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The Effect of a Mobile Node Speed in Vertical Handover between WiFi and WiMAX Networks

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Dedication

I dedicate this work to

Soul of my father,

My mother,

My wife,

My daughters Ghina and Marah,

My son Mohammad,

My brothers, sister and their families,

My parents in law.

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: ………..................................…

Nasim Kamal Mohammad Hamaydeh

Date: ……..................................……….

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Abstract

Mobile Communication systems have become a major component of modern lifestyle; the heterogeneity of the wireless access networks combined with the existence of multi-network interface smart mobile devices that support different wireless standards imposes many challenges. One of the most challenging issues is service continuity when such a node moves from one access technology to another different access technology; a process is called vertical handover. This thesis focuses on the vertical handover between WiFi and WiMAX networks. Both WiFi and WiMAX belong to the same IEEE 802 family of standards, technology dependent components and have different link-layer technologies. This complicates service continuity during a vertical handover between the two networks. One of the main techniques that assisted the vertical handover is the media independent handover services defined in IEEE 802.21. These services provide events, commands and information between the upper layers and lower layers. This research focuses on evaluating the performance of mobile applications in vertical handover scenarios between WiFi and WiMAX networks. We used simulation (NS-2) to study two scenarios: in the first scenario, the mobile node moves from WiFi to WiMAX and in the second one the mobile node moves from WiMAX to WiFi. The simulation utilizes the decision algorithm developed by the National institute of standards and Technology, which considers only the received signal strength to decide on the handover process. The metrics used for evaluating the performance are throughput, packet loss ratio, average end-to-end delay and handover latency. The measured values of some of these metrics were compared to International Telecommunication Union- Telecommunication sector standard (ITU-T); that defines threshold values for the applications in mobile networks. Some of the evaluation

metrics were modelled as function of mobile node speed and application bitrate to validate the obtained results and present the functional behaviour of the effect on these metrics.

The obtained results of some evaluation metrics namely, packet loss ratio and handover latency are competitive with the results of the latest studies in vertical handover assisted by Media Independent Handover standard. Results of throughput and delay were not presented by the studies in the related works. In addition, results modelling was presented as function of mobile node speed in this thesis and was not shown in the related works.

Those results showed that the mobility direction affects the performance of the mobile applications, and that the decision algorithm based on the received signal strength as a standalone metric is not sufficient to fulfil the Quality of Service (QoS) requirements for QoS-aware applications in vertical handover scenarios. Therefore, the speed of the mobile node should be considered carefully in the vertical handover scenario from WiFi to WiMAX networks for such applications to ensure that the minimum applications requirements are met.

Keywords: IEEE 802.21, WiFi, WiMAX, Packet Loss Ratio, Handover Latency, Curve Fitting.

ملخص الدراسة

أصبحت أنظمة الاتصالات المتنقلة عنصرا رئيسيا في نمط الحياة الحديثة؛ ونظراً لتنوع الشبكات اللاسلكية وتوفر الاجهزة النقالة الذكية التي تحتوي على العديد من محولات الشبكات "Interfaces" التي تدعم معايير مختلفة من معايير الشبكات اللاسلكية، فرض العديد من التحديات. ولعل من أهم هذه التحديات تحقيق استمرارية الخدمة عند انتقال هذا النوع من الاجهزة بين شبكتين لاسلكيتين تعملان وفق بروتوكولات مختلفة لطبقة وصل البيانات "Different Link Layer" والتي تعرف بعملية التسليم العمودي "Vertical Handover".

تركز هذه الدراسة على عملية التسليم العمودي عند انتقال الجهاز المحمول بين شبكتي WiFi وWiMAX. وبالرغم من أن هذين النوعين من الشبكات اللاسلكية ينتميان لنفس الفئة من المعيار (IEEE 802)، الا أنهما يعملان وفقا لبروتوكولات طبقة وصل البيانات مختلفة مما يؤدي الى تعقيد المحافظة على استمرارية الخدمة خلال عملية التسليم العمودي بين هذين النوعين. تعتبر خدمات التسليم المعرفة في المعيار (IEEE 802.21) والتي لا تعتمد على الوسط الناقل، من التقنيات الرئيسية التي تساعد على استمرارية الخدمة خلال عملية التسليم العمودي من خلال الاحداث والاوامر والمعلومات التي يتم تناقلها خلال عملية التسليم العمودي.

هنالك عوامل تؤثر على عملية التسليم العمودي تم تناولها في هذه الدراسة مثل سرعة الجهاز المحمول ونوع الشبكة اللاسلكية التي يتم الاتصال بها، حيث قمنا خلال هذه الدراسة بتوضيح تأثير هذه العوامل على جودة وكفاءة الخدمة لمستخدمي الشبكات اللاسلكية من خلال اعتماد المعايير التالية: معدل الانتاجية، نسبة فقدان الحزم، معدل التأخر في استقبال الحزم، والتأخير الناتج عن عملية التسليم العمودي.

وقد أظهرت النتائج أن القيم المقاسة لكل من معدل التأخر في استقبال الحزم، والتأخير الناتج عن عملية التسليم العمودي تقع ضمن المدى المقبول لضمان استمرارية الخدمة مقارنة بالقيم المعتمدة في المقاييس المعدة من قبل الإتحاد الدولي للإتصالات ITU-T لضمان جودة أداء التطبيقات لكل من الصوت والفيديو في بيئة الشبكات اللاسلكية. وعلى العكس من ذلك فقد أظهرت النتائج أن نسبة فقدان الحزم لم تكن ضمن المدى المقبول لضمان استمرارية الخدمة خلال عملية التسليم العمودي عند تجاوز سرعة حركة الجهاز النقال لسرعات معينة. بالإضافة الى ما سبق، فقد أظهرت النتائج أيضا أن القيم المقاسة للتأخير الناتج عن عملية التسلية العمودي عند الانتقال من

شبكة WiMAX الى شبكة WiFi أقل من القيم المقاسة لنفس المعيار عند الانتقال من شبكة WiFiالى شبكة WiMAX، وتجدر الإشارة الى ان هذه النتائج منافسة لأحدث الدراسات التي تعمل في نفس المجال.

وبناءً عليه فان هذه النتائج تثبت أن نوع الشبكة اللاسلكية يؤثر على أداء التطبيقات الحية وعليه فان الاعتماد على قوة الاشارة فقط ليس كافيا من خلال السيناريوهات التي تم استخدامها في هذه الدراسة بل يجب اعتماد عوامل اخرى بالإضافة الى قوة الإشارة لضمان توفير كفاءة وجودة عالية للتطبيقات الحية عند الانتقال بين الشبكات اللاسلكية الغير متجانسة. وهذا يشير الى أن استخدام الخوارزميات التي تعتمد على عدة معايير سيحسن عملية التسليم العمودي.

ومن أهم التوصيات في هذه الدراسة أنه يجب أخذ سرعة الجهاز المحمول بعين الاعتبار خلال عملية التسليم العمودي عند الانتقال من شبكة WiFi الى شبكة WiMAX وخصوصا عندما يتعلق الامر بالتطبيقات الحيوية بشكل يتناسب مع خصائص هذه الشبكات.

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Chapter 1
Introduction

Mobile Communication systems have become a major component of modern lifestyle, they are exploited and oriented toward almost all kinds of computing aspects. This is the cause and result of its several implementations with several heterogeneous technologies such as Wireless Fidelity (WiFi) and Worldwide Interoperability for Microwave Access (WiMAX). Service continuity between heterogeneous wireless networks is becoming an essential issue. In addition, Quality of Service (QoS) aware applications have their own constraints that should be met in any network. The diversity of heterogeneous networks, smart mobile devices with multiface capabilities and the demand of multimedia services increased service continuity challenges. These challenges happen when the mobile node changes its serving point of attachment when moving between these heterogeneous networks, this called vertical handover. Therefore, mechanisms are needed to ensure that the services on the mobile node are running all the time smoothly without interruption during the vertical handover process, matching network conditions with QoS constrains. The Media Independent Handover (MIH) or IEEE 802.21 standard [MIH09] addresses these mechanisms. IEEE standard association has approved this standard in early 2009. The purpose of the MIH standard is to provide seamless service continuity among heterogeneous networks including 3GPP, 3GPP2, and the IEEE 802 standard family [LKSW09]. MIH standard uses cross-layer concept through an abstraction layer implemented in the protocol stack. This layer includes Media Independent Handover Function (MIHF), which is the heart of the IEEE802.21 standard. It carries out the changes of the link characteristics and the application demands between the upper and lower layers of different protocol stacks. MIHF also coordinates for vertical handover with remote MIHF, implemented in other devices in the network.

1.1 Problem Statement

Service continuity and user mobility between heterogeneous networks must be achieved. The integration between heterogeneous wireless networks with different features is a challenge issue in terms of coverage area and bandwidth. This challenge during the vertical handover process affect the performance of the running services provided by these networks. Our work will focus on studying the performance of the mobile applications using key evaluation metrics that maybe affected by the mobile node speed and the application bitrate in vertical handover scenario between WiFi and WiMAX networks. The performance variations exist at cell's coverage boundaries, which is the most critical area during the handover process. Limitations and facilities exist in these access networks; the challenges exist in the limitations of coverage area such as WiFi, which affect the user mobility. Facilities are presented in supporting high data rates that help in achieving service continuity such as WiFi and WiMAX. Two vertical handover scenarios are used including two wireless access technologies from the IEEE 802 family; WiFi and WiMAX.

This thesis will address the following questions:

- How to achieve service continuity through the integration between WiFi and WiMAX networks based on IEEE 802.21 in the vertical handover scenarios?

- What is the effect of the mobile node speed on the performance of the mobile applications in the vertical handover scenarios between WiFi and WiMAX networks?

- What are the effect of the mobility direction and the applications bitrate in the vertical handover scenarios between WiFi and WiMAX networks?

- Are obtained results in this study acceptable with respect to the defined values for the QoS aware applications?

- How to model the obtained results from the vertical handover scenarios to present the functional behavior?

1.2 Thesis Contribution

In the network infrastructure, wireless access networks are the interface between the mobile nodes and the core networks that connect the users to the internet. The access networks are implemented based on the media types that are used. In heterogeneous wireless access networks, vertical handover is a challenge issue due to their different link-layer implementations. Therefore, standards are required to facilitate seamless handover between these heterogeneous access networks. This research will present a comprehensive study for the performance evaluation metrics to measure the performance of the mobile applications under the effect of the mobile node speed and application bitrate. Combining the performance evaluation metrics and the input parameters provide simulation results that may help the decision algorithm designers to consider the effective factors in enhancing the vertical handover process that is based on the received signal strength. This thesis have contributed in the following [HKBA13]:

- Building two vertical handover scenarios between WiFi and WiMAX networks using IEEE 802.21 standard.

- Investigating the effect of the mobility direction on the performance evaluation metrics in the vertical handover scenarios between WiFi and WiMAX networks.

- Studying the effect of the mobile node speed and applications bitrate on the performance evaluation metrics in the two scenarios and present their simulation results.

- Presenting the importance of the MIH services that enhanced the vertical handover process between WiFi and WiMAX networks.

- Modelling the simulation results obtained from the vertical handover scenarios and present the functional behavior as a function of mobile node speed.

1.3 Related Works

The research trends of vertical handover are directed toward MIH implementations and capabilities, performance analysis fulfilling QoS constrains, multi-criteria decision algorithms and mobility management using Mobile IPs [BCCM11]. In performance analysis; the research analysing the MIH primitives, observing input parameters affecting handover process and proposing evaluation metrics used in performance evaluation.

The research in [MRMR10] presents a description of the IEEE 802.21 implementation in NS-2, the handover process signaling between WiFi and WiMAX networks. The researcher provides a method to calculate the number of handovers and presents evaluation of the reliability and scalability of vertical handover scenarios based on IEEE 802.21 implementation using variable mobile nodes and different applications bitrate. Packet loss ratio, handover latency and number of handovers were the evaluation metrics in the researcher scenarios. These metrics are plotted as a function of number of mobile nodes and applications bitrate. The values of the performance evaluation metrics in [MRMR10] are compared to the ITU-T standard recommendations to ensure if they fulfil the QoS requirements or not. The results in [MRMR10] show that MIH implementation in NS-2 is reliable and scalable in addition, NS-2 is a major tool for building vertical handover scenarios.

The research in [RMT13] presents that the implementation of the MIH standard developed by the National Institute of Standards and Technology (NIST) is based on the received strength criteria in the decision algorithm. The Author claims that the received signal strength criteria is not enough in selecting target networks. The researcher proposes other criteria beside received signal strength such as user velocity, available bandwidth and type of network through "Multi Criteria Selection Algorithm" (MCSA). MCSA considers the network that has the highest bandwidth regardless of the cost. In MIH decision algorithm, WiFi is the preferable network although WiMAX has the highest bandwidth. WiFi, WiMAX networks and NS-2 were used to design the vertical handover scenarios. Packet loss and handover latency were the performance evaluation metrics used in work conducted by [RMT13] to evaluate the performance in the vertical handover scenarios. The results show that the NIST mobility package in NS-2 fails to fulfill the QoS requirements of the applications in vertical handover scenarios and the WiFi network is valid only for pedestrian.

The research in [CR11] proposes an implementation of a multi-criteria decision algorithm based on the NIST IEEE 802.21 add-on module to improve the packet drop during the vertical handover between WiFi and WiMAX networks. The decision algorithm "MNIST" considered available bandwidth, coverage radius, user mobility and power of the battery criteria beside the received signal strength. The author used NS-2 as simulation tool. Packet drop and number of handovers were used as an evaluation performance metrics.

The research in [DHF11] proposed the development of software platform for managing the interoperability between WiFi and WiMAX network, lost packet rate was the performance evaluation for the system during the vertical handover process. The simulation tools used in research [DHF11] are NS-2 and NIST mobility package.

The research in [MZ04] is one of the earliest studies in vertical handover, the author proposed a tutorial on the vertical handover using Mobile IP protocol and cost function for selecting the target networks.

The research in [AATH13] a real testbed for vertical handover scenario between WiFi and WiMAX using Open Dot Twenty One (ODTONE) which is an open source implementation for the IEEE 802.21 standard. Packet loss ratio and handover latency were the performance evaluation metrics.

In this research, our work has presented a comprehensive study for the key performance evaluation metrics in vertical handover scenarios between WiFi and WiMAX networks. In addition, we present the effect of the mobile node speed on these key metrics when moving between WiFi and WiMAX networks. Provide simulation results that may help designers to enhance the vertical handover process between heterogeneous access networks. The obtained results of some evaluation metrics namely, packet loss ratio and handover latency are competitive with the results of the latest studies in vertical handover assisted by MIH standard. Results of throughput and delay were not presented by the studies in the related works. In addition, results modelling was presented as function of mobile node speed in this thesis and was not shown in the related works in [MRMR10], [RMT13], [CR11], [DHF11], [MZ04] and [AATH13].

1.4 Research Methodology

To achieve the goals of this thesis as mentioned in section 1.2, the following methodology is used:

- Building two vertical handover scenarios as follows:

  WiFi to WiMAX scenario

  WiMAX to WiFi scenario

- The tools used to build the vertical handover scenarios are:

  The Network Simulator 2 (NS-2) version 2.29 [NS13] which is the major tool used to design and perform vertical handover scenarios [MRMR10]. IEEE 802.21 implementation NIST mobility package [ANTD13] based on draft 3 of IEEE 802.21, IEEE 802.16 and IEEE 802.11b add-on modules [MRMR10].

- Study the performance in the vertical handover scenarios between WiFi and WiMAX network by using performance evaluation metrics. These metrics are Normalized Throughput, Packet Loss Ratio, Average End-to-End Delay and handover latency.

Figure 1.1: Performance evaluation metrics

1.5 Thesis Organization

This thesis is organized as follows: Chapter 2 presents an overview about the wireless access networks IEEE 802.11 and IEEE 802.16, handover classifications and Media Independent Handover. Chapter 3 presents the simulation environment, simulation scenarios, and simulation parameters, and defines the performance evaluation metrics. Chapter 4 illustrates and discusses simulation results and analysis for the two vertical handover scenarios between WiFi and WiMAX networks. Chapter 5 presents modelling the simulation results obtained from the vertical handover scenarios using curve fitting toolbox in MATLAB as well as the discussion of these results and comparison to the related work in the same research area. Finally, chapter 6 concludes the thesis and provides the future direction.

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Chapter 2
Wireless Access Networks and Vertical Handover

2.1 Introduction

This chapter presents an overview about wireless access networks of IEEE 802 family standard that are used in this thesis. It also introduces the handover's definition and its classifications in the literature. In addition, this chapter presents an overview about the IEEE 802.21 standard and its services.

2.2 IEEE 802 family Wireless Access Networks

IEEE 802 family of standards define set of access networks. IEEE 802.11 and IEEE 802.16 standards are examples of the wireless access networks that belongs to the same family. These wireless access networks connect the wireless mobile devices to the wired network. They are heterogeneous wireless networks and have different link layer technologies. Recently, high revolution occurred on the mobile devices; they are equipped with multiple interfaces, and the high user mobility increased. In addition, the demand on the multimedia applications are increased. To fulfil these requirements and to support users' mobility, an integration between these access networks becomes essential. An example of wireless access networks of IEEE 802 family shown in Figure 2.1 that supports user mobility and access to an application server.

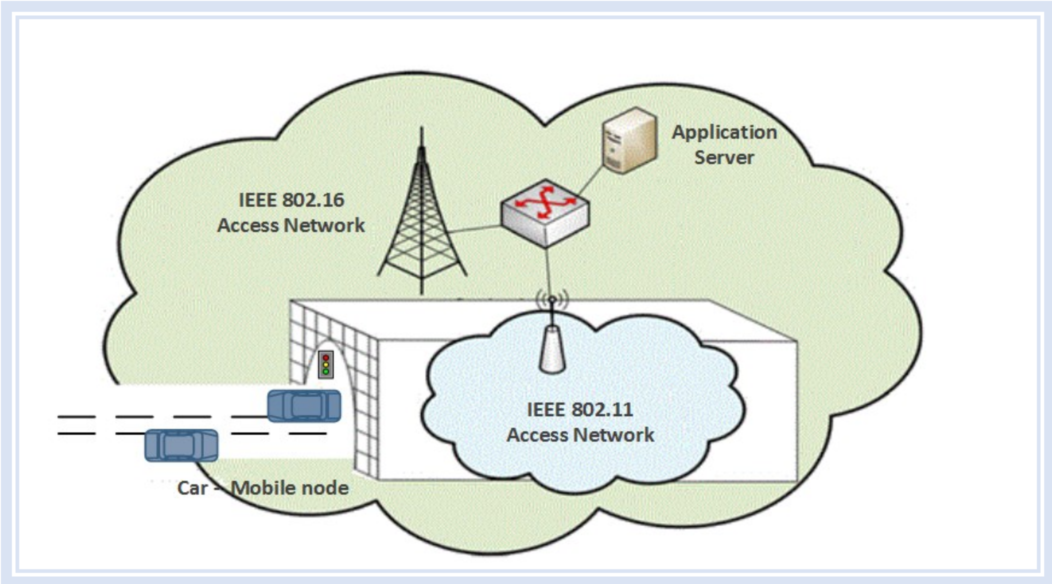

Figure 2.1: Example of wireless access networks of IEEE 802 family [AAMH11].

2.2.1 IEEE 802.16

WiMAX stands for Worldwide Interoperability for Microwave Access. It is the commercial name that is given by the WiMAX Forum to devices that fit to the IEEE 802.16 standard. WiMAX is Wireless Metropolitan Access Network (WMAN) based on IEEE 802.16 family of standards. IEEE 802.16 operates between 10 and 66 GHz Line of Sight (LOS) at a range up to 50 km. In October 2004, the IEEE 802.16-2004 was released; it is also known as IEEE 802.16d, operates between 2 to 11 GHz Non Line-of-Sight (NLOS) at a range up to 6 – 10 km targeted for the fixed users, and provides up to 75 Mbps bandwidth [ADH10]. IEEE 802.16e was one of the standard extensions published in 2005 to support user mobility up to 125 km/h. IEEE 802.16e operates between 2 to 6 GHz NLOS and provides up to 15 Mbps bandwidth. It is also known as mobile WiMAX, provides wireless broadband Internet access with low cost and considered the best technologies for last mile. IEEE 802.16 for both the fixed and mobile standards operates with the licensed (2.5, 3.5, and 10.5 GHz) and unlicensed (2.4 and 5.8 GHz) frequency spectrum and uses Orthogonal Frequency-Division Multiplexing (OFDM) [BC13].

The architecture of WiMAX described in Figure 2.2 consists of three parts. The first part is the Mobile Station (MS), which represents the user's device. The second part is the Access Service Network (ASN) that is considered the radio access; it includes one or more Base Stations (BS) that provides the air interface to the MS and one or more Access Service Network Gateways (ASN-GW), and finally the Connectivity Service Network (CSN). It is the core of the WiMAX network and offers ip based connectivity to the wimax clients [HMM13] [TT10].

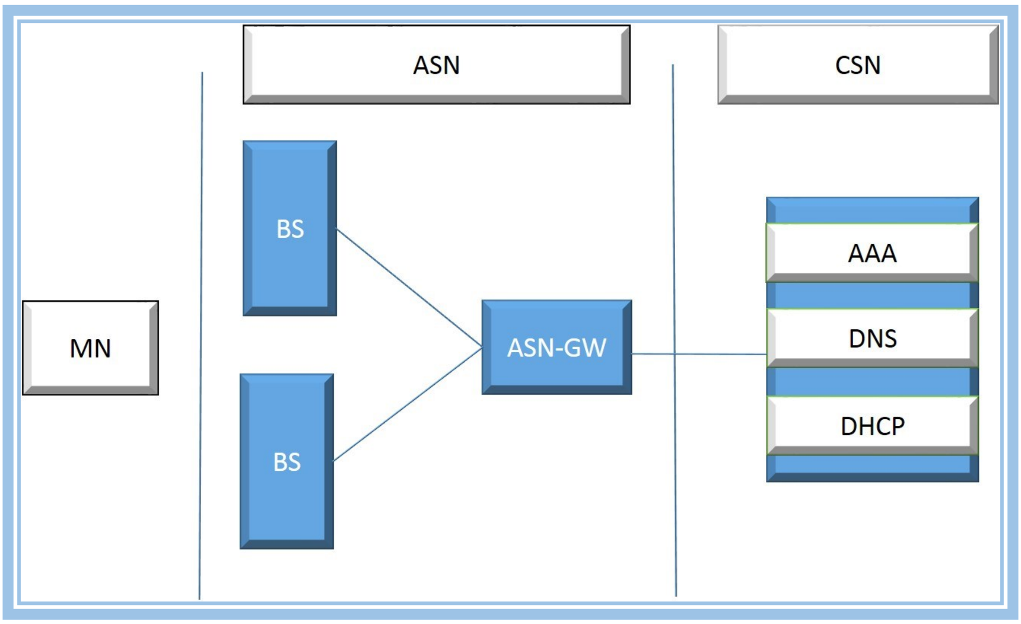

Figure 2.2: WiMAX architecture [TT10].

2.2.2 IEEE 802.11

WiFi stands for (Wireless Fidelity); it is Wireless Local Area Network (WLAN) with small coverage area defined in IEEE 802.11 standard. WiFi is a trademarked brand name for the wireless standard owned by the WiFi Alliance and given to the devices that conform to the IEEE 802.11 standard. In 1997, IEEE 802.11 standard was released with 1-2 Mbps bandwidth and has other extensions such as 802.11a, 802.11b, and 802.11g. WiFi is widely deployed on mobile devices such as laptops and smart phones and has been adopted in both home and enterprises because it supports high bandwidth and low cost. IEEE 802.11 standards use a MAC layer known as CSMA/CA (Carrier Sense Multiple Access/Collision Avoidance) [PV10] and uses Direct Sequence Spread Spectrum (DSSS) modulation technique. IEEE 802.11 can operate in two modes, infrastructure mode and ad hoc mode. In infrastructure mode, WiFi use Access Points (AP) to link the mobile devices with the wired network. In IEEE 802.11, network architecture is composed of Basic Service Sets (BSS) and Distributed Systems (DS). BSS is the basic part of the network that consists of stations such as laptops and mobile devices with WiFi interface. These stations are connected to the AP within specific coverage area known as Basic Service Area (BSA). Access points in different BSS communicates with each other through the DS that provides mechanisms for communication between stations in different BSSs. Extended Service Set (ESS) is the gateway for the wired network such as Internet to all stations in different BSSs and common DS [NAD06] [ME02].

In wireless ad-hoc network mode, also known independent basic service set (IBBS) there is no access points and the devices communicates directly with each other.

[TT10]. Figure 2.3 show the IEEE 802.11 network architecture. IEEE 802.11b was one of the extensions that published in 1999. It operates at unlicensed 2.4 GHz frequency and supports up to 11 Mbps bandwidth. The coverage area of IEEE 802.11b is around 100 meters, which is considered short coverage area and suitable for indoor mobility.

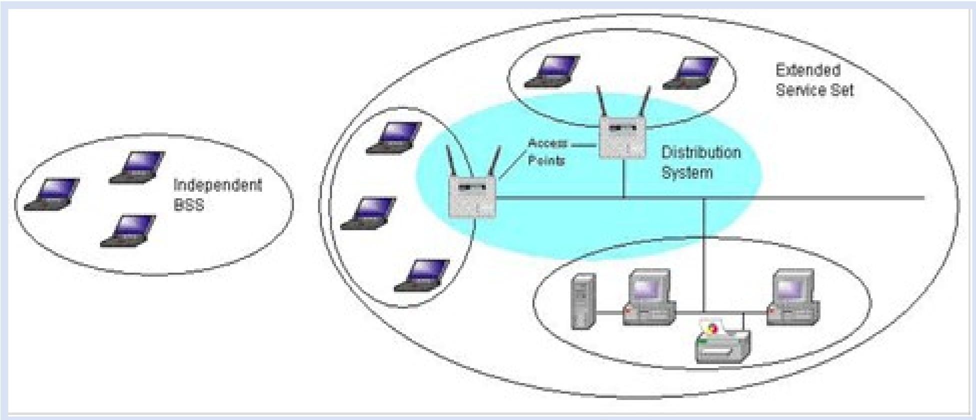

Figure 2.3: IEEE 802.11 network architecture [DHF11].

The parameters of WiMAX and WiMAX networks are shown in Table 2.1 as follows:

Table 2.1: Parameters of WiMAX and WiFi networks [PV10] [BC13].

Parameters	**802.16/WiMAX**	**802.11/WiFi**
Distance	**30 miles LOS** **6 miles NLOS**	**100m Omni-directional antenna**
Bandwidth	**Up to 75 Mbps**	**Up to 11Mbps "b"** **Up to 54 Mbps "a/g"**
Frequency	**2.5 GHZ, 3.5 GHZ, 5.8 GHZ** **Licensed & Unlicensed**	**2.4 GHZ, 5 GHZ** **Unlicensed**
Multiple Access Protocol	**Grant/Request, TDMA**	**CSMA/CA, Contention-based**

2.3 Handover Definition and classifications

Handover is the process by which the mobile node changes its serving Point of Attachment (PoA) and switches its access technology. This process allows the mobile node continue its ongoing session [KA13]. Handover is classified in various ways in literature based on type of access technology, number of connections and type of control; mobile or network initiated handover.

Handover based on the type of access technology is horizontal and vertical as shown in Figure 2.4. Horizontal handover occurs when the mobile node changes its serving PoA within the same access technology also known as intra-technology for example between two WiMAX BS. On the other hand, switching between points of attachment with different types of access technologies called vertical handover like WiFi and WiMAX. It is also known as inter-technology [Yan10] [ZZP11].

Another classification for handover based on the number of connections; hard handover and soft handover. In hard handover or break-before-make; the mobile node connection is associated with one access point at a time while in soft handover, the mobile node can establish connections with more than one point of attachment during handover this is also referred as make-before-break [Yan10] [ZZP11].

Another classification based on type of control; mobile or network initiated handover. Mobile initiated handover took place when the mobile node decides to handover on its own. Network initiated handover occurs when the network makes the decision for handover [Yan10] [ZZP11].

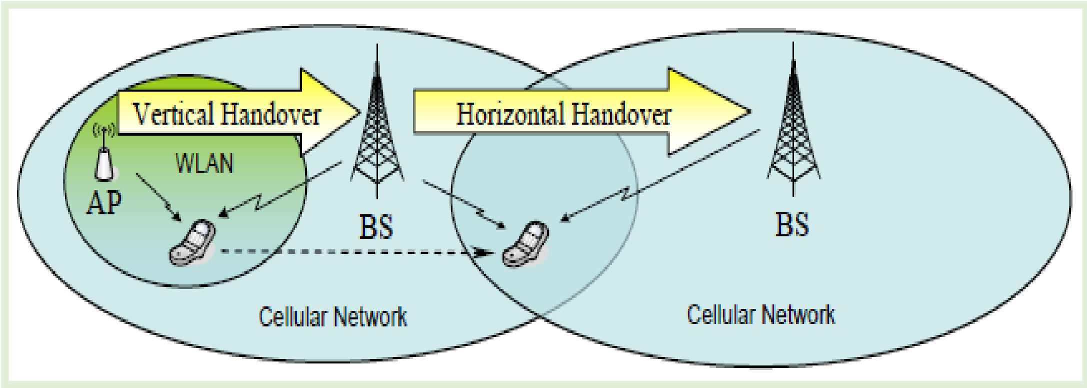

Figure 2.4: Horizontal and Vertical handover [Yan10].

Among these classifications, vertical handover based on the type of access technology is the difficult one since these technologies have different link layer technologies [MIH09]. Service continuity becomes a challenging issue when moving between these networks. Therefore, to perform vertical handover in heterogeneous environment; standards are needed to assist the vertical handover process. In addition, Mobile Node (MN) should be equipped with multiples interfaces to support the connection to different access networks [RMT13] as shown in Figure 2.5.

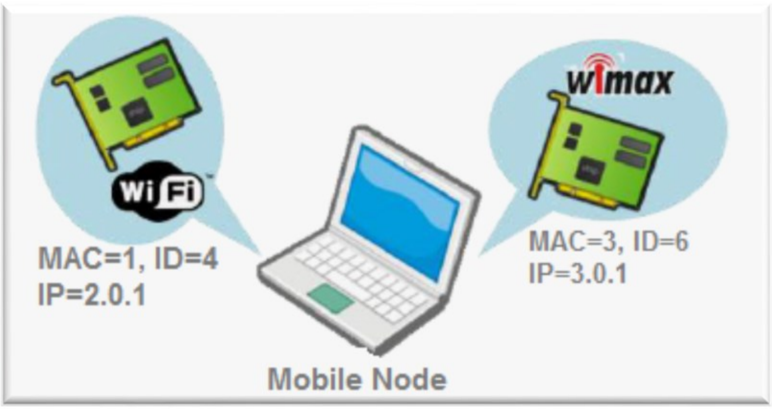

Figure 2.5: Mobile node with multiples interfaces [AAQ10].

2.4 Vertical Handover phases

Vertical handover as mentioned is the process of switching between points of attachment with different types of access technologies. In most of the research papers, the vertical handover consists of three phases; handover initiation, handover decision and handover execution as shown in Figure 2.6.

- **Handover Initiation**

  In this phase, information gathering took place about the network components and its properties such as mobile devices and access points. Other information includes also the properties of the available candidate networks such as received signal strength and bandwidth. The different interfaces on the mobile node are used to gather information about available access technologies. The gathered information will be used in the handover decision phase [BCCM11].

- **Handover Decision**

  The handover decision phase is considered the core phase of the vertical handover process. In this phase, the decision algorithm will evaluate and decide to handover based on decision criteria such as received signal strength. This algorithm decides when and where to handover, by determining the appropriate time of triggering the handover process and select the best candidate network respectively [BD13].

- **Handover execution**

In order to perform seamless handover with low handover latency and minimal packet loss. The gathered information in the first phase and the processed data by the decision algorithm in the second phase will be committed in the handover execution stage by triggering traffic redirection using mobile IP protocol [BAR12].

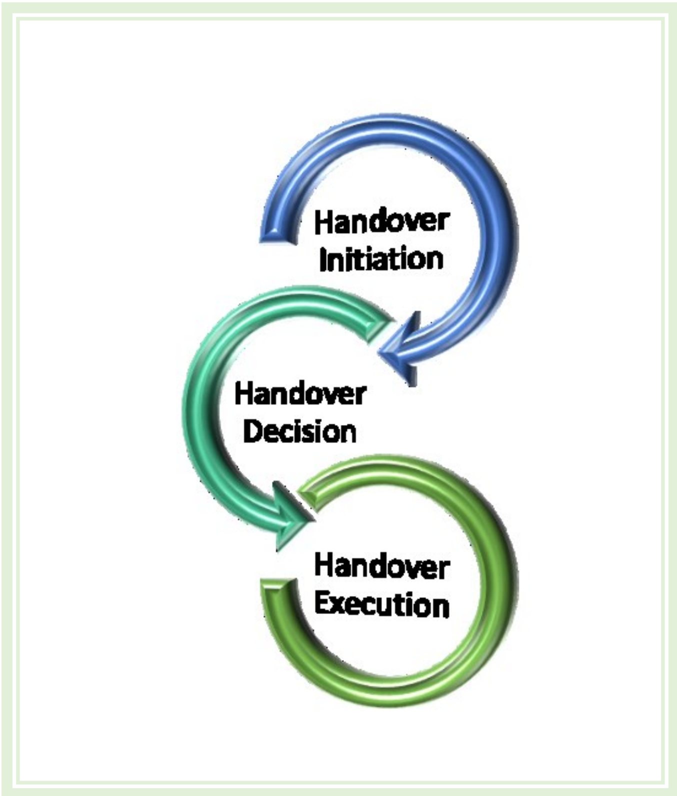

Figure 2.6: Vertical handover process phases.

2.5 IEEE 802.21 Media Independent Handover

IEEE 802.21 standard or Media Independent Handover (MIH) was published in 2009. It defines media access independent mechanisms and link layer intelligence for handover between IEEE 802 networks and non IEEE 802 networks such as cellular networks. The main purpose of the IEEE 802.21 is to assist the handover between these heterogeneous networks without service interruption [MIH09].

MIH standard supports service continuity for mobile nodes while moving between heterogeneous wireless networks, it uses cross-layer concept through an abstraction layer implemented in the protocol stack of a certain device. This layer includes Media Independent Handover Function (MIHF), which is the heart of the MIH standard. MIHF carries out the changes of the link characteristics and the application demand between the upper and lower layers of different protocol stacks. MIHF also coordinates for vertical handover with remote MIHF peers implemented in other networks. MIHF defines primitives that perform three types of MIH services as shown in Figure 2.7 that determine handover needs, initiation and decision to select the target network.

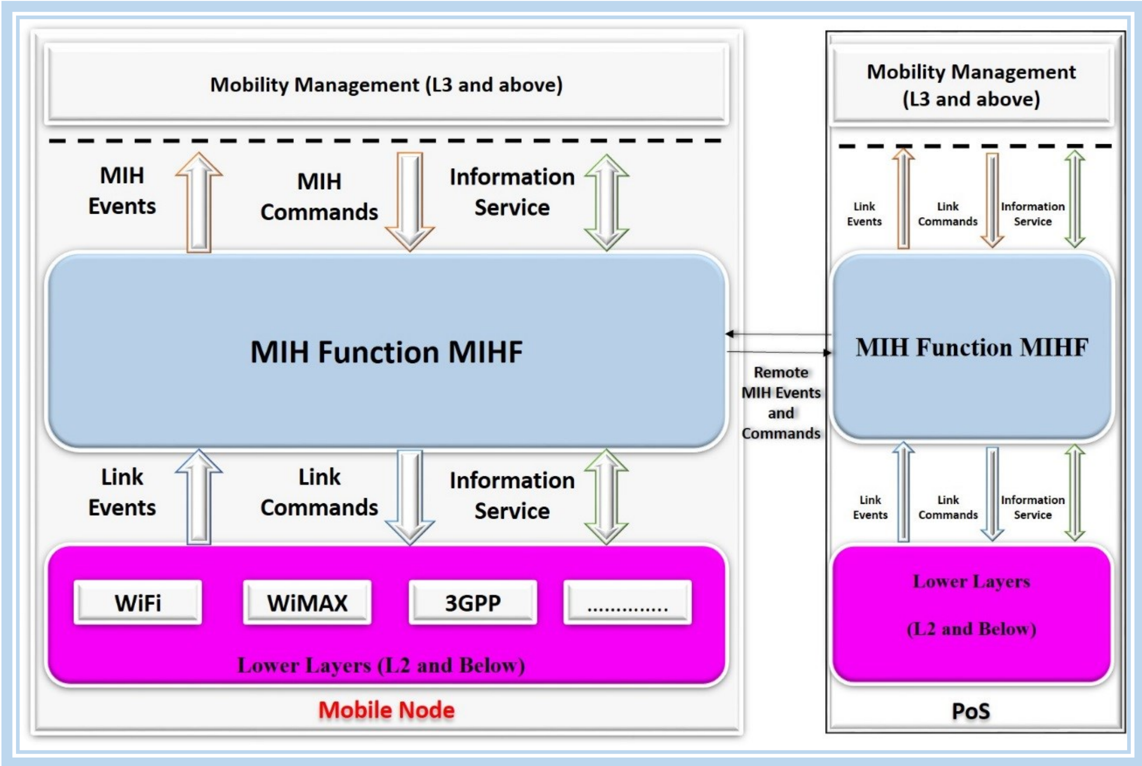

Figure 2.7: MIH Architecture [BC10].

2.5.1 Media Independent Handover Services

The Media Independent Handover provides three services as follows:

1. **Media Independent Event Service (MIES)**

This service detects the changes that occurs in the lower layers such as physical and data link layer and notify the MIHF with these changes through the link events. MIHF notifies the upper layers with the changes occurred in the lower layers through MIH events triggered from the lower layers. Example of these events are Link Status events such as Link Up, Link Down and Link Detected and Predictive event such as Link_Going_Down (LGD) [KHA12].

2. Media Independent Command Service (MICS)

MICS sent from the upper layers towards the lower layers in the protocol stack. MIH commands originated from the upper layers to the MIHF that determine the status of the link and control its behaviour [AAMH11].

3. Media Independent Information Service (MIIS)

MIIS carried information's about the neighbouring networks within a geographical area; it allows the MIHF to exchange these information's from local or remote MIHF. The information will help the handover process by showing a global view of the available networks and their features such as bandwidth, cost and location of the PoA [LKSW09].

2.5.2 Media Independent Handover Implementation

MIH is a newly standard and aims to facilitate and assist the handover process between heterogeneous access networks by providing events, commands and information to the entities that assist in the handover decision to select the target network. However, it is not implemented in the industry yet. IEEE 802.21 standard left the handover decision algorithm for competition between designers [MIH09]. MIH is implemented in wireless access technologies such as IEEE 802.11u and IEEE 802.16m. Therefore, a lot of simulations and testbed experiments are needed to evaluate the performance in vertical handover scenarios using IEEE 802.21. As far as we know, MIH has the following implementations as mentioned in literature:

- NIST add-on module developed by the national institute of standards and telecommunications for NS-2 version 2.29 and targeted for simulation environments [ANTD13].

- Open Dot Twenty One (ODTONE) is an open source implementation of MIH framework from the IEEE 802.21. It works with Windows, Linux, Android platforms and targeted for real testbed environments [Hng13].

2.6 Summary

This chapter provides an overview about the wireless access networks. WiFi and WiMAX belong to the IEEE 802 family of standards. This chapter also presents handover definition and classifications; the classifications of handover are based on type of access technology, number of connections and type of control. Among these calcifications, vertical handover based on the type of access technologies is the difficult one; also, IEEE 802.21 (MIH) standard was introduced. The MIH defines technology independent mechanisms and link layer intelligence for handover between IEEE802 networks and non IEEE 802 networks to support service continuity for mobile node while moving between heterogeneous wireless networks.

Chapter 3 explains the simulation environment including the vertical handover scenarios, the simulation tool used to design these scenarios, and finally define the performance evaluation metrics used to measure the performance in the vertical handover scenarios.

Chapter 3
Simulation Environment

3.1 Introduction

This chapter presents a description of the simulation environment, the vertical handover scenarios and the simulation parameters configured in these scenarios. This chapter also introduces an overview about the Network Simulator 2 (NS-2) which is the major tool used to design and perform vertical handover scenarios [MRMR10]. This chapter also defines the performance evaluation metrics used to observe the behaviour in the vertical handover scenarios. An overview about the trace file formats is presented and the analysing tools used to obtain the needed information from these trace files.

3.2 Simulation Tools

The National Institute of Standards and Technology (NIST) [ANTD13] with the cooperation of IEEE 802.21 working group built the implementation of IEEE 802.21 as an add-on module called NIST mobility package. The vertical handover scenarios are build using the following tools:

- The Network Simulator 2 (NS-2) version 2.29 [NS13].

- IEEE 802.21 implementation NIST mobility package [ANTD13] based on draft 3 of IEEE 802.21 [MRMR10].

- IEEE 802.16 add-on module, based on IEEE 802.16d-2004 standard and the mobility extension 802.16e-2005 [MRMR10] [NIST09].

- IEEE 802.11b add-on module [NIST07].

3.3 Simulation Scenarios

In this thesis, WiFi and WiMAX wireless access networks are used in the design of the vertical handover scenarios. These wireless networks are configured in two separated scenarios, in the first scenario, the Mobile Node (MN) moves from the WiFi to the WiMAX network and in the second scenario, the MN moves from the WiMAX to the WiFi network.

WiFi and WiMAX access networks are considered complementary solutions that can work together. The features diversity of these access networks such as bandwidth and coverage area affect the performance of the mobile applications. WiFi and WiMAX access technologies support high bandwidth with high bitrate applications. In addition the mobility direction shows the effect of the coverage area on the performance of the mobile applications; WiFi has limited coverage area compared to WiMAX coverage.

Figure 3.1 represents the topology of the vertical handover scenarios, which consists of one MN inside a moving car with constant speed. The simulation area is 3000x3000 m^2 with the deployment of one MN, one Access Point (AP) for WiFi and one Base Station (BS) for WiMAX. The scenarios have wired infrastructure between the network router and the media server. The wired links in the network are full duplex with bandwidth of 100 Mb/s, connecting the wireless AP and the BS with the network router and the router is connected to the media server. MIH components and network discovery are installed on each node in the network to facilitate the handover process and redirects the traffic from the lower layers to the upper layers.

The MN uses the concept of Multiface node, which is a virtual node that contains WiFi and WiMAX interfaces. The traffic is redirected from one interface to another while the mobile node is connected to the media server.

The range of the MN speed values used in the vertical handover scenarios are (5, 10, 15, 20, 25, 30, 40, 70, 100, 120) km/h. This range of speed values were selected due to the coverage area of both WiFi and WiMAX networks. To observe the impact of the WiFi limited coverage area on the mobility the low values of the MN are used, while in WiMAX the high values of the MN speed are used to observe the impact of the large coverage area on the mobility.

The traffic flow Constant Bitrate traffic (CBR) is used as mobile applications that generates traffic using the User Datagram Protocol (UDP). The applications bitrate values in the vertical handover scenarios used are (256, 512, 1024, 2048, 4096) kb/s. The applications bitrate values were selected to cover large category of the Internet applications that work on the mobile devices.

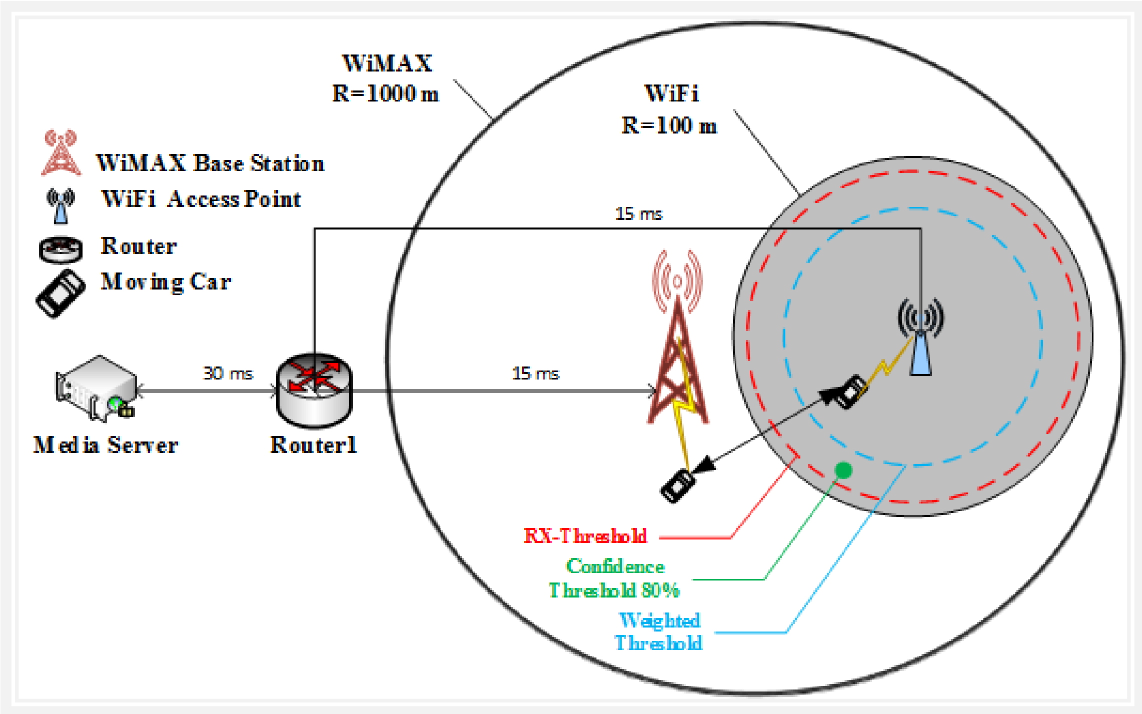

Figure 3.1: Vertical handover scenarios.

3.3.1 WiFi to WiMAX Scenario

In WiFi to WiMAX scenario, Figure 3.1 shows the MN is connected to WiFi network through the WiFi mobile interface, which is the serving Point of Attachment (PoA) at the beginning of the simulation time. The MN starts moving towards the direction of the WiMAX network at certain time with constant speed. When the MN reaches the boundaries of WiFi cell, it connects to the WiMAX network, which is the visited network through the WiMAX mobile interface due to the degradation of the received signal strength on the WiFi mobile interface. Therefore, WiMAX network becomes the new serving PoA. The simulation experiment is repeated many times by changing the speed of the MN on each simulation run.

3.3.2 WiMAX to WiFi Scenario

In WiMAX to WiFi scenario, Figure 3.1 shows the MN is connected to WiMAX network which is the serving PoA at the beginning of the simulation time. The WiMAX signal is considered available everywhere in the simulation topology due to its large coverage area. The MN start moving towards the WiFi network at certain time. As a result, the MN connects to the WiFi network when it detects the WiFi signal. WiFi is preferable network [RMT13]. This scenario was repeated many times by changing the speed of the MN on each simulation run.

3.4 Simulation Parameters

The simulation parameters shown in Table 3.1 are defined and configured in the vertical handover scenarios. Some of these parameters are based on [MRMR10] [RMT13].

Table 3.1: Simulation parameters for vertical handover scenarios [MRMR10] [RMT13].

Global Parameters	
Simulation Area	3000 x 3000 m
Simulation Time	50 sec.
Mobile speed	5, 10, 15, 20, 25, 30, 40, 70, 100,120 km/h
Applications Bitrate	CBR; 256, 512, 1024, 2048, 4096 kbps
Packet Size	1024 Byte
Wired Links	100 Mbps
Confidence Threshold	80%
WiFi Parameters	
Coverage area (Radius)	100 m
Radio Propagation Model	TwoRayGround
Antenna model	Omni Antenna
MAC Type	Mac/802_11
Frequency	2.412 GHz
Bandwidth	11 Mbps
Transmission Power	0.0134 W
RXThresh	1.31272e-10 W
Pr_limit	1.2
Weighted Threshold (Pr_limit * RXThresh)	1.575264e-10 W
WiMAX Parameters	
Coverage area (Radius)	1000 m
Radio Propagation Model	TwoRayGround
Antenna model	Omni Antenna
MAC Type	Mac/802_16
Frequency	3.5 GHz
Bandwidth	15 Mbps
Transmission Power	15 W
RXThresh	7.59375e-11 W
Lgd_factor	1.1
Weighted Threshold (Lgd_factor * RXThresh)	8.353125e-11 W

3.5 Network Simulator 2

Wireless network simulation is widely used in a variety of civilian and military applications to measure the performance of the network infrastructure. There are many tools used for wireless network simulation like NS-2, OPNET, QualNet, OMNeT++ and MATLAB. In this thesis, NS-2 was selected because it is the major tool used to design and perform vertical handover scenarios [MRMR10] and the availability of the MIH implementation through the NIST mobility package designed for NS-2 version ns-2.29. In addition, the mobility package provides the capabilities to create multiple interfaces on the MN that are necessary in this study to perform vertical handover between WiFi and WiMAX networks. Finally, NS-2 is an open source software that can be obtained freely by all users. In the other wireless network simulators, the implementation of MIH module built by the researches. Therefore, it is not easy to obtain this implementation and use it. In addition, some of these simulators are not an open source, which makes it difficult for the students and researches to obtain and use these simulators freely. In vertical handover, a set of evaluation tools used in the literature as shown in Table 3.2.

Table 3.2: Evaluation tools used in the literature [BCCM11].

Type	Tool	Usage %
Simulation	ns-2	14.3
	OPNET	4.1
	MATLAB	11.9
	Self-design	2.4
	Others (QualNet)	7.1
Testbed	Short scale	31.3
	Large scale	25.7

NS-2 is a discrete event driven network simulation tool developed by the University of California Berkeley, and dedicated for networking research [EG12]. NS-2 is written in two languages; C++ and Object-oriented Tool Command language (OTcl). The OTcl language acts as the frontend (user interface) while the C++ acts as the backend running the actual simulation. C++ and OTcl are linked together using TclCL. NS-2 uses OTcl to create and configure a network, and uses C++ to run simulation. C++ is fast to run but slow to change, making it suitable for detailed protocol implementation. OTcl is slow to run but fast to change making it ideal for simulation configuration [IH08] [SGB12].

The strength of NS-2 is its availability for download on a variety of operating systems freely because it is an open source software. The open source nature of NS-2 makes it very attractive for the students and researches in the communication networks field. The weakness of NS-2 is the lack of graphical presentation of the output data. In addition, it is not a user-friendly software because it has text base interface [SH11]. The component diagram of NS-2 is shown in Figure 3.2.

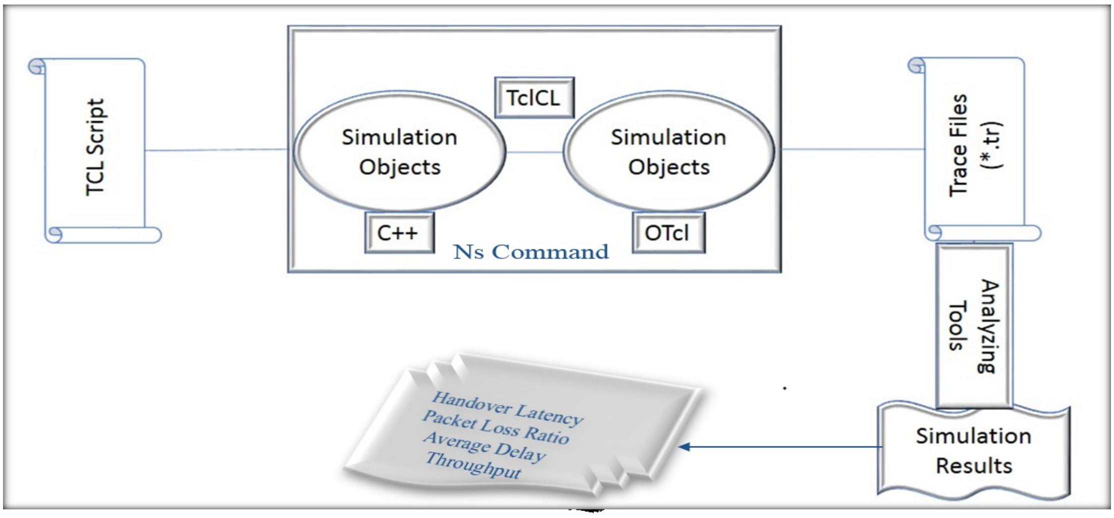

Figure 3.2: NS-2 architecture and simulation process.

3.6 Power Boundaries in NS-2

Three parameters used to identify the power boundaries in simulation as shown in Figure 3.3 for both WiFi AP and WIMAX BS that are defined in NS-2 as follows [MRMR10]:

- **CS Tresh** defines the minimum power level to sense wireless packets and switch the MAC from idle to busy.
- **RX Tresh** defines the minimum power level to receive wireless packets without error.
- **Weighted threshold** (RX Tresh ∗ pr_limit); defines the minimum power level that an interface senses before triggering MIH event "Link_Going_Down". Pr_limit is always equal or superior to 1. The higher the pr_limit coefficient, the sooner the event will be generated.

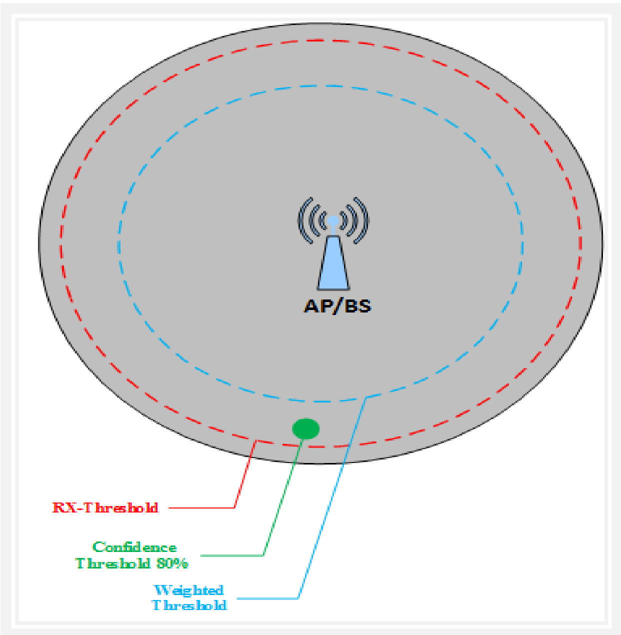

Figure 3.3: Power boundaries in NS-2 [MRMR10].

In WiFi to WiMAX scenario, two power level thresholds are considered, the received threshold (RxTresh) and the weighted threshold (Pr_limit* RxTresh). The Link-Going-Down event is a predictive event, it prevents the received signal strength to reach the RxTresh. When the received signal strength goes below the weighted threshold, the Link-Going-Down event is triggered with a probability of the link-down until it reaches the confidence threshold and the handover took place from WiFi to WiMAX.

In WiMAX to WiFi scenario, two power level thresholds are considered also, the received threshold and the weighted threshold. The received signal strength on the WiMAX mobile interface did not go below the weighted threshold while the MN was moving towards the WiFi network. When the WiFi signal is detected, MIH events LINK_Detected and LINK_UP are triggered and handover took place from WiMAX to WiFi.

3.7 Performance Evaluation Metrics

To evaluate the performance of the mobile applications in the vertical handover scenarios shown in Figure 3.1, key of performance evaluation metrics are used. The performance evaluation metrics are Normalized Throughput, Average End-to-End Delay, Packet loss Ratio and Handover Latency. These metrics are considered because they can describe the performance of the applications in the vertical handover scenarios when the mobile node moves from one access network to another different access network.

3.7.1 Average Throughput

Average throughput is the ratio of data packets delivered to the destination by time interval [MIH09]. It is measured in kilo bit per second (kb/s). Mathematically it is expressed in the following formula:

$$\boldsymbol{Average\ Throughput} = \frac{\sum_{i=1}^{N} r_i \times ps \times 8bit}{T} \quad \text{[MHA10]} \qquad (3.1)$$

Where r: Total Received Packets; ps: Packet Size in bytes; T: Time Interval.

To observe the behavior of throughput for all applications bitrate, Average Throughput was normalized. The Normalized Throughput is expressed by the following formula:

$$\boldsymbol{Normalized\ Throughput} = \frac{Average\ Throughput}{Applications\ bitrate} \qquad (3.2)$$

In this research, the mobile node moves from source towards the destination in the vertical handover scenarios. The connection time of the mobile node to its serving PoA and to the visited network is affected by the following formula:

$$\boldsymbol{Time} = \frac{\boldsymbol{Distance}}{\boldsymbol{Speed}} \tag{3.3}$$

3.7.2 Packet Loss Ratio

Packet Loss ratio (PLR) is the difference between the total number of packets sent by the correspondent node (CN) and the number of the packets received by WiMAX mobile interface and WiFi mobile interface divided by the total number of packets send by the CN [SMB11]. The lower value of the packet loss ratio indicates better application performance in the vertical handover scenarios. Mathematically it is expressed in the following formula:

$$\boldsymbol{PLR} = \frac{\sum_{i=1}^{N} s_i - r_i}{\sum_{i=1}^{N} s_i} \times 100 \qquad \text{[MHA10]} \tag{3.4}$$

Where s: Total Sent packets; r: Total Received Packets.

3.7.3 Average End-to-End Delay

Average End-to-End Delay (E2ED) is the average time or one-way latency a packet takes to reach the destination from a source node. E2ED Delay includes processing delay, network delay, in addition to prorogation, transmission and queuing delay [MIH09]. It is measured in millisecond (ms). This metric gives indication about the performance of the applications in the vertical handover scenarios by describing the packet delivery time inside the wireless access networks. Mathematically it is represented by the formula:

$$\boldsymbol{E2ED} = \frac{\sum_{i=1}^{N} \boldsymbol{tr_i - ts_i}}{\sum_{i=1}^{N} \boldsymbol{r_i}} \qquad \text{[MHA10]} \qquad (3.5)$$

Where tr: Packet Receive Time; ts: Packet Send Time; r: Total Received Packets.

3.7.4 Handover Latency

Handover Latency is a type of delay that occurs when the mobile nodes moves between the access networks. It is defined by [RMT13] as the difference between the time of the first packet received on the mobile interface of the visited network and the last packet received on the mobile interface of the serving PoA. The two lines shown in Figure 3.4 are an example of the received packets on both mobile node interfaces while the mobile node is connected to the media server in WiFi to WiMAX scenario. The first line represents the first packet received on the WiMAX mobile interface which has an ID=6, and the second line represents the last packet received on the WiFi mobile interface which has an ID=4. The two lines are used to calculate the handover latency during the vertical handover from WiFi to WiMAX.

First packet received on the WiMAX mobile interface at MN speed 5 km/h	r -t 37.766981416 -Hs 6 -Hd 12582913 -Ni 6 -Nx 1701.71 -Ny 1000.00 -Nz 0.00 -Ne -1.000000 -Nl MAC -Nw --- -Ma 0 -Md 2000000 -Ms 8 -Mt 0 -Is 0.0 -Id 12582913.0 -It cbr -Il 1024 -If 0 -Ii 1143 -Iv 29 -Pn cbr -Pi 1085 -Pf 0 -Po 0
Last packet received on the WiFi mobile interface at MN speed 5 km/h	r -t 37.638968097 -Hs 4 -Hd 8388609 -Ni 4 -Nx 1701.89 -Ny 1000.00 -Nz 0.00 -Ne -1.000000 -Nl MAC -Nw --- -Ma d4 -Md 1 -Ms 0 -Mt 800 -Is 0.0 -Id 8388609.0 -It cbr -Il 1024 -If 0 -Ii 1137 -Iv 29 -Pn cbr -Pi 1081 -Pf 1 -Po 0

Figure 3.4: First packet and last packet on mobile interfaces in WiFi to WiMAX scenario.

3.8 Trace Files

NS-2 generates trace files during the simulation process. These trace files are text files contain all the information about what happened during the simulation process and its extension (.tr).

3.8.1 Trace File Format

NS-2 has two types of trace formats; the first one is the normal format for wired networks and the other one is the new format for wireless networks, Figure 3.5 show two lines for the format of the wired network, the first line represents the traffic for packet send between the media server (node 0) and the gateway router (node1) at simulation time 3 seconds, the size of packet is 1024 byte and its type cbr. The source of the traffic is the media server with IP address (0.0.0.0) and the destination of the packet is the WiFi mobile interface with IP address (2.0.1.0). While the second line represents one packet send, the destination is the WiMAX mobile interface with ip address (3.0.1.0) at simulation time 37.72 seconds.

event	time	from node	to node	packet type	packet size	flags	fid	source address	destination address	sequence number	packet
+	3	0	1	cbr	1024	-------	0	0 0.0.0.0	2.0.1.0	0	18
+	37.72	0	1	cbr	1024	-------	0	0.0.0.0	3.0.1.0	1085	1143

Figure 3.5: Wired trace format and examples of trace line

Figure 3.6 shows an example of two lines for the format of wireless networks. The first line represents received packet on the WiFi mobile interface which has ID=4 with packet size 1024 byte and cbr traffic type at simulation time 3.046787617 seconds. While the second line represents received packet at the WiMAX mobile interface which has ID=6 with packet size 1024 and cbr traffic type at simulation time 37.766981416. In this thesis, WiFi and WiMAX are wireless networks that have the same trace formats.

```
r -t 3.046787617 -Hs 4 -Hd 8388609 -Ni 4 -Nx 1749.94 -Ny 1000.00 -Nz 0.00 -Ne
-1.000000 -Nl MAC -Nw --- -Ma d4 -Md 1 -Ms 0 -Mt 800 -Is 0.0 -Id 8388609.0 -It
cbr -Il 1024 -If 0 -Ii 18 -Iv 29 -Pn cbr -Pi 0 -Pf 1 -Po 0

r -t 37.766981416 -Hs 6 -Hd 12582913 -Ni 6 -Nx 1701.71 -Ny 1000.00 -Nz 0.00 - Ne
-1.000000 -Nl MAC -Nw --- -Ma 0 -Md 2000000 -Ms 8 -Mt 0 -Is 0.0 -Id 12582913.0 -
It cbr -Il 1024 -If 0 -Ii 1143 -Iv 29 -Pn cbr -Pi 1085 -Pf 0 -Po 0
```

Figure 3.6: Wireless trace format and example of trace lines

Table 3.3: Wireless Trace Format [NSN13]

Event	Abbreviation	Flag	Type	Value
Wireless Event On WiFi Interface	r: Receive	-t	3.046787617	Time (* For Global Setting)
		-Ni	4	Node ID
		-Nx	1749.94	Node X Coordinate
		-Ny	1000	Node Y Coordinate
		-Nz	0	Node Z Coordinate
		-Ne	-1	Node Energy Level
		-Nl	MAC	Network trace Level (AGT, RTR, MAC, etc.)
		-Nw	---	Drop Reason
		-Hs	4	Hop source node ID
		-Hd	int	Hop destination Node ID, -1, -2
		-Ma	D4	Duration
		-Ms	0	Source Ethernet Address
		-Md	1	Destination Ethernet Address
		-Mt	800	Ethernet Type
		-It	cbr	Packet Type
		-Il	1024	Packet Size
		-Pn	cbr	Packet Type

3.8.2 Debugging Messages

NS-2 provides messages during the simulation process by enabling the debugging mode as shown in Figures 3.7 and 3.8. These messages contain information about the MIH events, received signal strength, RxTreshold and weighted threshold.

```
At 37.670988098 Mac 1, rxp 1.362597e-10 thresh 1.312720e-10 weighted-thresh 1.575264e-10
At 37.670988 in 4.0.0 MIH Agent received LINK GOING DOWN trigger.
At 37.670988 in 4.0.0 Interface Manager received MIH event
At 37.670988 in 4.0.0 Handover1 received Link going down
        probability = 81%
        We fake a link down
At 37.670988 in 4.0.0 Handover1 received link down
        MacAddr=1
Studying flow 0 using interface 2.0.1
        Must redirect this flow to use interface 3.0.1
At 37.670988 MIPv6 Agent in 4.0.0 send redirect message using interface 3.0.1
At 37.670988098 Mac 1 (Node 2.0.1) drop packet because does not belong to bss_id -1
(hdv_state_=1)
At 39.458315 in Mac 3 weighted RXThresh: 8.353125e-11 rxp average 3.174274e-10
At 39.460305382 Mac 1 bss timer expired
At 39.460305382 Mac 1 received link_disconnect command
At 39.460305 in 4.0.0 MIH Agent received LINK DOWN trigger.
At 39.460305 in 4.0.0 Interface Manager received MIH event
At 39.460305 in 4.0.0 Handover1 received link down
        MacAddr=1
Studying flow 0 using interface 3.0.1
```

Figure 3.7: Example of MIH events in WiFi to WiMAX scenario.

```
At 45.298315 in Mac 3 weighted RXThresh: 8.353125e-11 rxp average 3.009469e-10
At 45.300305353 Mac 1 Recv Beacon from 0
At 45.300305 in 4.0.0 MIH Agent received LINK DETECTED trigger.
At 45.300305 in 4.0.0 Interface Manager received MIH event
At 45.300305 in 4.0.0 Handover1 link detected
        The new interface is better...connect
At 45.301511234 Mac 1, rxp 1.576611e-10 thresh 1.312720e-10 weighted-thresh
1.575264e-10
        Our new base station is : 0
At 45.301511 in 4.0.0 MIH Agent received LINK UP trigger.
At 45.301511 in 4.0.0 Interface Manager received MIH event
At 45.301511 in 4.0.0 Handover1 received link up
        type 19, MacAddr=1, MacPoA=0
At 45.310315 in Mac 3 weighted RXThresh: 8.353125e-11 rxp average 3.009186e-10
At 45.310334879 Mac 1, rxp 1.577030e-10 thresh 1.312720e-10 weighted-thresh
1.575264e-10
At 45.310360 in 4.0.0 Handover1 received new prefix 2.0.0
Studying flow 0 using interface 3.0.1
        The new up interface is better...checking for flows to redirect
Studying flow 0 using interface 3.0.1
        Must redirect flow from interface 3.0.1 to 2.0.1
At 45.310360 MIPv6 Agent in 4.0.0 send redirect message using interface 2.0.1
```

Figure 3.8 Example of MIH events in WiMAX to WiFi scenario.

3.8.3 Trace File Analysis

This section describes the tools and commands used to filter and analyse the generated trace files during the simulation process to measure the performance in the vertical handover scenarios. The "AWK" script and set of "grep" Linux command were used to analyse and filter the trace files that contain all the information needed during the simulation process. "AWK" is a programming language that is designed for processing text-based data, and was created at Bell Labs in the 1970s. The name AWK is derived from the family names of its authors - Alfred Aho, Peter Weinberger and Brian Kernighan [AWK12]. "grep" is a Linux command-line utility for searching plain-text data sets for lines matching a regular expression.

The Lines in Figure 3.9 are an example of the Through_E2ED.awk script that calculates the Average throughput between the media server and the mobile interfaces WiFi and WiMAX in addition to the Average end-to-end delay.

```
awk –f  Through_E2ED.awk src=0 dst=4 pkt=1024 flow=0 data5.tr

awk –f  Through_E2ED.awk src=0 dst=6 pkt=1024 flow=0 data5.tr
```

Figure 3.9: AWK script used to calculate the Average throughput and E2ED

Table 3.4: Through_E2ED.awk script parameters.

Src=0	Id of the source traffic (CN) or (media server)
dst=4	WiFi mobile interface id
dst=6	WiMAX mobile interface id
pkt=1024	CBR packet size
flow=0	Data flow is one way from (CN is sender; Multiface is receiver)
data5.tr	Name of the trace file generated when the mobile node speed was 5 km/h

The Lines in Figure 3.10 are an example of the grep Linux command that calculates the packets sent and received between the media server and both WiFi and WiMAX mobile interfaces, where IP=2.0.1, ID=4 are belong to the WiFi mobile interface and IP=3.0.1, ID=6 are belong to WiMAX mobile interface. .

```
grep "0 0.0.0.0 2.0.1" data5.tr | grep ^+ | grep "0 1 cbr"

grep "It cbr -Il 1024 -If" data5.tr | grep ^r | grep "Ni 4"
```

```
grep "0 0.0.0.0 3.0.1" data5.tr | grep ^+ | grep "0 1 cbr"

grep "It cbr -Il 1024 -If" data5.tr | grep ^r | grep "Ni 6"
```

Figure 3.10: Example of grep Linux command to calculate the send and received packets.

3.9 Summary

This chapter provides a description of the simulation environment; two vertical handover scenarios are defined. The vertical handover scenarios are WiFi to WiMAX and WiMAX to WiFi. This chapter also presents an overview about NS-2 which is the simulation tool used to design and configure these scenarios. This chapter also gives an overview about the performance evaluation metrics used to observe the behaviour in the vertical handover scenarios. In addition, this chapter also provides a description of the generated trace files from NS-2 and gives examples of the wireless trace formats and finally this chapter presents the analysing tools used to filter and analyse these trace files to obtain the needed information about what happened during the simulation process.

Chapter 4 presents the simulation results obtained from the performance evaluation metrics used in this thesis.

Chapter 4
Simulation Results

4.1 Introduction

This chapter presents the simulation results and analysis for the performance evaluation in WiFi to WiMAX and WiMAX to WiFi scenarios as shown in Figure 3.1. The behaviour of the evaluation metrics are observed as a function of the mobile node speed for different bitrate applications. The simulation results are presented in terms of Normalized Throughput, Packet Loss Ratio, Average End-to-End Delay and Handover Latency. The simulation results for the performance metrics namely, Packet Loss Ratio, Average End-to-End Delay and Handover Latency are compared to the International Telecommunication Union-Telecommunication (ITU-T) standard recommendations. This standard defines specific values for these performance metrics. The recommended values are very important and must be met to fulfil QoS requirements for the applications that is aware of QoS such as voice and video. This comparison ensures that the performance evaluation metrics have acceptable values or not according to the range of values specified by the ITU-T recommendations.

4.2 Normalized Throughput

Service continuity is a challenging issue in vertical handover when the mobile node moves between heterogeneous networks. Therefore, throughput becomes an important evaluation metric for the performance of the applications; specifically when the mobile node reaches the cell boundaries towards the visited network. The normalized throughput is plotted as a function of the MN speed for different bitrate applications.

4.2.1 WiFi to WiMAX Scenario

In WiFi to WiMAX scenario, at the beginning of the simulation, the MN is connected to the WiFi network, which is the serving point of attachment (PoA) through its WiFi mobile interface. The traffic flows between the media server and the WiFi mobile interface and the normalized throughput is calculated as shown in Figure 4.1. It can be noticed that as the mobile node speed increases the normalized throughput slightly decreases. In addition, for all bitrate applications, the normalized throughput at MN speed 5 km/h is higher than the normalized throughput at MN speed of 120 km/h. It is also observed that the normalized throughput for the low bitrate application is slightly higher than the high bitrate application.

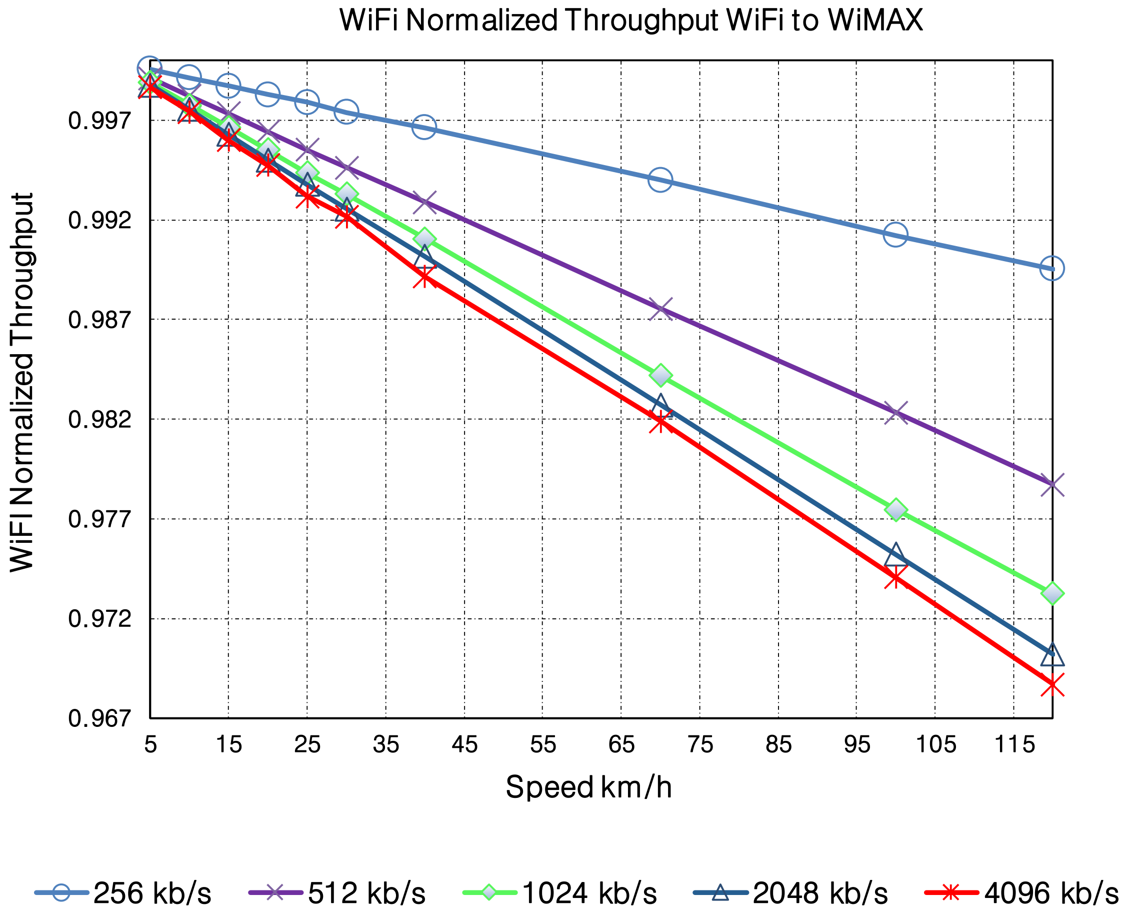

Figure 4.1: WiFi Normalized throughput in WiFi to WiMAX scenario.

The normalized throughput decreases with the increasing of speed because the distance from the WiFi access point increases and the received signal strength decreases when the mobile node moves far away from its serving PoA. Therefore, the connection time to the WiFi network becomes shorter and the mobile node reaches the WiFi cell boundaries faster based on (3.3). This decreases the received packets on the WiFi mobile interface as shown in Figure 4.2. As a result, when the mobile node speed increases the normalized throughput decreases accordingly based on (3.2). In addition, the normalized throughput at speed 5 km/h is slightly better than normalized throughput at speed 120 km/h because the packets received on the WiFi mobile interface at speed 5 km/his slightly higher than the packets received at speed 120 km/h. This is due to the fact that the connection time to the WiFi access point when the MN moves at speed 5 km/h is longer than the connection time when the MN moves at speed 120 km/h.

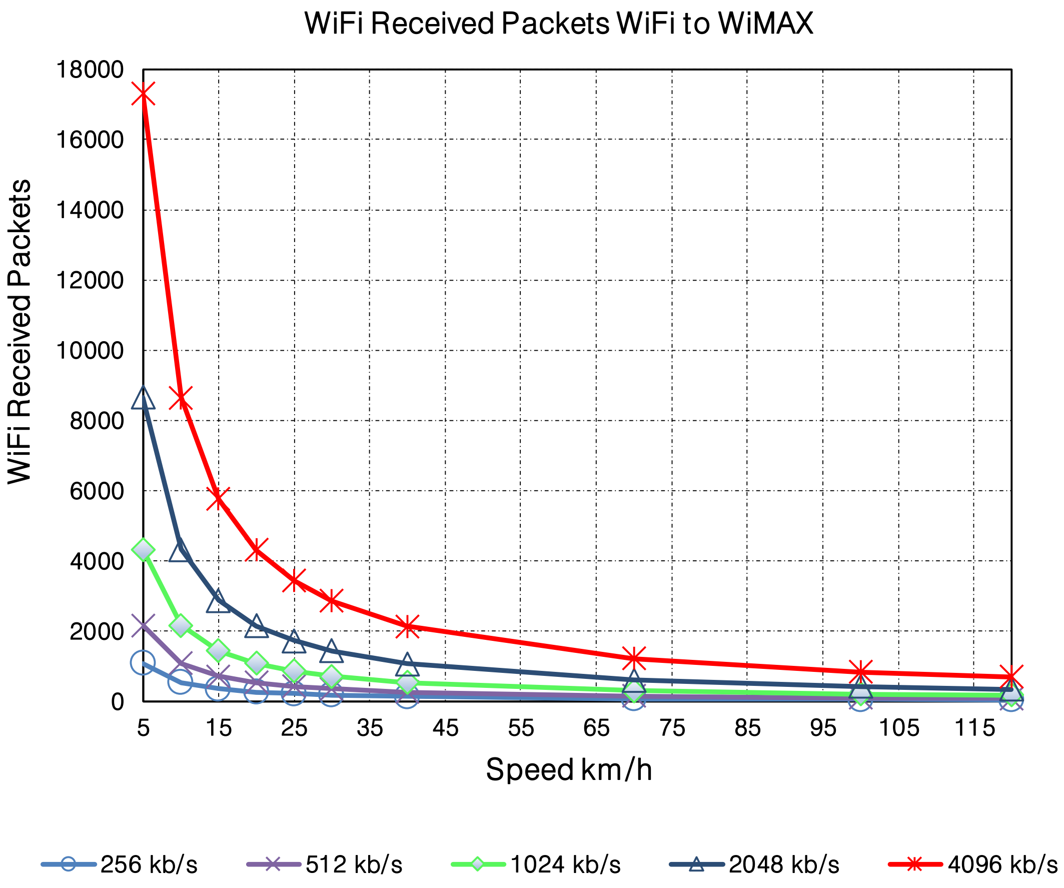

Figure 4.2: WiFi Received packets in WiFi to WiMAX scenario.

Now in the same scenario WiFi to WiMAX, when the MN enters the WiMAX network that is the visited network, the traffic flow is redirected to the WiMAX mobile interface while the MN keeps the connection with the media server. It is observed from Figure 4.3 that by increasing the MN speed, the normalized throughput in WiMAX is almost constant. This is because of the fact that the WiMAX network supports high mobility due to its large coverage area.

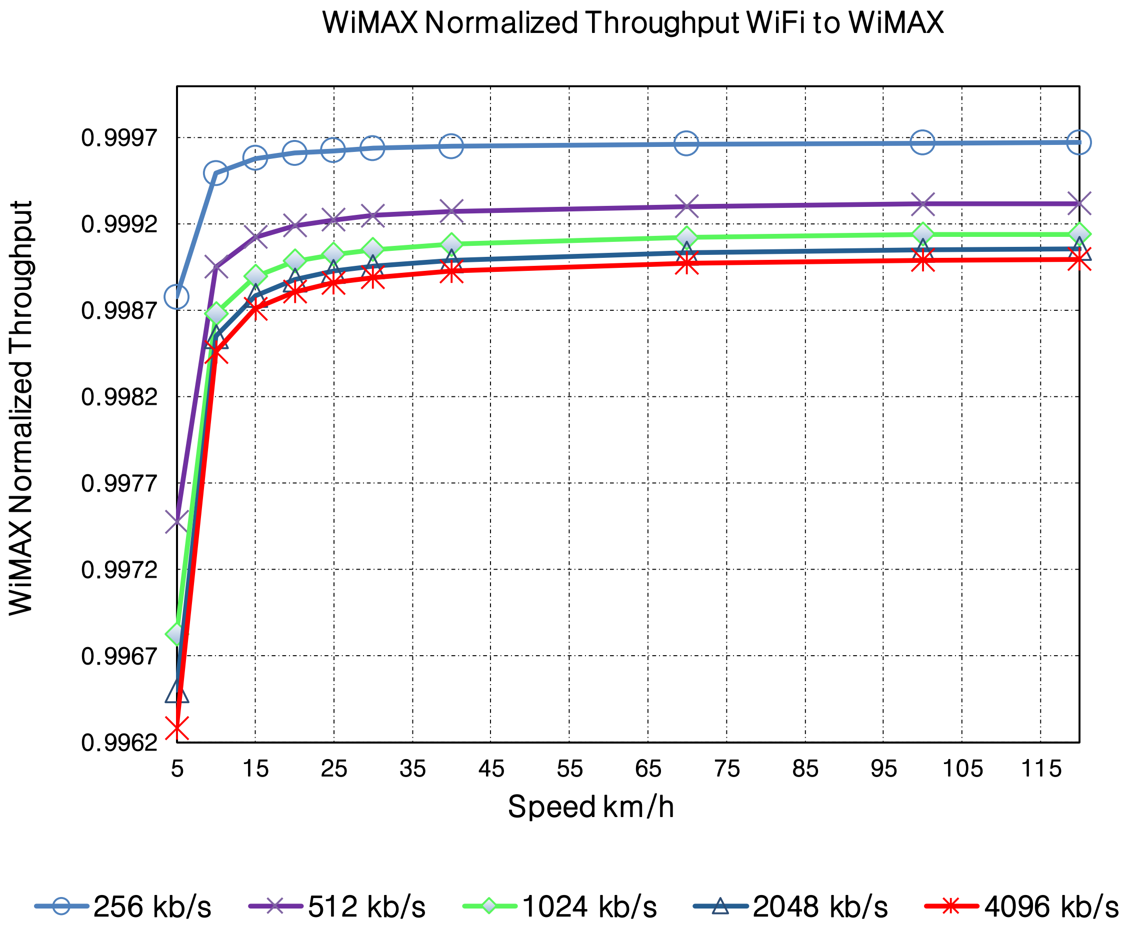

Figure 4.3: WiMAX Normalized in WiFi to WiMAX scenario.

To summarize the results of the throughput in WiFi to WiMAX scenario, In WiFi, the normalized throughput slightly decreases with increasing MN speed while it leaves the WiFi network. The normalized throughput on the WiMAX mobile interface was almost constant when the MN enters the WiMAX network. From the obtained results, we ensure that the service continuity is achieved in WiFi to WiMAX scenario.

4.2.2 WiMAX to WiFi Scenario

In WiMAX to WiFi scenario, the mobility direction of the MN is changed. In this scenario, and at the beginning of the simulation time, the MN is connected to the WiMAX network, the serving PoA and moves toward the WiFi network, which is the visited network. The traffic flows between the media server and the WiMAX mobile interface. It is observed from Figure 4.4 that the normalized throughput slightly decreases as the MN speed increases. In addition, the normalized throughput at speed 5 km/h is slightly higher than the normalized throughput at speed 120 km/h.

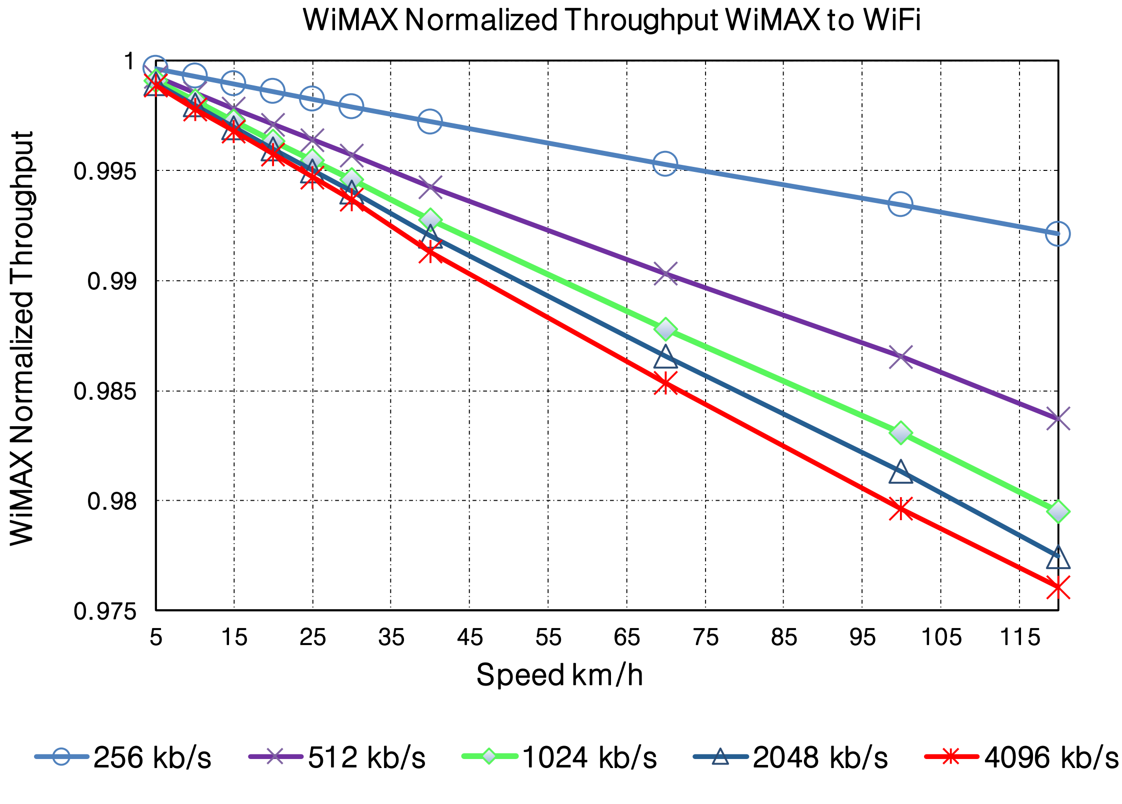

Figure 4.4: WiMAX Normalized throughput in WiMAX to WiFi scenario.

This slight decrease in the normalized throughput occurs because the connection time to WIMAX network becomes shorter when the MN moves far away from the WiMAX base station based on (3.3).This causes the received packets on the WiMAX mobile interface to decrease. As a result, the WiMAX normalized throughput decreases slightly based on (3.2). In addition, the normalized throughput at MN speed 5 km/h is slightly higher than the normalized throughput at 120 km/h because the received packets at speed 5 km/his higher than the received packets at speed 120 km/h. While in the same WiMAX to WiFi scenario, the traffic is redirected to the WiFi mobile interface when the MN enters the WiFi network, the visited network and the MN is still connected to the media server during traffic redirection. The normalized throughput is almost constant with increasing the speed of MN due to the increase in the WiFi signal strength.

Now to sum up the WiMAX to WiFi scenario, simulation results show that the performance of the applications is not affected by increasing the speed of the MN and service continuity is achieved without interruption when redirecting the traffic from the WiMAX mobile interface to the WiFi mobile interface.

To summarize the two scenarios WiFi to WiMAX and WiMAX to WiFi. The behaviour of the normalized throughput in WiFi to WiMAX and WiMAX to WiFi scenarios is directly related to the mobility direction. The normalized throughput in both scenarios is slightly decreased when the MN leaves WiFi and WiMAX networks and it is almost constant when the MN entering them. As a result, the normalized throughput as an evaluation metric is slightly affected with the MN speed when leaves its serving PoA, but this behaviour does not affect the performance of the applications. The results of the normalized throughput values were expected, because of the high bandwidth of both

WiFi and WiMAX networks and the assistance of the MIH standard services in redirecting traffic between the media server and the network interfaces on the MN.

4.3 Packet Loss Ratio

Packet loss ratio is another important metric that should be considered when evaluating the performance of mobile applications in the vertical handover scenarios. Its values should be within the acceptable ranges of standards recommendation for the applications that are aware of packet loss ratio. The packet loss ratio QoS constrains are defined clearly in the ITU-T standard. Therefore, the simulation results of this evaluation metric are compared to this standard to ensure if these values are within acceptable ranges or not. In the subsections below, all the packet loss ratio graphs are plotted as a function of the MN speed for different bitrate applications.

4.3.1 WiFi to WiMAX Scenario

In WiFi to WiMAX scenario, the packet loss ratio is measured when the MN is connected to WiFi and WiMAX networks. In WiFi, the traffic flows between the media sever and the WiFi mobile interface. It is noticed from Figure 4.5 that the packet loss ratio for all bitrate applications was affected by the MN speed. The packet loss ratio on the WiFi mobile interface increases by increasing the MN speed. It is also observed that the packet loss ratio at speed 20 km/h is 1.1% and the packet loss ratio at speed of 40 km/h is 2.1%. These values will not fulfil the QoS requirements, as the allowable standard recommendations is 1% and 2% for video and voice applications respectively.

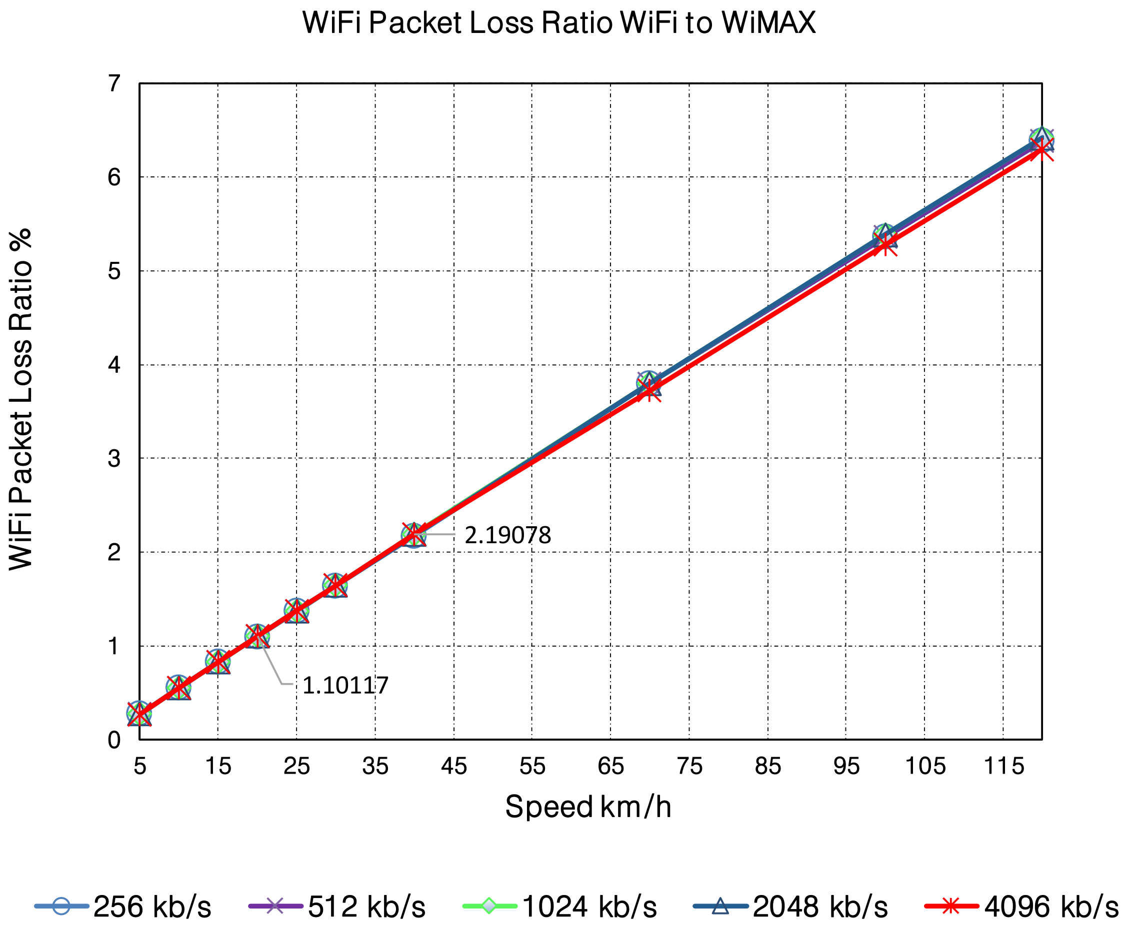

Figure 4.5: WiFi packet loss ratio in WiFi to WiMAX scenario.

The packet loss ratio increases with the increasing of the MN speed because the MN moves far away from the WiFi network and the distance increases. Therefore, degradation in the received signal strength occurs and the connection time to this network becomes shorter based on (3.3) by increasing the MN speed. As a result, the number of sent packets decreases accordingly. At a specific bitrate, the number of lost packets; which is the difference between the send and received packets on the WiFi mobile interface is almost constant for all speeds. These packets were lost during the vertical handover process due to the handover latency; which is the difference between the time for the first packet on the visited network and the time of the last packet on the serving PoA. Figure 4.6 shows the number of lost packets for all bitrate applications.

As a result, based on the definition of the packet loss ratio in (3.4), packet loss ratio increases on WiFi mobile interface with increasing the MN speed due to the decrease in sent packets and constant lost packets for specific bitrates.

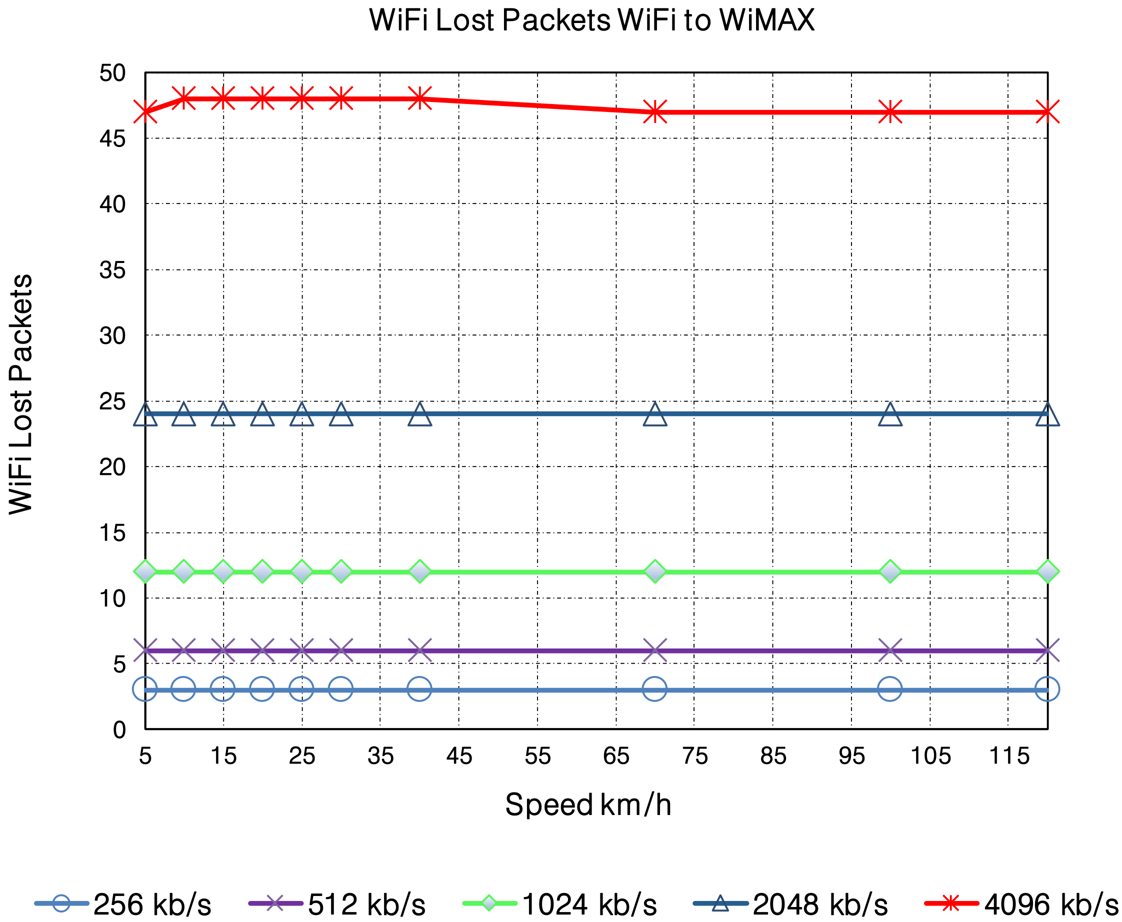

Figure 4.6: WiFi Lost packets in WiFi to WiMAX scenario.

The Simulation results of the packet loss ratio degrades to unacceptable values at certain MN speed. These values are compared to the ITU-T standard recommendations. The packet loss ratio degrades to 2.1% when the MN moves at speed over 40 km/h for voice mobile applications. The video mobile applications suffer from packet loss and degrades to 1.1% when the MN speed exceeds 20 km/h. Therefore, based on these results, the speed of the mobile node should be considered carefully by the decision algorithm's designers in the vertical handover scenarios from WiFi to WiMAX networks for the applications that is aware of packet loss ratio.

Now in the same WiFi to WiMAX scenario, the packet loss ratio is observed when the MN enters the WiMAX network and the traffic is redirected to the WiMAX mobile interface. It is noticed from Figure 4.7 that when the mobile speed increases, the packet loss ratio on the WiMAX mobile interface is almost constant. Packet loss values are acceptable and within the range of ITU-T standard.

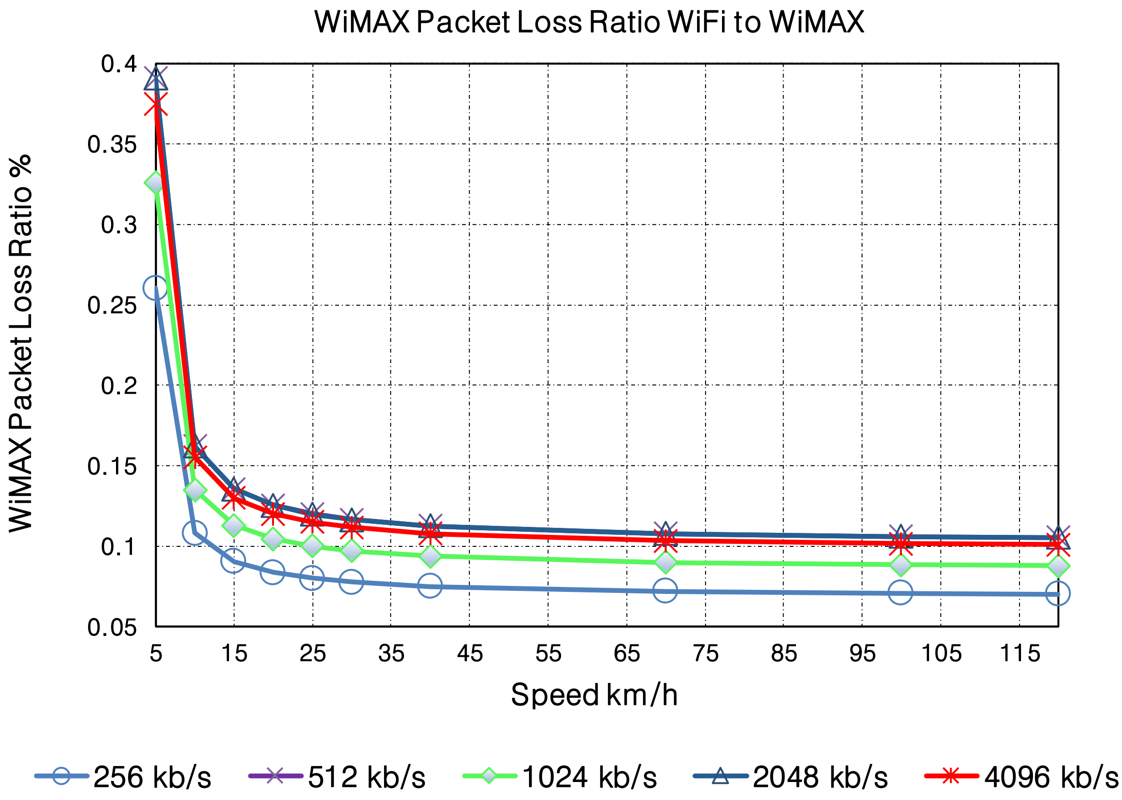

Figure 4.7: WiMAX packet loss ratio in WiFi to WiMAX scenario.

To sum up the WiFi to WiMAX scenario, the packet loss ratio on the WiFi mobile interface increases due to the decrease in connection time and sent packets with increasing MN speed when it is leaving the WiFi network. Therefore, the packet loss ratio will affect the performance of the mobile applications that is aware of packet loss ratio at Specific MN speed. While the packet loss ratio on the WiMAX mobile interface in the same WiFi to WiMAX scenario is almost constant when the MN enters the WiMAX network. The values of the packet loss ratio are acceptable and within the range of the ITU-T standard.

4.3.2 WiMAX to WiFi Scenario

In the WiMAX to WiFi scenario, the packet loss ratio on the WiMAX mobile interface is 0% for all bitrate applications with increasing the MN speed. This is because there are no lost packets on the WiMAX mobile interface due to the high user mobility of WiMAX network and the availability of the signal everywhere in the simulation area due to its large coverage area. Therefore, the sent packets from the media server are delivered successfully to the WiMAX mobile interface. As a result, there was no packet loss ratio on the WiMAX mobile interface with the increasing of the MN speed. This behaviour indicates that the packet loss ratio is not affected by increasing speed when the traffic is redirected to the WiFi mobile interface during the vertical handover.

In the same WiMAX to WiFi scenario, the packet loss ratio, shown in Figure 4.8, on the WiFi mobile interface is almost constant when the MN speed is increasing. The values are acceptable and within the range of the ITU-T standard and does not affect the performance of the applications that is aware of packet loss ratio.

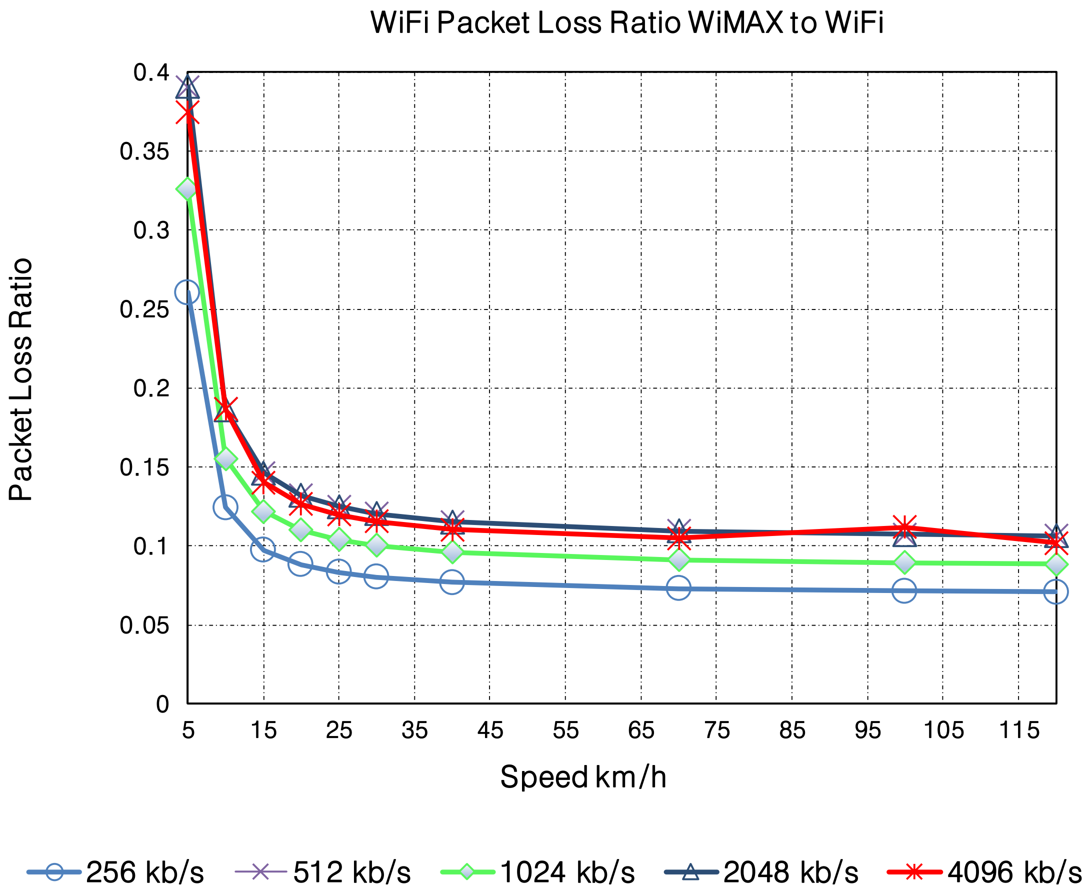

Figure 4.8: WiFi packet loss ratio in WiMAX to WiFi scenario.

To sum up, the simulation results in WiMAX to WiFi scenario show that no packet loss ratio on WiMAX mobile interface when the mobile node leaves the WiMAX network with the increasing of the MN speed because WiMAX network supports high mobility. While when the MN enters the WiFi network, the packet loss ratio on the WiFi mobile interface is almost constant and does not affect the performance of the mobile applications with increasing the MN speed.

In summary, the packet loss ratio as an evaluation metric in both scenarios WiFi to WiMAX and WiMAX to WiFi is affected by the mobility direction. In WiFi to WiMAX scenario, the user's mobility is limited to specific MN speeds. Therefore, the speed of the mobile node should be considered carefully in the vertical handover scenario from

WiFi to WiMAX networks for such applications to ensure that the minimum applications requirements are met. The decision algorithm's designers should consider these speeds carefully for the applications that is aware of the packet loss ratio. However, in WiMAX to WiFi scenario, the application performance is not affected by the increasing of the MN speed.

4.4 Average End-to-End Delay

The Average end-to-end delay is observed on both MN interface. This metric is considered in the evaluation to ensure that its value in each access technology and for all used bitrates are within the acceptable range defined by the ITU-T recommendation.

WiFi to WiMAX and WiMAX to WiFi Scenarios

The Average end-to-end delay gives information about the packet delivery time on the mobile interfaces. This metric is measured based on (3.5). Figures 4.9 and 4-10 show WiFi and WiMAX average delays as a function of the MN speed in both WiFi to WiMAX and WiMAX to WiFi scenario for different bitrate applications; it is observed that there is no effect for the MN speed on the average end-to-end delay. At a specific bitrate application, the average delay is almost constant at all MN speed. The cause of this delay was due to the links delay between the media server and mobile node interface as shown in Figure 3.1. The values of the Average delay are acceptable and within the range of the ITU-T standard.

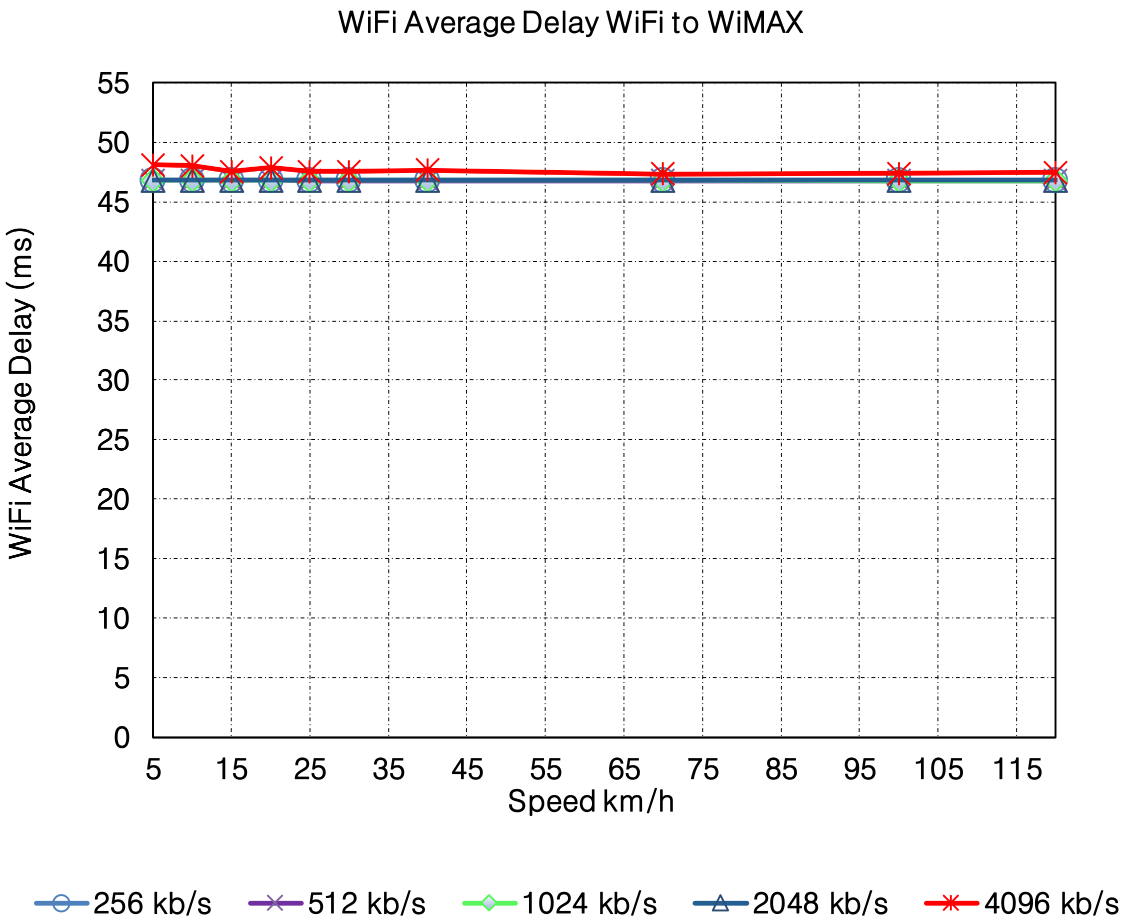

Figure 4.9: WiFi Average Delay in WiFi to WiMAX Scenario.

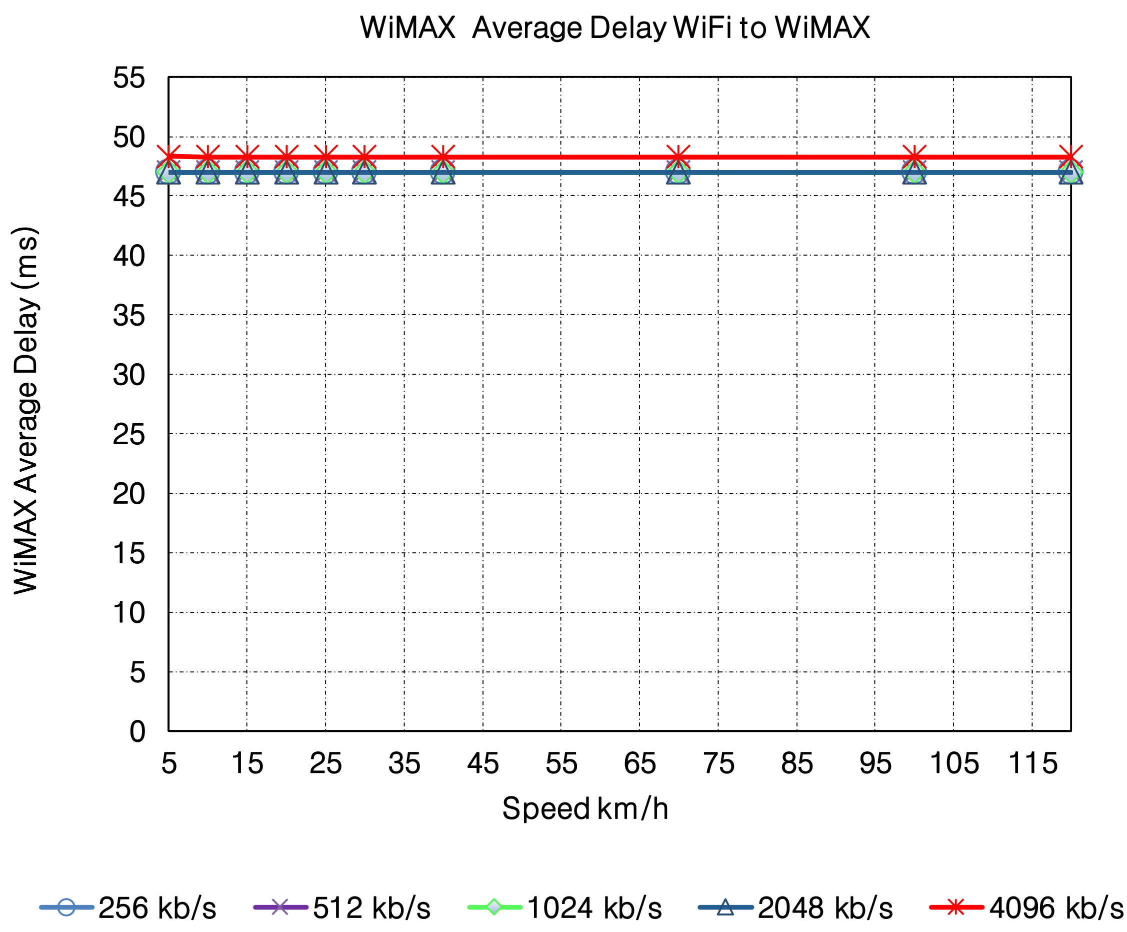

Figure 4.10: WiMAX Average Delay in WiFi to WiMAX scenario.

To Sum up, the results show that the average end-to-end delay on both WiFi and WiMAX mobile interfaces in the two vertical handover scenario is not affected by the MN speed or the mobility direction from WiFi to WiMAX or WiMAX to WiFi. The Average end-to-end delay is affected by the links delay between the media server and both WiFi and WiMAX mobile interfaces. The delay in the two scenarios were observed and their values are acceptable and within the range of ITU-T standard.

4.5 Handover Latency

The handover latency is studied in both mobility directions as follows:

4.5.1 WiFi to WiMAX Scenario

Handover latency is an important evaluation metric in the vertical handover scenarios for applications that are aware of delay. The handover latency is a type of delay and happened one time in each simulation scenario when vertical handover took place from WiFi to WiMAX network and vice versa. The handover latency is measured when the MN moves from WiFi to WiMAX network. It is observed from Figure 4.11 that there is no effect for the MN speed on the handover latency. The simulation results show that the values of the handover latency in WiFi to WiMAX vertical handover scenario are almost constant at specific bitrates for all MN speed. Whereas, in Figure 4.12, the handover latency is plotted as function of bitrate. It is observed that the handover latency decreases with the increasing of the applications bitrate. The cause of this behaviour is due to the variable transmission time of the packets for the different applications bitrate. The higher bitrates have smaller transmission time between packets than lower bitrates. Therefore, the time between consecutive packets is shorter and packets reach the visited network earlier. As a result, handover latency decrease with increasing the applications bitrate. The lower bitrates have higher latency than higher bitrates as well. In addition, the handover latency for application bitrates from 256 kb/s to application bitrates 4096 kb/s varies between 100 ms to 128 ms. These values are acceptable and within the ranges of ITU-T recommendations for both voice and video applications. These values ensure that the MIH implementation based on the received signal strength criteria fulfils the QoS requirements for the both voice and video applications.

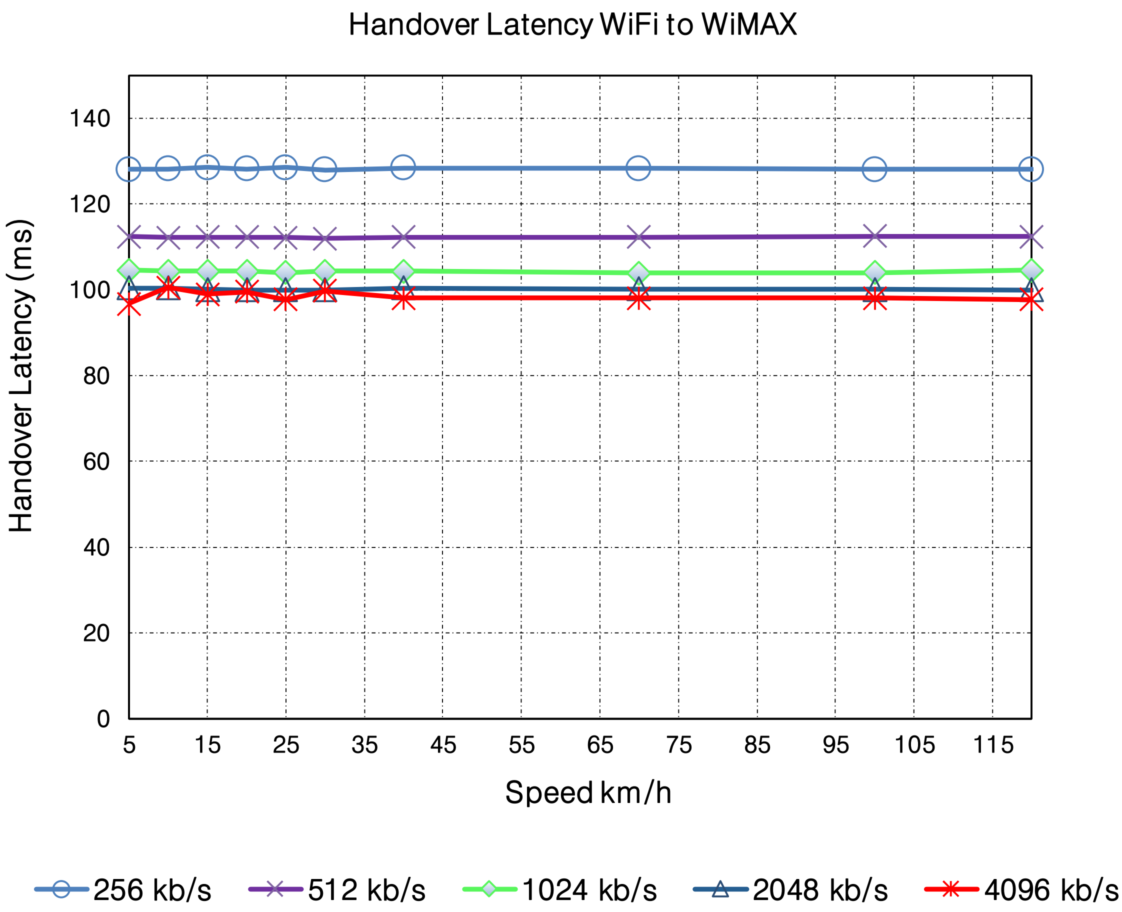

Figure 4.11: Handover Latency as a function of MN speed in WiFi to WiMAX scenario.

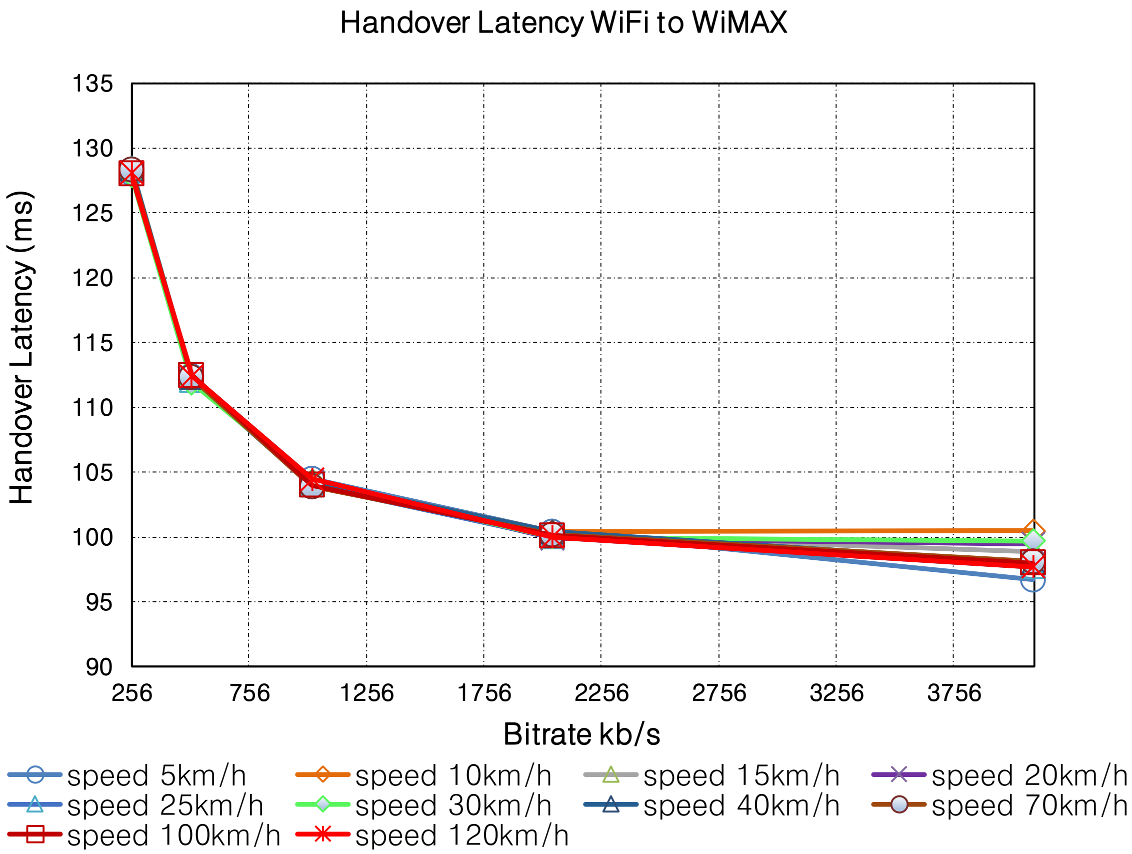

Figure 4.12: Handover Latency as a function of applications bitrate in WiFi to WiMAX scenario.

4.5.2 WiMAX to WiFi Scenario

Now Figure 4.13 shows the results of the handover latency when the mobile node moves from WiMAX to WiFi network, it is noticed that there is no effect for the MN speed on the handover latency. Whereas, Figure 4.14 shows the handover latency as a function of the applications bitrate. The simulation results show that the values of handover latency in WiMAX to WiFi scenario decreases with the increasing of the applications bitrate. This behaviour is due to the time between the consecutive packets for the higher bitrates is smaller than the lower bitrates and packets reach the visited network earlier. The values of the handover latency in this scenario are acceptable and within the range of the ITU-T standard. These values again ensure that the MIH implementation based on the received signal strength fulfils the QoS requirements for both voice and video applications.

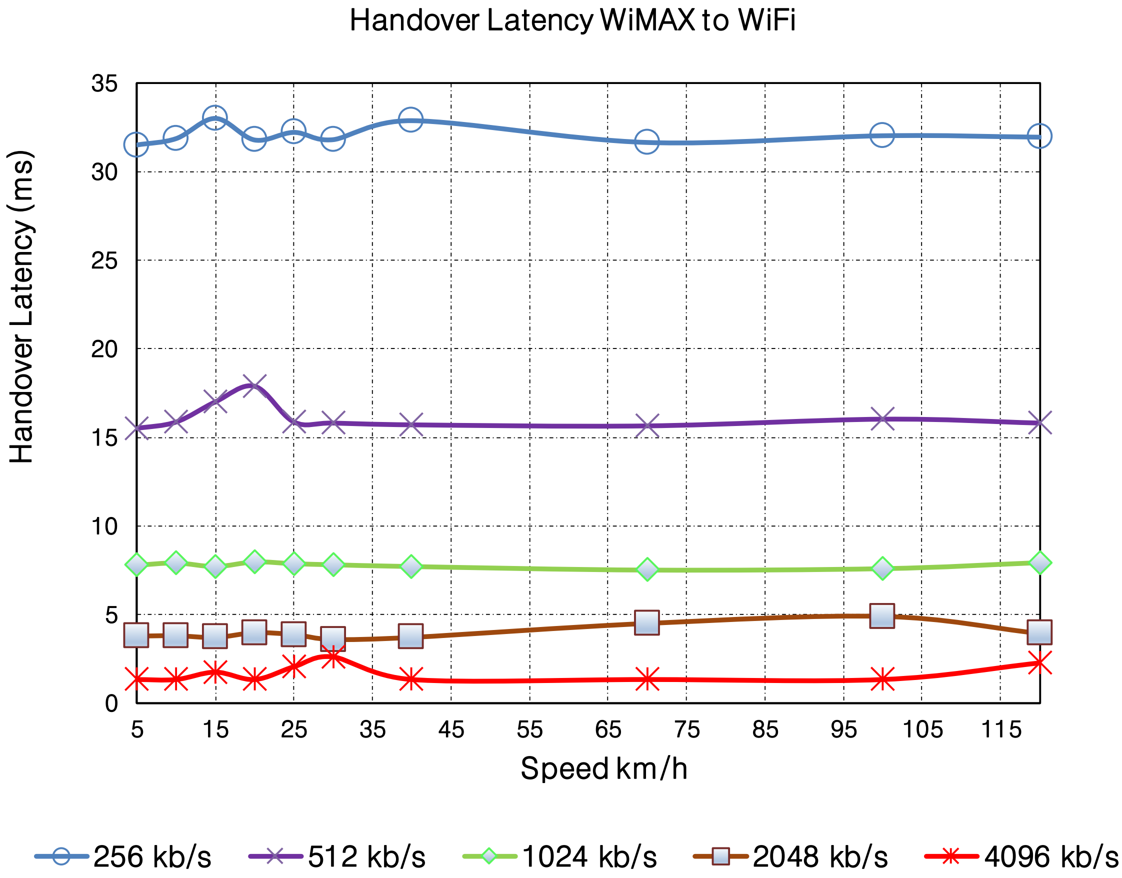

Figure 4.13: Handover Latency as a function of MN speed in WiMAX to WiFi scenario.

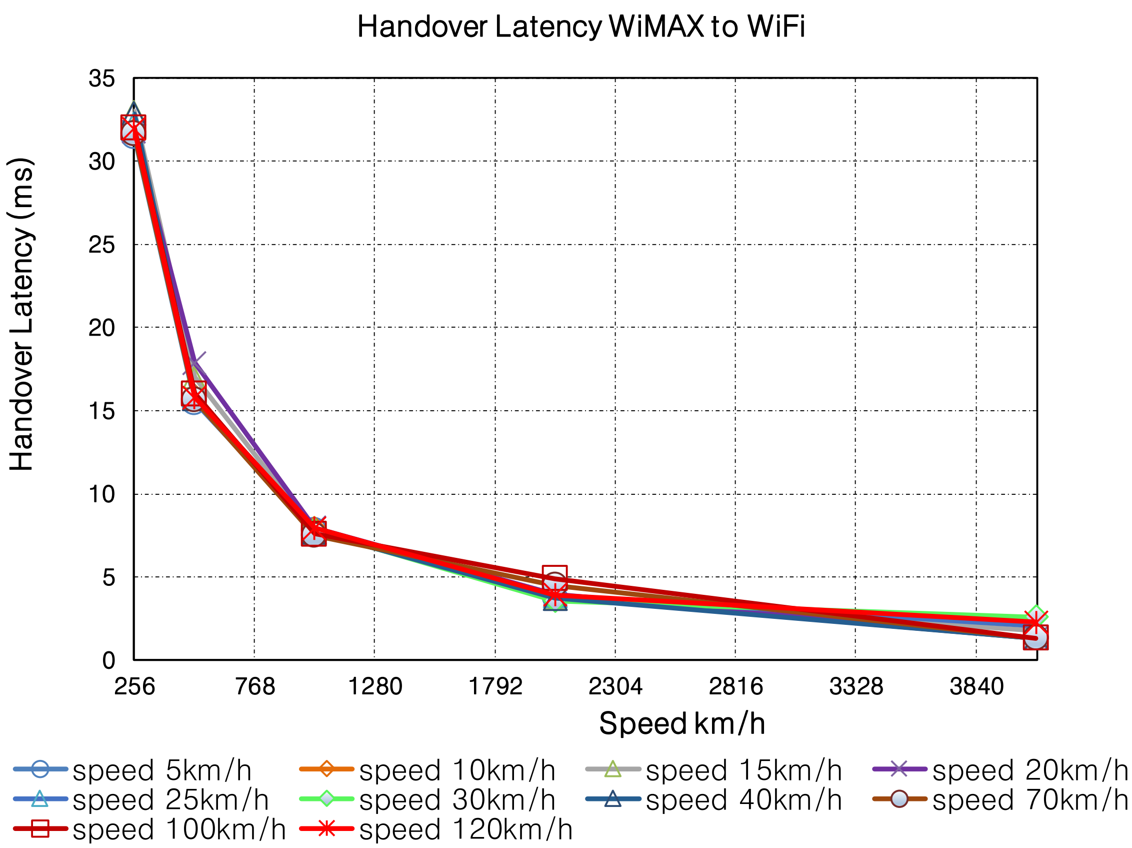

Figure 4.14: Handover Latency as a function of applications bitrate in WiMAX to WiFi scenario.

In summary, The MN speed has no effect on the handover latency in both vertical handover scenarios. This latency occurred one time in each simulation scenario, WiFi to WiMAX and WiMAX to WiFi when the handover took place. On the contrary, there was an effect for the applications bitrate. The handover latency decreases with the increasing of the applications bitrate due to the short time between the consecutive packets for higher applications bitrate and packets reach the visited network earlier. In the WiFi to WiMAX scenario, the values of handover latency vary between 100 ms to 128 ms. According to ITU-T recommendations these values are acceptable for both voice and video applications. Therefore, the MIH implementation based on the received signal strength fulfils the QoS requirements for the applications bitrate from 256 kb /s to 4096 kb/s.

In WiMAX to WiFi scenario, the handover latency is not affected with the increasing of the speed of the MN and decreases with increasing the applications bitrate. The obtained values are acceptable and within the range of the ITU-T recommendation. These results also ensures that the MIH implementation based on the received signal strength fulfils the QoS requirements for both voice and video applications bitrate with the range from 256 kb/s to 4096 kb/s.

The handover latency from WiMAX to WiFi is less than the handover latency from WiFi to WIMAX. In WiFi to WiMAX scenario, When the MN is connected to WiFi and moves to the WiMAX, it reaches the limit coverage area of WiFi and generates MIH “Link_Going_Down” trigger. In this case, a scan process starts looking for a new network delaying the connection to WiMAX BS. However, in handover from WIMAX to WiFi network, the MN do not trigger this event because it is still in the coverage area of WIMAX and the signal of the WiMAX network is available everywhere. Only MIH events LINK_Detected and LINK_UP are triggered.

4.6 Summary

This chapter presents the simulation results for the two vertical handover scenarios used in this thesis. To ensure service continuity, normalized throughput was observed under the effect of the mobile node speed. Packet loss ratio was measured to observe how it is affected by increasing the MN speed; it affected the performance of the mobile applications and limits mobility at specific MN speed. Average end-to-end delay and handover latency values give indication about fulfilling the QoS requirements for the applications that is aware of delay. The obtained results are compared to the ITU-T standard to ensure if they are within the range of this standard or not. Finally, the obtained results of handover latency and packet loss ratio are compared to the related work in the same research area.

Chapter 5 presents the conclusion of this work and gives an outlook for the future work.

Chapter 5

Modelling Simulation Results and Discussion

5.1 Modelling Results

In this chapter, modelling for the obtained results from the simulation scenarios that shown in the previous chapter are presented to validate these simulation results. Curve Fitting Toolbox in MATLAB [PHI13] is used to choose the best model that represents the simulation results from the different models exists in the curve fitting toolbox. Curve fitting refers to fitting curved lines to the data. The goal of curve fitting is to gain insight into the data obtained from the simulation. The Curve Fitting Toolbox supports set of Goodness of Fit Statistics that are used after choosing the best fitting model for the simulation results:

Sum of Squares Due to Error (SSE): This statistic is also called the summed square of residuals and it is used to measure the total deviation of the response values from the fit to the response values [PHI13].

R-Square: This statistic is also called the square of the multiple correlation coefficient and the coefficient of multiple determination. It measures how successful the fit is in explaining the variation of the data [PHI13].

Adjusted R-Square: This statistic uses the R-square statistic defined above, and adjusts it based on the residual degrees of freedom [PHI13].

Root Mean Squared Error (RMSE): This statistic is also known as the fit standard error and the standard error of the regression [PHI13].

As mentioned in the previous chapter, the behaviour in the vertical handover scenarios from WiFi to WiMAX and WiMAX to WiFi scenarios was observed through key of performance evaluation metrics. Some of these metrics were selected for curve fitting by choosing the suitable model exists in the curve fitting toolbox. Two applications bitrate were selected for curve fitting, which are (256 kb/s) that represents the minimum value and (4096 kb/s) that represents the maximum value for each performance evaluation metric that has been selected for modelling. The Goodness of Fit Statistics measures used after choosing the suitable model are (SSE, R-Square, Adjusted R-Square and RMSE). The evaluation metrics are shown as a function of speed with range varies from 5 km/h to 120 km/h. The handover latency evaluation metric, are represented as a function of applications bitrate with range varies from 256 kb/s to 4096 kb/s.

5.1.1 WiFi to WiMAX Scenario

In WiFi to WiMAX vertical handover scenario, the below performance evaluation metrics are selected for curve fitting through choosing the suitable fitting model:

5.1.1.1 WiFi Normalized Throughput

The obtained results of the WiFi Normalized Throughput in WiFi to WiMAX scenario were shown in Figure 4.1. The two applications bitrate selected for fitting are (256 kb/s), which represents the minimum value and (4096 kb/s), which represents the maximum value. The obtained results from the simulation scenarios and the curves that fitting these results are shown in Figure 5.1. The type of the curves fitting are linear model polynomial of degree 2 function as expressed in (5.1) and (5.2) for the two applications bitrate 256 kb/s and 4096 kb/s respectively.

The curve fitting function for the applications bitrate 256 kb/s is:

$$\boldsymbol{f(x) = p1 * x^2 + p2 * x + p3} \tag{5.1}$$

Coefficients for the applications bitrate 256 kb/s is:

$p1 = -2.999\text{e} - 008$
$p2 = -8.391\text{e} - 005$
$p3 = 1$

Goodness of fit for applications bitrate 256 kb/s:

$SSE = 1.574\text{e} - 008$
$R^2 = 0.9999$
Adjusted $R^2 = 0.9998$

$RMSE = 4.741e - 005$

The curve fitting function for the application bitrate 4096 kb/s is:

$$f(x) = p1 * x^2 + p2 * x + p3 \quad (5.2)$$

Coefficients for the application bitrate 4096 kb/s is:

$p1 = 2.731e - 008$

$p2 = -0.0002626$

$p3 = 0.9999$

Goodness of fit for applications bitrate 4094 kb/s:

$R^2 = 0.9998$

$RMSE = 0.0001849$

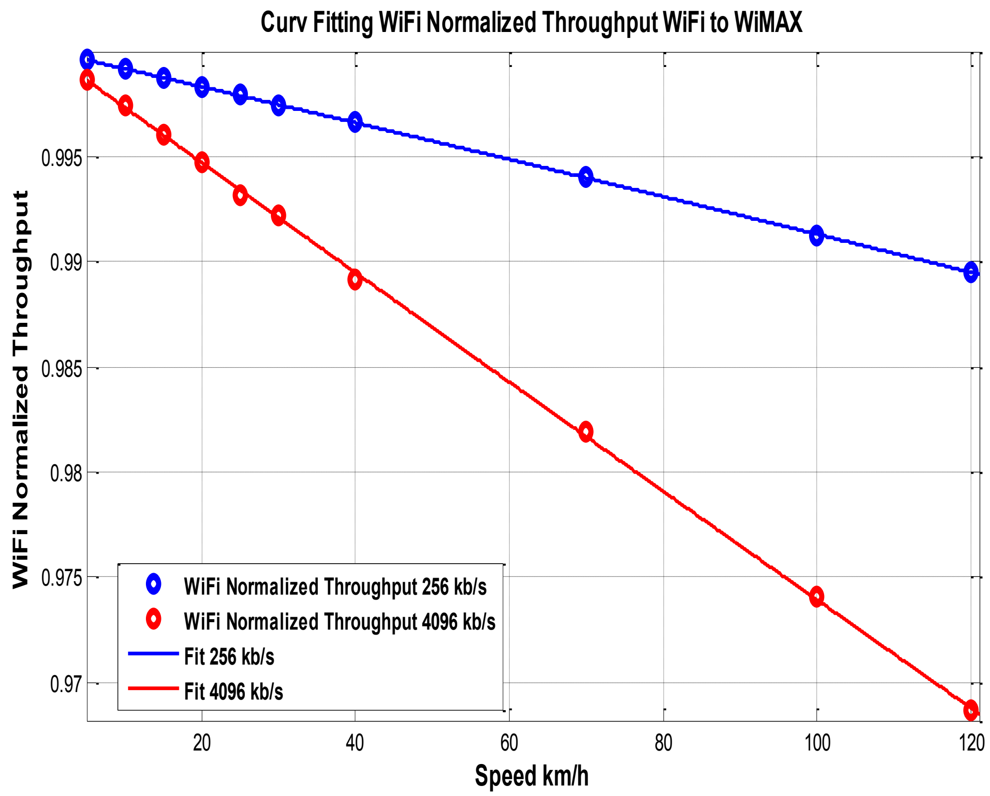

Figure 5.1: Curve Fitting for WiFi Normalized Throughput WiFi to WiMAX

5.1.1.2 WiFi Received packets

The results of the WiFi Received Packets in WiFi to WiMAX scenario were shown in Figure 4.2. The two applications bitrate selected for fitting are (256 kb/s), which represents the minimum value and (4096 kb/s), which represents the maximum value. The obtained results from the simulation scenarios and the curves that fitting these results are shown in Figure 5.2. The type of the curves fitting are model power of degree 2 function as expressed in (5.3) and (5.4) for the two applications bitrate 256 kb/s and 4096 kb/s respectively.

The curve fitting function for the applications bitrate 256 kb/s is:

$$\boldsymbol{f(x) = a * x^{b} + c} \tag{5.3}$$

Coefficients for the applications bitrate 256 kb/s is:

$a = 5402$

$b = -0.9983$

$c = -1.363$

Goodness of fit for the applications bitrate 256 kb/s:

$R^2 = 1$

$RMSE = 0.2998$

The curve fitting function for the applications bitrate 4096 kb/s is:

$$f(x) = a * x^b + c \tag{5.4}$$

Coefficients for the applications bitrate 4096 kb/s is:

$a = 8.669e + 004$

$b = -1$

$c = -22.39$

Goodness of fit for the applications bitrate 4096 kb/s:

$R^2 = 1$

$RMSE = 0.7196$

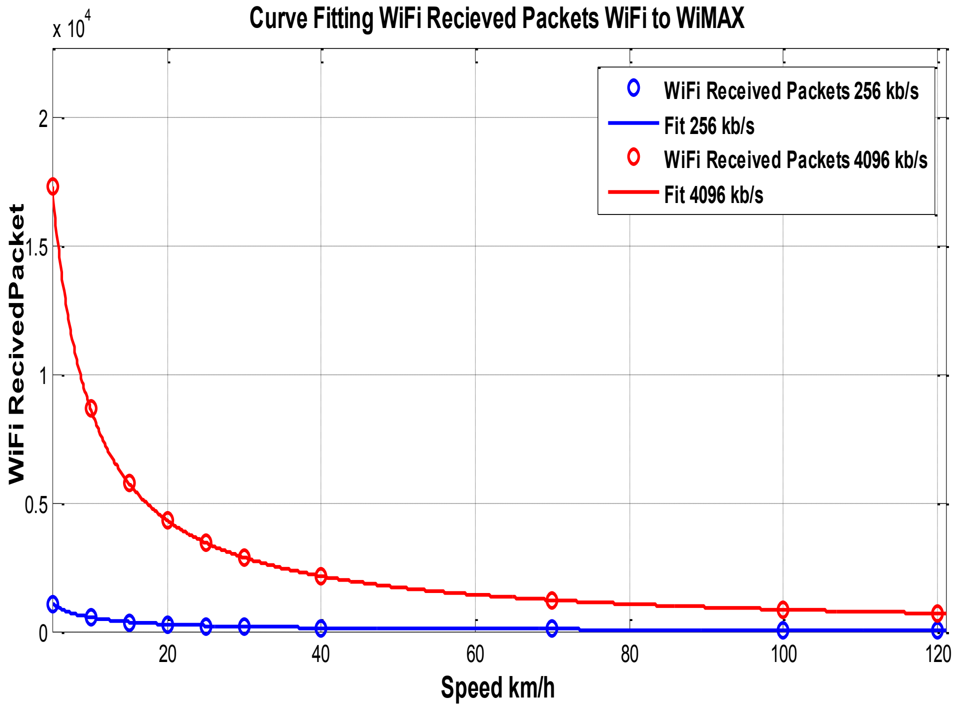

Figure 5.2: Curve Fitting for WiFi Received Packets WiFi to WiMAX

5.1.1.3 WiMAX Normalized Throughput

The results of the WiMAX Normalized Throughput in WiFi to WiMAX scenario were shown in Figure 4.3. The two applications bitrate selected for fitting are (256 kb/s), which represents the minimum value and (4096 kb/s), which represents the maximum value. The obtained results from the simulation scenario and the curves that fitting these results are shown in Figure 5.3. The type of the curves fitting are model exponential of degree 2 function as expressed in (5.5) and (5.6) for the two applications bitrate 256 kb/s and 4096 kb/s respectively.

The curve fitting function for the applications bitrate 256 kb/s is:

$$\boldsymbol{f(x) = a * e^{\wedge}(b * x) + c * e^{\wedge}(d * x)} \tag{5.5}$$

Coefficients for the applications bitrate 256 kb/s is:

$a = 0.9996$
$b = 8.728\text{e} - 007$
$c = -0.002846$
$d = -0.2516$

Goodness of fit for the applications bitrate 256 kb/s is:
$R^2 = \quad 0.9781$
$RMSE = 4.936\text{e} - 005$

The curve fitting function for the applications bitrate 4096 kb/s is:

$$\boldsymbol{f}(\boldsymbol{x}) = \boldsymbol{a} * \boldsymbol{e}\hat{}(\boldsymbol{b} * \boldsymbol{x}) + \boldsymbol{c} * \boldsymbol{e}\hat{}(\boldsymbol{d} * \boldsymbol{x}) \tag{5.6}$$

Coefficients for the applications bitrate 4096 kb/s is:

$a = 0.9988$

$b = 2.586\text{e} - 006$

$c = -0.008857$

$d = 2.586\text{e} - 006$

Goodness of fit for the applications bitrate 4096 kb/s is:

$R^2 = 0.9798$

$MSE = 0.0001439$

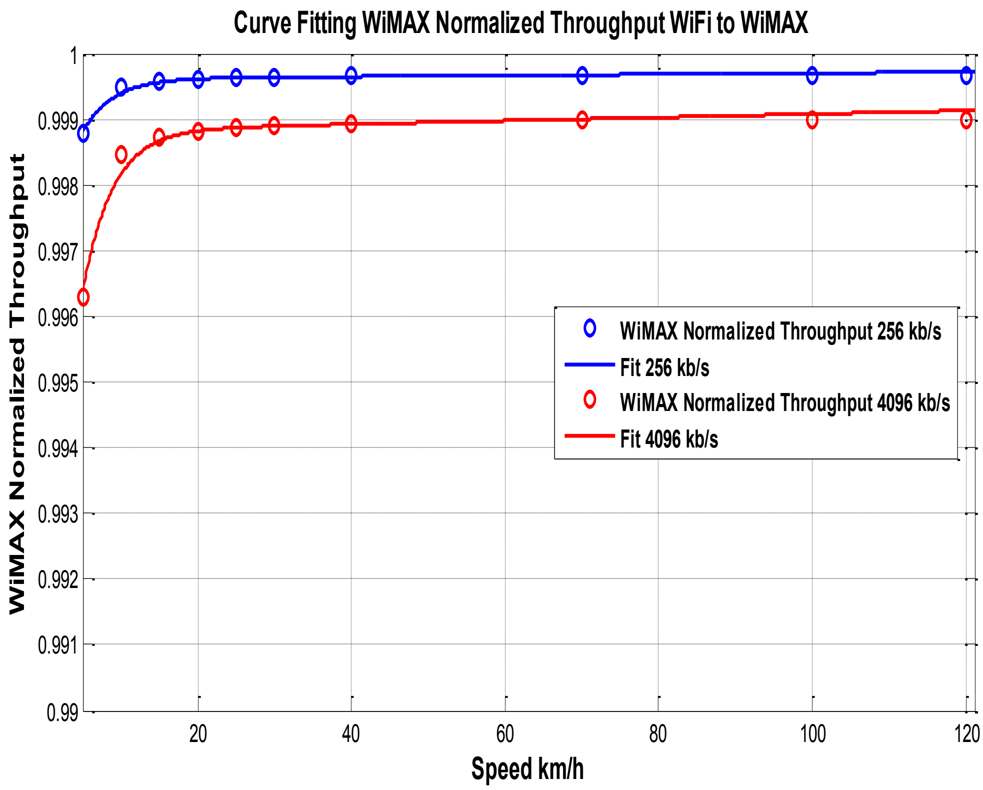

Figure 5.3: Curve Fitting for WiMAX Normalized Throughput WiFi to WiMAX

5.1.1.4 WiFi Packet Loss Ratio

The results of the WiFi Packet Loss Ratio in WiFi to WiMAX scenario were shown in Figure 4.5. The two applications bitrate selected for fitting are (256 kb/s), which represents the minimum value and (4096 kb/s), which represents the maximum value. The obtained results from the simulation scenario and the curves that fitting these results are shown in Figure 5.4. The type of the curves fitting are linear model Polynomial of degree 2 function as expressed in (5.7) and (5.8) for the two applications bitrate 256 kb/s and 4096 kb/s respectively.

The curve fitting function for the applications bitrate 256 kb/s is:

$$\boldsymbol{f(x) = p1 * x^2 + p2 * x + p3} \tag{5.7}$$

Coefficients for the applications bitrate 256 kb/s is:

$p1 = -1.792\text{e} - 005$
$p2 = 0.05538$
$p3 = -0.002288$

Goodness of fit for the applications bitrate 256 kb/s is:

$R^2 = \quad 1$
$RMSE = 0.006098$

The curve fitting function for the applications bitrate 4096 kb/s is:

$$f(x) = p1 * x^2 + p2 * x + p3 \quad (5.8)$$

Coefficients for the applications bitrate 4096 kb/s is:

$p1 = -2.2e-005$

$p2 = 0.05492$

$p3 = 0.009276$

Goodness of fit for the applications bitrate 4096 kb/s is:

$R^2 = 1$

$RMSE = 0.01431$

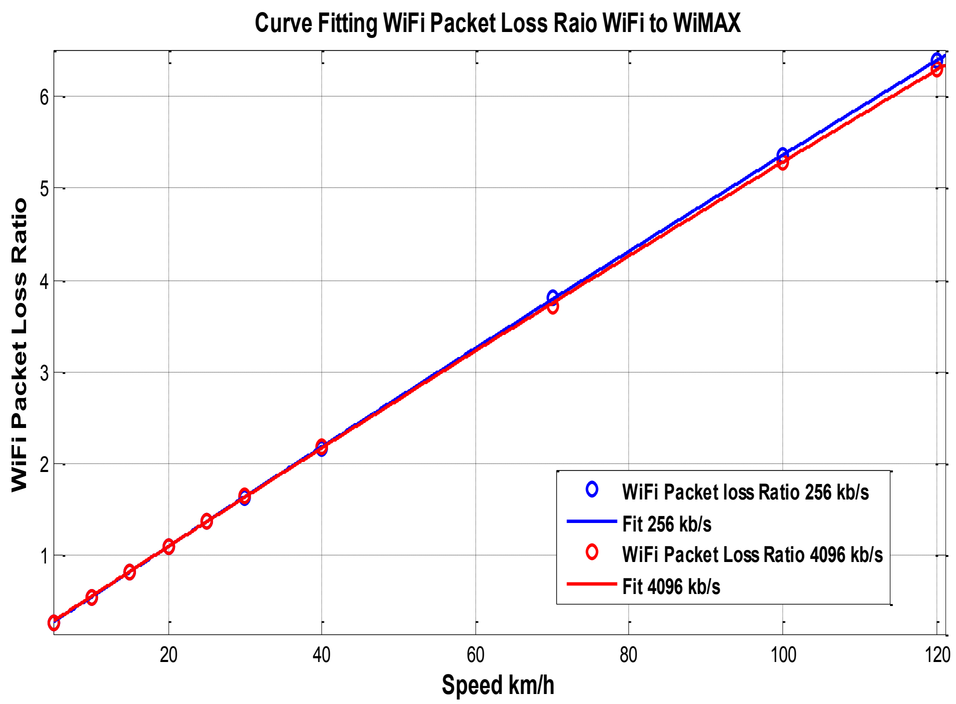

Figure 5.4: Curve Fitting for WiFi Packet Loss Ratio WiFi to WiMAX

5.1.1.5 Handover Latency

The results of the handover latency in WiFi to WiMAX scenario were shown in Figure 4.12. The applications bitrate selected for fitting vary from (256 kb/s) to (4096 kb/s). The obtained results from the simulation scenario and the curves that fitting these results are shown in Figure 5.5. The type of the curves fitting are model power of degree 2 function as expressed in (5.9) and (5.10) for the two mobile node speeds 5 km/h and 120 km/h respectively.

The curve fitting function for the applications bitrate 256 kb/s is:

$$\boldsymbol{f}(\boldsymbol{x}) = \boldsymbol{a} * \boldsymbol{x}^{\boldsymbol{b}} + \boldsymbol{c} \tag{5.9}$$

Coefficients for the applications bitrate 256 kb/s is:

$a = 3799$
$b = -0.851$
$c = 93.98$

Goodness of fit for the applications bitrate 256 kb/s is:

$R^2 = 0.9987$
$RMSE = 0.6369$

The curve fitting for the applications bitrate 4096 kb/s is:

$$f(x) = a * x^b + c \tag{5.10}$$

Coefficients for the applications bitrate 4096 kb/s is:

$a = 5510$

$b = -0.9237$

$c = 95.2$

Goodness of fit for the applications bitrate 4096 kb/s is:

$R^2 = 0.9999$

$RMSE = 0.1521$

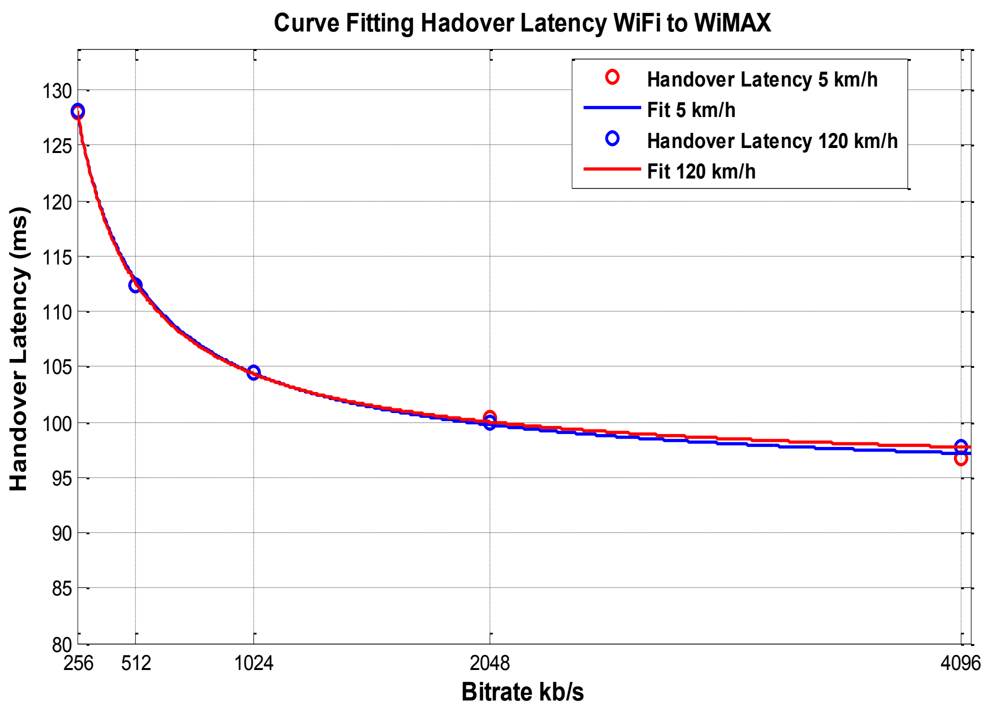

Figure 5.5: Curve Fitting for Handover Latency WiFi to WiMAX

5.1.2 WiMAX to WiFi Scenario

In WiMAX to WiFi vertical handover scenario, the below performance metrics, are selected for curve fitting:

5.1.2.1 WiMAX Normalized Throughput

The obtained results of the WiMAX Normalized Throughput in WiMAX to WiFi scenario were shown in Figure 4.4. The two applications bitrate selected for fitting are (256 kb/s), which represents the minimum value and (4096 kb/s), which represents the maximum value. The obtained results from the simulation scenarios and the curves that fitting these results are shown in Figure 5.6. The type of the curves fitting are linear model polynomial of degree 2 function as expressed in (5.11) and (5.12) for the two applications bitrate 256 kb/s and 4096 kb/s respectively.

The curve fitting function for the application bitrate 256 kb/s is:

$$\boldsymbol{f(x) = p1 * x^2 + p2 * x + p3} \qquad (5.11)$$

Coefficients for the application bitrate 256 kb/s is:

$p1 = 3.777e - 008$
$p2 = -6.966e - 005$
$p3 = 1$

Goodness of fit for applications bitrate 256 kb/s:

$R^2 = \quad 0.9999$
$RMSE = 2.941\mathrm{e} - 005$

The curve fitting function for the application bitrate 4096 kb/s is:

$$\boldsymbol{f(x) = p1 * x^2 + p2 * x + p3} \quad (5.12)$$

Coefficients for the application bitrate 4096 kb/s is:

$p1 = 1.957e - 007$

$p2 = -0.0002238$

$p3 = 1$

Goodness of fit for applications bitrate 4096 kb/s:

$R^2 = 0.9999$

$RMSE = 8.98e - 005$

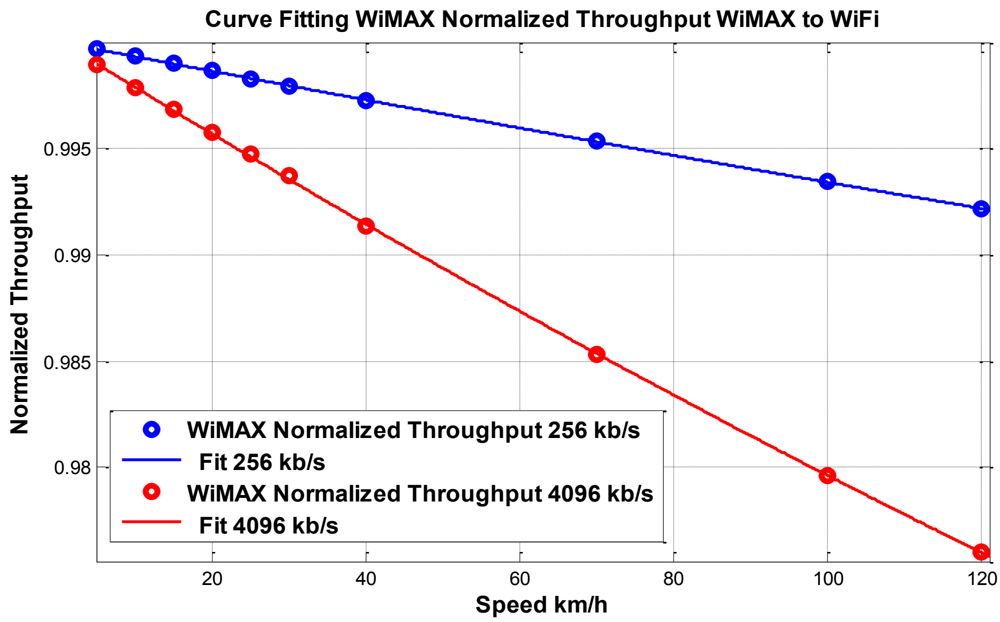

Figure 5.6: Curve Fitting for WiMAX Normalized Throughput WiMAX to WiFi

5.1.2.2 Handover Latency

The results of the handover latency in WiMAX to WiFi scenario were shown in Figure 4.14. The applications bitrate selected for fitting vary from (256 kb/s) to (4096 kb/s). The obtained results from the simulation scenario and the curves that fitting these results are shown in Figure 5.7. The type of the curves fitting are model power of degree 2 function as expressed in (5.13) and (5.14) for the two mobile node speeds 5 km/h and 120 km/h respectively.

The curve fitting function for the application bitrate 256 kb/s is:

$$\boldsymbol{f(x) = a * x^{b} + c} \tag{5.13}$$

Coefficients for the application bitrate 256 kb/s is:

$a = 7200$
$b = -0.9762$
$c = -0.63$

Goodness of fit for the application bitrate 256 kb/s is:
$R^2 = 0.9998$
$RMSE = 0.2442$

The curve fitting function for the application bitrate 4096 kb/s is:

$$\boldsymbol{f}(\boldsymbol{x}) = \boldsymbol{a} * \boldsymbol{x}^{\boldsymbol{b}} + \boldsymbol{c} \tag{5.14}$$

Coefficients for the application bitrate 4096 kb/s is:

$a = 9899$

$b = -1.037$

$c = 0.4$

Goodness of fit for the application bitrate 4096 kb/s is:

$R^2 = 1$

$RMSE = 0.1118$

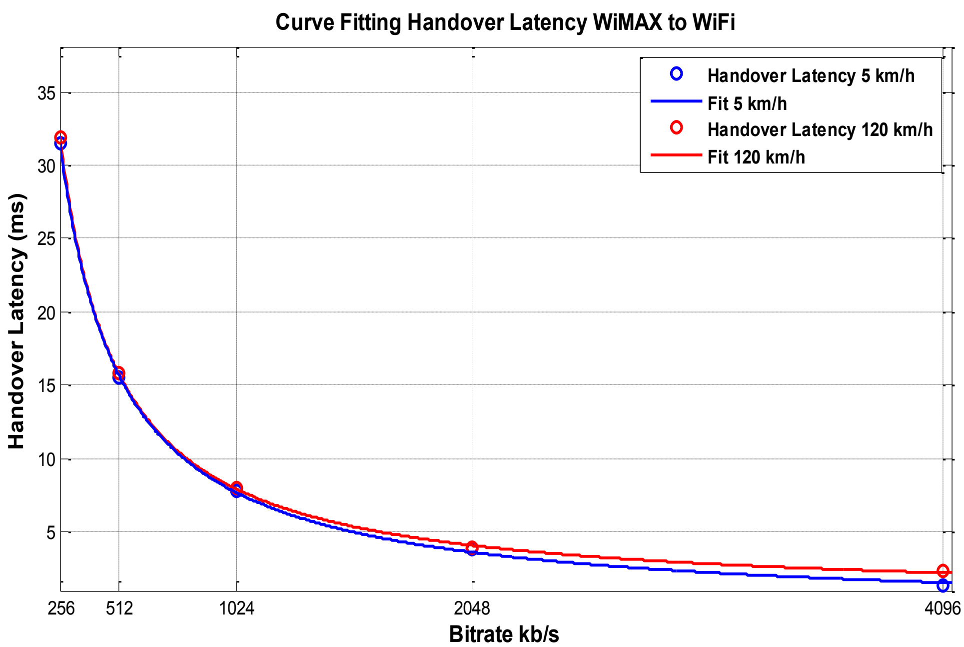

Figure 5.7: Curve Fitting for Handover Latency WiMAX to WiFi

To sum up, Tables 5.1 and 5.2 present the curve fitting functions for the selected evaluation metrics in the used vertical handover scenarios. In addition, the goodness of fit statistics measures are presented in the same tables for the applications bitrate 256 kb/s and for the mobility direction from WiFi to WiMAX and from WiMAX to WiFi respectively.

Table 5.1: Summary of Curve Fitting for the metrics in WiFi to WiMAX Scenario

Mobility Direction	**Performance Evaluation Metric**		**Curve Fitting function**
WiFi to WiMAX	**Throughput**	**WiFi Normalized Throughput**	**Curve fitting for WiFi Throughput:** $f(x) = p1 * x^2 + p2 * x + p3$ Goodness of fit for 256 kb/s $SSE = 1.574e - 008$ $R^2 = 0.9999$ Adjusted $R^2 = 0.9998$ $RMSE = 4.741e - 005$
		WiMAX Normalized Throughput	**Curve fitting for WiMAX Throughput:** $f(x) = a * e^{(b*x)} + c * e^{(d*x)}$ Goodness of fit for 256 kb/s $R^2 = 0.9781$ $RMSE = 4.936e - 005$
	Packet Loss	**WiFi Packet Loss Ratio**	**Curve fitting for WiFi Packet Loss Ratio:** $f(x) = p1 * x^2 + p2 * x + p3$ Goodness of fit for 256 kb/s $R^2 = 1$ $RMSE = 0.006098$
	Handover latency		**Curve fitting for Handover Latency:** $f(x) = a * x^b + c$ Goodness of fit for 256 kb/s $R^2 = 0.9998$ $RMSE = 0.2442$

Table 5.2: Summary of Curve Fitting for the metrics in WiMAX to WiFi scenario

Mobility Direction	**Performance Evaluation Metric**		**Curve Fitting function**
WiMAX to WiFi	**Throughput**	**WiMAX Normalized Throughput**	**Curve fitting for WiMAX Throughput:** $\boldsymbol{f(x) = p1 * x^2 + p2 * x + p3}$ Goodness of fit for 256 kb/s $\boldsymbol{R^2 = 0.9999}$ $\boldsymbol{RMSE = 2.941e-005}$
	Handover Latency		**Curve fitting for Handover Latency:** $\boldsymbol{f(x) = a * x^b + c}$ Goodness of fit for 256 kb/s $\boldsymbol{R^2 = 0.9998}$ $\boldsymbol{RMSE = 0.2442}$

5.2 Results Behaviour and Comparison

In both vertical handover scenarios; WiFi to WiMAX and WiMAX to WiFi, the performance of the mobile applications were observed using a key of performance evaluation metrics under the effect of the MN speed, direction of mobility and applications bitrate. The performance metrics are Normalized Throughput, Packet Loss Ratio, Handover Latency and Average end-to-end delay. The mobile node speed used in these scenarios varies from 5 km/h, which represents the lowest speed to 120 km/h, which represents the highest speeds. In addition, the applications bitrate vary from 256 kb/s to 4096 kb/s. The behaviour of the performance evaluation metrics are observed in the used vertical handover scenarios. Some of these metrics were affected by the mobile speed, applications bitrate and direction of mobility as shown in Table 5.3. Normalized throughput and packet loss ratio affected by the mobile node speed and the direction of mobility, the normalized throughput slightly decreases by increasing the mobile node speed when the mobile node leaves it's serving PoA in both mobility directions. Whereas, the packet loss ratio increases by increasing the mobile node speed when the mobile node leaves the WiFi network due to its small coverage area. Moreover, the packet loss ratio is null when the mobile node leaves the WiMAX network in the opposite mobility direction. Handover latency was not affected by increasing the mobile node speed, it was affected by the applications bitrate, and it decreases by increasing the applications bitrate. However, the handover latency when the mobile node moves from WiFi to WiMAX is larger than when moving from WiMAX to WiFi.

The obtained results from the used vertical handover scenarios are compared to the values defined by the ITU-T standard [MRMR10] in the mobile networks that defined QoS requirements for QoS-aware applications as shown in Table 5.4. The obtained results of average end-to-end delay (46 ms - 48 ms) and handover latency (100 ms – 128 ms) shows acceptable values compared to the ITU-T recommendations. The packet loss ratio have unacceptable values when the mobile speed exceeds certain values due to the small coverage area of the WiFi.

Table 5.3: Behaviour of performance evaluation metrics.

Performance Metric	WiFi to WiMAX		WiMAX to WiFi	
	WiFi	WiMAX	WiMAX	WiFi
Throughput	Polynomially decreases with increasing MN speed	Almost constant with increasing MN speed	Polynomially decreases with increasing MN speed	Almost constant with increasing MN speed
End-to-End Delay	Almost constant with increasing MN speed	Almost constant with increasing MN speed	Almost constant with increasing MN speed	Almost constant with increasing MN speed
Packet Loss Ratio	Polynomially increases with increasing MN speed	Almost constant with increasing MN speed	No packet loss at all MN speed	Almost constant with increasing MN speed
Handover Latency	▪ Almost constant with increasing MN speed. ▪ Decreases as Power of degree 2 with increasing application bitrate.		▪ Almost constant with increasing MN speed. ▪ Decreases as Power of degree 2 with increasing application bitrate.	

Table 5.4: Obtained Results for the evaluation metrics compared to the ITU-T Recommendations [MRMR10].

Performance Metric	Mobile Applications	Acceptable values recommended by ITU-T Standard [MRMR10]	Obtained results in WiFi to WiMAX	Obtained results in WiMAX to WiFi
Packet Loss Ratio	video	**1%**	1.1% at MN speed 20 km/h 2.1% at MN speed 40 km/h when the MN leaves WiFi Less than 1% and acceptable for all speeds when the MN enters WiMAX	0% at all MN speeds when the MN leaves WiMAX Less than 1% and acceptable for all speeds when the MN enters WiFi
	voice	Less than **2%**		
Handover Latency	voice	**150 - 200 ms**	**100 ms – 128 ms**	**2 ms - 32 ms**
	video	**280 ms**		
Average End-to-End Delay	voice	**150 - 200 ms**	**46 ms – 48 ms** In WiFi and WiMAX	**46 ms - 48 ms** In WiFi and WiMAX
	video	**280 ms**		

5.3 Discussion of Results

In this section, packet loss ratio and handover latency behaviour and results are discussed and compared to the related work and results mentioned in the same research area in the literature as shown in Figure 5.8. The research [MRMR10] [RMT13] [CR11] used in the discussion and results comparison. The researchers used the same methodology as used in this research. They used NS-2, WiFi and WiMAX in different vertical handover scenarios. The performance evaluation metrics mentioned in some of these research papers are packet loss ratio and handover latency.

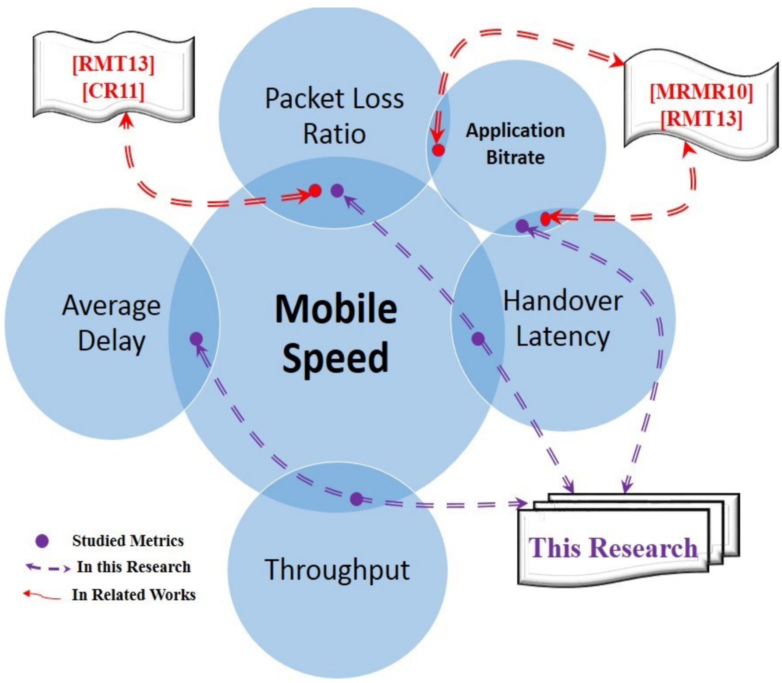

Figure 5.8: performance metric compared to the related work in the same research area

5.3.1 Packet Loss Ratio

The obtained results from the packet loss ratio evaluation metric in this research are summarized and discussed in the two vertical handover scenarios with the results of the packet loss ratio mentioned in the research [MRMR10] [RMT13] [CR11] as follows:

5.3.1.1 WiFi to WiMAX scenario

[1] The packet loss ratio was 1.1% at 20 km/h and 2.1% at 40 km/h. These values limits the mobility of the MN at specific speeds 20 km/h and 40 km/h respectively. Therefore, voice applications degrades to unacceptable quality at 40 km/h whereas, video applications degrades to unacceptable quality at 20 km/h.

Result [1] disagrees with the result mentioned in research [RMT13], which claims that the mobility in WiFi is limited to 1m/s (pedestrian). The values of packet loss ratio mentioned in result [1] were not mentioned in research [CR11]. The packet loss ratio in research [MRMR10] was not considered as a function of mobile node speed, but the researcher considers the packet loss ratio as a function of number of mobile nodes and applications bitrate. The researcher showed that the packet loss ratio increases by increases the applications bitrate and number of mobile nodes.

[2] The packet loss ratio was affected by the MN speed when the MN leaves the WiFi network. It increases with increasing the speed. In addition, at specific bitrate the number of lost packets are almost constant.

Number of lost packets as a function of MN speed is considered in research [RMT13].The researcher showed that the number of lost packets increase with increasing the speed of the MN, but the researcher did not mention the application bitrate. Result [2] disagrees with the result in [RMT13]. Result [2] agrees with the result in research [CR11] for the number of lost packets, which remains constant by increasing the MN speed using the MIH implementation, although the application bitrate was not mentioned in this research [CR11].

[3] The packet loss ratio was almost constant when the traffic received on the mobile interface that belongs to the visited network. It was not affected by the MN speed.

Result [3] disagrees with the result in research [RMT13], [MRMR10] and [CR11]. Packet loss ratio was not mentioned when the traffic redirected to the visited network.

5.3.1.2 WiMAX to WiFi scenario

[4] The packet loss ratio is 0% when the traffic was received on the WiMAX mobile interface for speeds from 5 km/h to 120 km/h because WiMAX supports high user mobility.

Result [4] agrees with the result in research [RMT13] that has mentioned the same value. Result [4] disagree with the result in the research [MRMR10] and [CR11]. 0% was not mentioned in the research [MRMR10] and [CR11].

Table 5.5 presents summary for the discussion results compared to the related work in the same research area regarding packet loss ratio evaluation metric.

Table 5.5: summary for discussion results for packet loss ratio

Result	[1]	[2]	[3]	[4]
WiFi to WiMAX	**Disagrees with [RMT13]** **Disagrees with [CR11]** **Agrees with [MRMR10]**	**Disagrees with [RMT13]** **Agrees with [CR11]** **Disagrees with [MRMR10]**	**Disagrees with [RMT13]** **Disagrees with [CR11]** **Disagrees with [MRMR10]**	✗
WiMAX to WiFi	✗	✗	✗	**Agrees with [RMT13]** **Disagrees with [CR11]** **Disagrees with [MRMR10]**

5.3.2 Handover Latency

The obtained results of the handover latency values are summarized and discussed in the below subsections in the two vertical handover scenarios used in this thesis with the results of the handover latency studied by the research [MRMR10] [RMT13] as follows:

5.3.2.1 WiFi to WiMAX Scenario

[5] The handover latency was affected by the applications bitrate that have range from 256 kb/s to 4096 kb/s; it decreases as the applications bitrate increase. The values of latency range from 100 ms to 128 ms. The handover latency was not affected by the MN speed.

Result [5] agrees with the result mentioned in the research [RMT13] on the handover latency behaviour, which decreases with increasing the applications bitrate. However, the handover latency was not studied by [RMT13] as a function of mobile node speed. Researcher in [RMT13] presents handover latency values over 150 ms for the applications from 120 kb/s to 170 kb/s. the researcher claims that the MIH implementation fails to fulfil the QoS for this range of applications bitrate. The applications bitrate in this thesis vary from 256 kb/s to 4096 kb/s with handover latency values from 100 ms to 128 ms. This result agrees in values and behaviour with the results and behaviours mentioned in research [RMT13] for the applications bitrate from 256 kb/s to 1000kb/s.

Research in [MRMR10] provides value of 230 ms for handover latency to WiMAX. The author claimed that the handover latency affected with number of mobiles and applications bitrate. The work in this thesis did not consider the number of mobiles. Result [5] agrees with research [MRMR10] that handover latency is affected with applications bitrate but the researcher did not show the behaviour of the handover latency as function of the application bitrate.

5.3.2.2 WiMAX to WiFi Scenario

[6] The handover latency was affected by the applications bitrate that have range from 256 kb/s to 4096 kb/s; it decreases as the applications bitrate increase. The values of latency vary from 2 ms to 32ms. The handover latency was not affected by the MN speed from 5 km/h to 120 km/h when the traffic was redirected to the WiFi mobile interface.

Result [6] agrees with the result in research [RMT13] on the behaviour and values of the handover latency for bitrates from 256 kb/s to 1000 kb/s. In this research, the applications bitrate from 256 kb/s to 4096 kb/s have been considered and the values of the handover latency vary from 2 ms to 32 ms.

Result [6] also agrees with the result in research [MRMR10] regarding the value of handover latency. The researcher did not present the behaviour of handover latency as function of bitrate but the author presents 5ms handover latency to WiFi.

[7] Handover latency from WiFi to WiMAX is higher than the handover latency from WiMAX to WiFi. The results of handover latency from WiMAX to WiFi vary from 100 ms to 128 ms, whereas, the handover latency from WiMAX to WiFi varies from 2 ms to 32 ms.

Result [7] agrees with the results in [MRMR10] [RMT13] that the handover latency to WiMAX is higher than the handover latency to WiFi network.

[8] The results of handover latency in WiFi to WiMAX and WiMAX to WiFi scenarios ensures that the MIH implementation based on the received signal strength fulfils the QoS requirements for the applications bitrate from 256 kb/s to 4096 kb/s at speeds from 5km/h to 120 km/h.

[RMT13] Claims MIH implementation failed to fulfil the QoS requirements from 120 kb/s to 170 kb/s in WiFi to WiMAX scenario. The value of handover latency is over 150 ms and the obtained result in this research has handover latency of 128 ms at bitrate 256 kb/s. Therefore, result [8] agrees with the result in [RMT13] for the applications bitrate from 256 kb/s to 1000 kb/s.

Table 5.6 presents summary for the discussion results compared to the related work in the same research area regarding handover latency evaluation metric.

Table 5.6: summary for discussion results for handover latency

Result	[5]	[6]	[7]	[8]
WiFi to WiMAX	**Agrees with [RMT13]** **Agrees with [MRMR10]**	✗	✗	✗
WiMAX to WiFi	✗	**Agrees with [RMT13]** **Agrees with [MRMR10]**	**Agrees with [RMT13]** **Agrees with [MRMR10]**	**Agrees with [RMT13]** **Agrees with [MRMR10]**

5.4 Summary

This chapter validates the simulation results mentioned in the previous chapter by choosing the suitable model that fits the obtained results. The modelling was done using the curving fitting toolbox in MATLAB. This chapter also presents the behaviour of the performance evaluation metrics used in this research. The obtained results were compared to the ITU-T standard. The results show that the packet loss ratio has unacceptable values when the mobile node exceeds certain values. Finally, the obtained results for packet loss ratio and handover latency are compared to the related work in the same research are, the obtained results are competitive to the results mentioned in the research area.

Chapter 6 concludes the thesis and provides the future direction.

Chapter 6

Conclusion and Future Work

Wireless access networks are widely implemented to support user mobility. The heterogeneity of these wireless access networks complicates the integration between them due to their different link layer technologies. The mobile devices are equipped with multiple interfaces, therefore unified communication between these interfaces are needed to solve the service continuity challenge in the vertical handover. WiFi and WiMAX are heterogeneous wireless networks. Therefore, Interoperability mechanisms are needed between these wireless networks to serve users mobility and to fulfil the QoS requirements of the increasing demand on the multimedia applications. The purpose of these mechanisms is to keep service continuity while moving between these heterogeneous networks. IEEE 802.21 standard provides these mechanisms to facilitate the integration between these heterogeneous wireless access networks and assist the vertical handover process.

NS-2 is the simulation tools used to build the vertical handover scenarios integrated with the NIST framework. This framework contains both WiFi and WiMAX add-on modules. Therefore, two-separated vertical handover scenarios are defined and used in this thesis; WiFi to WiMAX, and WiMAX to WiFi. The performance in vertical handover scenarios was observed through key of performance evaluation metrics under the effect of the speed of the mobile node, direction of mobility and applications bitrate. These metrics are Normalized Throughput, Packet loss ratio, Average end-to-end delay and Handover Latency. The simulation results of the vertical handover scenarios are compared to the ITU-T standard recommendations as a reference point to ensure if they fulfil the QoS requirements or not; for the applications that are aware of packet loss and delay. In addition, the obtained results are compared to the latest studies in the same research area between WiFi and WiMAX networks. Finally the obtained results are validated through curve fitting by selecting the suitable model that fits the obtained results accompanied with the goodness of fit statistical measures.

6.1 Conclusion

From the obtained results of the performance evaluation metrics in the vertical handover scenarios from WiFi to WiMAX and WiMAX to WiFi, we conclude the following:

Regarding the packet loss ratio:

- The user mobility is limited to specific MN speed in WiFi network due to its small coverage area when the mobility direction of the MN was from WiFi to WiMAX network. Voice applications have unacceptable values of packet loss ratio when the MN moves at speed over 40 km/h. For the video applications bitrate, it suffers from packet loss ratio by increasing the speed of the MN and degrades to unacceptable values when the MN speed exceeds 20 km/h. Packet loss ratio polynomially increases as function of mobile node speed while the mobile node is leaving the WiFi network. We conclude that, MIH implementation based on received signal strength criteria failed to fulfil the QoS requirements at MN speeds 20 km/h for video and 40 km/h for voice applications. The values of the MN speed should be considered in a multi-criteria decision algorithm for the applications bitrate that is aware of packet loss. This packet loss ratio occurs due to the handover latency to WiMAX network.

- When the mobility direction of the MN was from WiMAX to WiFi scenario, the packet loss ratio was not affected by the MN speed and the lost packets are zero in the WiMAX network due to the WiMAX signal availability everywhere in the simulation area. While it was almost constant in the WiFi network. The results are acceptable based on the ITU-T recommendations.

Regarding the handover latency:

- When the mobility direction was from WiFi to WiMAX. The handover latency was not affected by the speed of the MN, but it was affected by the applications bitrate. Therefore, the handover latency of the applications bitrate from 256 kb/s to 4096 kb/s has acceptable values and within the ranges of the ITU-T standard. From these values, we conclude that the MIH implementation based on received signal strength criteria fulfils the QoS requirements for the applications bitrate from 256 kb/s to 4096 kb/s.

- While when the mobility direction of the MN was from WiMAX to WiFi network, the handover latency was not affected by the speed of the MN but it was affected by the applications bitrate. However, these values are acceptable and within the range of ITU-T recommendations and the performance was not affected in this scenario. These simulation results ensures that the MIH implementation is reliable and fulfils the QoS requirements for the applications bitrate from 256 kb/s to 4096 kb/s.

- The handover latency to WiMAX network is higher than the handover latency to WiFi network.

- In both vertical handover scenarios, and while the mobile node is leaving its PoA (WiFi or WiMAX), the modelling of the handover latency as function of application bitrate shows decrease in handover latency as Power of degree 2 function.

Regarding the normalized throughput:

- The normalized throughput is related to the mobility direction from WiFi to WiMAX or from WiMAX to WiFi. It is polynomially decreased by the increasing of the speed of the MN when it is leaving the WiFi and WiMAX networks. On the contrary, it is almost constant by increasing the speed of the MN when it is entering these networks. We conclude that the normalized throughput as an evaluation metric is slightly affected with increasing the MN speed but does not affect the performance of the applications bitrate. In addition, the normalized throughput values ensures that service continuity is achieved with the assistance of the MIH.

Regarding the Average end-to-end delay:

- The Average end-to-end delay on both WiFi and WiMAX mobile interfaces is not affected by the MN speed in the two scenarios. Average end-to-end delay shows acceptable values compared to the ITU-T recommendations. We conclude that the performance in these scenarios are acceptable for the applications bitrate that are aware of delay.

The importance of this study is to investigate the performance of the mobile applications in vertical handover scenarios between WiFi and WiMAX networks using IEEE 802.21. This evaluation is presented by the key metrics that affect the QoS of specific applications such as voice and video. The results were presented as a function of the MN speed. The small coverage area of the WiFi network limited the mobile node to specific speed when the mobile node moves from WiFi to WiMAX scenario at speed 20 km/h for video applications and at speed 40 km/h for voice applications. In addition, this study provides the range of applications bitrate from 256 kb/s to 4096 kb/s have acceptable handover latency values and within the range of ITU-T standard. These results may help the designers if they are considered in the implementation of the multi-criteria decision algorithm, beside the received signal strength criteria that is used in the MIH implementation. The obtained results in this study are competitive to the latest studies in the same research area. In addition, results modelling was presented in this thesis and was not proposed in the related works.

6.2 Future Work

The vertical handover scenarios used in this thesis were designed based on WiFi and WiMAX networks. WiFi was completely inside WiMAX network. As a future work, it is recommend designing partial overlapped vertical handover scenarios between WiFi and WiMAX networks and study the performance in the vertical handover scenarios considering the effect of the mobile node speed, mobility direction and applications bitrate. The same performance evaluation metrics defined in this thesis could be used using the received signal strength decision algorithm implemented by IEEE 802.21.

WiFi and WiMAX are wireless access networks that belong to the IEEE 802 family of standards and have small and large coverage areas respectively; both wireless networks provide high bandwidth. As future work, it is recommend designing vertical handover scenarios between IEEE 802 and non IEEE 802 families. WiMAX and Universal Mobile Telecommunication System (UMTS) for example could be used in vertical handover scenario to study and evaluate the effect of the mobile node speed and the applications bitrate. Both access networks provides high user mobility due to their large coverage area. However, WiMAX provides high bandwidth and UMTS network provides limited bandwidth.

In mobility direction from WiMAX to WiFi scenario used in this thesis, handover took place when the MN reaches the boundaries of the WiFi cell although WiMAX BS signal considered being available everywhere in the topology. The received signal strength on the WiMAX mobile interface did not reach the weighted threshold. As future work, it is recommend implementing handover necessity algorithm as pre-stage algorithm before the vertical handover decision algorithm. The purpose of this algorithm is to determine the handover necessity through calculating the travelling time in WiFi network before decide to make handover. This algorithm could reduce unnecessary handovers by considering the mobile node speed.

As future work, real testbed in small-scale between WiFi and WiMAX wireless networks is recommend to be implemented using Open Dot Twenty One (ODTONE) that is an open source implementation of MIH framework from the IEEE 802.21. ODTONE works with the platforms; Windows, Linux, Android [Hng13].

Service continuity is a challenging issue in vertical handover between heterogeneous networks due to the different link layer technologies. MIH services based on the IEEE 802.21 standard used to assist the vertical handover process and achieve service continuity by providing information from the lower layer to the upper layers through its events and commands. Vertical handover take place using decision algorithm based on received signal strength criteria. As future work it is recommend to consider other criteria in addition to the criteria studied in this thesis such as (Bandwidth, Cost, Power Consumption, User Preferences and Security).

Acronyms and Abbreviations

AP	Access Point
ASN	Access Service Network
ASN-GW	Access Service Network Gateways
BS	Base Station
BSA	Basic Service Area
BSS	Basic Service Sets
CBR	Constant Bitrate
CSMA/CA	Carrier Sense Multiple Access/Collision Avoidance
CSN	Connectivity Service Network
DS	Distributed Systems
DSSS	Direct Sequence Spread Spectrum
E2ED	Average End-to-End Delay
ESS	Extended Service Set
IBBS	independent basic service set
IEEE	Institute of Electrical and Electronics Engineering
ITU-T	International Telecommunication Union-Telecommunication
LGD	Link_Going_Down
LOS	Line of Sight
MAC	Medium Access Control
MICS	Media Independent Command Service
MIES	Media Independent Event Service
MIH	Media Independent Handover

MIHF	Media Independent Handover Function
MIIS	Media Independent Information Service
MN	Mobile Node
MS	Mobile Station
NIST	National Institute of Standards and Technology
NLOS	Non Line-of-Sight
NS-2	Network Simulator 2
ODTONE	Open Dot Twenty One
OFDM	Orthogonal Frequency-Division Multiplexing
OTcl	Object-oriented Tool Command language
PLR	Packet loss Ratio
PoA	Point of Attachment
QOS	Quality of Service
UDP	User Datagram Protocol
UMTS	Universal Mobile Telecommunication System
WiFi	Wireless Fidelity
WLAN	Wireless Local Area Network
WMAN	Wireless Metropolitan Area Network

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Appendix A

Published Paper

Nasim Hamaydeh, Abedelaziz E. Khalil, Samer Bali and Labib Arafeh, "**The Impact of Mobile Speed on Vertical Handover Process Between WiFi and WiMAX Networks**" in proceeding of the 2013 IEEE International RF and Microwave Conference (RFM2013), Penang, Malaysia, pp.126-131, December 9-11, 2013.

The Impact of Mobile Speed on Vertical Handover Process Between WiFi and WiMAX Networks

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Abstract — **In mobile communications, seamless mobility is needed among heterogeneous wireless networks. Service continuity can be maintain by using an accurate vertical handover scheme. IEEE802.21 standard facilitates handover between heterogeneous networks by presenting media independent handover (MIH) reference models for different link layers technologies. In this paper, we carried out a comprehensive analysis for the key metrics that affects the Quality of Service (QoS) during the vertical handover between WiFi and WiMAX networks. The main objective is to study the effect of the mobile speed on these metrics to measure the performance of vertical handover process through the interoperability between WiFi and WiMAX networks using MIH. The simulation results can help the network designers to implement algorithms such as multi criteria decision-making (MCDM) algorithms in MIH framework to enhance the vertical handover process and consider the mobile speed in the design.**

Keywords—Vertical Handover, MIH, IEEE802.21 WiFi, WiMAX, Throughput, Delay, Handover Latency.

I. Introduction

Mobile Communication systems have become a major component of modern lifestyle, they are exploited and oriented toward almost all kinds of computing aspects. Service continuity between heterogeneous wireless networks is becoming an essential issue. In addition, Quality of Service (QOS) aware applications have their own constraints that should be met in any network. The diversity of heterogeneous networks, smart mobile devices and the demand of multimedia services increased service continuity challenges. Therefore, mechanisms needed to ensure that the services on mobile nodes are running smoothly without interruption while moving between heterogeneous wireless networks, matching network conditions with QoS constrains. Vertical Handover is the process by which a mobile node redirects traffic flow between network interfaces, based on obtained features from mobile access networks. These Issues addressed by the Media Independent Handover (MIH), which defined in IEEE802.21 standard. MIH offers extensible mechanisms for handover between implementations of IEEE802 family and Cellular networks, based on reference models for different link layer technologies. MIH standard uses cross-layer concept through an abstraction layer implemented in the protocol stack of a certain device [1].

II. Related Work

The research trends of vertical handover directed toward MIH implementations and capabilities, performance analysis fulfilling QoS constrains, MCDM algorithms and mobility management using Mobile IPs. In performance analysis, the research analyzes the MIH primitives, observing input parameters affecting handover process and proposing evaluation metrics used in performance evaluation. Research in [2] presents experiments to evaluate the vertical handover performance based on MIH standard among WiFi, WiMAX and UMTS. Although the proposed scenarios only consider the instant throughput and latency, the results show that technology-aware vertical handover mechanisms are able to achieve an adequate performance when traffic congestion is low. The work in [3] presents performance evaluation of different traffic flow over WiFi and WiMAX using MIH standard. Throughput, delay and packet loss rate used as evaluation metrics. In [4], vertical handover decision algorithm from WiMAX to WiFi proposed; the decision made based on the mobile node speed and session priority using four traffic flows. The proposed algorithm improves some of the performance metrics such as latency, packet loss and average throughput. Research in [5] provides a description of IEEE802.21 implementation in ns2, handover process signaling between WiFi and WiMAX networks and method to calculate the number of handovers while using multiple mobile nodes.

In this research, we carried out a comprehensive analysis for the QoS key metrics during the vertical handover process between WiFi and WiMAX. Mobile node speeds (5, 10, 15, 20, 25, 30, 40, 70, 100, and 120) km/h used as input parameter and changed every simulation run. Throughput, Delay, Packet Loss Ratio, Packet Delivery Ratio and handover latency used as evaluation metrics to measure the performance of the vertical handover scenarios using MIH. The most common traffic flow types used are Voice and Video. The selected traffic flow types relies on User Datagram Protocol (UDP) using constant bit rate (CBR). The bit rates used in all simulation scenarios are (64, 100, 200, 400, 800, 1600, 2400, 3200, 4000) kb/s. this paper will contribute through presenting a useful simulation results from the comprehensive performance analysis for the vertical handover process between two heterogeneous networks WiFi and WiMAX using MIH in terms of mobile node speed. These results will help designers to enhance the vertical handover process and consider mobile node speed in the design.

The rest of the paper organized as follows; Section II discusses the wireless access networks. Section III introduce the vertical handover concept. Section IV discusses the simulation environment including parameters and metrics. Section V exhibits results and analysis, Section VI concludes and summarizes the work.

III. VERTICAL HANDOVER IN WIRELESS ACCESS NETWORKS

A. WiFi Networks:

The first published standard for WiFi was IEEE802.11 in 1997. WiFi is expected to be embedded in most communication devices; working on unlicensed frequency band. One of the limitations on WiFi networks is the signal degradation in large areas; making the coverage area and device's mobility limited. Related to vertical handover, an emerging protocol IEEE802.11u published in 2011 enables interworking with 3G cellular networks based on MIH standard.

B. WiMAX Networks:

Worldwide Interoperability for Microwave Access (WiMAX) published as IEEE802.16 standard in 2001. It is intended for metropolitan networks, providing wireless for large area coverage with high bit rate. Mobile nodes in WiMAX have high mobility and coverage for several kilometers. For vertical handover, mobile WiMAX networks are IP-based wireless broadband technology; easily integrated with Cellular networks such as 3G and other wireless networks.

C. Vertical Handover

Handover process takes place whenever the mobile node moves from one wireless cell to another. If the mobile node is moving within the same access technology, the process called horizontal handover. Vertical handover means moving to another access technology, this process also called inter-technology handover. In the literature, handover process consists of three stages; network discovery, handover decision and handover execution. The actual transfer of data packets to a new wireless link occurs in the execution stage. Data link and network layer signaling take place in this stage to redirect traffic [6].

IV. SIMULATION ENVIRONMENT

In this research we used Network Simulator 2 (ns-2) integrates with the MIH mobility package for ns-2.29 developed by the National Institute of Standard and Technology (NIST); this mobility package consists of an implementation for the IEEE802.21 standard, it is used to simulate WiFi and WiMAX technologies and performing vertical handover scenarios among them based on IEEE 802.21 standard [7]. The network parameters used in WiFi and WiMAX shown in Table I.

Table I. Simulation Parameters for WiFi and WiMAX

Global Parameters	
Propagation Model	TwoRayGround
Antenna model	Omni Antenna
Topology Range	3000 x 3000 m
Simulation Duration	210 sec
Mobile node speeds	5, 10, 15, 20, 25, 30, 40, 70, 100,120 km/h
Bit rates	CBR; 64, 100,400, 800, 1600, 2400, 3200,4000 kb/s
Wired Links	100 Mb/s
WiFi Parameters	
Coverage area	100 m
MAC Type	Mac/802_11
Frequency	2.412 GHz
Bandwidth	11 Mb/s
Transmission Power	0.0134 W
RXThresh	1.31272e-10 W
CSThresh	90% of RXThresh
Pr_limit	1.2
WiMAX Parameters	
Coverage area	1000 m
MAC Type	Mac/802_16
Frequency	3.5 GHz
Bandwidth	10 Mb/s
Transmission Power	15 W
RXThresh	7.59375e-11 W
CSThresh	90% of RXThresh
Lgd_factor	1.1

A. Simulation Scenario

The simulation scenarios in this research consist of mobile node connected to wireless access network and moves toward another network with constant speeds (5, 10, 15, 20, 25, 30, 40, 70, 100 and 120) km/h. In WiFi to WiMAX scenario, the mobile node is located in the coverage area of the WiFi network and so its access point represents the serving point of attachment (PoA) while WiMAX base station represents the target or candidate PoA. In WiMAX to WiFi scenario, the mobile node is moving from WiMAX; the serving PoA to WiFi, which represents the target PoA. The area is 3000 m² with the deployment of one mobile node, one access point for WiFi and one base station for WiMAX. For the wired infrastructure, two network routers deployed. The network links are duplex with bit rate of 100 Mbit/s, connecting the wireless access points and base stations with routers and the media server. Each node in the network has MIH components to facilitate the handover process.

Fig. 1 shows the mobility scenarios for a mobile node inside a car while establishing a connection to a media server. The mobile node has always WiMAX connectivity and while it moves, it discovers a WiFi network and performs a vertical handover and vice versa.

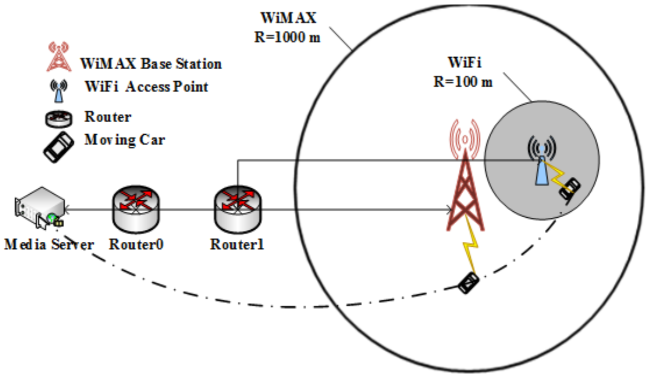

Fig. 1. Simulation Scenario

B. Performance Metrics

The mobile node in the scenarios move in the direction of WiFi to WiMAX or vice versa. Several experiments with random seeds configured to evaluate performance metrics. These performance metrics are widely mentioned in the literature [5] [8] [9].

- *Average Throughput:* the ratio of data packets delivered to the destination by time interval [1]. Measured in kilobit per second (kb/s).
- *Average Delay:* measured in millisecond (ms), it is the average time or one way latency a packet takes to reach the destination from a source node. Delay includes processing delay, network delay, in addition to prorogation, transmission and queuing delay [1].
- *Total Packet Loss Ratio:* is the difference between the total number of packets sent by the source and the number of the packets received by the mobile node in both WiMAX and

WiFi interfaces divided by the total number of packets sent by source.

- *Handover Latency:* amount of time that elapses between an interface sending MIPv6 redirect request to the media server and receiving the correspondent redirect acknowledgment from the media server [5]. Measured in millisecond.
- *Total Packet Delivery Ratio*: defined as the ratio of the total packets delivered successfully to the destination to the total packets generated by the traffic source [10].

V. Resuls and Analysis

A. Average Throughput

Fig. 2 shows WiFi throughput versus mobile node speed in WiFi to WiMAX vertical handover scenario with different bit rate applications. We notice that as the mobile node speed increases there is slight decrease in throughput values due to the degradation of the received signal strength when the mobile node moves far away from its serving point of attachment (PoA). By increasing the mobile speed, the travelling time becomes shorter until it reaches the WiFi cell boundaries and the number of received packets decreased accordingly. For high bit rate applications, the decrease in throughput is higher than the decrease in low bit rate applications. The throughput decreased by 1.02% when the mobile node moves from 5 km/h to 120 km/h for the 64kb/s bit rate application. The throughput decreased by 1.69% when the mobile node moves from 5 km/h to 120 km/h for the 4 Mb/s bit rate application. Fig. 3 shows WiMAX throughput versus mobile node speed in WiFi to WiMAX vertical handover scenario for different bit rate applications. We observe that when the mobile node speed increases there is a slight increase in throughput values. This slight increase in the throughput values is due to the increase of the received signal strength on the mobile WiMAX interface when the mobile moves towards the WiMAX base station and hence, the number of received packets increased accordingly. Regarding bit rate, the increase in throughput values for high bit rate applications is higher than the increase in low bit rate application. The throughput increased by 0.003% when the mobile node moves from 5 km/h to 120 km/h for the 64kb/s bit rate application. The throughput increased by 0.005% when the mobile node moves from 5 km/h to 120 km/h for the 4 Mb/s bit rate application. Fig. 4 shows WiMAX throughput versus mobile node speed in WiMAX to WiFi vertical handover scenario for different bit rate applications, slight decrease observed in the throughput values as the mobile speed increases. The decrease in high bit rate application is higher than the decrease in the lower bit rate application. The results show that there is a decrease by 0.84% when the mobile node moves from speed 5 km/h to speed 120 km/h for 64 kb/s bit rate application. For the 4 Mb/s bit rate applications the decrease is 1.26% when the mobile node moves from the speed at 5 km/h to the speed at 120 km/h. The slight decrease in the throughput values is due to degradation of the received signal strength when the mobile node moves far away from its serving point of attachment (PoA). As the mobile node speed increases, the travelling time towards the candidate network becomes shorter which decreases the number of received packets on the mobile WiMAX interface. In addition to the mobile node detects new candidate network that considered a preferred network with higher bandwidth and lower cost. Fig. 5 shows the WiFi throughput against mobile node speed in WiMAX to WiFi vertical handover scenario for different bit rate applications, as the mobile node speed increases a slight increase in throughput are observed. The increase in the high bit rate applications is higher than the increase in low bit rates, but the value of thought for low bit rate applications 64 kb/s is the highest. On the one hand, when the mobile node moves at speeds from 5 km/h to 120 km/h, the throughput for the application with bit rate 64kb/s increased by 0.007%. On the other hand, the throughput for the 4 Mb/s bit rate application is increased by 0.013% when the mobile node moves from lowest speed at 5 km/h to the highest speed at 120 km/h. This slight increase in the throughput values is due to the increase of the received signal strength on the mobile WiFi interface when it is moving towards the WiFi access point and the received packets increased.

B. Average Delay

Measured on the mobile node interface that is related to each access technology in both scenarios; WiFi to WiMAX and WiMAX to WiFi. Fig. 6 shows WiFi average delay versus mobile node speed in WiFi to WiMAX vertical handover scenario for different bit rate applications, we observed that there is no effect for the mobile speed on the average delay. The results show that higher bit rate applications have higher delay compared to the delay in lower bit rate applications.

For example, the 64 kb/s bit rate application has a delay of 46.14 ms at 5 km/h and 120 km/h speeds compared to average delay of 51.3 ms at 5 km/h speed and 51.6 ms at 120 km/h speed for the 4 Mb/s bit rate application. Fig. 7 shows WiMAX average delay versus mobile node speed in WiFi to WiMAX vertical handover scenario for different bit rate applications, there is no effect of the mobile speed on the average delay. As the bit rate increases the average delay increases accordingly; the 64 kb/s bit rate application has average delay of 46.44 ms at 5 km/h and 120 km/h speeds compared to average delay of 49.18 ms for the 4 Mb/s bit rate application at the same speeds. Fig. 8 shows the WiMAX average delay versus the mobile node speeds in WiMAX to WiFi vertical handover scenario for different bit rate applications; we notice that there is no effect of the mobile speed on the average delay. The delay of high bit rate applications is higher than the delay of low bit rate applications. We notice a delay of 46.44 ms for 64 kb/s bit rate applications at 5 km/h and 120 km/h speeds compared to a delay of 49.18 ms for the 4 Mb/s bit rate applications at the same speeds. Fig. 9 shows WiFi average delay versus mobile node speeds in WiMAX to WiFi vertical handover scenario for different bit rate applications, there is slight effect of the mobile speed on the average delay. The results show the high bit rate applications have higher delay than the low bit rate applications. For example, the 64 kb/s bit rate application has a delay 46.15 ms at 5 km/h and 120 km/h speeds compared to a delay of 51.2 ms for the 4 Mb/s bit rate application at the same speeds. In general, we conclude that the mobile speeds do not affect the average delay in both networks, WiFi and WiMAX; because the two networks have high available resources in terms of bandwidth, but the average delay increases as the application's bit rate increases due to network traffic load.

C. Total Packet Loss Ratio

Fig. 10 shows the total packet loss ratio versus the mobile node speed in WiFi to WiMAX vertical handover scenario for different bit rate applications. There is no impact of the mobile speed on the packet loss ratio for voice applications that has bit rate 64 kb/s, and there is slight effect to the mobile node on the packet loss ratio for bit rates over 64 kb/s. The results show the higher bit rate applications have higher packet loss ratio than the lower bit rate applications. For example, the mobile voice application with 64 kb/s bit rate has packet loss ratio of 0.075% at 5 km/h and 120 km/h speeds compared to 0.081% at 5 km/h speed and 0.084% at 120 km/h speed for the 4 Mb/s bit rate video application. The packet loss ratio values for both voice and video is acceptable based on ITU-T recommendations due to the high available resources of the two access technologies WiFi and WiMAX in terms of bandwidth regardless of the coverage areas and user mobility. Fig. 11 shows the total packet loss ratio versus the mobile node speeds in WiMAX to WiFi vertical handover scenario for different bit rate applications. There is no effect of the mobile speed on the packet loss ratio for bit rates less than 4 Mb/s, but there is slight effect of the mobile speed on the packet loss ratio for bit rate 4 Mb/s application. The bit rates less than 4 Mb/s has a packet loss ratio of 0.027% at 5 km/h and 120 km/h speeds compared to 0.033% at 5 km/h and 120 km/h speeds for bit rate application 4 Mb/s. The value of total packet loss ratio is low due to the high available resources of the two technologies WiFi and WiMAX in terms of bandwidth in both access and core networks regardless of the coverage areas and user mobility.

D. Handover Latency

Fig. 12 shows the handover latency versus the mobile node speed in WiFi to WiMAX vertical handover scenario for different bit rate applications, there is no effect of the mobile speed on the handover latency. The handover latency in WiFi to WiMAX vertical handover scenario ranges from 96.72 ms to 101.45 ms. Fig. 13 shows the handover latency versus the mobile node speed in WiMAX to WiFi vertical handover scenario for different bit rate applications, there is no effect of the mobile speed on the handover latency. The handover latency in WiMAX to WiFi vertical handover scenario ranges from 94.7 ms to 95.1 ms. MIPv6 affects the handover latency during redirection of the traffic flow to the new mobile interface.

E. Total Packet Delivery Ratio

Fig. 14 shows the total packet delivery ratio versus mobile node speed in WiFi to WiMAX vertical handover scenario for different bit rate applications, there is slight effect of the mobile speed on the packet delivery ratio for video application. The results show that the packet delivery ratio in low bit rate applications is higher than the packet delivery ratio in high bit rate applications. In general, the total packet delivery ratio is over 99.91% for all applications at all mobile speeds due to the high available resources of the two access technologies WiFi and WiMAX in terms of bandwidth regardless of their coverage areas and user mobility. Fig. 15 shows the total packet delivery ratio versus the mobile node speed in WiMAX to WiFi vertical handover scenario for different bit rate applications, there is slight effect of the mobile speed on the packet delivery ratio. The packet delivery ratio is over 99.96% for all bit rate applications at all speeds due to the higher available resources of the two access technologies WiFi and WiMAX in terms of bandwidth regardless of their coverage areas and user mobility.

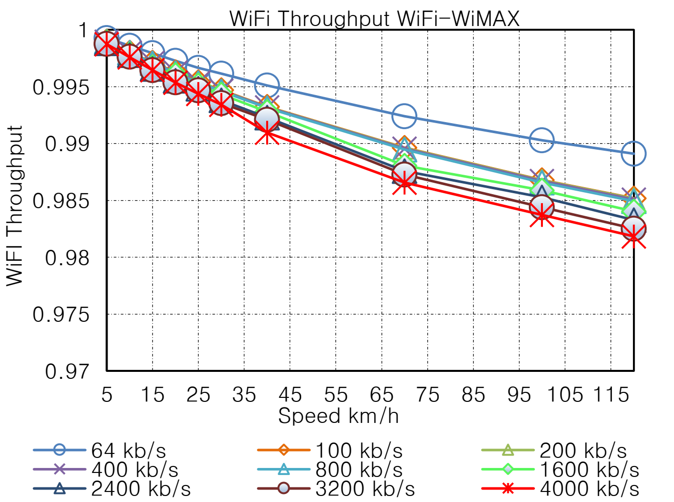

Fig. 2. Normalized throughput measured between media server and WiFi interface on the mobile node for different bit rates in WiFi to WiMAX scenario.

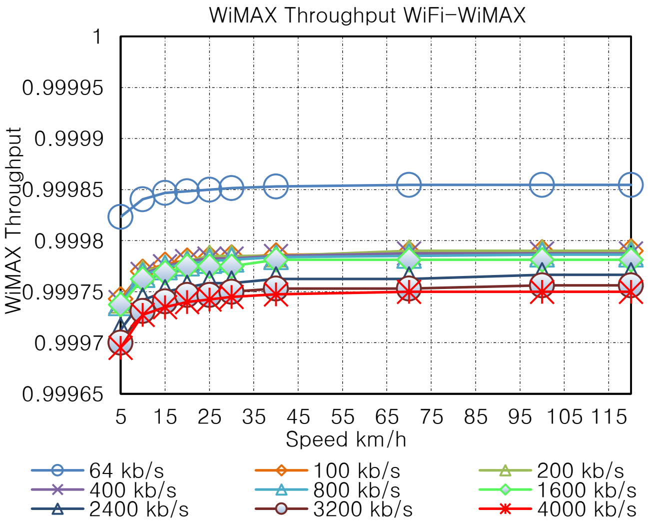

Fig. 3. Normalized throughput measured between media server and WiMAX interface on the mobile node for different bit rates in WiFi to WiMAX scenario.

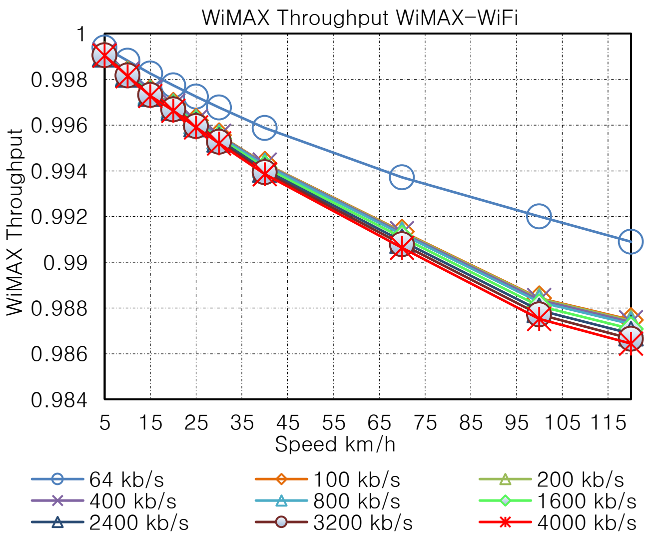

Fig. 4. Normalized throughput measured between media server and WiMAX interface on the mobile node for different bit rates in WiMAX to WiFi scenario.

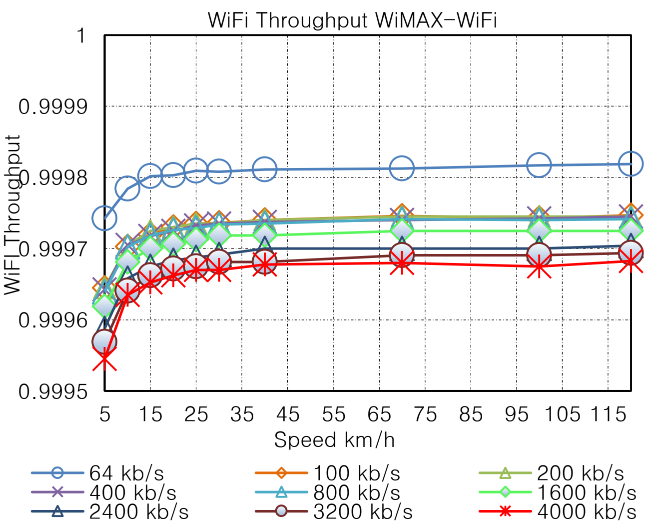

Fig. 5. Normalized throughput measured between media server and WiFi interface on the mobile node for different bit rates in WiMAX to WiFi scenario.

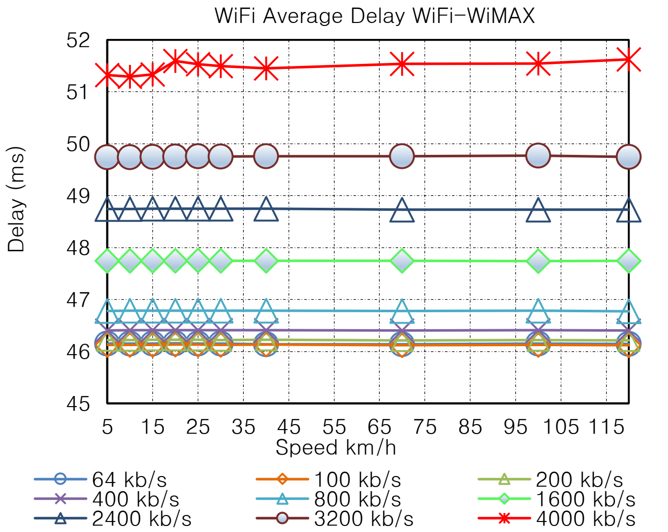

Fig. 6. Average End-to-End Delay measured between media server and WiFi Interface of the mobile node for different bit rates.

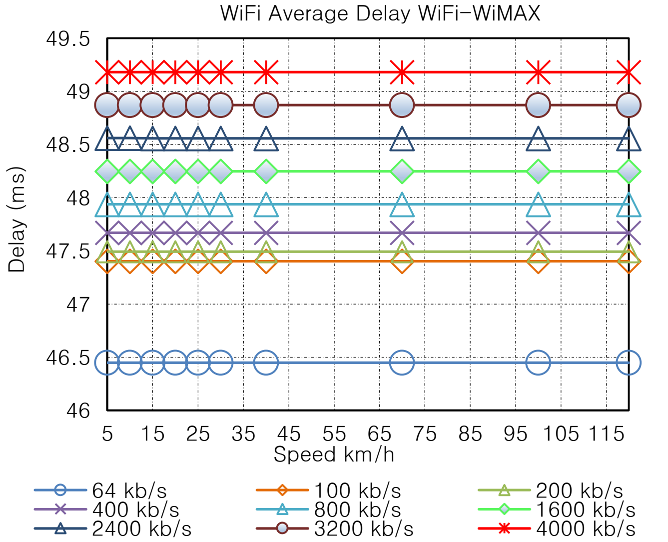

Fig. 7. Average End-to-End Delay measured between media server and WiFi interface of the mobile node for different bit rates.

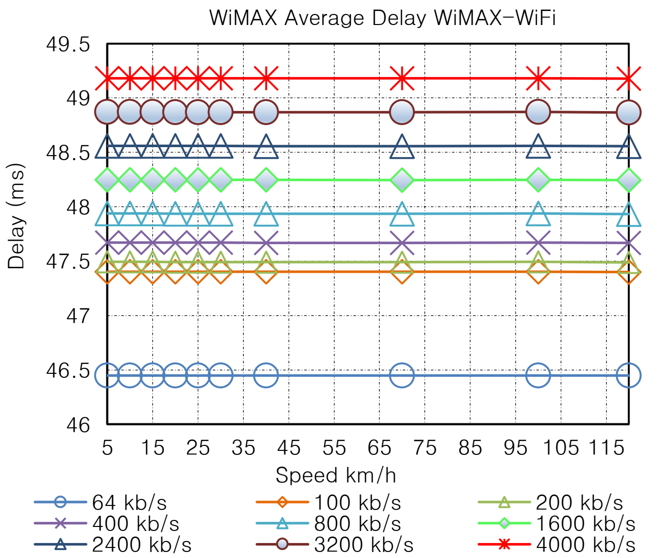

Fig. 8. Average End-to-End Delay measured between media server and WiMAX interface of the mobile node for different bit rates.

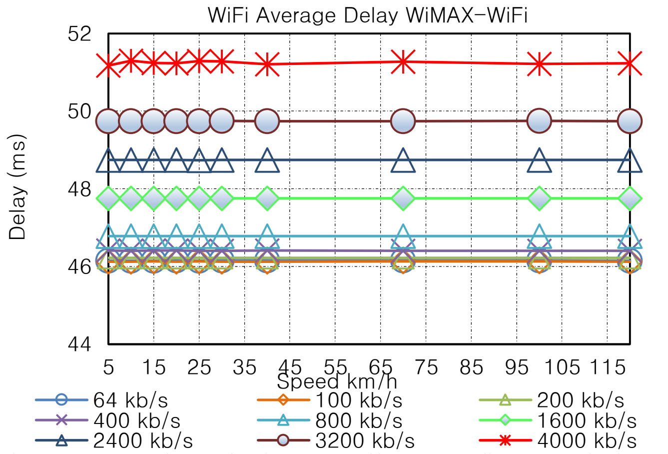

Fig. 9. Average End-to-End Delay measured between media server and WiMAX interface of the mobile node for different bit rates.

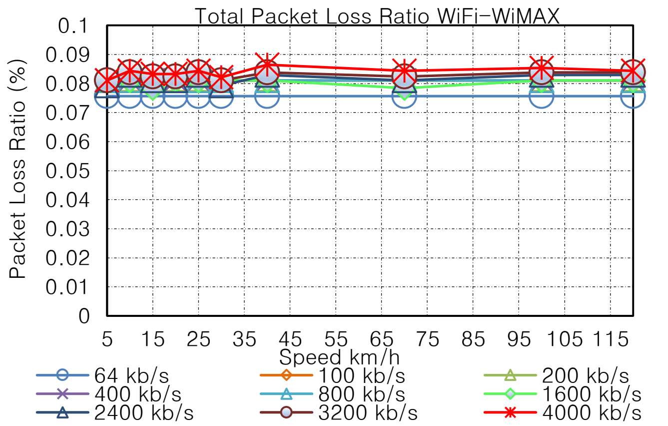

Fig. 10. Total Packet Loss Ratio for different bit rates when the mobile node moves from WiFi to WiMAX network.

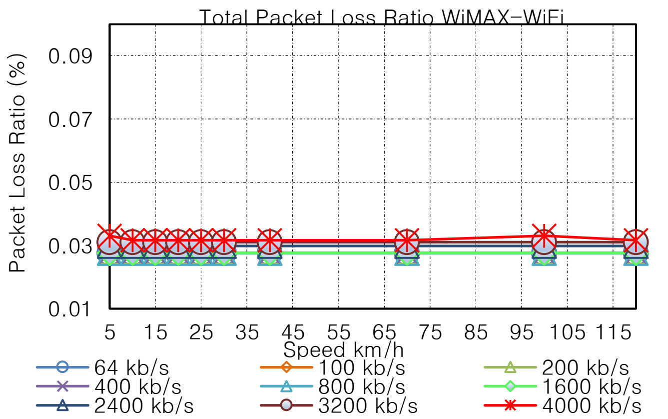

Fig. 11. Total Packet Loss Ratio for different bit rates when the mobile node moves from WiMAX to WiFi network.

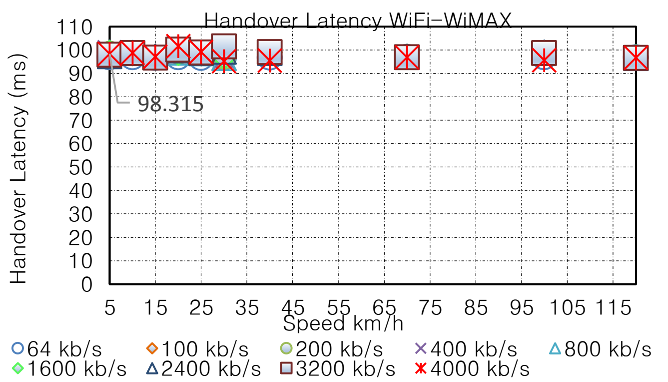

Fig. 12. Handover latency measured between media server and mobile node for different bit rates when the mobile node moves from WiFi to WiMAX.

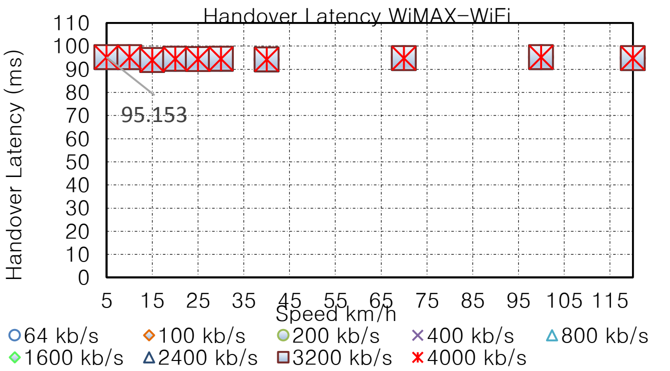

Fig. 13. Handover latency measured between media server and mobile node for different bit rates when the mobile node moves from WiMAX to WiFi.

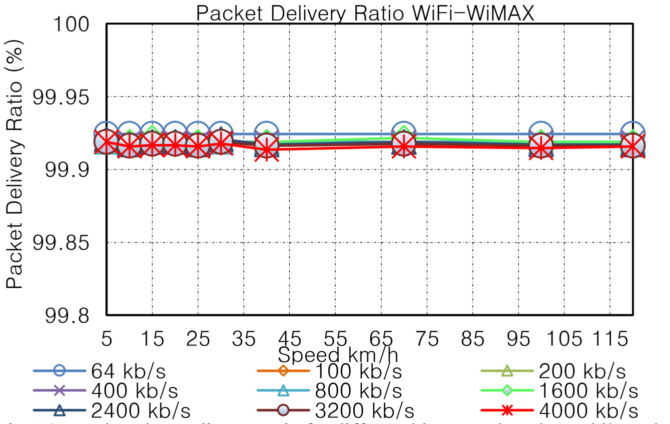

Fig. 14. Total Packet Delivery Ratio for different bit rates when the mobile node moves from WiFi to WiMAX network.

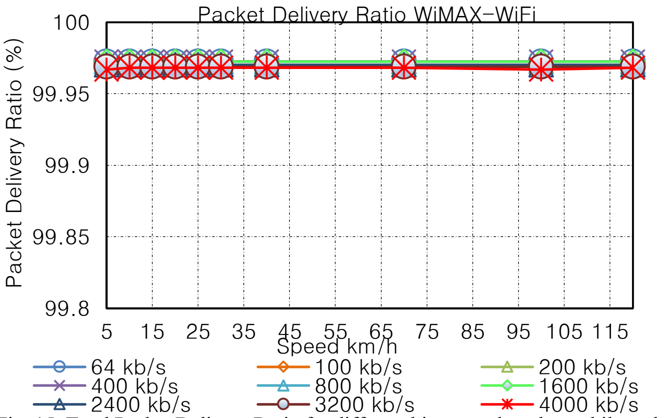

Fig. 15. Total Packet Delivery Ratio for different bit rates when the mobile node moves from WiMAX to WiFi network.

VI. Conclusion

In this research, we presented a comprehensive analysis for the performance evaluation metrics that used to evaluate the performance of the vertical handover process between WiFi and WiMAX networks using MIH. From the simulation results, we conclude that there is slight effect of the mobile speed. The results of throughput in both access technologies show high throughput values with no interruption in the ongoing session. The throughput value decreases as mobile speed increases when the mobile moves far away from the serving PoA due to the degradation of the received signal strength and the number of received packets decreased accordingly. The throughput value increases as the mobile speed increases when the mobile is moving towards the serving PoA due to the increase of received signal strength and hence, the number of received packets increased accordingly. For the average End-to-End delay, in both networks mobile speed has no effect on the delay because the two networks have high available resources in terms of bandwidth, and the average delay increases as the application bit rate increases due to the network traffic load. Therefore, performance in terms of delay is acceptable according to the ITU-T recommendations [5]. Recommended values is less than 150 ms for voice applications and 280 ms for non-interactive video applications. For the total packet loss ratio the simulation results present that, the performance in terms of packet loss ratio is acceptable. The total packet loss ratio in WiMAX to WiFi is 0.027% at 5 km/h and 120 km/h speeds for voice applications and 0.033% at 5 km/h and 120 km/h for video applications. While the total packet loss ratio in WiFi to WiMAX is 0.075% at 5 km/h and 120 km/h speeds for voice applications and 0.081% at 5 km/h speed, 0.084% at 120 km/h speed for video applications. The recommended packet loss ratio less than 2% for voice applications in mobile broadband access networks and 1% for non-interactive video applications in mobile networks [5] based on the recommendation of the ITU-T. Regarding the Handover Latency, there is no effect for the mobile speed on the handover latency but there is effect for the MIPv6, the latency in WiMAX to WiFi is less than the latency in WiFi to WiMAX scenario. For the total packet delivery ratio, there is slight effect of mobile speed; simulation results present high performance in terms of total packet delivery ratio. The packet delivery ratio in WiMAX to WiFi is higher than WiFi to WiMAX. In summary, the simulation results show slight effect of mobile speed, the values of the performance metrics are acceptable due to the high bandwidth of the two networks. However, due to the low coverage of the WiFi network, in WiFi to WiMAX scenario the packet loss ratio in WiFi becomes 2% for voice applications when the mobile moves with speed over 40 km/h, 1% for non-interactive video applications for speed over 20 km/h, which makes the user mobility low in WiFi. In general, the results show it is better to make handover from WiMAX to WiFi than making handover from WiFi to WiMAX. WiFi can used as hot spots inside the WiMAX network.

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