مثل : . link going down factor

وفي النتيجة وجدنا في تجاربنا ان هذا العامل link-going-down-factor هو اهم العوامل واكثرها تاثيرا على وحدة "واي ماكس" والتي ينعكس تاثيرها على "عملية الانتقال" وبالتالي وجدنا ان افضل قيمة يمكن لهذا العامل والتي يمكن ان تعكس افضل حالة للتحول هي عندما تكون قيمته تماما 1.4 ، على الصعيد الاخر وجدنا ان افضل قيمة للمتغير scan_iteration هو"اطارين(2 frames) " ، كما ان متغير interleaving interval وهي فترة المغادرة والتسليم كانت افضل قيمها "4 اطارات(4 frames)"، ومتغير البحث عن dl-map كان من المتغيرات المؤثرة وذات الاهمية على نتيجة "عملية الانتقال" والتي كان افضل قيمها هو 5 ميللي من الثانية.

ان عملية القياس لكل من "عملية الانتقال" شملت "معدل البث(throughput)" ومعدل وقت التاخير (end-to-end delay) ، بالاضافة الى تعديل المتغيرات الخاصة بالمحاكاة كما ذكر تفصيلا من اجل الوصول الى افضل قيم تخص "عملية الانتقال" ووضعنا اساس عملية المقارنة لهذه النتائج بان تكون المرجعية هي النتائج التي اعلن عنها مؤتمر "واي ماكس"، حيث ان هذا المؤتمر يعتبر كمرجعية علمية وعملية في العالم بما يخص "واي ماكس"، وقد نشر نتائج تفيد بان "واي ماكس" باستخدام الموبايل تدعم "عملية الانتقال" حتى سرعة 72 كم/ساعة وبالمقابل يجب ان تكون "عملية الانتقال" تقل عن 50ميللي من الثانية كحد اعلى ، وعليه كانت النتائج التي حصلنا عليها تفيد بان هناك بعض المتغبرات التي يمكن التحسين على قيمها بما يكفل التخفيض من وقت

التسليم والتحول مع الحفاظ على الحد الاعلى ليكون اقل من 50 ميللي من الثانية والذي اظهرت دراستنا انه تم المحافظة على وقت التسليم ليكون في احسن قيمة نصل اليها وهو 28ميللي من الثانية كحد اعلى وبسرعة 100 كم /ساعة وهي قيم مهمة جدا واكثر فعالية .

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Chapter One: Introduction

1.1 Background

Several years ago WiMAX Forum developed the most modern wireless technology named WiMAX, which is a telecommunications protocol that provides fixed and fully mobile Internet access. There are many positive aspects of this technology; one of the most important is the support of a large coverage area. WiMAX provides the support of wireless connectivity with a minimum range of 30 miles. WiMAX technology also offers high speed broadband access to mobile users, which transfers data, voice, and video. In WiMAX, when a user uses a 20 MHz of bandwidth , the corresponding data rate can be up to 75 Mbps..

Broadband access technology has significant influences on the telecommunication industry. It does not only provide faster web surfing but also quicker file downloads, several multimedia applications and reliable voice communications. Until recent times, broadband users have been restricted to digital subscriber line (DSL) technology which provided broadband over twisted-pair copper wires as well as to cable modem technology which was delivered over coaxial cable. Both of these wired lines infrastructures are highly expensive and consumes time to deploy compared to the wireless technology. Another way for getting broadband access is satellite service, but it is costly and there is half a second delay between the data transmission and reception. Wireless technology also has clear advantage in rural areas and developing countries that lacks wired infrastructures for broadband services. WiMAX is a broadband wireless technology which brings broadband experience to a wireless technology. There are two different types of broadband wireless services. One is the fixed wireless broadband which is similar to the traditional fixed line broadband access technology like DSL or cable modem but using wireless as a medium of transmission. Another type is the broadband wireless, also known as mobile broadband, which has additional functionality of portability, mobility. The IEEE 802.16 family WiMAX is designed to accommodate both fixed and mobile broadband application. WiMAX promises to solve the last mile problem which refers to the expense and time needed to connect individual homes and offices to trunk route for communications. WiMAX also offer higher peak data rates and greater flexibility than 3G networks. [1] Figure 1.1 shows the different models of WiMAX.

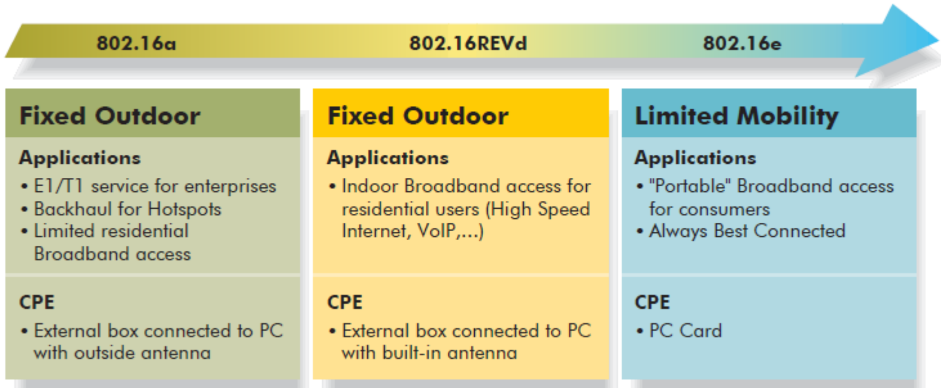

Figure 1.1: The different models of WiMAX[2]

This thesis endeavor to find out best values of some parameters for handoff in WiMAX .

The network architecture of Mobile WiMAX is defined by the WiMAX Forum [1]. The 802.16-2005 [2] is the new, mobile version of the older WiMAX specification known as 802.16-2004 [3], which is a fixed wireless data transmission scheme for providing broadband connection to metropolitan areas.

The traditional WiMAX does not support mobility which means the user is allowed to move anywhere but still the service is the issue. A moving user needs to change the serving base station i.e. a handoff, which creates demands for the Mobile WiMAX. The handoffs should be fast enough so that the ongoing video call or Voice over IP (VoIP) conversation are not interrupted, at least not for a long period of time that a user can notices it.

The communications industry is heading towards wireless data transfer with great speed and several competing technologies are emerging to replace the old ones. The traditional Wireless Local Area Network (WLAN) has gained a strong place in the market and is definitely the leader for short distance wireless networks. However, the coverage and mobility are adequate for indoor usage only. The Mobile WiMAX is planned to be independent or to extend the mobile access when a user exits in the WLAN hotspot coverage area.

WiMAX is one of the states of art broadband wireless technology that offers high speed, last mile broadband services. In this chapter, we present the evolution of WiMAX and its features.

1.2 Thesis Objectives

1. Study homogeneous mobility, which is the movement of a MS between networks of the same technology.
2. Study affecting parameters on handoff latency.
3. Define the best value for affecting factors that leads to less time for handoff, more throughputs, and less end-to-end delay.

It is supposed to use mobile WiMAX in Palestine in the near future. In this thesis, a practical WiMAX network scenario is designed. Then, a performance evaluation is carried out to determine the main factors affecting the handoff process of this scenario.

1.3 Motivation

The rapid innovation in the communication area, especially in the mobility sector, lead the companies to think big, in order to reach the maximum number of customers who always need to be online. WiMAX become very vital player in the communication market all over the world, for the coverage area and mobility issues, therefore this technology started emerging in the Middle East (i.e Jordan) and now thinking to start in Palestine and this represent good motivation to search deeply in this technology's critical issues.

Several researchers in the WiMAX field tried to study the handoff while exploring 802.16e and they showed us that it is possible to reduce the handoff using applications (software), in this research I will be basing my test and results on hardware changes to achieve the desired results of reduced numbers of handovers, handover interruptions and handover delays.

another motivation for me to start this case study was to show how changing some factors will enhance the results and at the same time we can change the study in many direction while keeping focus on the handoff delay , so we study many factors and also the velocity of mobiles vs. number of stations with different distance to satisfy my research and try to give fixed value for all sensitive parameters and to open the door for mixing many methodologies in the same study with focusing on the main target .

1.4 Problem Statement

Mobility for communication devices is a capability that is becoming increasingly desired by end users together with emerging services such as audio/video streaming. The methods for supporting various degrees of device mobility, e.g. portability, roaming and full mobility, often vary between technologies and define the mobility characteristics of each.

This thesis will attempt to answer the following questions:

- What are the mobility capabilities of the WiMAX network architecture in terms of coverage areas and handoff latency?
- What are the factors affecting handoff process on a WiMAX network?
- What are the best values for these factors to obtain less handoff time, more throughputs and less end-to-end delay?

1.5 Literature Survey

A Mobile WiMAX technology which provides a high-level knowledge in WiMAX network evolution, baseline network reference model, air interface, basic protocol structure, frame structure and physical channelization is proposed in [20].

In [5], authors reveal some challenges that mobile users face when travelling across different base stations in a Mobile WiMAX environment and study the handoff latency and throughput performance with respect to different velocities, on that paper they didn't mentioned or go through any other factors that may affect these values , also they mentioned one very important factor (link going down factor) without any values or effects.

Authors in [8] present a comparative study only, based on comparing the quality of service with hard handover and soft handover. They have analyzed the proposed technique with an existing scheme for soft handover in WiMAX with simulation results. They used the standard values for both soft and hard handoff and can prove that using the techniques of soft hand off can reach the best values of throughput for 70% on velocity of 110 km/h, and this value in our results can be reached using the hard handoff with using of different values of adjusted factors which is more reliable than soft handoff.

Authors in [23] focus on the throughput and did the same comparison as [8] did, with some enhancement on the soft handoff algorithm but didn't study the handoff latency and reached the same results of soft handoff. Comparing these results to our results for the hard handoff, we found out that using the hard handoff is more significant and reliable.

In [6] authors tried to use the UDP protocol instead of using TCP/IP as standard protocol, they got the best hand off but couldn't increase the throughput which was in its worse value and is not acceptable.

In [9] authors focused on comparing the use of layer 2(ASN) with layer 3 (IP) and recommend using layer 2 as the handoff latency had the best value. The major weakness of this comparison is that the study was done on 1 km coverage area and there is no mention of the throughput value accordingly.

Authors in [24] tried to use the 3rd type of handoff, FBSS, which focuses on the number of handoffs during data transition without taking into consideration the handoff time which is more important than counting them

In [27] authors study the handoff time with all aspects and mentioned all the factors that affect the handoff time but they used standard values for these factors which eliminate any choice of changing these values that may reflect new options for enhancing the handoff time and throughput.

1.5.1 Overall Researchers Discussion

Since WiMAX technology is expected to do more for Metropolitan Area Networks (MANs) which can't be done using Wi-Fi, WiMAX is presented to integrate with Wi-Fi and not to replace it, by connecting Wi-Fi networks to each other or the Internet through high-speed wireless links. This will extend the power and range of Wi-Fi and cellular networks. For that WiMAX become an important wireless technology in developing countries since Wi-Fi and cellular networks do not cover as vast areas as WiMAX does.

Many researchers focused their efforts on the quality of service and the coverage of WiMAX, yet neglecting the Handoff variable, which is the main evaluating factor when deciding to use WiMAX in the new revolution of communication and internet technology. All of those researches were working on the following:

1- The base station (BS) coverage area: Many researchers are doing their simulation on the base station to cover only one kilometer area and this may increase the cost of having more numbers of stations which represents a very significant factor for the investors and can increase the cost rapidly and in a very high rate.
2- Most of the researchers point to the handoff latency factor only, and some of them are working on the throughput factor in their simulation on the handoff. These factors (but not only them) can have some effects on handoff and cause changes to it.
3- The researchers' simulations are done in labs without any mention to the real world implementation that can change some of the facts and make it closer to the practical environment. This makes the results unreliable and does not reflect the actual results
4- The scenario that most of these researchers implemented in the labs is focusing on the base stations and changing the velocity only, and this eliminates the other factors that can give some other results; however, all the researchers, in the best case, concluded that the handoff factor can be enhanced to reach what we are looking for in developing the WiMAX technology. But, if we can merge these results and change other factors, we can get more and more coverage of the BS without changing the quality of service or the WiMAX transmission efficiency.

1.5.2 Our Contribution

Our study handles the following:

1- The base station (BS) coverage area

    Our simulation on the base station aims to cover up to 8 kilometer and this is done to reduce the cost and maintain the quality without losing any of the WiMAX characteristics and advantages.

2- Our study does not only focus on the handoff latency factor but it also takes into consideration many other factors that have or can have influence on the handoff such as throughput, end-to-end delay to reduce the time required for making the handoff significant.

3- Our study takes into consideration the real world implementation while doing our simulation in the labs. We revised and visited two sites to stand on some facts of the BS distribution; one of them is in Palestine BCI that has already started installation and will start work mid-2013 and the other site is the Jordan with Zain which installed everything but has not started operating the WiMAX.

4- We use two scenarios in our simulation :

   a. In the first scenario, we set the number of stations, make the change in velocity and try to monitor the changes to all other factors until we reach the best results that can reduce the handoff.

   b. In the second scenario, we set the velocity, change the density (No. of mobile nodes) and try to get the best results of all other factors that influence the handoff results.

1.6 Document Structure

This thesis is divided into three major parts: In chapter 2 we will discuss the PHY and MAC properties of Mobile WiMAX, the Mobile WiMAX mobility, handoff and the simulation of the real world, in addition to prefer information related to the WiMAX from the beginning.

In Chapter 3 the design of WiMAX simulation environments in network simulator NS-2 is presented, and our experimental results are discussed.

Finally, chapter 4 summarizes and concludes this thesis as well as it provides an outlook for future work.

Chapter 2: Mobile WiMAX Radio Networks & WiMAX Mobility Management

In this chapter we will mainly discuss the PHY and MAC properties of Mobile WiMAX, Later on, mobility is discussed with only very basic mobility capabilities, since the mobility issues have been dedicated their own chapter after this one. The material in this chapter is based mostly on references [3], [15], and [31].Additionally, some possibly competing or co-existing technologies in wireless communications are introduced. The traditional WLAN (802.11-family) is mentioned with the post-GSM technologies as well as some other IEEE 802 standards.

2.1 What is WiMAX

WiMAX has the potential to replace a number of existing telecommunications infrastructures. In a fixed wireless configuration it can replace the telephone company's copper wire networks, the cable TV's coaxial cable infrastructure while offering Internet Service Provider (ISP) services. In its mobile variant, WiMAX has the potential to replace cellular networks. How do we get there?[31]

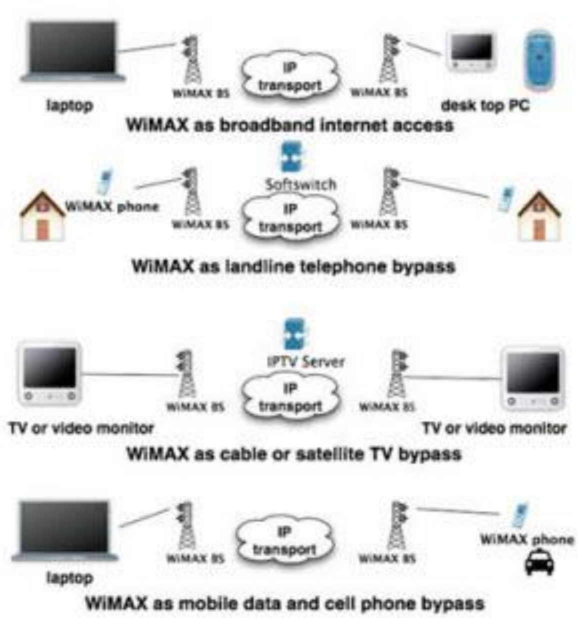

Figure 2.1: WiMAX has the potential to impact all forms of telecommunications [31]

What is WiMAX or Worldwide Interoperability for Microwave Access? WiMAX is an Institute of Electrical and Electronics Engineers (IEEE) standard designated 802.16-2004 (fixed wireless applications) and 802.16e-2005 (mobile wire-less). The industry trade group WiMAX Forum has defined WiMAX as a "last mile" broadband wireless access (BWA) alternative to cable modem service, telephone company Digital Subscriber Line (DSL) or T1/E1 service.[31]

Fixed WiMAX

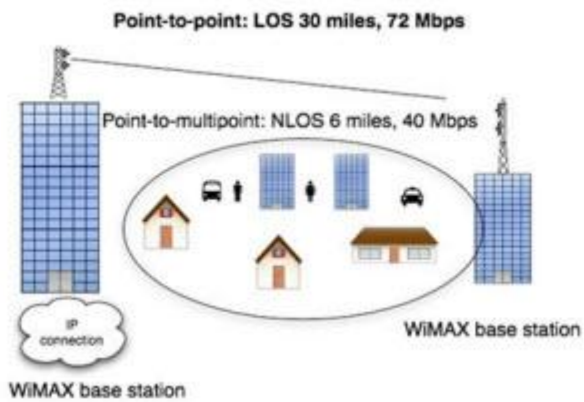

Figure 2.2: Fixed WiMAX offers cost effective point to point and point to multi-point solutions [31]

What makes WiMAX so exciting is the broad range of applications it makes possible but not limited to broadband internet access, T1/E1 substitute for businesses, voice over Internet protocol (VoIP) as telephone company substitute, Internet Protocol Television (IPTV) as cable TV substitute, backhaul for Wi-Fi hotspots and cell phone towers, mobile telephone service, mobile data TV, mobile emergency response services, wireless backhaul as substitute for fiber optic cable.[31]

WiMAX provides fixed, portable or mobile non-line-of sight service from a base station to a subscriber station, also known as customer premise equipment (CPE). Some goals for WiMAX include a radius of service coverage of 6 miles from a WiMAX base station for point-to-multipoint, non-line-of-sight (see following pages for illustrations and definitions) service. This service should deliver approximately 40 megabits per second (Mbps) for fixed and portable access applications. That WiMAX cell site should offer enough bandwidth to support hundreds of businesses with T1 speeds and thousands of residential customers with the equivalent of DSL services from one base station. [31]

Mobile WiMAX

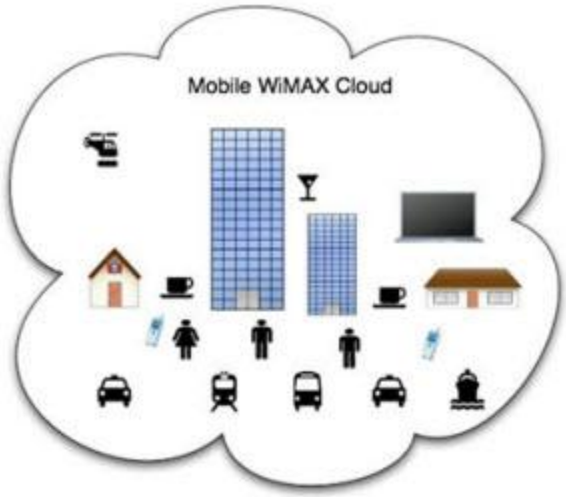

Figure 2.3: Mobile WiMAX allows any telecommunications to go mobile [31]

Mobile WiMAX takes the fixed wireless application a step further and enables cell phone-like applications on a much larger scale. For example, mobile WiMAX enables streaming video to be broadcast from a speeding police or other emergency vehicle at over 70 MPH. It potentially replaces cell phones and mobile data offerings from cell phone operators such as EvDo, EvDv and HSDPA. In addition to being the final leg in a quadruple play, it offers superior building penetration and improved security measures over fixed WiMAX. Mobile WiMAX will be very valuable for emerging services such as mobile TV and gaming.[31]

WiMAX is not Wi-Fi

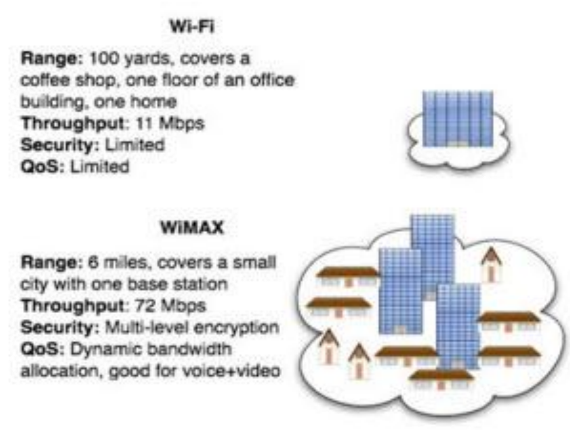

Figure 2.4: Where Wi-Fi covers an office or coffee shop, WiMAX covers a city [31]

One of the most often heard descriptions of WiMAX in the press is that it is "Wi-Fi on steroids". In truth, it is considerably more than that. Not only does WiMAX offer exponentially greater range and throughput than Wi-Fi (technically speaking 802.11b, although new variants of 802.11 offer substantial improvements over the "b" variant of 802.11), it also offers carrier grade quality of service (QoS) and security. Wi-Fi has been notorious for its lack of security. The "b" variant of 802.11 offered no prioritization of traffic making it less than ideal for voice or video. The limited range and throughput of Wi-Fi means that a Wi-Fi service provider must deploy multiple access points in order to cover the same area and service the same number of customers as one WiMAX base station (note the differences in nomenclature). The IEEE 802.11 Working group has since approved upgrades for 802.11 security and QoS.[31]

Objections to WiMAX

A discussion of WiMAX is not complete without taking on objections to the technology. Before anyone can sell a high technology product, they must first sell the customer on the technology as shown in figure 2.5.

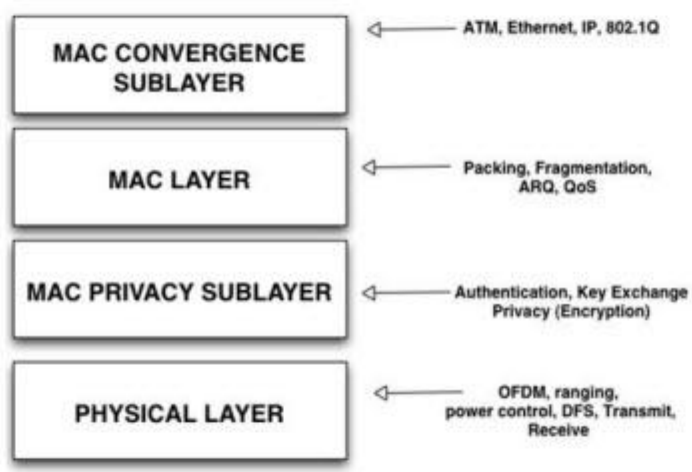

Figure 2.5: Objections to WiMAX are best understood via the provisions built into the WiMAX Physical and MAC layers [31]

Technology sales people invariably encounter objections to the technology they are selling. The primary objections to WiMAX are:

1. Interference: Won't interference from other broadcasters degrade the quality of the WiMAX service?
2. Quality of Service (QoS): Wireless is inherently unstable so how can it offer voice and video services?
3. Security: Is WiMAX secure? Can anything wireless be secure?
4. Reliability: Nothing can be as reliable as the telephone company's service (rumored to offer "five 9s" of reliability or 5 minutes of downtime per year).

The answers to those objections are best understood via the Physical (known as the PHY, pronounced "fi") and Medium Access Control (MAC pronounced "mac") Layers. The WiMAX Working Group no doubt were aware of these objections based on experiences with earlier wireless technologies (Wi-Fi, LMDS, MMDS, CDMA, GSM) and have engineered WiMAX to fix failures of past wireless technologies. [31]

2.2 WIMAX PHY Layer

The first version of the 802.16 standard released addressed Line-of-Sight (LOS) environments at high frequency bands operating in the 10-66 GHz range, whereas the recently adopted amendment, the 802.16a standard, is designed for systems operating in bands between 2 GHz and 11 GHz. The significant difference between these two frequency bands lies in the ability to support Non-Line -of-Sight (NLOS) operation in the lower frequencies, something that is not possible in higher bands.

Consequently, the 802.16a amendment to the standard opened up the opportunity for major changes to the PHY layer specifications specifically to address the needs of the 2-11 GHz bands. This is achieved through the introduction of three new PHY-layer specifications (a new Single Carrier PHY, a 256 point FFT OFDM PHY, and a 2048 point FFT OFDMA PHY); Some of the other PHY layer features of 802.16a that are instrumental in giving this technology the power to deliver robust performance in a broad range of channel environments are; flexible channel widths, adaptive burst profiles, forward error correction with concatenated Reed-Solomon and convolution encoding, optional AAS (advanced antenna systems) to improve range/capacity, DFS (dynamic frequency selection)-which helps in minimizing interference, and STC (space-time coding) to enhance performance in fading environments through spatial diversity. Table 1 gives a high level overview of some of the PHY layer features of the IEEE 802.16a standard. [10][15]

Table 2.1: 802.16a PHY Features

Feature	Benefit
256 point FFT OFDM waveform	• Built in support for addressing multipath in outdoor LOS and NLOS environments
Adaptive Modulation and variable error correction encoding per RF burst	• Ensures a robust RF link while maximizing the number of bits/ second for each subscriber unit
TDD and FDD duplecing support	• Address varying worldwide regulations where one or both may be allowed
Flexible Channel sizes (e.g. 3.5MHz, 5MHz, 10MHz etc)	• Provide the flexibility necessary to operate in many different frequency bands with varying channel requirements around the world
Designed to support smart antenna system	• Smart antenna are fast becoming more affordable and as these costs come down their ability to suppress interference and increase system gain will become important to BWA deployments

2.3 IEEE 802.16a MAC Layer

The 802.16a standard uses a slotted TDMA protocol scheduled by the base station to allocate capacity to subscribers in a point-to-multipoint network topology. By starting with a TDMA approach with intelligent scheduling, WiMAX systems will be able to deliver not only high speed data with SLAs, but latency sensitive services such as voice and video or database access are also supported. The standard delivers QoS beyond mere prioritization, a technique that is very limited in effectiveness as traffic load and the number of subscriber's increases. The MAC layer in WiMAX certified systems has also been designed to address the harsh physical layer environment where interference, fast fading and other phenomena are prevalent in outdoor operation. [10][15]

Table 2.2: 802.16a MAC Features

Feature	Benefit
TDM/ TDMA Scheduled U/D link frames	• Efficient bandwidth usage
Scalable from 1 to hundreds of subscribers	• Allows cost effective deployments by supporting enough subs to deliver a robust business case
Connection-Oriented	• Per Connection QoS • Faster packet routing and forwarding
QoS support Continuous GrantReal Time Variable Bit RateNon Real Time Variable Bit RateBest Effort	• Low latency for delay sensitive service)TDM voice, VoIP) • Optimal transport for VBR traffic(e.g. video) Data prioritization
Automatic Retransmission request (ARQ)	• Improves end-to-end performance by hiding RF layer induced errors from upper layer protocols
Support for adaptive modulation	• Enable highest data rate allowed by channel conditions, improving system capacity
Security and encryption (Triple DES)	• Protects user privacy
Automatic Power Control	• Enable cellular deployment by minimizing self interference

2.4 WiMAX Scalability

At the PHY layer the standard supports flexible RF channel bandwidths and reuse of these channels (frequency reuse) as a way to increase cell capacity as the network grows. The standard also specifies support for automatic transmit power control and channel quality measurements as additional PHY layer tools to support cell planning/deployment and efficient spectrum use. Operators can re-allocate spectrum through sectorization and cell splitting as the number of subscribers grows. In the MAC layer, the CSMA/CA foundation of 802.11, basically a wireless Ethernet protocol, scales about as well as does Ethernet. That is to say - poorly. Just as in an Ethernet LAN, more users results in a geometric reduction of throughput, so does the CSMA/CA MAC for WLANs. In contrast the MAC layer in the 802.16 standard has been designed to scale from one up to 100's of users within one RF channel, a feat the 802.11 MAC was never designed for and is incapable of supporting.

2.5 IEEE 802.16 Extensions

The IEEE 802.16 group was formed in 1998 to develop the radio air interface for wireless broadband. The initial focus of this group was the development of a line of sight based point to multipoint wireless broadband system that will operate 10 to 66 GHz band. The first version of the 802.16 completed in December 2001 which is based on the single-carrier physical layer and the burst time division multiplexed (TDM) MAC layer. Due to the technological advances, the IEEE 802.16 standards have seen many changes and adopted several extensions. The family of IEEE 802.16 standards offers enormous design flexibility, licensed and license-exempt frequency bands, QoS establishment, strong security measurements, low packet loss handoffs and multicast support.

IEEE 802.16 a

The IEEE has developed 802.16a-2003 which is optimized for operation between frequencies from2 to 11 GHz. This lower range of frequencies can easily penetrate barriers and thus do not require a line of sight. It is also flexible in channel width choices where narrow channels like1.75 MHz allows it to be used where only small allocations are available. It is also includes mesh network modes of operation which extends basic 802.16’s transmission range by pass a single communication from one transceivers to other transceivers. This version attracts most commercial interest because its range covers a number of popular bands around the world.

IEEE 802.16 b

IEEE 802.16 b – 2003 extension clarifies broadband wireless access metropolitan network functions and capabilities of the radio-air interface. License-exempt BWA metropolitan networks support multimedia services. It also increases the spectrum of 5 and 6 GHz frequency bands and provides quality of service which ensures priority transmission for real time voice and video.

IEEE 802.16 c

In January 2003 IEEE published the version 802.16c which aimed to develop the 10-66 GHz BWA system profiles to aid interoperability specification. This version has been replaced by IEEE 802.16-2004 which recommends the coexistence of different FBWA system in both the10 to 66 GHz and 2 to 11 GHz bands. 802.16-2004 was very useful which guides the coexistence criteria, minimization of interference and recommends equipment design parameters and mitigation techniques to avoid case by-case coordination.

IEEE 802.16d

IEEE 802.16d is based on 802.16a with some minor improvements. This extension supports both time division duplex (TDD) and frequency division duplex (FDD) transmission and also creates system profiles for conformance testing of 802.16a equipments.

IEEE 802.16 e

This technology adds support for mobile subscriber stations. It would also support communication for the user who moved at vehicular speed for its technological advances of high speed signal handoffs. The IEEE 802.16e has some clear advantage over 802.16-2004.IEEE 802.16 e has multicast and broadcast service feature. It also enhances the techniques of Multiple-Input Multiple-Output (MIMO) and adaptive antenna system (AAS). Its security feature also completely updated and introduce privacy sub layer. It has also introduced power save modes for mobility supporting MSs.

IEEE 802.16f

Improve the coverage area by using the mesh networking. Mesh networking has the ability to bypass obstacles and only a small amount of meshing can largely improve the coverage area of base station.

IEEE 802.16 g

This technology support mobility at higher layer and across backhaul. It’s not yet fixed whether OFDM or OFDMA will be the transmission technique.

In table 3.1 we see the summary of 802.16 WiMAX radio link.

Table 2.3: Summary of 802.16 Radio Link

Completion Date	**802.16** **Dec 2001**	**802.16a/802.16REVd** **Jan 2003** **Q3 2004**	**802.16e** **2005**
Spectrum	10 to 66 GHz	<11 GHz	<6 GHz
Channel Condition	Line-of-Sight only	Non-Line-Of Sight	Non-Line-of-Sight
Bit Rate	32 to 34 Mbps	75 Mbps max 20 MHz Channelization	15 Mbps max 5 MHz Channelization
Modulation	QPSK 16QAM 64QAM	OFDM 256 subcarrier QPSK 16QAM 64QAM	Same as 802.16a
Mobility	Fixed	Fixed	Pedestrian mobility Regional roaming
Channel Bandwidths	20, 25 and 28 MHz	Selectable between 1.25 and 20 MHz	Same as 802.16a with uplinksub channels
Typical Cell Radius	1 to 3 miles	3 to 5 miles (30 miles max based on tower height, antenna gain, and power transmit)	1 to 3 miles

2.6 OFDMA system

Figure 2.6 show OFDMA system, OFDM exploits the frequency diversity of the multipath channel by coding and interleaving the information across the sub-carriers prior to transmissions. OFDM modulation can be realized with efficient Inverse Fast Fourier Transform (IFFT), which enables a large number of sub-carriers (up to 2048) with low complexity. In an OFDM system, resources are available in the time domain by means of OFDM symbols and in the frequency domain by means of sub-carriers. The time and frequency resources can be organized into sub-channels for allocation to individual users. Orthogonal Frequency Division Multiple Access (OFDMA) is a multiple-access/multiplexing scheme that provides multiplexing operation of data streams from multiple users onto the downlink sub-channels and uplink multiple accesses by means of uplink sub-channels.

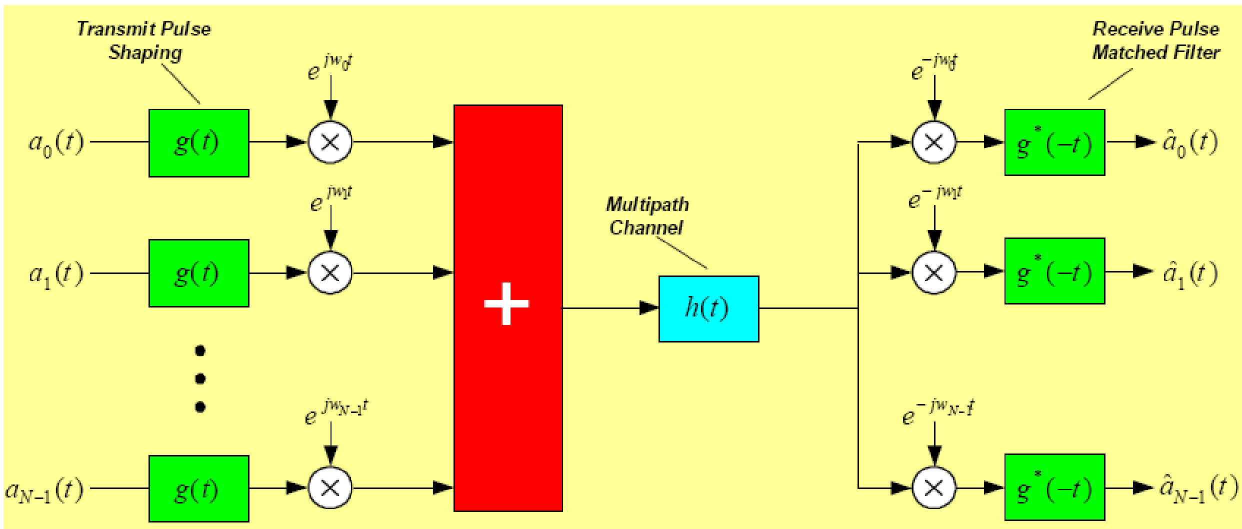

Figure 2.6: Basic Architecture of an OFDM System

Orthogonal Frequency Division Multiplexing (OFDM) is a digital modulation scheme suited especially well for terrestrial broadcasting. It can handle multipath propagation and delays between received signals. The OFDM is sensitive to frequency changes as Doppler shift while the Mobile Station (MS) is moving. However, the delay spread is not a great problem in the OFDM because of the increased symbol duration.

The Orthogonal Frequency Division Multiple Access (OFDMA) is a version of OFDM and intended for several user mobile communications environments. It is the solution considered to be the modulation scheme in most future advanced wireless communications technologies, as examples can be mentioned the Long Term Evolution (LTE, the Mobile Broadband Wireless Access (MBWA), or the Mobile WiMAX.

The OFDMA has several advantages over traditional Code Division Multiple Access (CDMA)-versions used in post-GSM 3G technologies. The spectral efficiency is higher and the fading can be tolerated better. In OFDMA data streams from different users are combined to sub-channels in both Downlink (DL) and Uplink (UL). However, there are some drawbacks as well. Since the manufacturing of OFDMA electronics is rather complex, the expenses rise at the same time. Additionally, the Co-Channel Interference (CCI) from neighbouring cells is less disturbing in CDMA than in OFDM. The CCI can although be mitigated by using Fractional Frequency Reuse. [15]

OFDM Basic Principle with OFDM the used bandwidth is divided into several frequency sub-carriers so that they are orthogonal to each other. The stream of input data is separated into multiple, parallel sub-streams with reduced data rate. Then the sub-streams are modulated individually and sent on separate sub-carriers. Consequence of this is the increase in symbol duration. Since the long signal duration decreases Inter Symbol Interference (ISI) caused by multipath propagation, it is efficient to transmit the low-rate streams in parallel, instead of one high-rate stream. The signal duration is long, so by using a proper guard interval, the ISI can be avoided totally, assuming the guard interval is longer than the difference between the first and last multipath echo.

The information is coded and modulated across the sub-carriers before performing an Inverse Fast Fourier Transform (IFFT). The IFFT takes advantage of the frequency diversity of the multipath channel. Finally, before transmitting the data, the streams are combined to a single signal and sent to the air interface. At the receiver end the procedure is the same, but in reversed order. The 802.16e specification defines the Fast Fourier Transform (FFT) size to be 128, 512, 1024, or 2048 with respective channel bandwidths 1.25,5, 10, and 20 MHz. However, the Mobile WiMAX allows other bandwidth profiles to be used as well, but the sub-carrier frequency cannot be kept constant anymore.

The available resources of OFDM can be divided into time and frequency domains. In the time domain OFDM symbols can be used and frequency domain has sub-carriers. Both of these can be utilized for individual users by using sub-channels. [15]

Scalable OFDMA (S-OFDMA or SOFDMA) creates the basis for 802.16e-2005. Basically S-OFDMA means a possibility to adjust the used bandwidth and this way different environments with varying spectral requirements can be served. The bandwidth adjustment can be chosen between 1.25-20 MHz as described in Table 2.4 below. The scalability is realized with FFT size variations and the frequency spacing of sub-carriers is defined to be10.94 kHz.

Table 2.4: OFDMA Scalability Parameters [4]

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

2.7 Handoff

A special requirement for a mobile device is the ability to change the serving BS if there exists another BS with, for example, better link quality in the reach of the MS. The handoff, in some sources referred as handoff, is a procedure with an intention to switch the network connection access point of the MS without data loss or disturbing the existing connection(s).

First, for a handoff to be even possible, one needs to have at least two BSs, the currently serving and the handoff target(s), and an MS within reach of both BSs. The handoff usually is understood as a change of serving BS, but it does not necessarily mean that the BS must be changed. In some cases the handoff can occur also within the same BS, though within different channels. This handoff type is called intra-cell handoff, while the other option is called inter-cell handoff. Handoffs between different technologies are also possible, as already mentioned while discussing the MIH standard. The horizontal handoff was defined to be a handoff within a single technology network, while the vertical handoff changes the network. The reasons for handoff can be various and here are listed only some of them:

- Signal strength is not enough for maintaining proper connection at the edge of the cell
- BS capacity is full and more traffic is pending
- Disturbing co-channel interference from neighboring cell
- Behavior of MS changes, for example in a case of fast-moving MS suddenly stopping.

A large cell size can be adjusted to a smaller one with better capacity faster or cheaper network is available (if vertical handoffs are supported) the handoff has roughly two major types, a hard and a soft handoff, with different variants of these depending on the used technology. The hard handoff is performed, when the connection to the serving BS is broken before creating the new connection with the target BS. With soft handoff the connection is transferred to the new BS and after successfully continuing communications the old BS can be released. The hard handoff can be very efficient regarding the channel usage, since only one channel is occupied simultaneously. This makes the equipment also cheaper because it does not have to support two or more channels in parallel. However, it can cause unrecoverable damage to the connection in case the handoff fails. The benefit of soft handoff is the reliability since the connection is broken only after finding a working connection. The drawback of soft handoffs is the required computational capacity in the equipment, which consumes money and power. Additionally, the use of several channels per user decreases the overall capacity of the BS.

Usually, the handoff process follows a common pattern. The BS maintains a list of neighbors that can be used in a case a served MS needing to perform handoff. The connection quality is constantly monitored and at some point the decision for a handoff is made. The criteria for the decision maybe for example something listed in handoff reasons above. Before performing handoff an appropriate candidate must be chosen and then the handoff procedure is continued based on the current application and technology. The exact procedures vary depending on used technology and usually within the technology several alternatives are available as well.

In WiMAX scenarios the technology has to be 802.16e-2005 since the 802.16-2004 does not support handoffs at all. Additionally, there must be way to measure connection quality; since the transmission medium is constantly in change. To be able to perform handoffs, the technology must define a scheme for decision making to initiate them. A procedure for discovering competing BSs is also needed.

The handoff should also be as fast as possible, at least fast enough to keep current IP connections alive. Data traffic is not so sensitive to larger delays but real-time voice or video (or both simultaneously) requires a swift change of the serving BS.[26]

2.7.1 Handoff Types

Using mobile subscriber terminals in terrestrial cellular networks require that some form of handoff mechanism be employed at the physical layer, and that other mobility management issues be addressed.

The mobile WiMAX standard supports three physical-layer handoff mechanisms:

1. Hard Handoff: this is a ‘break before make’ handoff in which the subscriber terminal is disconnected from one base station before connecting to the next base station.

The hard handoff is a procedure to change the serving BS using a "brake-before-make" -way, in other words the connection to the old BS is broken before a new BS is connected. This way the excess signaling traffic can be avoided during the handoff, but the time before the connection is again in normal operation can be longer. [7]

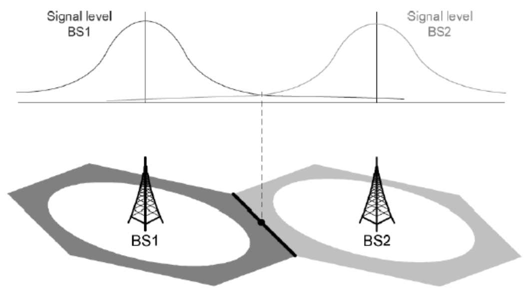

Figure 2.7: Hard Handoff Realization [7]

While connected to a BS, the MS listens to the link-layer messages in case a new BS‘s periodically broadcasted neighbor advertisement message (MOB_NBR—ADV) is received. These messages are used for identification of networks and distributing the properties they have. The information received can give, for example, facts about the signal quality from neighboring BS. If a better BS is not found, the MS can store the information for possible future handoffs. While introducing the handoff process, Figure 2.7 above demonstrates the situation when a moving user reaches a point where the signal level is better with another BS. Additionally, a decision criteria hysteresis needs to be included to avoid constant handoffs back and forth between BSs.[7]

2. Macro-diversity handoff (MDHO): the subscriber maintains a simultaneous connection with two or more base stations for a seamless handoff to the base station with the highest quality connection.

Hard Handoff is the most bandwidth-efficient and is mandated by WiMAX Forum profiles, while FBSS and MDHO are optional handoff modes.

The MDHO is an optional handoff scheme for the Mobile WiMAX and therefore needs to be supported by both the MS and the BS. The MS keeps a list of BSs capable to the MDHO on its coverage area (as can be seen in Figure 2.8). This group is called a diversity set, or in some sources an active set. There is always one BS in the diversity set that is defined as an anchor BS. The normal functionality is a special case of MDHO when there is only one BS in the diversity set.[26]

There might be also BSs that can be reached with the MS, but the signal is too weak for real traffic. These BSs are kept outside the diversity set and named as neighbor BSs. Naturally, while moving towards a neighbor BS, at some moment the signal is strong enough and the BS can be included in the diversity set, or the other way round. The measured factor is long-term CINR which is compared to the defined limits for adding/dropping a BS from the diversity set.[7]

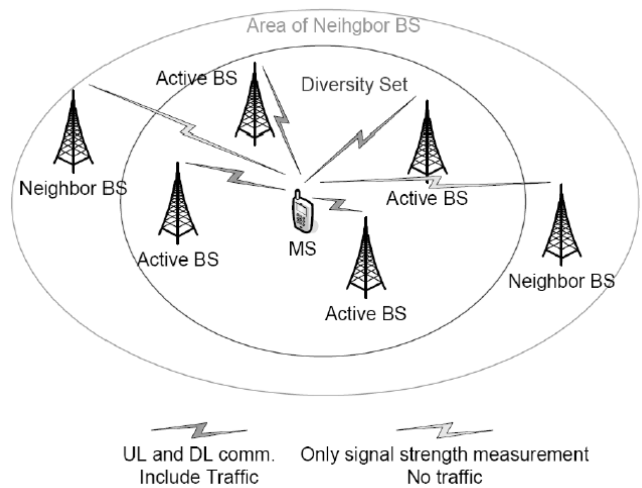

Figure 2.8: Macro Diversity Handoff [7]

The MS has two ways to monitor DL control information and broadcast messages. Either it listens to only the anchor BS for burst allocation information of other (non-anchor) BSs in the diversity set or it listens to all the BSs in the diversity set. While monitoring all the diversity set BSS, a DL/UL—MAP message from any BS may include information for the other BSs. The procedure of MDHO is started by the MS when it decides to receive and/or transmit from multiple BSs at the same time interval. For DL traffic, two or more BSs transmit the data to the MS and the diversity combining is performed in the MS. For the UL traffic, the transmission from the MS is received by the diversity set BSs and selection diversity is performed.

The MDHO requires several terms to be fulfilled before it can be used. First of all, the involving BSs communicate through the RRAs at each station and they are synchronized on a connection time source, since the frames sent by the BSs at a certain time frame have to be received at the MS within the prefix interval. The BSs frame structures have to be synchronized and the frequency assignment has to be the same. Additionally, the same set of CIDs has to be used by all the BSs that form connections with the MS. Furthermore, all the BSs should send the same MAC/PHY PDUs to the MS. Finally, the BSs involved in MDHO must share MAC context. By MAC context is meant everything a BS and an MS usually share from encryption information to information exchanged during network entry. [7]

3. Fast base station switching (FBSS): the network hands-off the subscriber between base stations while the connection with the core network remains with the original base station.

The FBSS is based on a similar principle as the MDHO above. Again both the MS and the BSs have to support the FBSS. A diversity set is kept in the MS and the BS but the MS communicates only with one BS in the diversity set (see Figure 2.9 below). The currently serving BS is named as an anchor BS. In FBSS the communication, including the signaling traffic focuses on only one BS at a moment but the anchor BS can be changed for every frame separately. Naturally, the changing is possible only if there are multiple BSs in the diversity set. The adding/dropping of members of the diversity set is similar to the one with MDHO above.

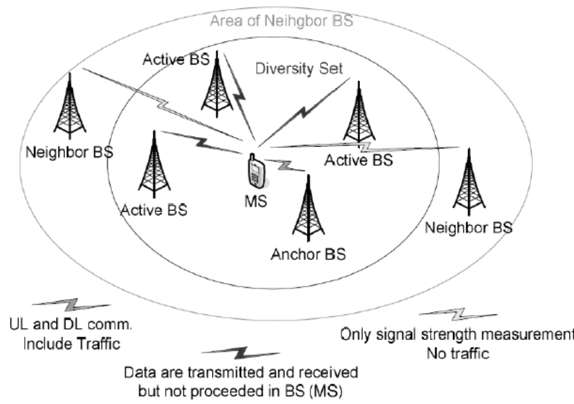

Figure 2.9: Fast Base Station Switching [7]

In fact, all the BSs in the diversity set receive the data addressed to the MS, but only one of them transmits the data over the air interface while the others eventually drop the received packets. The operation of FBSS is based on the decisions of MS regarding the used (anchor) BS and these decisions are transmitted on the CQICH channel or by MS/BS initiated request message. Again, the decision of MS overrules the ones of BS. The requirements of F BSS are the same as earlier with MDHO without the demand for same set of CIDs and MAC/PHY PDUs. [7]

In addition to physical-layer handoffs, the overall end-to-end network infrastructure must support the processes of inter-network and inter-vendor handoff to ensure the continuity of the ongoing session, security and authentication, QoS provisioning, and billing. The WiMAX Forum's networking working group (NWG) has defined the end-to-end network as an all IP network to make handoff and service continuity easy to implement and use.

The WiMAX forum [1] has been working on the HHO designing enhanced techniques to achieve handoffs (layer 2) in less than 50 milliseconds.

The Table 2.5 presents the greatest difference between the traditional WiMAX and the new mobile version. as can be seen, the traditional WiMAX does not support handoffs at all.[26]

Table 2.5: Comparison of Mobility in 802.16-2004 and 802.16e-2005

Access	Location / Speed	Handoff	802.16-2004	802.16e-2005
Fixed access	Single / stationary	no	yes	Yes
Nomadic access	Multiple / stationary	no	yes	Yes
Portability	Multiple / walking speed	Hard handoff	no	Yes
Simple mobility	Multiple / low vehicular speed	Hard handoff	No	Yes
Full mobility	Multiple / high vehicular speed	Soft handoff	No	Yes

2.7.2 Handoff Process

The handoff process in Mobile WiMAX is described in the following sub-subsections. The Mobile WiMAX specification [2] defines the procedures during the handoff but the making of handoff decision is left outside the scope of it. Generally, the decision for a handoff can be determined based on various properties and values. As described in [27], the decision attribute is a combination of network conditions, system performance, application types, power requirements, MS conditions, user preferences, security, and cost. The network conditions and system performance can be improved by balancing the load of heavily occupied BSs to less active BSs, assuming possible within other requirements. Different applications in the mobile device can set requirements to the currently serving BS and it might be that it does not support all the needed technologies. Additionally, if a new BS can provide sufficient service with better power saving or security properties than the currently serving BS, it can be useful for the MS to perform a handoff to the new one. The costs and user preference can define that the network of the own service provider is used from several available networks. The MS conditions are measured constantly and, if a certain level of degradation is noticed in some of the defined parameters, the handoff decision can be initiated. These parameters may include signal strength, BS coverage area, data rate, service cost, reliability, security, battery power, and network latency. [27]

In Figures 2.10and 2.11, a combination of network entry and handoff processes is presented. It can be seen that the two procedures are very similar to each other.[27]

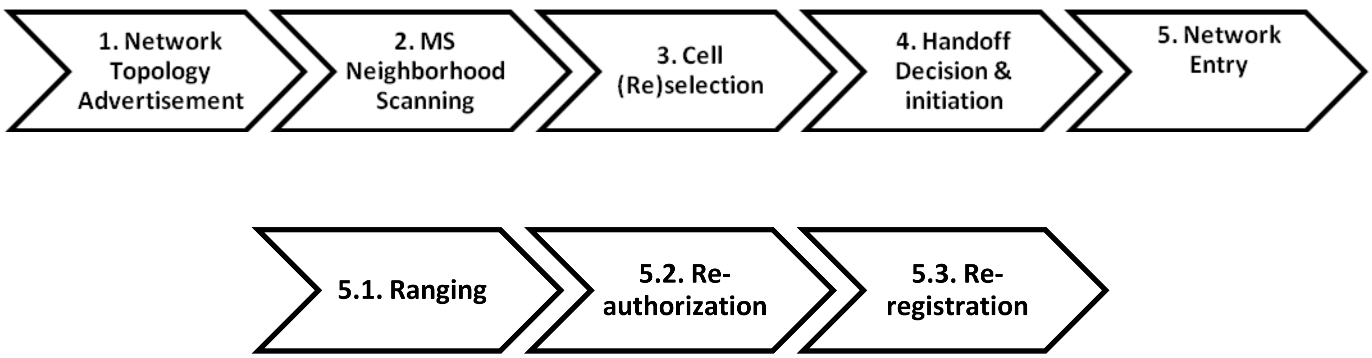

Figure 2.10: Handoff procedures

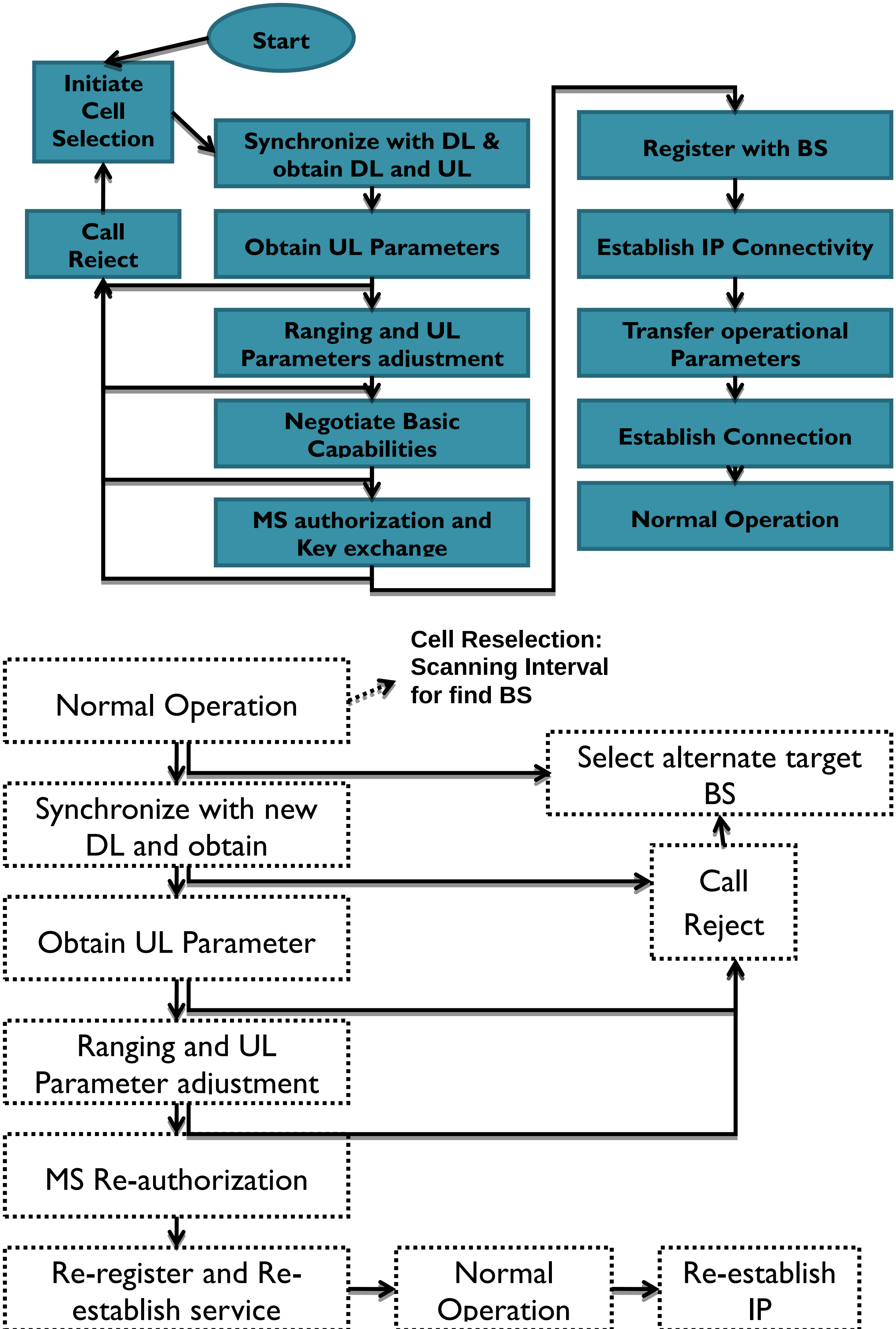

Figure 2.11: Initial Network Entry and Handoff

Cell Reselection

The cell reselection is a process with intention to find a potential BS for handoff. The MS has several possibilities to use while evaluating the possible change of the serving BS. It can exploit the information in neighbour advertisement messages (MOB_NBR-ADV). The MOB_NBR-ADV message is sent periodically by the BS and the intention is to identify the network and to give the MS information about neighbour BS(s) for possible handoff or initial network entry. The BS stores the MAC addresses and indexes of neighbour BS(s) as mapping tables and transmits them in the MOB_NBR-ADV message. The message includes also several other fields and is described in greater detail in [2]. Additionally, the MS can send a request for scanning interval(s) or sleep-intervals to be used for scanning and/or ranging the neighbouring BS(s). This process is just a survey about handoff alternatives and the connection is not yet broken with the serving BS as shown in figure 2.12.

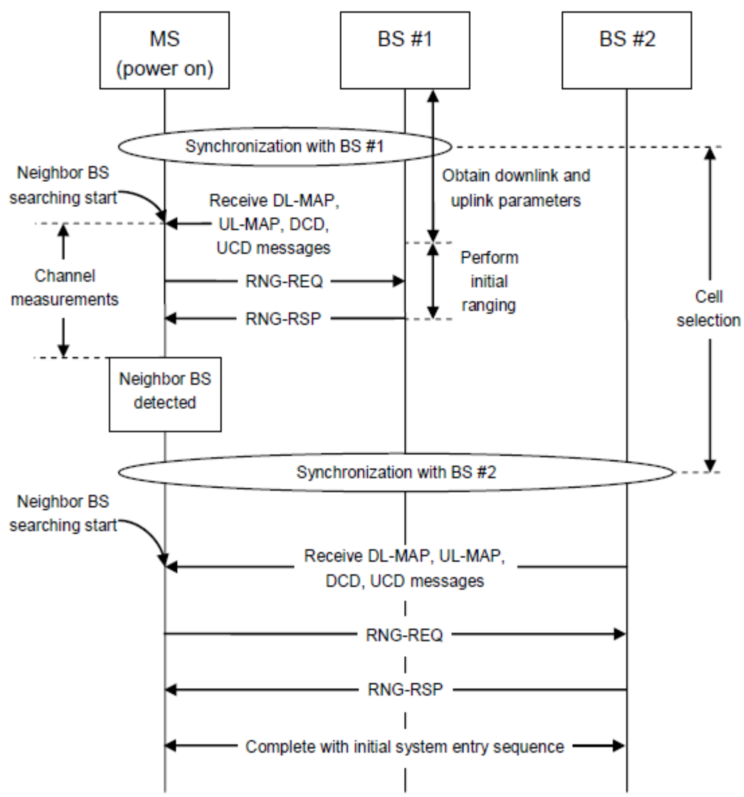

Figure 2.12: Cell Selection with Ranging [2]

Figure 2.13 describes the performed procedures during cell (re)selection, including ranging. The process begins with synchronization to the first BS and DL/UL parameters (DL and UL-MAP, DCD, and UCD messages) are acquired. When the air interface parameters are received the channel measurements can be launched by sending a ranging request message (RNG-REQ). The BS responds with a ranging response message (RNG-RSP). These steps are described in more detail in the following sub-subsections.[27]

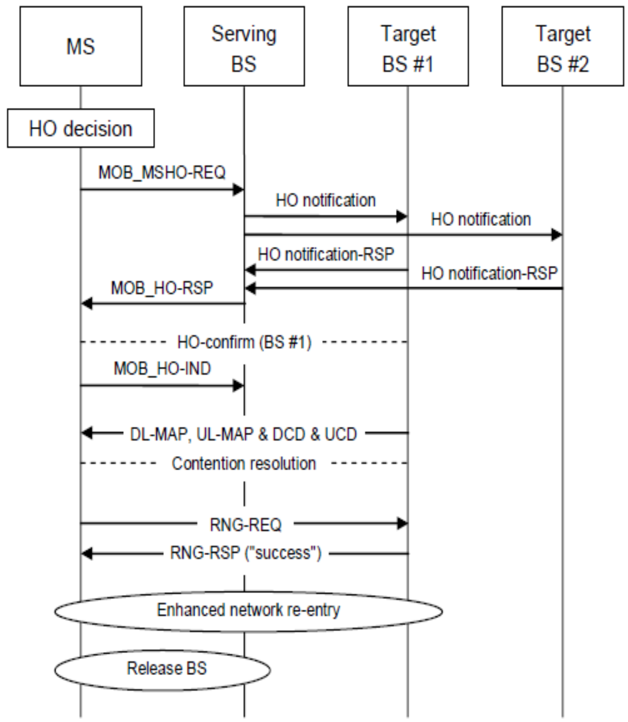

Figure 2.13: Messaging during a MS Initiated Handoff [2]

Handoff Decision and Initiation

The actual handoff begins when a decision is made that the MS changes the serving BS. The decision can be made at the MS, the BS, or on the network. The following step is sending a notification message, not obligatory but recommended, by either the MS (MOB_MSHOREQ) or the BS (MOB_BSHO-REQ). However, if the notification message is sent, a response (MOB_MSHO-RSP or MOB_MSHO-RSP) is required. In a case when both send notification messages, the one sent by the MS has a priority over the one sent by the BS. Both notifications may include one or more possible target BS(s), which have been for example scanned earlier. There is also a possibility for the serving BS to communicate through the backbone with the possible target BS(s).

The serving BS has only a possibility to force the MS to handoff, not to define the target BS.

The MS can choose or neglect recommended options for the target BS without restrictions.

The handoff decision is confirmed with a MOB_HO-IND message. The MOB_HO-IND is sent by the MS and it tells the BS whether the MS is really proceeding with the handoff or not. The message can include also other information related to BS selection:

- 0b00: HO (serving BS release, HO cancel, or HO reject)
- 0b01: MDHO/FBSS anchor update (confirm, cancel, or reject)
- 0b10: MDHO/FBSS diversity set update (confirm, cancel, or reject)
- 0b11: Reserved

Synchronization to Target BS DL

After the handoff is initialized the MS synchronizes with target BS's DL and UL transmissions by obtaining the required parameters. If the MS has received a neighbor advertisement earlier, the synchronization procedure can be faster. The advertisement needs to include target BS Identity (BSID), physical frequency, DCD, and UCD. If a handoff notification was sent by the serving BS and received by the target BS (via backbone connection), non-contention-based initial ranging opportunities can be assigned.

Ranging

After the synchronization of the DL/UL parameters the MS starts the ranging phase. The two possibilities available are initial or handoff ranging. The ranging is a phase that consists of several processes between the MS and the target BS in order to communicate the properties of the transmission link. As a reaction to the MS ranging the BS broadcasts a ranging response message marked with the sent slot and code for the MS to identify the correct response. The response is broadcast since the BS cannot know which MS sent the ranging code. The response message includes also all the needed adjustments (such as power, time, or frequency corrections) with status notification. If the status is "continue", the MS will repeat sending the ranging code, generated according to the description above. With "success" status the BS allocates bandwidth for the MS and the ranging is over. The difference with handoff ranging is that the sent CDMA code is selected from a special handoff-ranging domain. Additionally, if the target BS is informed in advance about the coming handoff, it can directly allocate the needed bandwidth. Another possibility for shortening the handoff duration is to use target BS information acquired earlier during scanning interval. This information can decrease the amount of needed RNG-REQ/RSP interactions, but it has to be recent enough to qualify accurate.

Network Re-entry

The network re-entry is performed in a similar way as the initial network entry, when a MS is turned on. The process of re-entry during handoff can, however, be enhanced and therefore made faster. Figure 3.12 (initial network entry and handoff) already described the phases of network (re-)entry and the handoff process so far has included the ranging phase. The next step is to negotiate the basic capabilities regarding for example modulation/demodulation. The reauthorization of MS and key exchange is performed and the MS registers with the target BS, which is intended for agreement of for example ARQ or CRC capabilities. Now, the MS has re-entered the network of the target BS and the service flows can be re-established with proceeding to the normal operation. Finally, the old serving BS can be released.

The target BS can acquire information from the serving BS via backbone connect ion, or even from other network entities. With this information, the basic capabilities negotiation, registration, privacy key management, authentication and/or encryption key establishment phases can be skipped for enhancement of the network re-entry and therefore the entire handoff process. [2]

Handoff Cancellation

The MS can cancel the handoff process anytime after the sending of MOB_MSHO/BSHO_REQ message, as long as the above mentioned Resource_Retain_Timer has not expired. The cancellation is done by sending a message (MOB_HO-IND) containing a handoff cancels option.

Termination of MS Context

After the handshake with the target BS is completed the connection to the serving BS has to be broken. The termination message (MOB_HO-IND) with a code indicating BS release is sent to the serving BS. Upon receiving the message, the serving BS starts a Resource_Retain_Timer. This timer defines when all context (information in queues, counters, timers, etc.) related to the MS is retained. However, in a case when the target BSs ends a backbone message of successful MS network attachment with it, the timer can be bypassed and the MAC context and PDUs related to the MS removed from the old serving BS.

Drops during Handoff

There can be a situation during the handoff process when the MS has stopped communicating with the serving BS before the normal cell selection or termination of MS context have been completed. This situation is called a drop and the MS can detect it by failed demodulation of DL, or by exceeding the limit for consecutive RNG-REQ retires. On the other hand, the BS can notice a drop when the limit for inviting ranging request messages is exceeded. If the MS detects a drop while trying to establish a connection with a target BS, it can attempt network re-entry with its preferred target BS as through cell reselection. Additionally, it can resume communicating with the serving BS by sending a handoff cancellation message.

2.8 Summery

The decision for a handoff can be determined based on various properties and values. As described in this chapter, the decision attribute is a combination of network conditions, system performance, application types, power requirements, MS conditions, user preferences, security, and cost. The network conditions and system performance can be improved by balancing the load of heavily occupied BSs to less active BSs. If a new BS can provide sufficient service with better power saving or security properties than the currently serving BS, it can be useful for the MS to perform a handoff to the new one. An evaluation of Handoff process performance in WiMAX will be handled in the next chapter by simulation.

Chapter 3: Simulation Environment and Results Discussions

WiMAX deployment grows at a rapid pace. Since Mobile WiMAX has the key advantage of serving large coverage areas per base station, it becomes a popular emerging technology for handling mobile clients. However, serving a large number of Mobile Stations (MS) in practice requires an efficient handoff scheme. Currently, mobile WiMAX has a long handoff delay that contributes to the overall end-to-end communication delay. Recent research is focusing on increasing the efficiency of handoff schemes.

Our goal in this thesis is to experiment the properties of Mobile WiMAX in practice, for this purpose, we use the network simulator version 2.34 with additional modules (WiMAX and Mobility) from NIST project, which is the best simulator that support mobile WiMAX.[21][25]

The WiMAX add-on package defines the main supported features of PHY layer in wireless MAN-OFDM with only TDD, messages for network entry management without support for authentication, 802.16e extensions for scanning and handoff, fragmentation and assembly of frames [21].

3.1 WiMAX Handoff Scenario

In our scenario, we define three BSs aligned on a line in a way that the coverage areas of two neighbouring BSs have some overlap. We try to enhance the handoff time by considering some constant values i.e. the cell size, the transmit power of BSs, the route of MS, and then we try to adjusting the factors of the WiMAX module in the NS-2.

As we discussed before in chapter 2, most of the simulation experiments and tests used the same module for WiMAX, NS-2 (the best recommended module), using some but not all IEEE default factors but in different ways and scenarios -since the environment almost the same- with changing in parameters and factors. The main issue in our research is to make the simulation very close to the real environment and try to use most of these factors and get the best values for each.

At the end, the test for performance metrics are also done with speeds 1-40 m/s (3.6-144 km/h) and number of MS with 1-100 MS. The assumed traffic is constant bit rate with data rate of 1.2 Mbit/s. It is obvious in many researches included in the references such as [26].

The basic idea is shown below in Figure 3.1. There is a MS travelling through the coverage areas of three **802.16e** BSs (BS0, BS1, and BS2). [26]

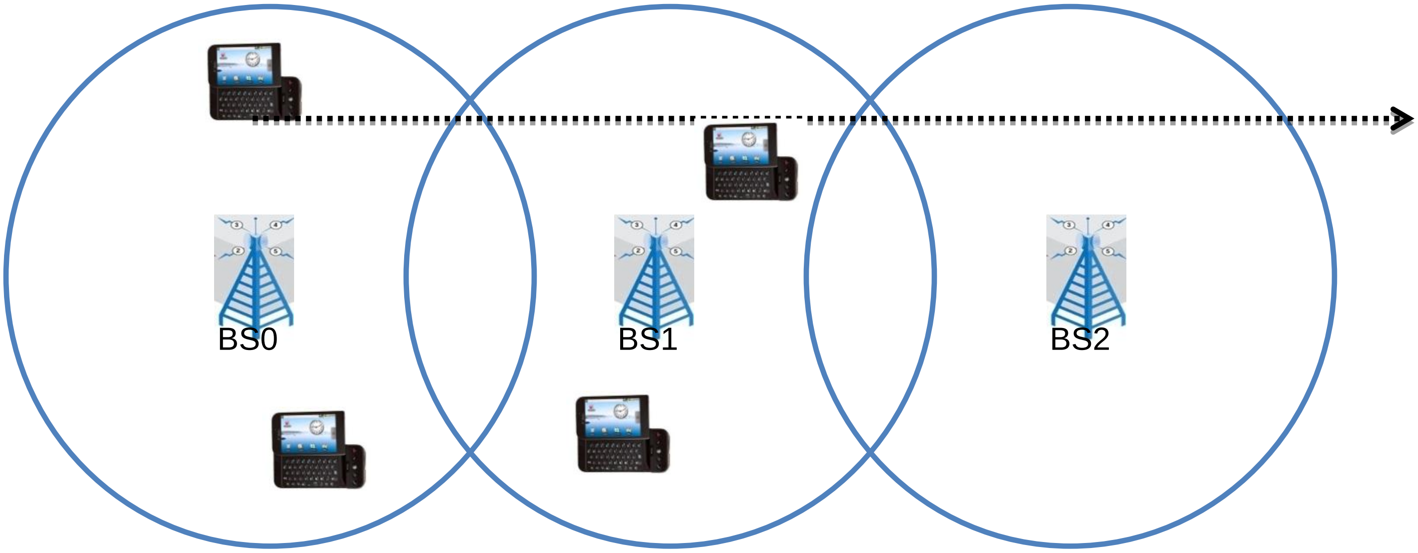

Figure 3.1: Simulation Scenario

The BSs are aligned on a straight line so that they have the following values as shown in table 3.1.

Table 3.1: Distance between BS's and Ms

BS to Bs distance	coverage area radius	distance between MS &BS0
15 Km	8Km	2Km

The MS begins moving, as shown in Figure 3.1, as the distance between the MS and Bs is variable and changing with speed we try to keep the shortest distance to the straight line of BSs is2Km. This value could be anything else in the reach of the BS coverage.

The difference here between any researcher and the other is in the coverage area and the distance between each Bs and the best scenario is to make simulation closest to the real environment.

3.2 Simulation Environment

The simulation is based on the Mobility and WiMAX two packages used in the NIST simulator, especially the Neighbour Discovery (ND) and Media Independent handoff (MIH) modules were the simulator key elements used in the simulation code. [21]

3.2.1 Neighbour Discovery –module

The Neighbour Discovery (ND) module was designed to provide movement detection for layer3. Its task is to create IP addresses when a network is changed. The module is a part of the MIH packet, (will be described in the next subsection) and is intended to support multiple interface types, such as Ethernet, WLAN, UMTS, and, in this case, Mobile WiMAX. The ND agent uses broadcast or unicast messages according the technology in use. The ND agent is located in all nodes, but the configuration in NS-2 has to be done according the type of the node in the network. For example, Ethernet or UMTS networks do not have a capability to send broadcast messages in NS-2 whereas WLAN has. The ND agent can be configured to send unicast messages according a pre-configured list of targets. The functionality of the ND agent depends on the role of the node in the network, in other worlds, whether the node is a router or a host. The router functionality consists of sending unsolicited Router Advertisements (RA) periodically to the hosts. The possible sending periods defined with parameters *minRtrAdvInterval* and *maxRtrAdvInterval*. In case a route receives a Router Solicitation (RS) from a host, it sends an RA, assuming the time from previous sending is between the values of parameters described above. If a router receives an RA, it is discarded.[26]

The hosts can ask for an RA with RS messages. When an RA is received the included prefix information is compared to the existing tables and possibly new values are added. Additionally, an expiration timer is attached to an RA message, which tells when to abandon the prefix information in case a new one is not received. [21] [26]

3.2.2 Media Independent Handoff –module

The Media Independent Handoff (MIH) module, is a part of the NIST Seamless Mobility project, and was developed to control handoffs with various technologies. The functionality is based on MIH Function (MIHF). It works on layer 3 and can communicate between local and remote interfaces. The remote interfaces can be contacted via another MIHF. This is illustrated in Figure 3.2 below.

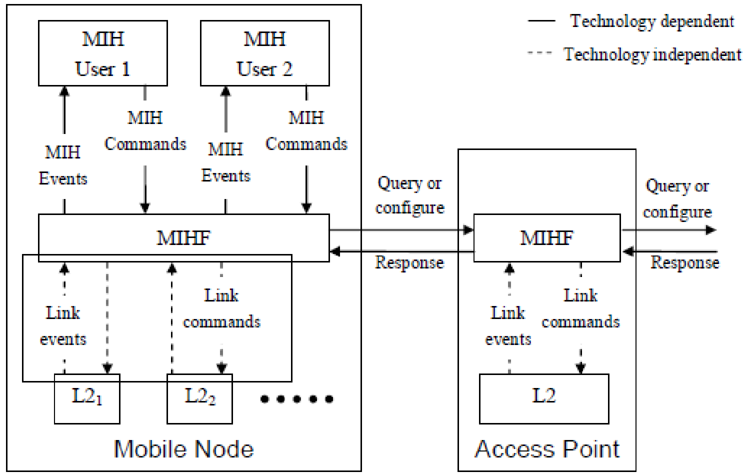

Figure 3.2: MIH Design Overview [26]

The NS-2 required enhancements since the handoffs are not supported by default. The additions included the support for multiple technologies and modification of default implementation intended for 802.11. Additionally, a special node suitable for multiple interfaces had to be designed with support for subnet discovery and change of address (ND module). The solution was called a *MultiFaceNode* which is a virtual node controlling the different technologies and interfaces. [21][26]

3.3 Parameters

There are two types of parameters in the simulation: scenario parameters that depend on the nature of scenario, and simulator parameters. Both set of parameters are discussed in the following subsections.

3.3.1 Scenario Parameters

The BS coverage area and transmission power as well as operating frequency are unchanged, and they are the same for all three BSs. The topology of simulation is the same for all simulations. This included the locations of BSs and the route of the MS. The details have already been described earlier in section 3.1.

Reference to the NIST documents and guides, and as all banks on the data are sent with constant bit rate, so that the packet size was 1500 bytes and a packet is sent with 10 ms interval. This results in bit rate of l.2 Mbit/s. The selected bit rate is nearly sufficient to provide MPEG-l video stream. [27].

3.3.2 Simulator Parameters

Section 3.4 presents the adjusted parameters one-by-one with brief description of the parameter function, and the possible influence to the handoff, and these factors are essential for the simulation process, regardless its value will be constant, default or variable since these parameters will be used in different ways in each simulation, depend on the effect that the researcher will study, and the results he aims to reach, and this is what distinguish any research from others.

The adjustments show that some of the parameters do not have an influence at all to the handoff, but there are others that have an obvious impact. The *Link Going Down –factor* is one of the parameters with significant influence. It determines the detection sensitivity of a failing link. It is important to detect the link failure, on one hand, early enough, before the connection is broken, or on the other hand, late enough, to avoid unnecessary handoffs. Several timer and timeout parameters have also their impact on the handoff latency. This is quite understandable since they usually define some time to wait before some function is performed. If the function is somehow related to the handoff process, it can delay the process even significantly. One of these is the *t2l _timeout_*, which defined the time for a MS to search for the DL-MAP message on a certain channel.

There might be even better values for the parameters, since some of them have a rather unpredictable influence on the handoff times. As mentioned earlier, the main goal was to find the parameters that are the most sensitive in influencing the handoff duration.

3.4 Adjusted parameters in simulation

We will describe in this section, and as other researchers do all the parameters adjusted values and the description for each parameter, in addition to its adjustment and influence of these adjustments on the handoff latency, throughput and end-to-end delay during the simulation. These parameters are provided by the Mac/802_16 of NS-2,and are presented first, following the parameters of the ND module. Finally, some other adjusted parameters are discussed as well dependent on NIST modules. [21]

This list of parameters almost the same for every researcher, who is studying the handoff latency, but the results and the influence will be different, based on the values of these parameters and the adjustment of these values through the simulation process.

Adjustments are done, based on experiments with constant number of MS (20 MS), constant velocity (20m/s) to determine the best value of parameter dependent on range values that defined by NIST module [25], then the velocity is changed to ensure that best result and all scenarios after that run at these values.

Mac/802_16

The following parameters are a part of the WiMAX module.

lgd_factor_

The Link Going Down Factor is one of the most important parameters of the WiMAX module, as it determines the sensitivity of detecting a falling link. We need to set this factor to generate a Link Going Down. When the received power of a signal is less than factor RXThresh, a trigger is generated to initiate scanning for neighbour BSs.[21]

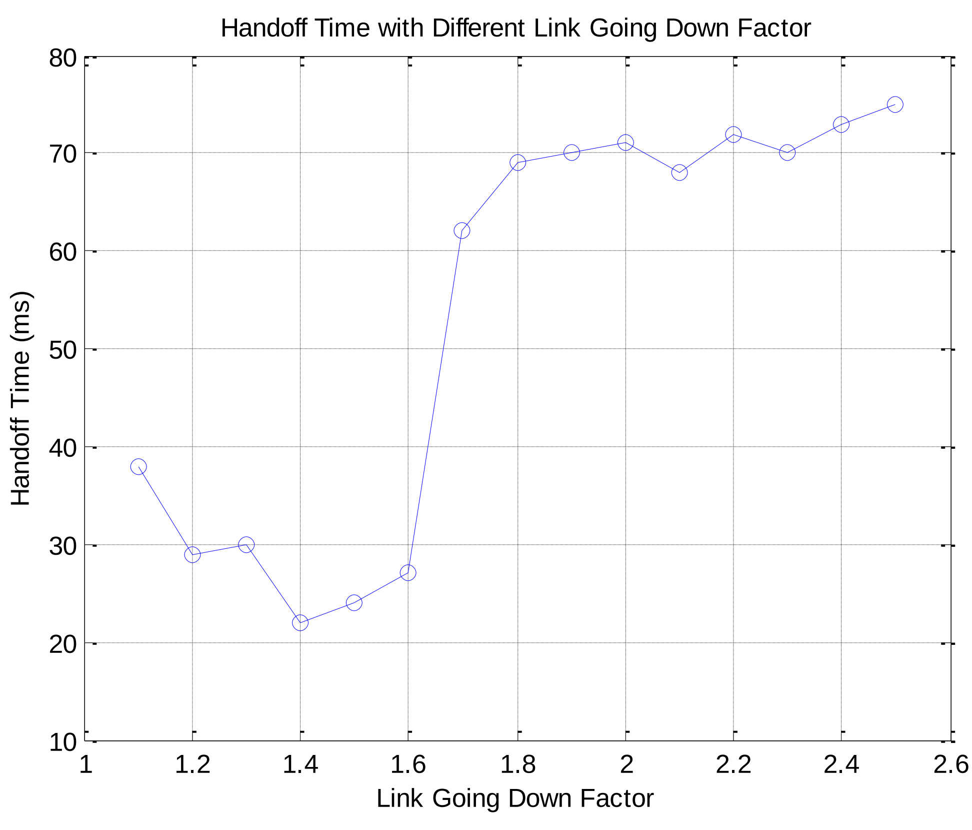

Figure 3.3: Handoff Time with different Link Going Down Factor

As shown in figure 3.3 for the coverage are certainty at the edge , we use the RXThresh value which defines the limit of that area that means outside of that area the data packet will be discarded.

When the factor value is 1, no falling link is detected and we find that the optimal value of the factor is ranged from 1.2 to 1.6 as suggested in NIST [21], we find the best value of this factor is 1.4 and this value can eliminate some others costs and effects when using any other value between 1.2 and 1.6 and reflect the best value of handoff latency.

As it is clear in figure 3.3 the best value of lgd_factor, that's generated in the simulator by changing the velocity of mobile station to ensure that the fastest handoff times versus velocities are achieved when the value is set to 1.4 and this value will keep the minimum data packet that will be discarded and will be closed to 0 as shown in figure 3.4.

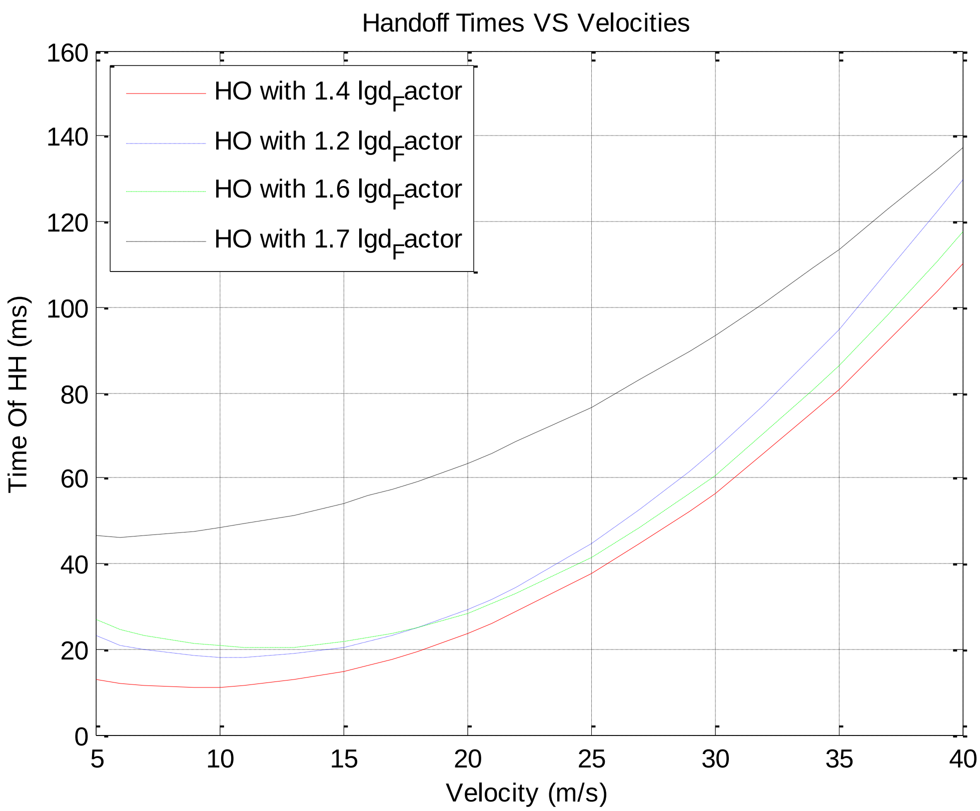

Figure 3.4: Handoff Times with different velocities at different lgd_Factor

scan_iteration_

We simulate this parameter to Scan iteration which defines the requested number of iterating scanning interval by an MS, which reflects no of times the MS will complete the scanning procure. The results we got that as the more iteration time provided, the longer handoff duration time.

As shown in figure 3.5, the best value is two iterations dependent on NIST as the standard acceptable value, so when changing other factors to get the best handoff latency, we have to keep scan_iteration_ value in its best practice and standards, to void addition cost and side effects.

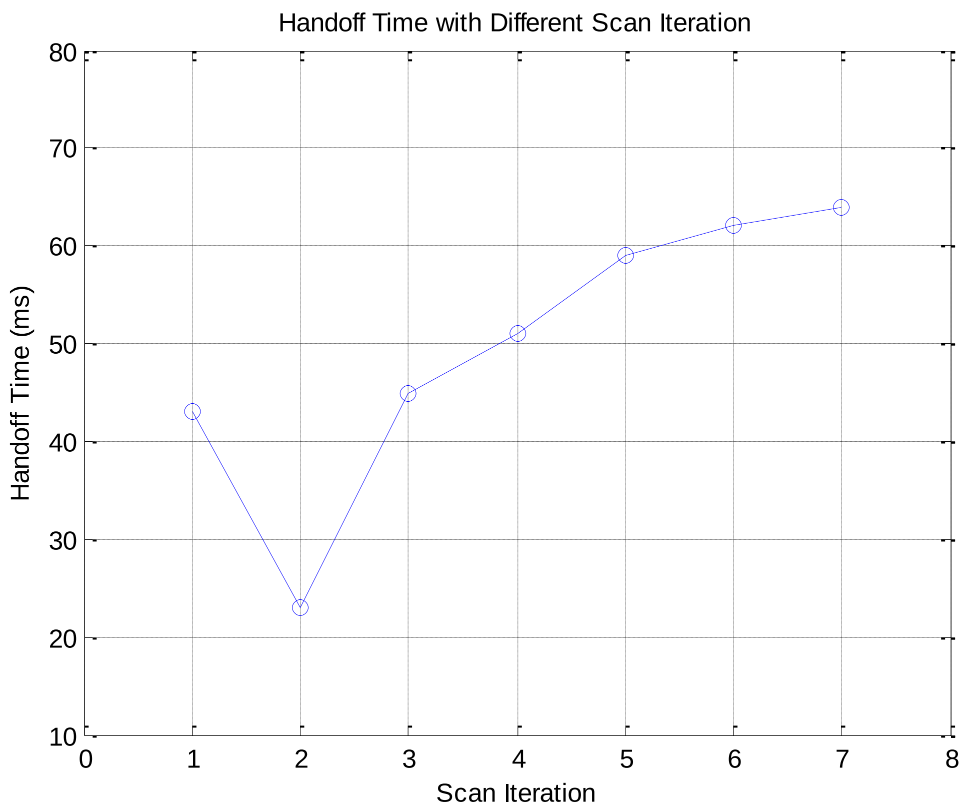

Figure 3.5: Handoff Time with Different Scan Iteration

The influence is easy to understand, “**more iteration means longer durations for handoffs.** As shown in figure 3.6 the fastest handoff time versus velocities is achieved when the value of **scan_iteration_** is 2.

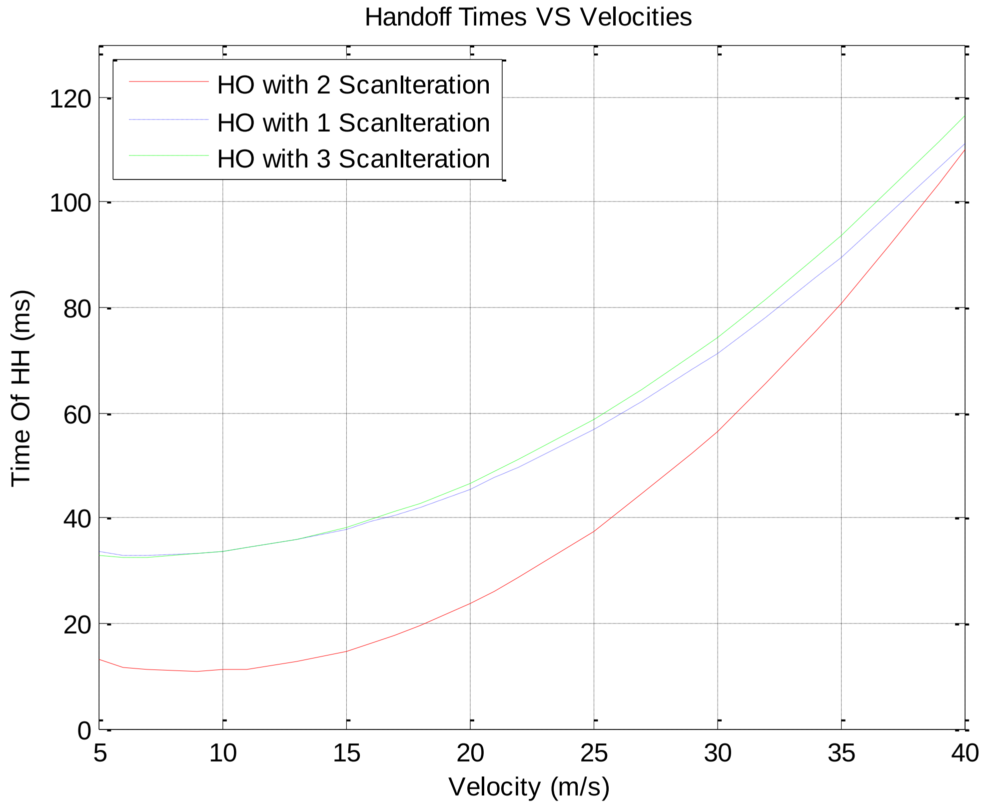

Figure 3.6: Handoff Times with different velocities at different scan iteration

interleaving_interval_

Interleaving interval is the parameter that defines the time duration between the normal operation and scanning periods of the MS in frames.

As shown in Figure 3.7, if the parameter value is less than or equal to **twenty** frames it will affect the handoff time with a small variation.

However, increasing the value to more than twenty frames causes longer handoff times.

The best value we got in simulation is 4 frames.

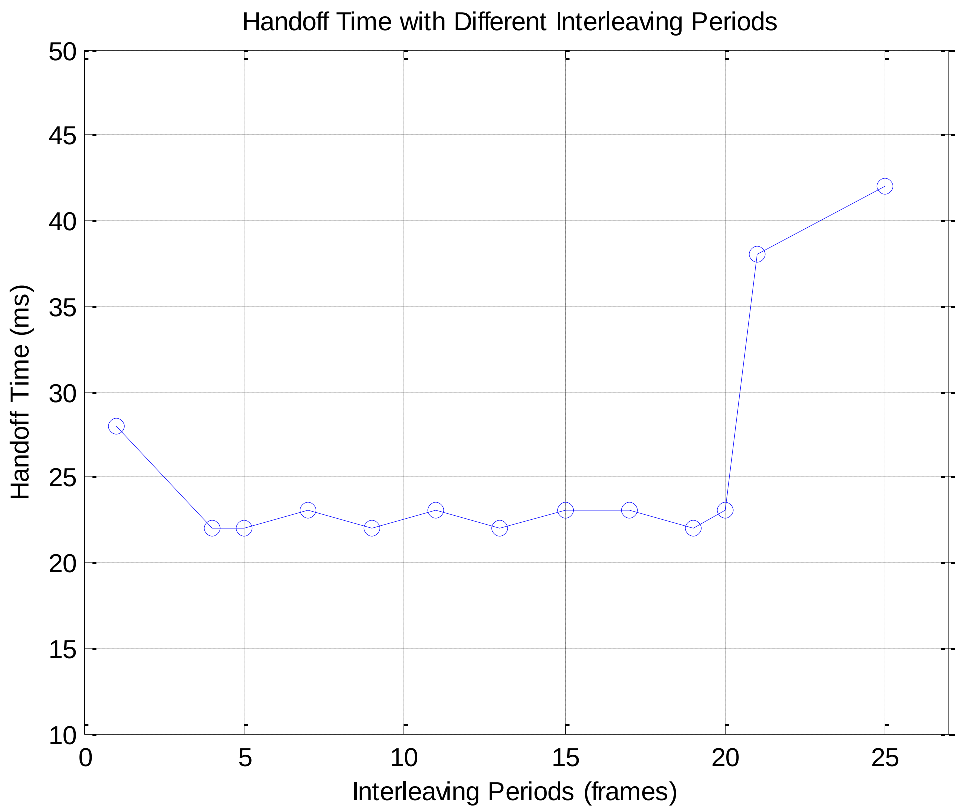

Figure 3.7: Handoff Time with Different Interleaving Periods

As shown in Figure 3.8 shows that the fastest handoff time versus velocities is achieved when the value is set to 2.

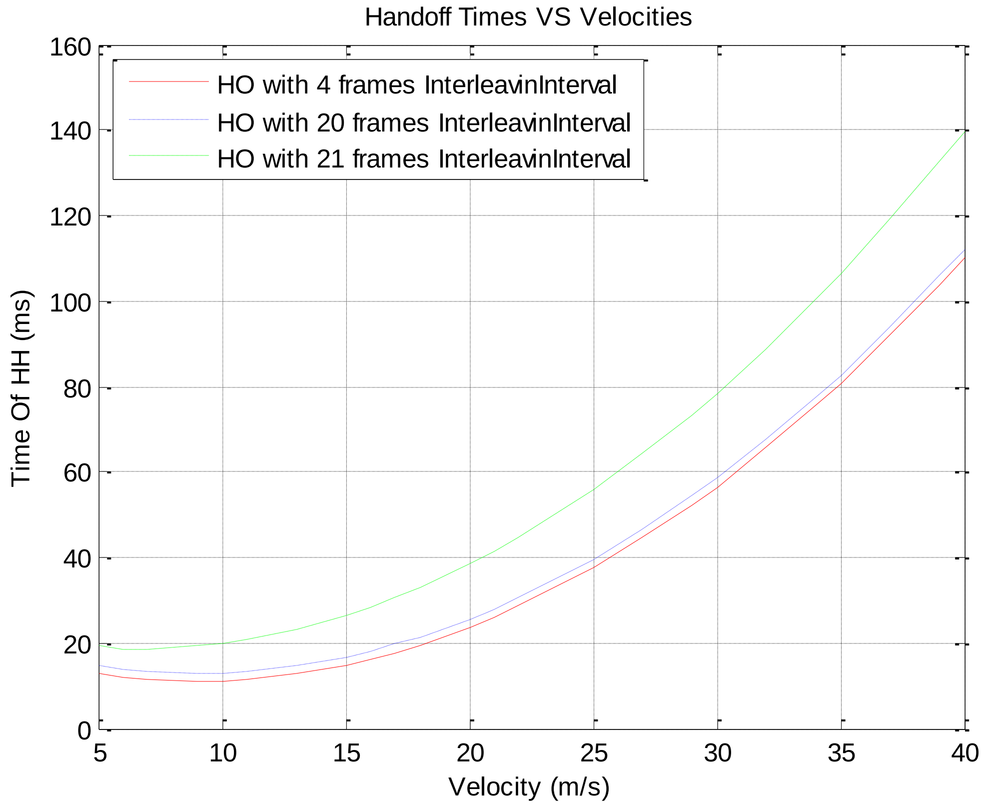

Figure 3.8: Handoff Times with different velocities at different Interleaving interval

t21_timeout

Is the parameter that defines the timeout value for the MS for searching the DL-MAP message, which represents the MS needs to find a DL-MAP message within this period.

The results in the simulation are "we get the same handoff time when the parameter value between 5 and 35 ms, as shown in figure 3.9". However, if we increase 1 ms after 35 ms, we will increase the handoff time drastically.

The best value for this parameter is 5 ms.

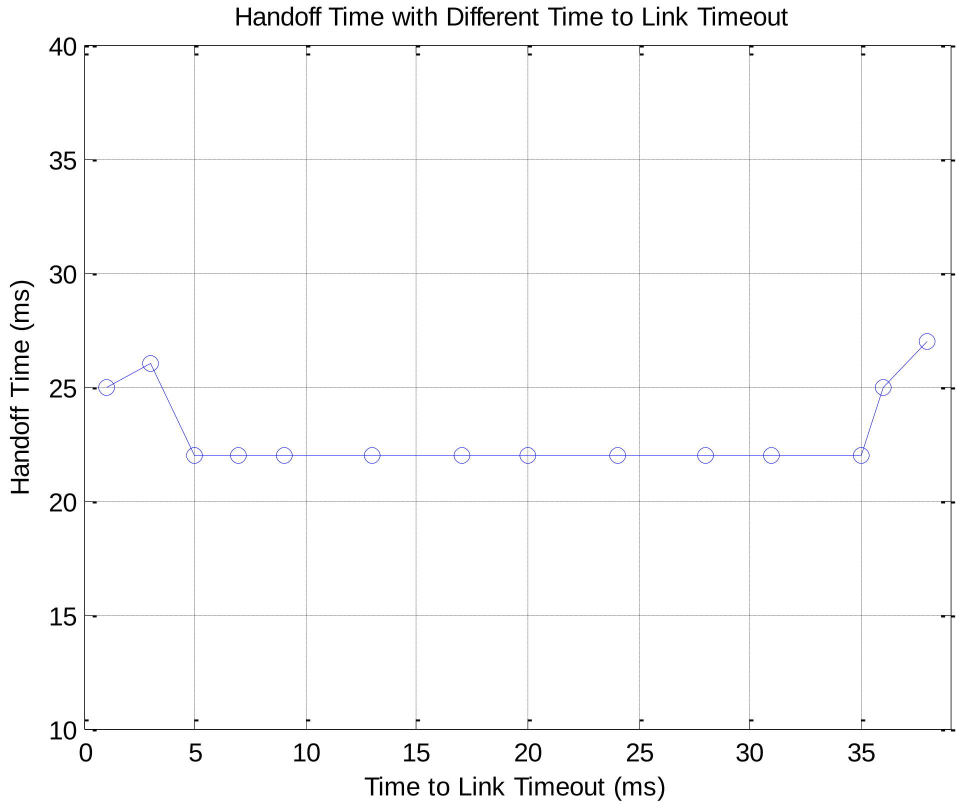

Figure 3.9: Handoff Time with Different Time to Link Timeout

The fastest handoff time versus velocities is achieved when the value is set between 5 and 35 ms, we recommend the value of 5ms to finding the DL-MAP as shown in figure 3.10.

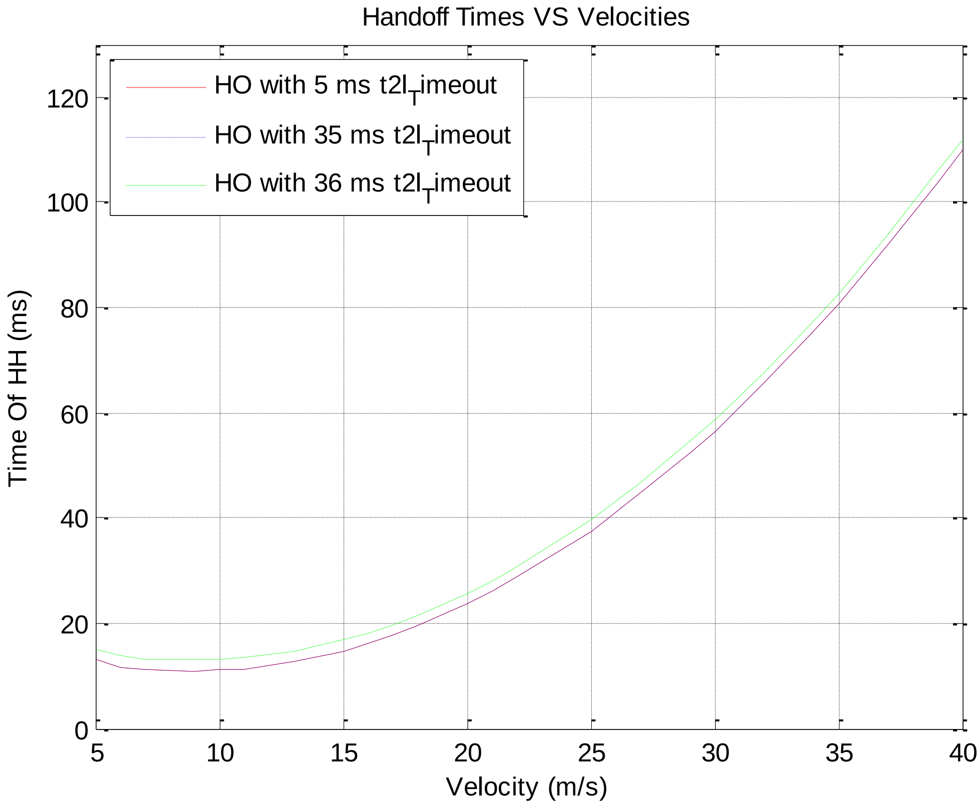

Figure 3.10: Handoff Times with different velocities at different t2l_timeout

scan_duration_

The duration of scan interval, in frames, defines the length of the scanning period. The value should be maintain long enough to ensure successful scanning, but on the other hand, it will be the shortest to keep the elapsed time moderate as shown in figure 3.11 , we recommend the value of 4 frames as best value.

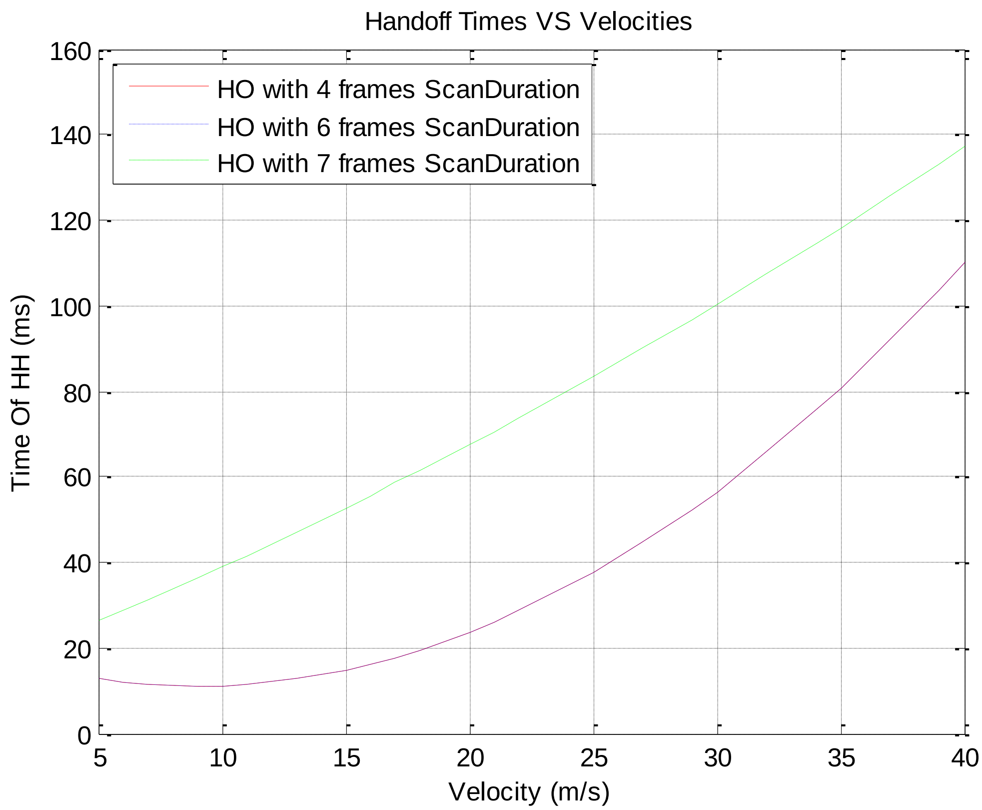

Figure 3.11: Handoff Times with different velocities at different scan duration

Sometimes the 3rd curve in the figure not appear since it has exactly the same results of other curve (continuous curve here)

Also the following parameters are used as shown in table 3.2.

Table 3.2: The parameter description for simulation

Parameter name	Description and conclusion
client_timeout_	The client_timeout_ defines a timer value for detecting out of range MS. There did not seem to be a great influence on selecting the timeout, The best value is the default value is 5 ms
queue_length_	The queue_length_ describes the size of the sending buffer of the MS. Since the used data rate is not very demanding, there is not a need for large buffer. With the selected data rate already size of 2 packets was enough to keep simulation undisturbed. If the buffer size is only 1packet, there is some degeneration in the handoff times.
lost_dlmap_interval_	This parameter is a timeout value for last reception of a DL-MAP message.

	If a new DL-MAP does not arrive within the interval, the MS loses synchronization with the BS. The default value (0.6 s) is chosen.
lost_ulmap_interval_	This is the same as above but for the UL-MAP message. Here the critical limit was 7 ms, which still resulted in good results. With 4ms the NS-2 reported "Segmentation fault" and shorter times meant there was no effect. The default value (0.6 s) was again chosen for the simulation
rng_backoff_start_	This parameter defines the initial backoff window size for ranging. The window size should be 2, 3, or 4 slots. These values gave the same results and larger ones increased the handoff times, even rather significantly. The chosen value was 2 slots.
t44_timeout_	The t44_timeout_ is a timeout value for scan requests. The results indicated that the timeout value should be at least 5 ms, or larger. The chosen value was the default, 10ms. The following parameters of the Mac/802_16 did not have any influence on the handoff times.
dcd_interval_	DCD is a message providing information about the physical conditions of the DL channel and the dcd_interval_ defines the broadcast interval of the DCD.
ucd_interval_	This is basically the same as the previous one, but for the UL channel.
contention_rng_retry_	Number of retries on ranging requests (contention mode).
invited_rng_retry_	Number of retries on ranging requests (invited mode).
request_retry_	Number of retries on bandwidth allocation requests.
reg_req_retry_	Number of retries on registration requests.
dsx_req_retry_	Number of retries on DSx requests.
dsx_rsp_retry_	Number of retries on DSx responses.
rng_backoff_stop_	Maximal backoff window size for ranging.
bw_backoff_start_	Initial backoff window size for bandwidth.
bw_backoff_stop_	Maximal backoff window size for bandwidth.
scan_req_retry_	Number of retries on scan requests.
max_dir_scan_time_	Maximum scanning time for each neighbor BSs.
nbr_adv_interval_	Interval between two MOB-NBR_ADV (Neighbor Advertisement) messages. There was no influence, at least when keep below 10 seconds.

	As shown in [21]
t3_timeout_	T3_timeout_ is the timeout value for receiving a ranging response message. There was no influence on the simulation results. As shown in [21]
t6_timeout_	Registration response timeout is defined with t6_timeout_. No influence, except with 1 ms the NS-2 gave "Segmentation fault".
t16_timeout_	The bandwidth request timeout is set with t16_timeout_. This parameter did not have an impact on the simulation results, at least while keep below 5 seconds.
Agent/ND	The following four parameters are a part of the Neighbor Discovery module. [21][26]
minRtrAdvInterval_	The minimum interval between consecutive RAs is defined with minRtrAdvInterval_. The default value is zero.
maxRtrAdvInterval_	This is the opposite for above minimum RA interval, hence, the maximum interval. The selected value was 10 seconds, as default value.
minDelayBetweenRA_	This parameter identifies the minimum time between two consecutive RAs by overriding the default value. The best handoff latency value was reached with 30 ms. Default value as shown in [26]
maxRADelay_	The maxRADelay_ defines the maximum delay for replying to an RS. This parameter can be recommended to keep very low. The handoff times increased already with 50 ms delay. The most efficient handoff was accomplished when the delay was chosen at 5 ms, or below. The delay of 5 ms was selected to be used in the simulation. As shown in NIST module.[21][26]
Others	
seed	Seed is used for creation of random numbers in a NS-2 simulation. Different values of seed have small influence on the handoff performance.
default_modulation	The AMC offers different modulation techniques for Mobile WiMAX to compensate different scenario requirements, for example lower modulation can be chosen with poor connection. However, the used NS-2 WiMAX model did not provide support for AMC and it was only possible to select

	the preferred modulation used in the simulation. The available modulations were BPSK(1/2), QPSK(1/2, 3/4), 16QAM(1/2, 3/4), and 64QAM(2/3, 3/4). The BPSK and QPSK alternatives resulted in greater amounts of dropped packets and longer times for the handoff. The options to be considered for this simulation were the QAM-modulations. The differences between these were minimal and the 16QAM 3/4 was chosen.
contention_size	This parameter is used for definition of the number of contention slots allocated for initial ranging and bandwidth requests in each frame. It did not have an influence on the handoff latency.

3.5 performance evaluation

The goal of simulation is to find factors affecting the performance of the handoff process. These factors will affect the performance metric that will be measured in the simulation. The measured values are numbers of sent packets, received packets, and dropped packets. Three performance metrics are calculated. The time of the handoff is determined to be the time difference between the last received packet from the old BS and the first received packet from the new BS. It is found that the handoff time varied from a few milliseconds to a few tens of milliseconds. The throughput is the ratio of the total of the data packets that is delivered to the destinations which is divided by the time interval. It was found that the throughput varied from 90% to 50%. The end-to-end delay is measured in milliseconds, and it is the total delay time from a sender to a destination. It was found that the end-to-end delay varied from 0.5 second to 2 second.
Simulation experiments carried out while changing the velocity of nodes and the density of the nodes, to find how this affects the performance metrics, i.e., handoff latency, throughput and End-to-End delay. Compared to [27], our research is more comprehensive and it is the closest to reality.

3.5.1 Velocity of MS

When the adjustments of NS-2 and WiMAX-module parameters are performed, the influence on velocity of the MS is also investigated. In this section the number of the MSs is set to constant 20 MS. Also each experiment is repeated 10 times and the average value adopted.

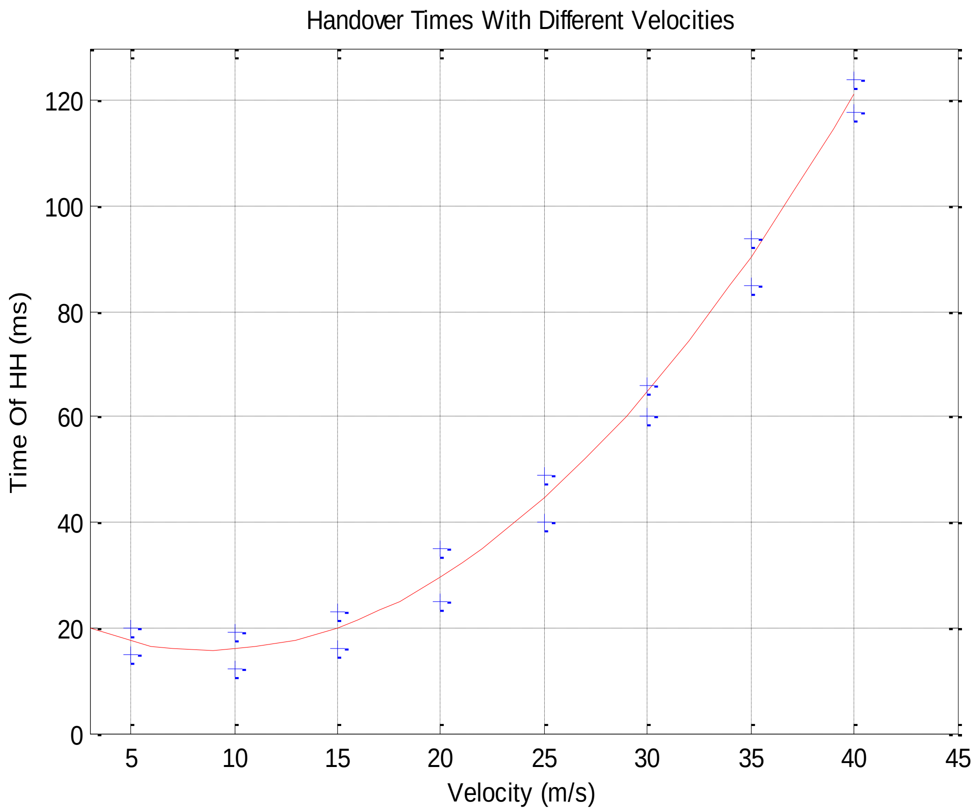

Figure 3.12: Handoff Times with different velocities

The simulation is done with MS speeds between 1 and 40 m/s with 1 m/s step increasing. The results are plotted in figure 3.12. The 40 m/s equals to 144 km/h. The handoff times vary in the region around 40 ms and stayed good below the 50 ms limit until the MS reaches the velocity of **28 m/s** which is acceptable and complies with WiMAX Forum's specifications.

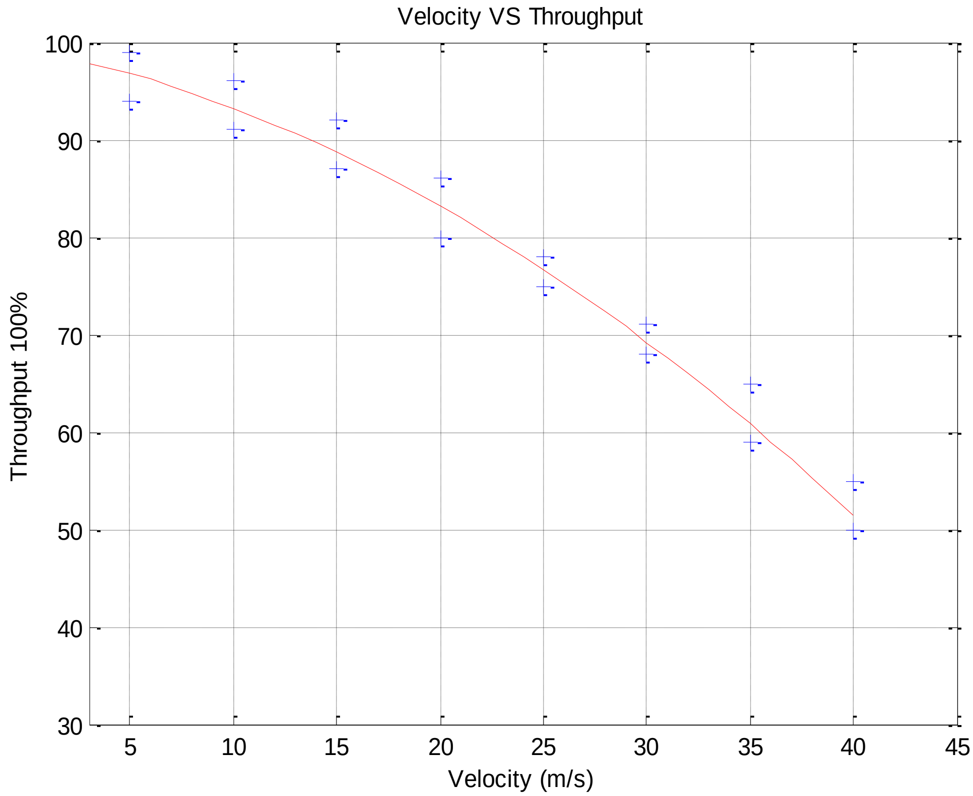

Figure 3.13: Throughput with different velocities

Figure 3.13 shown the average packet throughput is varying with the velocity of MS, the average throughput steadily decreases while the velocity is increasing. Throughput remains reliable and good for the velocity up to 30 m/s (or 108 Km/h). As shown above when the velocity increase the handoff time increase and the throughput decrease which is acceptable and complies with WiMAX Forum’s specifications.

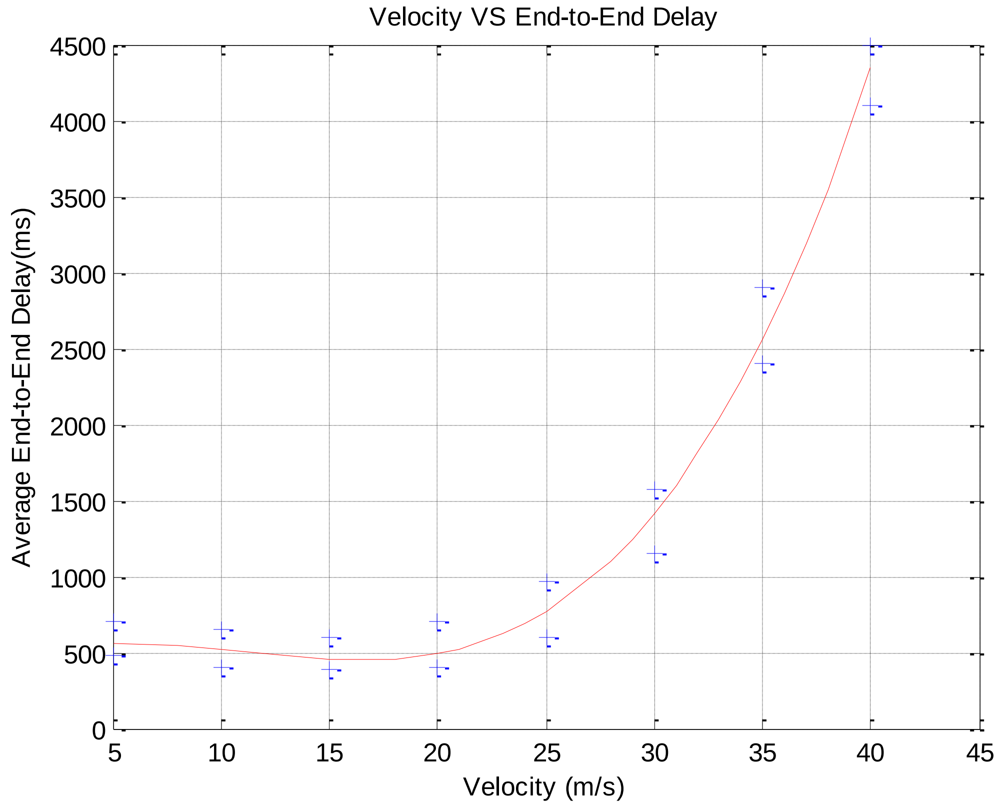

Figure 3.14: End-to-End Delay with different velocities

Figure 3.14 shown the average End-to-End delay is varying with the velocity of MS, the average End-to-End delay steadily increase while the velocity is increasing. End-to-End delay remains reliable and good when velocity is below 20 m/s (or 72 Km/h). At higher speeds, a steady increase is noticed while the velocity grew. So we get the best value for mobile speed at the range between 80Km/h and 110Km/h which obtain the same less handoff, throughput, and End-to-End delay which is acceptable and complies with WiMAX Forum's specifications. What we are doing in this simulation as it is clear in this chapter is to include in the study more than one factor which make our case study is distinguish from the others whom are working on one or two factors maximum while we use more than two factors in addition to handoff latency such as throughput, end-to-end delay.

3.5.2 Mobile densities

In this section we will discuss the other side of the simulation, which is the number of mobile parameter, and its influence on the handover. Most of the researchers used only one mobile in the simulation, while we try to adjust the number of mobiles in the simulation to reflect the influence on the Handoff time based on this change.

When the adjustments of NS-2 and WiMAX-module parameters are performed, the influence of number of the MS is also investigated. In this simulation case the speed of the MSs is set to constant 10 m/s (36 km/h) (***as average based on number of mobiles***). In these simulations the parameters are kept unchanged and only the number of the MS is changed.[1]

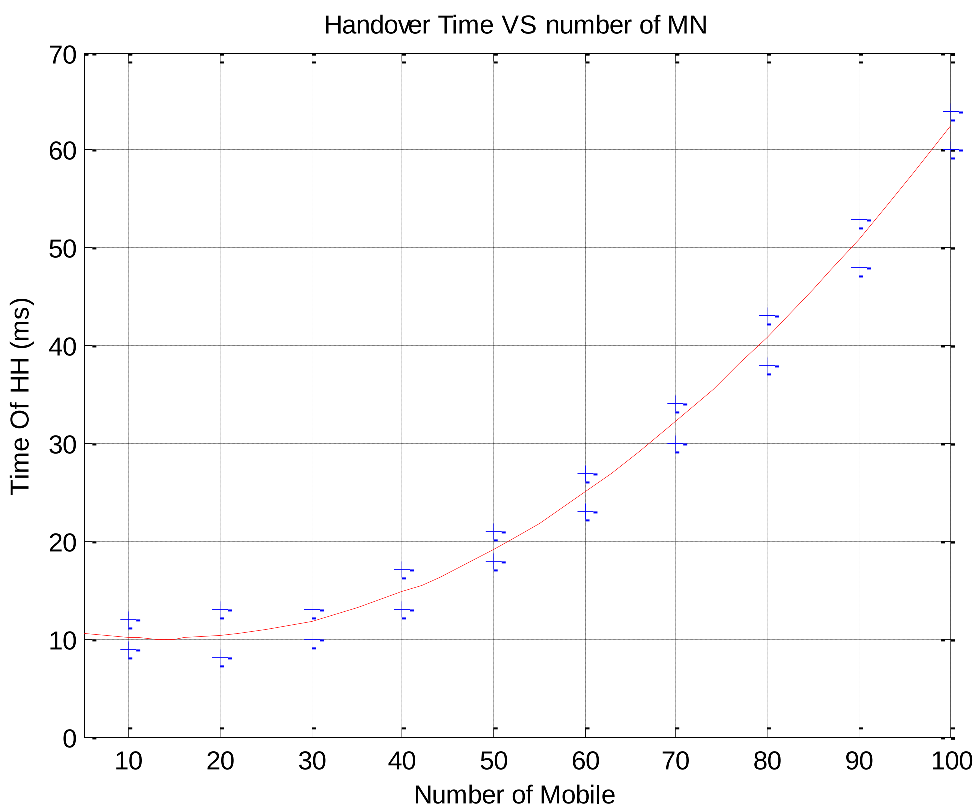

Figure 3.15: Handoff Times with different number of MS

The simulation is done with MS density between 1 and 100 mobile with 10 m/s speed. The handoff times vary in the region of 10 ms and stay good below the 50 ms limit until the number of MS reaches90, apart from few exceptions that exceeded the limit by only few milliseconds as shown in figure 3.15.

---

[1]The results here are calculated as average based on the number of mobiles make handoff

If we compare the handoff time in both scenarios we get at 10m/s and 20 MS which represents a rational value which is also acceptable and complies with WiMAX Forum's specifications.

Previous Scenario	current scenario
13ms	**11ms**

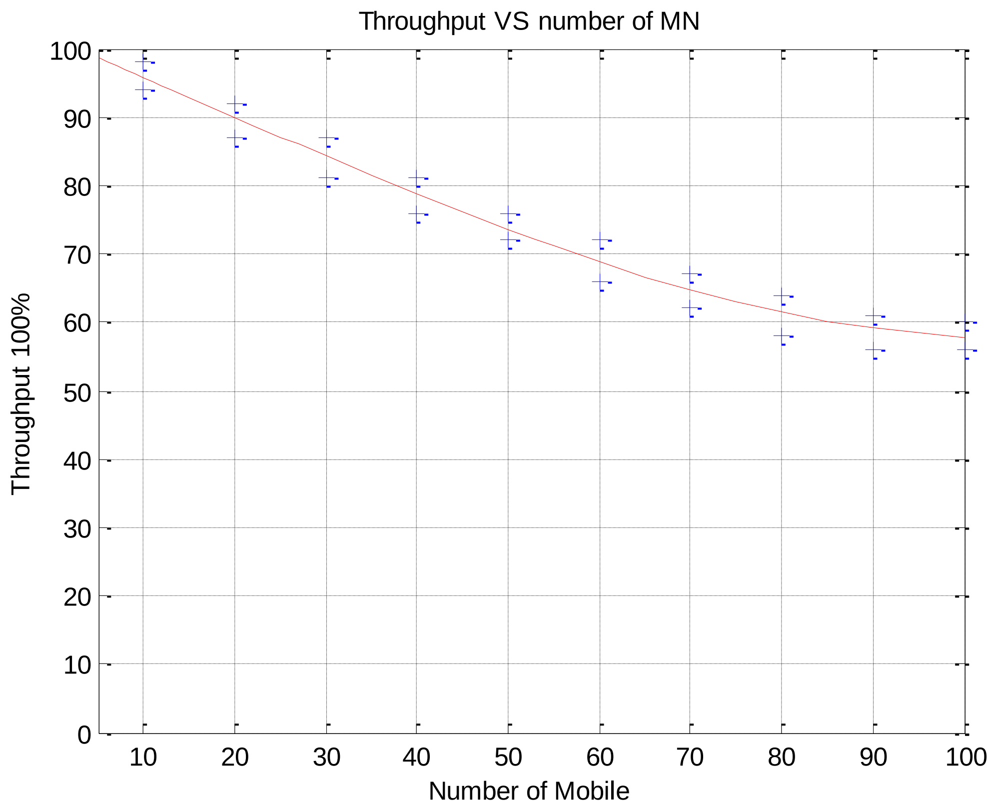

Figure 3.16: Throughput with different number of MS

Figure 3.16 show the average packet throughput is varying with the number of MS, the average throughput steadily decreases while the MS number is increasing. Throughput remains reliable and good for MS number up to 60 MS. At higher number of MS, throughput shows also a steady decrease while the number of nodes grows. The handoff time with 100 MS, throughput just above 50% which is acceptable and complies with WiMAX Forum's specifications[2]

[2]The results here are calculated as average based on the number of mobiles make handoff

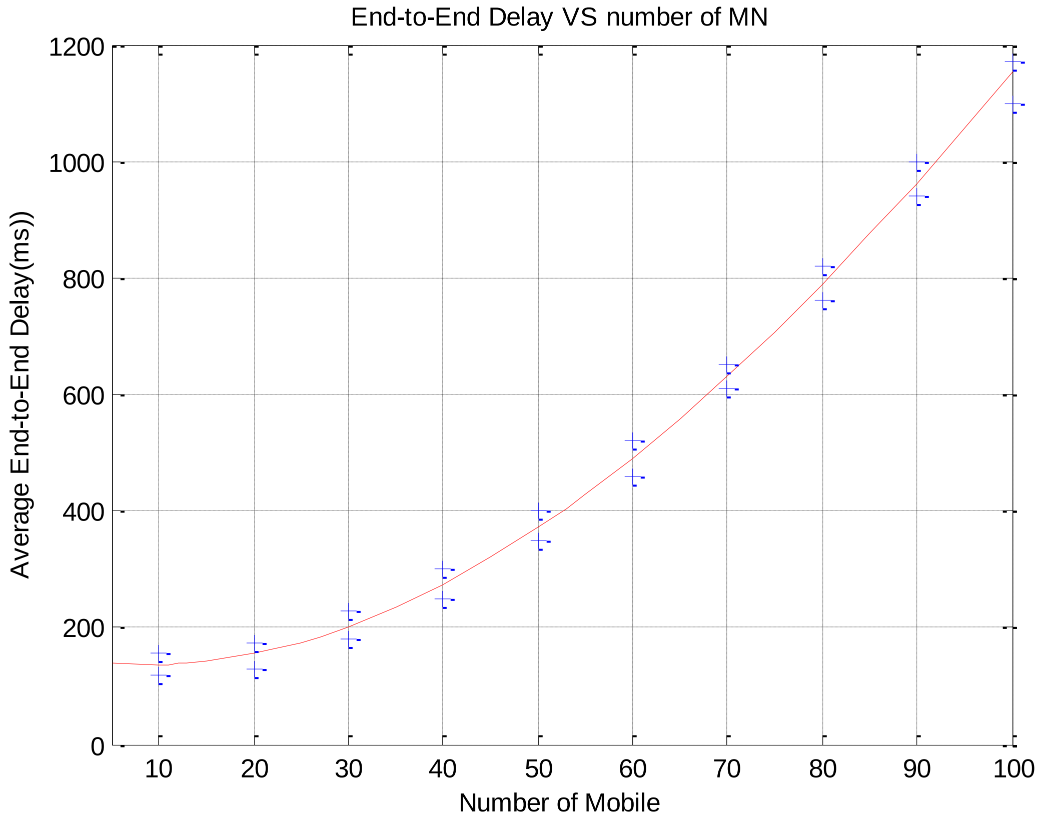

Figure 3.17: end-to-end Delay with different number of MS

Figure 3.17 shows the average end-to-end delay varying with the number of MS, simulation reflects that the average end-to-end delay steadily increases while the MS number increasing. end-to-end delay remains reliable and good for MS number up to 70 MS. At higher MS number, average end-to-end delay shows also a steady increase while the MS number grows.[3]

The end-to-end delay average time with 100 MS, was just below1.5 second which is acceptable and complies with WiMAX Forum's specifications.

[3]The results here are calculated as average based on the number of mobiles make handoff

3.6 Summary

This chapter discussed the simulation part of the thesis. The designed scenario consists of three BSs placed equally in a row and the MS moving through the coverage areas of all of them. The used software isNS-2 with two add-on modules from NIST[21].

Firstly, the simulation is done at constant number of MS, constant velocity to determine the best value of parameter dependent on rang values that defined by NIST module [26].Then, the velocity is changed to ensure that best result and all scenarios after that run at these values.

Secondly, the handoff latency, throughput and End-to-End delay is measured during the handoffs with different velocity and different density of MS.

The goal is to find out the parameters with the most influence on handoff and comparing of the values to the 50 ms limit set by the WiMAX Forum.

We find the link going down factor, is the most important factors of the WiMAX module that influence on handoff and the best value we get is **1.4**, the scan iteration is **two** iteration, inter leaving interval is **4** frames, and the time to searching the DL-Map is influenced factor that affecting on handoff it is set to **5ms**.

After the adjustments are performed and the best possible values for these scenarios are chosen. The performance evaluation is carried out with different velocities between **1-40** m/s, and different number of MS from **1-100**, where the mobile station travel at the speed of **28 m/s**. However, up to **110** km/h, handoff latency of less than **50 ms**, throughput is more than **70 percent**, and end-to-end delay less than **1.5second**, and when the number of mobile station is **80,** we find the best result for performance metric, handoff time less than **40 ms**, throughput is more than **60 percent** and end-to-end delay less than **1 second**.

Chapter 4: Conclusions and Future Work

4.1 Conclusions

The purpose of this research work is to study the factors affecting handoff in mobile WiMAX networks. In order to accomplish these performance evaluations were carried out. The performance metrics are: Handoff Latency, Throughput, End-to-End delay.

This is done under changing two conditions: The travelling speed of mobile station and the density of mobile station in each cell.

The main task for the simulation is to determine the parameters that have the greatest impact on handoff process. Based on results, it is concluded that some of the parameters do not influence the handoff times at all. However, changing some of other factors, even slightly, have direct impact. For example, link Going Down-factor, which determines the sensitivity for detecting a failing link constitute significant impact on the results.

Table 4.1 below will summarize the best values for the parameters that gave us the smallest handoff latency

Table 4.1: The best value of factor effecting on handoff latency

Parameter name	Best value with smallest Handoff latency
scan_iteration	**2**
lgd_factor	**1.4**
scan_duration	**4**
interleaving_interval	**4**
t21_timeout	**26 ms**
client_timeout	**5 ms (default)**

queue_length	**1 packet (default)**
frame_duration	**4ms (default)**
lost_dlmap_interval	**0.6 ms (default)**
lost_ulmap_interval	**0.6 ms (default)**
rng_backoff_start	**2 slot (default)**

Two things were completed in this thesis:

First, handoff in the mobile WiMAX is simulated using NS-2 with WiMAX and mobility modules. The goal of this simulation is to find the best value for factors effecting handoff time and the relationship between the handoff latency, throughput, and end-to-end delay with velocity of mobile stations. It can be seen that the current handoff mechanisms which is used in the NS-2 module meets the requirement of seamless handoff in mobile WiMAX when the mobile station travels at the speed of 28 m/s.

However, up to 110 km/h, handoff latency of less than 50 ms, throughput is more than 70 percent and end-to-end delay less than 1.5second. These values are acceptable because the WiMAX forum states the best case for velocity of MS up to 72 km/h to obtained handoff time less than 50ms.

Second, the simulation experiments are repeated with the goal of finding the relationship between the handoff latency, throughput, end-to-end delay and the number of mobile station, i.e., node density. We were able to determine that the current handoff mechanism used in the NS-2 module meets the requirement of seamless handoff in mobile WiMAX when the number of mobile station is in the 80's . However, up to 90 mobile stations, handoff latency of equal to 50 ms, and throughput that is more than 60 percent and with an end to end delay that is less than 1second. As a result of these experiments we found that the best case is as shown in table 4.2.

Table 4.2: The best case for scenario result

Performance Metric	The best case for velocity of MS in our scenario	The best case for density of MS in our scenario
Handoff Latency **(less than 50ms)**	**28 m/s**	**90 MS**
Throughput **(more than 70%)**	**30 m/s**	**60 MS**
End-to-End delay **(less than 1s)**	**20 m/s**	**90 MS**

4.2 Future Work

Handoff delay is one of the key parameters that researchers seek to optimize as to produce effective mobility architecture. Another significant parameter is scanning delay. With the increased growth rate of the wireless industry, there are many bandwidth-heavy applications offered for users to enjoy. Normally, handoff management works independently from the QoS point of view (e.g. prioritized packed scheduling). However, with the growing demand for bandwidth-heavy applications, handoff management should consider bandwidth requirements before selecting the next BS for the handoff. This ideally requires historical knowledge of the way in which these applications are being served from different host entities such as BSs. In our future research, we will use history-based selection of BS and network-based handoff to reduce the scanning time and the handoff delaying mobile WiMAX. Finally, a lot of research in the field of handoff mechanisms in layer 3 is being conducted, but this is done without considering the capabilities of lower layers. A cross-layer design is a promising research topic for WiMAX network.

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Abbreviations

AAS	Adaptive Antenna System
AES	Advanced Encryption Standard
AP	Access Point
ASK	Amplitude Shift Keying
BS	Base Station
BSC	Base Station Controller
BSS	Base Station Subsystem
BST	Base Station Transceiver
BWA	Broadband Wireless Access
CAC	Connection Admission Control
CID	Connection Identifier
CPS	Common Part Sublayer
CS	Convergence Sublayer
DSL	Digital Subscriber Line
EAP	Extensible Authentication Protocol
FCC	Forward Control Channel
FDD	Frequency Division Duplex
FFT	Fast Fourier Transform
FDMA	Frequency Division Multiple Access
FSK	Frequency Shift Keying
LLC	Logical Link Control
MAC	Medium Access Control
MSC	Mobile Switching Server
NAS	Network Access Server
OFDM	Orthogonal Frequency Division Multiplexing
PDU	Protocol Data Unit
POP	Point of Presence
PSK	Phase Shift Keying
PPP	Point to Point Protocol

PKM	Public Key Management Protocol
PSTN	Public Switched Telephone Network
QAM	Quardrature Amplitude Modulation
QoS	Quality of Service
RADIUS	Remote Authentication Dial-In User Services
SA	Security Association
TDM	Time Division Multiplex
TDD	Time Division Duplex
TEK	Traffic Encryption Keys
VLAN	Virtual Local Area Network
WT	Wireless Terminal
Wi-Fi	Wireless Fidelity
3G	Third-Generations
3GPP	Third-Generation partnership project
3GPP/2 3rd	Generation Partnership Project/version 2
AAA	Authentication, Authorization and Accounting
AC	Access Concentrator
ACK	Acknowledgment
AES-CCM	AES-CTR mode with CBC-MAC
AK	Authorization Key
AKA	Authentication and Key Agreement
AMC	Adaptive Modulation and Coding
AMS	Adaptive MIMO Switching
ASN	Access Service Network
ASN-GW	Access Service Network Gateway
BE	Best Effort
BPSK	Binary Phase Shift Keying
BSID	Base Station Identity
BTC	Block Turbo Code
CBC-MAC	Cipher Block Chaining Message Authentication Coder
CC (I)	Chase Combining

CC (2)	Convolution Coding
CCI	Co-Channel Interference
CDMA	Code Division Multiple Access
CINR	Carrier to Interference plus Noise Ratio
CMAC	Cipher based Message Authentication Code
CP	Cyclic Prefix
CQICH	Channel Quality Indicator Channel
CRC	Cyclic Redundancy Check
CSN	Connectivity Service Network
CTC	Convolution Turbo Coding
CTR	Counter Mode Encryption
DC	Direct Current
DCD	DL Channel Descriptor
DL	Downlink
DoA	Direction of Arrival
DP	Decision Point
DSL	Digital Subscriber Line
DSx A, C, D;	Dynamic Service Addition/Change/Deletion
EP	Enforcement Point
ertPS	Extended Real Time Polling Service
FBSS	Fast Base Station Switching
FCH	Frame Control Header
FSS	Frequency Selective Scheduling
FTP	File Transfer Protocol
FUSC	Full Usage of Sub-channels
FuTURE	Future Technologies for a Universal Radio Environment
GMC	Generalized Multi-Carrier
GPRS	General Packet Radio Service
GRD	Guard (interval)
GSM	Global System for Mobile communications
HA	Home Agent

HARQ	Hybrid Automatic Repeat Request
HHO	Hard Handoff
HMAC	Hash Message Authentication Code
HO	Handoff or handoff
HSDPA	High Speed Downlink Packet Access
HSOPA	High Speed OFDM Packet Access
HSPA	High Speed Packet Access
HSUPA	High Speed Uplink Packet Access
ID	Identifier
IE	Information Element
IEEE	Institute of Electrical and Electronics Engineers
IFFT	Inverse Fast Fourier Transform
IMTA	International Mobile Telecommunications Advanced
IP (v4 or v6)	Internet Protocol (version 4 or 6)
IR	Incremental Redundancy
ISI	Inter Symbol Interference
ITU	International Telecommunication Union
KEK	Key Encryption Key
LDPC	Low Density Parity check Code
LSB	Least Significant Bit
LTE	Long Term Evolution
MBS	Multicast and Broadcast Service
MBWA	Mobile Broadband Wireless Access
MD5	Message Digest algorithm 5
MDHO	Macro Diversity Handoff
MIH	Media Independent Handoff
MIMO	Multiple Input Multiple Output
MPEG	Moving Picture Experts Group
MS	Mobile Station
MSB	Most Significant Bit
MS-CHAP	Microsoft-Challenge Handshake Authentication Protocol

NACK	Negative Acknowledgment
NAP	Network Access Provider
ND	Neighbor Discovery
NIST	National Institute of Standards and Technology
NRM	Network Reference Model
nrtPS	Non Real-Time Polling Service
NS-2	Network Simulator version 2
NSP	Network Service Provider
NWG	Network Working Group
OFDMA	Orthogonal Frequency Division Multiple Access
PDA	Personal Digital Assistant
PKMvl/2	Privacy Key Management version 1 or 2
PMP	Point-to-multipoint
PRBS	Pseudo-Random Binary Sequences
PUSC	Partial Usage of Sub-channels
QPSK	Quadrature Phase Shift Keying
RA	Router Advertisement
RoF	Radio over Fiber
RRA	Radio Resource Agent
RRC	Radio Resource Controller
RRM	Radio Resource Management
RS	Router Solicitation
RTG	Receive/Transmit Transition Gap
rtPS	Real—Time Polling Service
SA	Security Association
SAID	Security Association Identity
SAP	Service Access Point
SDMA	Space-Division Multiple Access
SDU	Service Data Unit
SPN	Single Frequency Network
SIM	Subscriber Identity Module

SIMO	Single Input Multiple Output
SM	Spatial Multiplexing
SNR	Signal-to-Noise Ratio
S-OFDMA	Scalable OFDMA (also SOFDMA)
SS	Subscriber Station
STBC	Space-Time Block Code
STC	Space-Time Coding
TCP/IP	Transmission Control Protocol/lntemet Protocol
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
TEK	Traffic Encryption Key
TLS	Transport Layer Security
TTG	Transmit/Receive Transition Gaps
TTLS	Tunneled TLS
TUSC	Tiled Use of Sub-channel
UCD	UL Channel Descriptor
UGS	Unsolicited Grant Service
UL	Uplink
UMTS	Universal Mobile Telecommunications System
VoIP	Voice over IP
WAVE	Wireless Access for the Vehicular Environment
WCDMA	Wideband Code Division Multiple Access
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
WPA(2)	Wi-Fi Protected Access (version 2)
WRAN	Wireless Regional Area Network
VR-(N)RT	Variable-Rate (Non»)Real-Time