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Performance Study of the Effective Factors in Vertical Handover between UMTS and WiFi Enhanced by IEEE802.21

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Dedication

I would like to dedicate my thesis to my father, Dr.Esam and my mother Dr.Amal for their support and motivation throughout my life and career. I learned from my parents the value of hard work and determination to succeed. I dedicate my work also to my wife Eng.Lena with appreciation for her encouragement and understanding as well as my newly born baby girl Rania, who lit our life through this period. The work is dedicated also to my brothers Ahmad and Eng.Hassan for their unlimited support, they deserve my wholehearted thanks as well, in addition to my grandmothers and to the souls of my grandfathers, to my parents-in-law, to my whole family and my lovely city Jerusalem – Palestine.

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

Abedelaziz Esam Abedelaziz Khalil

Date: ……..……….

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Abstract

Mobile communication systems experienced high technical revolution. Nowadays, smart mobile devices have advanced computing aspects. In addition, they are equipped with multiple network interfaces. WiFi and 3G networks represented in UMTS are heterogeneous with respect to their implementations, therefore their interfaces on the mobile devices suffer the lack of interworking mechanisms that will result in session interruption when the traffic is redirected between them. The traffic redirection between these networks is addressed by the vertical handover process. Recently, vertical handover enhanced by the IEEE802.21 standard has been proposed in the literature. It is an effective technique which enables seamless mobility and interworking between most of the wireless access networks.

The work in this thesis presents a comparative performance study for the integration between WiFi and UMTS networks by taking advantage of the IEEE802.21 standard services that facilitate the integration between WiFi and UMTS networks. The factors that affect the vertical handover process in this integration were studied such as; the mobile node speed, the application bitrate and the direction of mobility from WiFi to UMTS and vice versa. Vertical handover scenarios were implemented and extensive simulation experiments were carried out using NS-2 simulator. To reveal the influence of the effective factors on the vertical handover scenarios; performance evaluation metrics were studied such as throughput, delay, packet loss and handover latency. The behaviour of the performance evaluation metrics were modelled and observed under the effect of the studied factors.

Results of delay, handover latency and total packet loss ratio were compared to the ITU-T and the IEEE802.20 standard recommendations to show how the proposed scenarios

in this thesis are close to reality and to what extent the results are acceptable and fulfil the QoS requirements.

The simulation scenarios in this thesis were implemented based on the direction of mobility; from WiFi to UMTS and vice versa, thus the obtained results will be discussed accordingly. Mobile node speed varies between 5 km/h and 60 km/h whereas application bitrate varies between 64 kb/s and 3840 kb/s. Metrics were highly affected by the UMTS low bandwidth; therefore most of the metrics' values changed in UMTS network when using application bitrate more than 384 kb/s.

Finally, the obtained results demonstrate the importance of considering the studied factors as decision criteria, in addition to the traditional criterion used in vertical handover to select a candidate network based on Received Signal Strength. We believe that considering the contribution in this research will for sure have a rational impact on the users' mobility by serving them with high bandwidth and low cost network when handover to WiFi network when it is available whereas handover to UMTS will serve them with high mobility network. This handover is subject to the studied criteria and their effect on the vertical handover process.

Keywords: Vertical handover, QoS, MIH, IEEE802.21, WiFi, UMTS, Throughput, Delay, Handover Latency, Packet loss.

ملخص الدراسة

أنظمة الإتصالات اللاسلكية تتطور بشكل كبير في السنوات الأخيرة. فالهواتف اللاسلكية النقالة أصبح لديها مواصفات فنية عالية لتلبية الإحتياجات الحاسوبية لمستخدميها. الهواتف اللاسلكية الذكية يمكنها الإتصال أيضا مع أكثر من شبكة لاسلكية وذلك بسبب وجود كرتات لاسلكية مثبتة لكل شبكة (Interface). شبكات الجيل الثالث (3G) و شبكة الإتصال المحلية اللاسلكية (WiFi) والتي تعمل على معيار (IEEE 802.11) هما أكثر الشبكات إنتشارا، ولكن هذه الشبكات وكرتات الإتصال الخاصة بها تعمل بشكل منفصل على الأجهزة اللاسلكية الذكية، و بالتالي فهي تعاني من مشكلة التكاملية والتوافق في العمل مع بعضها البعض، لذلك هنالك حاجة إلى ألية لتسليم الإتصال من شبكة إلى أخرى دون إنقطاعه. بما أن هذه الشبكات مختلفة في تصميم طبقاتها الفيزيائية فإن الإنتقال السلس بين هذه الشبكات يتم من خلال تطوير ألية التسليم العمودي للإتصال (Vertical Handover).

تناول الباحث في هذه الدراسة مشكلة التسليم العمودي بين شبكات الجيل الثالث وشبكات (WiFi) بإستخدام معيار (IEEE802.21) والذي يوفر خدمات تساعد على التكاملية بين طبقات تصميم الشبكات المذكورة كما وأن التسليم العمودي بإستخدام هذا المعيار يعتبر من أحدث الطرق لحل هذه المشكلة.

هنالك عوامل تؤثر على عملية التسليم العمودي تمت دراستها مثل سرعة الهاتف النقال وتردد البيتات في التطبيقات المختلفة ونوعية الشبكة اللاسلكية التي يتم الإتصال بها. كما وقمنا بتوضيح تأثير هذه العوامل على جودة وكفاءة الخدمة لمستخدمي الشبكات اللاسلكية من خلال قياس معايير مثل، معدل فقد الحزم، معدل الإنتاجية، معدل التأخير للحزمة الواحدة والتأخير بسبب عملية التسليم العمودي.

توصل الباحث إلى نتائج مرضية فيما يتعلق بالقيم الخاصة بمعايير جودة الخدمة وقد تمت مقارنة النتائج الخاصة بمعدل فقد الحزم ومعدل التأخر لكل حزمة والتأخر بسبب عملية التسليم العمودي مع القيم المحددة للتطبيقات الحساسة للتأخير وفقد الحزم مثل الصوت والفيديو والموضحة في المرجع المعد من قبل الإتحاد الدولي للإتصالات (ITU-T). ومن الجدير بالذكر أن النتائج الذي توصل اليها الباحث في هذه الدراسة هي منافسة للنتائج التي توصل لها الباحثون في هذا المجال.

من أهم التوصيات في الدراسة، أن التطبيقات الحية التي ستعمل على الهواتف اللاسلكية في السيناريو المطروح والذي يجمع بين (WiFi) وشبكة الجيل الثالث (3G) يفضل أن يستخدم سرعة وتردد بيتات يتناسبان مع خصائص شبكات WiFi وشبكات (3G).

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Chapter 1
Introduction

1.1 Motivation

Nowadays mobile Systems are equipped with multiple network interfaces. WiFi - stands for Wireless Fidelity - and 3G - stands for 3rd Generation - are widely implemented. Wireless access technologies were implemented to serve mobile users; including wireless local area network implemented by IEEE802.11 and cellular 3G systems represented in the Universal Mobile Telecommunication Systems (UMTS) implementation [Jan11]. Nowadays, most modern mobile devices suffer from the interoperability between the WiFi and 3G interfaces, each access technology serves the user independently and therefore these technologies suffer the lack of interworking mechanisms and service continuity [Fer12]. Integration between heterogeneous wireless networks becomes a major issue to achieve service continuity and seamless mobility; enabling the mobile node to redirect traffic flow between network interfaces based on obtained features from mobile access networks, this process is called vertical handover [Akk06].

Vertical handover challenges are addressed by the Media Independent Handover (MIH) standard defined in IEEE802.21. MIH defines extensible mechanisms for handover between the implementations of IEEE802 family and Cellular networks [IEEE09].

In this thesis, the researcher focused on achieving vertical handover between WiFi and UMTS networks enhanced by MIH standard. The integration between WiFi and UMTS networks must provide service continuity and meet the Quality of Service (QoS) constrains of the applications categories. The purpose is to study the mobility challenges in heterogeneous wireless networks concerning WiFi and UMTS, in addition to identifying the capabilities and constrains of the technology dependent wireless access technologies by observing some network parameters and proposing specific evaluation metrics.

Precise identification of Pros and Cons of integrating WiFi with UMTS networks by identifying the limitations of each technology with respect to the maximum allowable application bitrate, will be represented in the evaluation metrics and will show its impact on the vertical handover process.

It is important to differentiate between the categories of QoS aware applications, thus determine the performance for running these applications in WiFi and UMTS integration. According to International Telecommunication Union-Telecommunication (ITU-T) recommendations, results will be analysed to figure out if the performance acceptable values were met.

To achieve the goal of this thesis, the researcher is going to implement two mobility scenarios. In the first scenario, the wireless infrastructure consists of one mobile node connected to the WiFi network and moves toward UMTS network. WiFi network is the serving network while UMTS is the candidate network in WiFi to UMTS scenario. In the second scenario, the mobile node moves from UMTS which is the serving network to the WiFi network which represents the candidate network. In addition to the mobile node, each network entity in the wireless infrastructure has MIH components to facilitate handover. In both scenarios; WiFi to UMTS and UMTS to WiFi, a range of applications bitrates were used. This range was selected to be realistic in terms of wireless access technology features and the bitrate of the internet mobile applications.

Range of mobile node speed was also selected to study the effect of the mobile node speed on the vertical handover scenarios.

1.2 Problem Statement

Based on the vertical handover challenges proposed in the literature, this work will focus on the integration between WiFi and UMTS networks. Studying the integration between two access networks from two different categories; WiFi from the 802 family of standards and UMTS as 3G cellular network. The obstacles in this integration are presented in the vertical handover stages; trying to achieve service continuity. QoS metrics will be affected in vertical handover; which means that the performance of this integration may not satisfy the QoS requirements for some applications which is recommended by the ITU-T. WiFi is considered in the literature of vertical handover as preferred network because of the low cost and high bandwidth compared to UMTS; which means that the mobile node will handover to a better network with respect to bandwidth and vice versa with respect to user mobility because of the large coverage area of UMTS. In both scenarios, this research will address the following issues:

1. What are the key factors that affect the QoS in the vertical handover scenarios?
2. How to implement vertical handover scenarios that is applicable to observe the needed evaluation metrics?
3. How will the QoS metrics be affected when moving to high bandwidth network (WiFi) and to low bandwidth one (UMTS)?
4. What is the impact of the application bitrate on the QoS metrics when moving from a network with high bandwidth (WiFi) and to low bandwidth network

(UMTS)? Specify constrains and acceptable values according to ITU-T recommendations for sensitivity to delay and packet loss when moving in both directions.

5. How do the low mobility in WiFi and High mobility in UMTS affect the vertical handover scenarios?
6. What is the rational impact for implementing the proposed scenarios?
7. What are the obstacles for integrating WiFi and UMTS networks using IEEE802.21 standard?

1.3 Thesis Contribution

Although MIH standard provides extensible mechanisms for vertical handover between WiFi and UMTS, many obstacles facing user mobility because of vertical handover process. In order to achieve seamless mobility for multi interface mobile node this thesis will handle the following challenges:

1. Building mobility scenarios that include the integration of WiFi and UMTS networks, these scenarios must be harmonized with the vertical handover aspects; observing the behaviour of the evaluation metrics and how they are affected.
2. Observing the behaviour in the vertical handover area to figure out the effect of the MIH standard services on the vertical handover process.
3. Determining the application categories that can work in the integration between WiFi and UMTS networks with acceptable performance. This can be achieved by using various bitrates and observing the behaviour of the evaluation metrics.

4. Studying the impact of the limited coverage area of WiFi on the evaluation metrics and showing the importance of considering this limitation on vertical handover stages. The behaviour in WiFi network will be compared to the behaviour in UMTS network to figure out how the networks features affect the vertical handover process.
5. Precisely analysing the MIH services during handover preparation and decision stages, including the triggers in the technology protocol stack; lower layers events and the upper layers commands. This analysis can be achieved by monitoring some indicators at the lower layers such as Received Signal Strength (RSS), Link Going Down (LGD) probability derived from MIH standard and link detected trigger, the impact of WiFi limited coverage area will be depicted in these stages. Handover Latency is an important metric that will be measured at the execution stage.
6. Achieving service continuity in order to analyse the evaluation metrics needed.
7. Modelling the behaviour of some evaluation metrics by showing functional description for their behaviour under the effect of the mobile node speed and application bitrate.

1.4 Related Works

The research trends of vertical handover are directed toward studying two major aspects; multi criteria decision making (MCDM) algorithms and mobility management techniques using Mobile IP (MIP) [Bar11]. One of the earliest studies in vertical handover was presented in [Mcn04], the authors presented a tutorial on the design and performance issues, focusing on the vertical handover decision policies based on RSS and cost function for network selection criteria. The study includes some possible architectures for exploiting the MIP in the 4G environment. Later studies focus on mobility management. Seamless handover between heterogeneous wireless networks was proposed in the literature using intermediate layers of the TCP/IP protocol stack such as MIPv4 [Per02] and MIPv6 [Joh04], however these techniques have some challenges regarding security and session continuity.

Decision making algorithms are responsible for completing the vertical handover decision stage. RSS based decision algorithms were proposed in the literature in order to enhance vertical handover process. These algorithms rely on determining signal power thresholds to trigger the handover process, this is called the handover preparation stage. In addition, handover decision stage took place based on these thresholds by selecting the candidate network with the highest RSS. MIH standard was combined with these algorithms to achieve seamless mobility.

The research in [Cha11] proposed a handover mechanism between WiFi and Worldwide Interoperability for Microwave Access (WiMAX) networks using MIH standard. The impact of the LGD factor and probability confidence on the handover latency and packet loss were studied. However the impact of some key indicators in vertical handover were not considered such as applications bitrate and mobile speed as input parameters and their effect on the average throughput, End to End (E2E) delay, packet loss and handover latency.

The work in [Lin12] presents a cross-layer scheduling scheme based on exploiting the LGD trigger to predict handover requirements, in addition, the network traffic was categorized according to the QoS classes of services. Several evaluation metrics were studied to evaluate the performance of integrating UMTS and WiMAX, as well as WiFi and WiMAX networks. This study shows an enhancement in term of service continuity for the QoS sensitive applications, however the integration of WiFi and UMTS networks is not considered.

The research in [Rah13] proposed an algorithm called Multi Criteria Selection Algorithm (MCSA) to consider additional parameters to the RSS criterion implemented in Network Simulator-2 (NS-2) to select the best candidate network among WiFi and WiMAX. The available bandwidth, mobile node speed and the impact of network type were studied as multi criteria to improve QoS. Packet loss ratio and handover latency were studied as evaluation metrics. However the behaviour of the metrics under the effect of the mobile speed and application bitrate was not modelled. In addition, this study does not consider the UMTS and WiFi network. Throughput and delay were not measured for the vertical handover scenarios.

The research in [Mar10] studied the performance of the MIH standard implemented in NS-2 for vertical handover scenarios between WiFi and WiMAX networks. The paper proposed a novel approach to determine the expected number of handovers in NS-2 and the impact of increasing the number of mobile nodes and application bitrate on two performance indicators; handover latency and packet loss ratio. Results were compared to the ITU-T recommendations to check if it fulfils the QoS requirements of specific applications such as voice and video. However, this research does not study the impact of the mobile node speed on the performance metrics, only one mobile node speed of 50 km/h was used for all scenarios. Other performance metrics such as throughput and delay were not addressed. The study also lack of modelling the behaviour of the studied metrics.

The research in [Ast13] use different methodology than the one used in this research. The vertical handover scenario between WiFi and WiMAX was carried out based on real testbed using Open Dot Twenty One (ODTONE) which is an open source implementation for the MIH standard. Handover latency and packet loss ratio were studied. Small range of mobile node speed was used (30 km/h to 40 km/h) and one application bitrate of 256 kb/s that represent Skype application traffic. The results in this research were compared to the ITU-T recommendations to assess the performance of the application. The study does not present a functional description for the metrics behaviour. In addition, UMTS network was not considered in the vertical handover scenarios.

The research in [So08] proposed vertical handover decision algorithms for WiFi and CDMA networks, a roaming client software was implemented to enhance handover, the study does not consider the MIH standard in the implementation. Handover latency to CDMA and WiFi was studied for two vertical handover algorithms; soft handover and hard handover. In soft handover, the connection is redirected to the candidate network without breaking the session. This type of handover is close in concept to the vertical handover enhanced by the MIH standard, therefore the handover latency for this algorithm will be compared with the algorithm used in this research.

In this research, we carried out a comprehensive simulation study for the key performance indicators that affect the vertical handover process between UMTS and WiFi networks. Two major scenarios were proposed based on the methodology used in [Rah13] [Mar10] and [Cha11].

1.5 Research Methodology

In this thesis, the proposed scenarios have been implemented using the mobility environment for the vertical handover in NS-2 which is the most widely used simulation tool in the literature to evaluate vertical handover [Bar11]. Exploitation of two wireless modules implemented in NS-2; IEEE802.21 module contributed by the National Institute of Standards and Technology (NIST) [Ant09] and UMTS module contributed by Enhanced UMTS Radio Access Network Extension (EURANE) [Eur06]. Figure 1-1 shows the evaluation metrics used in this study. To achieve the contribution in this thesis, simulation tools will be used as follows:

1. In each scenario, WiFi and UMTS networks were implemented in NS-2 as wireless access technologies.
2. Building wire infrastructure that represents the backbone for wireless access technologies. Wire infrastructure consists of media server, network links and gateway router that is connected to the WiFi Access Point (AP) and UMTS Base Station (BS) that represent the wireless infrastructure.
3. Mobile node will be built with multi-interfaces; WiFi and UMTS, this mobile node moves between WiFi and UMTS networks while it is connected to the media server. MIH components were configured on the wireless infrastructure and the mobile node.
4. The parameters for all network entities will be precisely selected and configured. These parameters include, wired and wireless infrastructure parameters such as network bandwidth, coverage area and transmission power, in addition to the range of mobile node speeds and applications bitrate that are running between the media server and the mobile node.

5. The behaviour of the evaluation metrics such as average throughput, delay, packet loss ratio and handover latency can be observed in the output of the simulation that is placed in the logging and trace files. This can be achieved by using data extraction scripts applied to these files in order to search for regular expressions that will lead to performance evaluation.

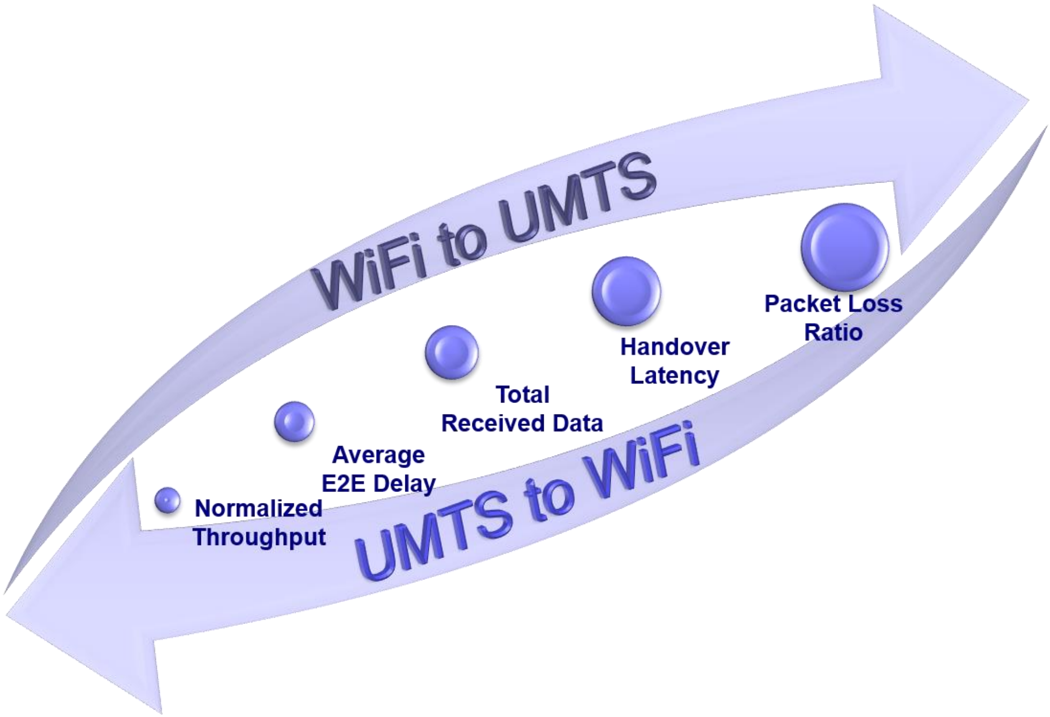

Figure 0-1: Performance Evaluation Metrics in WiFi to UMTS and UMTS to WiFi scenarios.

1.6 Thesis Organization

The rest of the thesis is organized as follows; Chapter 2 discusses the wireless access networks used (WiFi and UMTS) and introduces the vertical handover stages and simulators in addition to IEEE802.21 standard services. Chapter 3 presents the simulation scenarios details including input parameters and evaluation metrics in addition to the simulation tools. Results and analysis for the evaluation metrics are presented in Chapter4. In Chapter 5, results' modelling, discussion and the main contribution of this thesis are presented. Finally, conclusion, future works and recommendations are presented in Chapter 6.

Chapter 2
State of the Art

2.1 Wireless Access Technologies

In our research, the wireless access technologies used were defined by two different families of standards; IEEE802.11 standard belongs to IEEE 802 family of standards whereas UMTS belongs to the 3G cellular network standard.

2.1.1 IEEE802.11 Standard

IEEE 802 family of standards consists of networking standards developed by IEEE. Each standard has its scope in defining the design specifications for different TCP/IP layers. This family includes some of the well-known networking standards such as IEEE802.3 Ethernet, IEEE802.11 Wireless LAN (WLAN), and IEEE802.16 Wireless Metropolitan Area Network (WMAN).

IEEE802.11 standard was published in 1999 and revised in 2007. It defines the WLAN Medium Access Control (MAC) and physical layer (PHY) specifications for wireless connectivity that is established by fixed and moving devices within Local Area Network (LAN) [IEEE12]. To deliver services with high throughput and continuous network connection such as the services delivered by wired network, several amendments were added to the original standard such as IEEE802.11a, b, g. The wireless device that is manufactured based on the IEEE802.11 standard and compliant to operate in WLAN is known as WiFi-certified and therefore these devices and connections are also known as WiFi [Wif13].

Figure 2-1 shows IEEE802.11 architecture; the Basic Service Set (BSS) is WLAN with one AP connecting the wireless stations (STA) within its coverage area. AP is connected to a wired network called Distributed System (DS). All STAs connect to the DS through one AP; it also provides bridging connectivity between STAs within the same BSS or with other components in the DS. This is called infrastructure mode. Multiple BSSs connected to the same DS form the Extended Service Set (ESS). ESS consists of one or more BSS. When two or more STAs connected to each other without AP and have no access to the DS, independent basic service set (IBSS) is the wireless network for them. This is also called the ad hoc mode [Tha10].

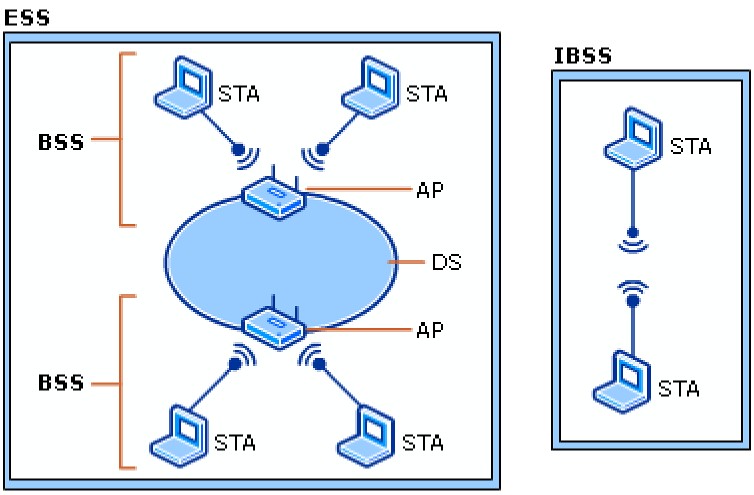

Figure 2-1: IEEE802.11 Architecture [Tec13].

IEEE 802.11b is a physical layer standard for WLAN, it operates on 2.4 GHz unlicensed frequency band. The theoretical bandwidth supported by IEEE 802.11b is 11 Mbps with coverage area around 100 meters. The physical layer implementation is based on Direct Sequence Spread Spectrum (DSSS) modulation which multiply signal by chipping code using code division multiple access (CDMA) that is spread over wide spectrum because of the high rate signal variations [Hie10].

2.1.2 Cellular Networks

High technical evolution occurs in mobile communication systems. Figure 2-2 shows the successive cellular generations starting from the 1st and 2nd generations, toward 3rd and 4th generations. UMTS network is defined by the 3rd Generation Partnership Project (3GPP) as an umbrella term for the 3G radio technologies development. 3GPP is now working on Long Term Evolution (LTE), which is built on UMTS for the generation beyond 3G [3gp13].

Figure 2-2: Cellular Generations [Kaa05].

3G systems represented in UMTS technology offer services such as voice, video and SMS transfer. The radio interface in UMTS is based on Wideband Code Davion Multiple Access (WCDMA). Frequency allocation for uplink is 1920-1980 MHz and for downlink is 2110-2170 MHz. UMTS channel carrier width is 5 MHz and the theoretical bitrates up to 384 kb/s with high mobility in urban areas and 2 Mb/s in stationary environment and for short range applications [Kav07].

Figure 2-3 shows the UMTS architecture that has two major networks; the core network of the UMTS consists of circuit switched and packet switched network that includes the Serving General Packet Radio Service (GPRS) Support Node (SGSN) and Gateway GPRS Support Node (GGSN). The functionality of the SGSN is to forward data packets while the mobile node is moving, it is responsible for delivering data packets from and to the mobile node in the packet switched network. Location registration, packet routing, mobility management and authentication were handled by the SGSN node. [Kaa05]. GGSN is the gateway between the GPRS network and the external packet data network, it is responsible for interworking between GPRS network and the packet switched network such as Internet [Pat11]. The UMTS Terrestrial Radio Access Network (UTRAN) handles all the radio resources and the mechanisms needed to reach the UMTS core network. It provides the air interface access method with the mobile node that is included in the BS which is referred as (Node-B). Radio Network Controller (RNC) for Node-B in the UMTS access network is responsible for handover control [Dje11]. Iu, Iub and Uu are interfaces between the UMTS network entities; RNC connects to multiple Node-Bs via the Iub interface. Uu is the UMTS air interface between the mobile node and the UTRAN [Akk06].

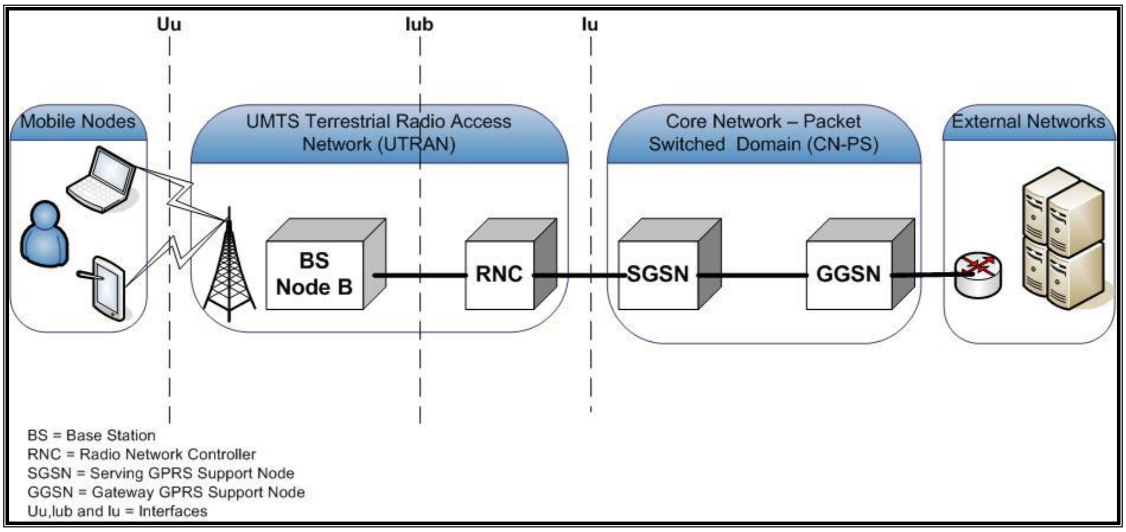

Figure 2-3: UMTS Architecture

2.2 Vertical Handover

The wireless access technologies such as WiFi and UMTS are technology dependent with different link layer specification. Some of the differences in features are shown in Table 2-1. The physical and MAC layers in the technology protocol stack is referred as lower layers; the implementation of these lower layers are different and they work independently on mobile nodes, therefore to achieve seamless mobility and service continuity with QoS; intelligence mechanisms are needed to facilitate interworking between the different protocol stack implementations. The integration between different link layers technologies will help in solving major problems arise in a process called vertical handover process.

Table 2-1: Characteristics of UMTS and WiFi [Kav07] [Dje11]

Wireless Technology	Coverage area	Bandwidth	Mobility	Spectrum
UMTS	10 Km	384 kb/s ~ 2 Mb/s	High	Licensed
IEEE802.11 WiFi	50 ~ 300 m	Up to 54 Mb/s	Low	Unlicensed (free)

2.2.1 Definitions

Vertical handover is the process that enables the mobile node to redirect traffic flow between network interfaces based on obtained facilities from different wireless access networks [IEEE09]. The handover between access points and networks using same radio technology is denoted as Horizontal Handover [Zek12]. Figure 2-4 shows a general scenario for vertical and horizontal handover when mobile nodes in a bus are using web applications that connect to the Internet via UMTS and WiFi access networks.

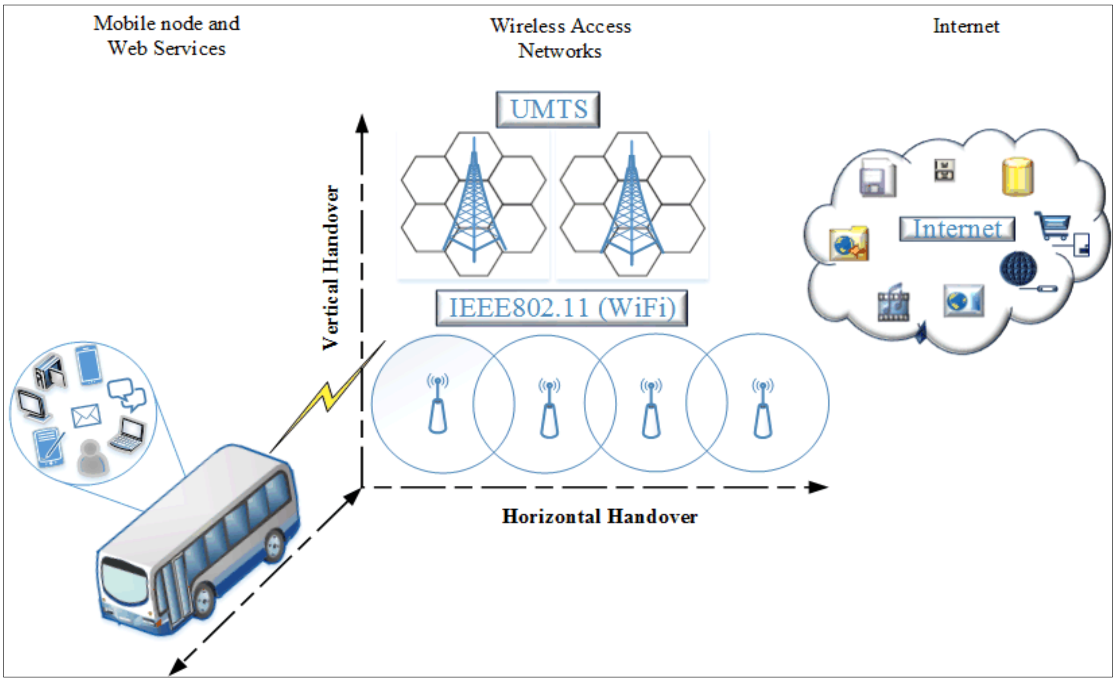

Figure 2-4: General scenario for vertical and horizontal handover.

2.2.2 Vertical Handover Stages

In the literature, vertical handover process was divided into three stages; network discovery, handover decision and execution stages shown in Figure 2-5 [Kha13].

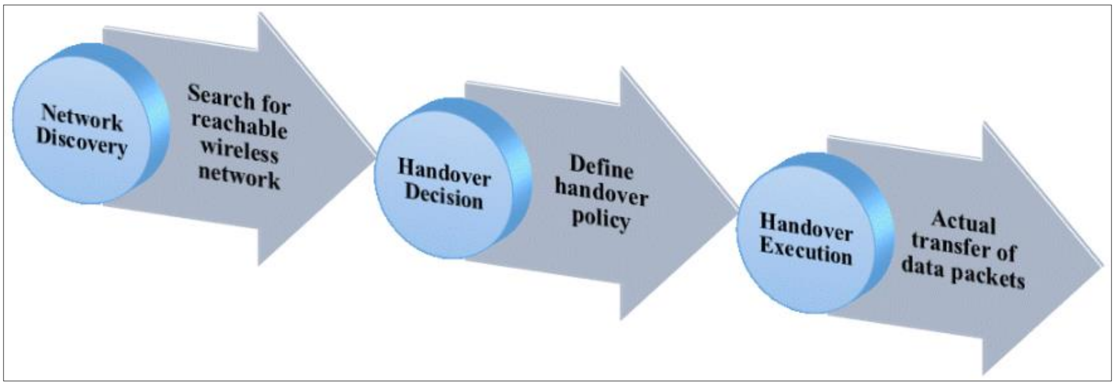

Figure 2-5: Vertical handover stages.

1. **Network Discovery:** Includes searching for reachable wireless access networks to be included in the list of candidate networks. Information gathering about these networks also took place at this stage such as bandwidth, cost and coverage area.

2. **Handover Decision:** In this stage, the best candidate network will be selected based on predefined policies in the decision algorithm. The gathered information in the previous stage will be used by the decision algorithm to decide whether to handover or not, when to handover and to which candidate network.

3. **Handover Execution:** Actual transfer for data packets took place in this stage. The mobile node will redirect the traffic flow to a new wireless link. Data link and network layer are responsible for signalling in this stage.

2.2.3 Vertical Handover Challenges

To achieve the goal of Always Best Connected (ABC) proposed in the literature; vertical handover challenges should be considered and expressed in the integration between heterogeneous wireless networks. In ABC scenario the mobile node is not to be only always connected, but also being connected in the best possible way [Gus03]. The performance optimization in vertical handover faces many challenges such as reducing signalling overhead, handover latency, flexibility and automation. Seamlessness, flexibility and automation must be achieved. Some of these challenges can be realized by IP and agent technology such as interworking of fixed and mobile networks [Pan03]. Other challenges can be solved by achieving enhancements in vertical handover stages; for example, network discovery stage needs useful information about the candidate networks such as cost, bandwidth, power consumption and user preferences to be considered in network selection. Handover decision stage will select the best candidate network based on certain policies; these policies were applied on the available network parameters or indicators. RSS is the basic indicator that is measured in this stage in both horizontal and vertical handover but in vertical handover, it is useful to combine RSS with other indicators or parameters such as cost and bandwidth to form multi criteria indicator and decide to handover accordingly. This mechanism is addressed by multi criteria decision algorithms that consider decision parameters such as network conditions and user preferences in order to select the best candidate network. The challenges in the handover execution stage are represented in the performance of the MIP and authentication process. There are some challenges in determining whether the handover process will be user-initiated (the user request to handover to one of the candidate networks) or network-initiated handover (handover process will be triggered by the network). In addition, QoS aware applications have their performance requirements that should be met and considered in vertical handover.

In order to solve the vertical handover challenges; a framework that includes interworking mechanisms and procedures were published called MIH standard (IEEE802.21).

2.3 IEEE802.21 Media Independent Handover

MIH is an IEEE standard published in 2009. Figure 2-6 shows the timeline of the standardization efforts done by the 802.21 working group. Nowadays, the standard has three amendment projects; IEEE802.21a to define security extensions to MIH services, IEEE802.21b for handovers with downlink only technologies and IEEE802.21c amendment that includes optimization for single radio handovers [Iee13].

MIH standard defines extensible mechanisms for handover between implementations of IEEE802 family of standards and Cellular networks. MIH bridges the gaps for integrating technology dependent networks by providing a global view of all the heterogeneous candidate networks to the mobile node. In addition, it provides MIH functionality that facilitates network and mobile initiated handovers [Kha12].

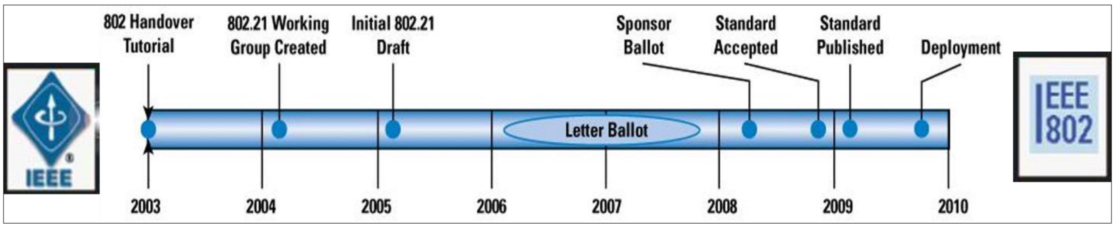

Figure 2-6: Timeline of the IEEE802.21 standardization efforts [Cis13].

2.3.1 Scope of Standard

MIH scope includes handover initiation and preparation; including network discovery, selection and handover negotiation in the handover initiation. MAC layer and IP connectivity in the handover preparation to setup new link. Handover policy, security mechanisms and higher layer (layer 3 and above) enhancements are outside the scope of the MIH standard. The actual decision algorithms to be implemented that includes decision criteria and policies are left to the designers [IEEE09].

MIH standard is not yet implemented in the communication industry; more than three amendments projects are still under development. Many solutions regarding decision and security algorithms have been proposed in the literature but still none is implemented in the communication industry. These algorithms that define the handover policy and security mechanisms were not addressed by MIH standard and were left to the researchers.

2.3.2 MIH Elements

MIH standard uses cross-layer concept through an abstraction layer between the MAC and network layer called MIH Function (MIHF). MIHF 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 vertical handover with other peer MIHF implemented in other devices in the network. MIHF includes three types of services as shown in Figure 2-7; Media Independent Event Service (MIES), Media Independent Command Service (MICS) and Media Independent Information Service (MIIS). MIES detects link layer changes and reports events accordingly form both local and remote MIH implementation in network entities. MICS provides commands from the upper layers to the lower layers in local MIH and to remote MIH to control link state. MIIS provides useful information about neighbour networks including some parameters needed for handover. MIH users presented in the upper layers of the mobile node protocol stack sends MIH commands and receives MIH events from MIHF. Both local and remote MIH commands can pass to lower layers as link commands. Link events such as Link_Up, Link_Down and Link_Going_Down indicate changes in the lower layers and can be passed as MIH Events to the upper layers (MIH Users) through the MIHF [Tan09].

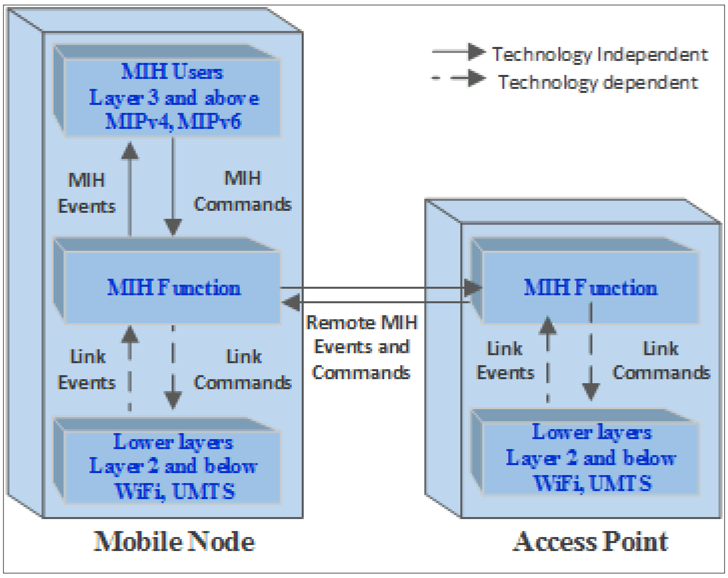

Figure 2-7: Services provided in the abstraction layer of IEEE802.21

2.4 Vertical Handover Research Tools

The evaluation methods for vertical handover vary between network simulators and testbed; NS-2 is the most widely used simulation tool in the literature to evaluate vertical handover, OPNET is used to evaluate network environment and MATLAB is used to evaluate mathematical models. Regarding testbed; ODTONE is used as an open source implementation for the MIH standard [Bar11] [Kha13] [Cor11].

2.4.1 Vertical Handover Modules in NS-2

- **UMTS Module**

Since NS-2 does not support simulation for UMTS by default; EURANE was developed as a UMTS add-on module in NS-2 [Aiy10]. Referring to UMTS architecture, UTRAN components were implemented in NS-2 that include RNC, Node-B (BS) and air interfaces, in addition to the core network components which are the backbone of UMTS network such as SGSN and GGSN that are connected to the Internet. Figure 2-8 shows the simulation topology of UMTS network implemented in NS-2 [Vra10].

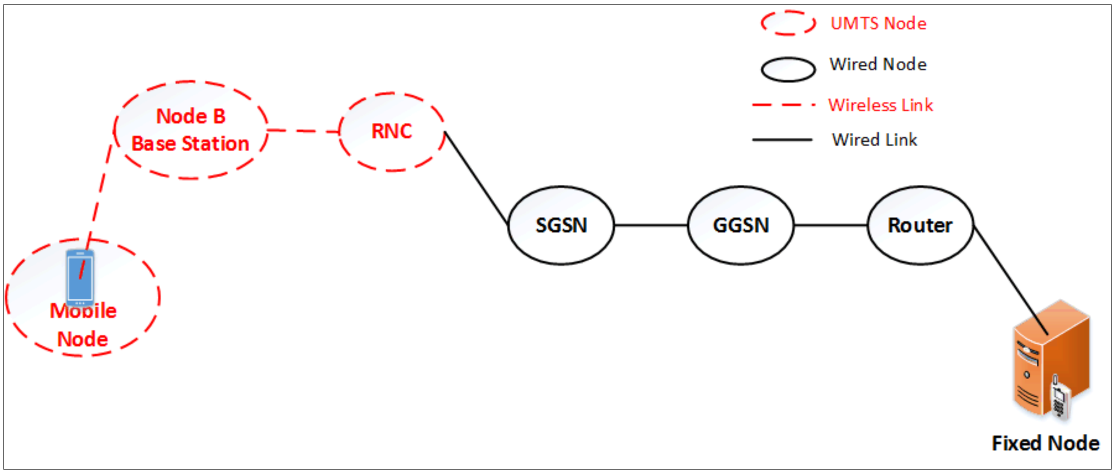

Figure 2-8: UMTS Simulation Topology [Vra10].

- **NIST Module**

Simulation of vertical handover scenarios that include mobile node and heterogeneous wireless networks with MIH standard were performed using NIST add-on module in NS-2. The add-on module contains an implementation of the MIH draft version 3 for NS-2 version ns-2.29 [Kha12]. WiFi implementation in NS-2 were also integrated with the NIST add-on module [Mac07]. MIPv6 extension and neighbour discovery were also added to the NIST add-on module that were used to create new IP address in the new network and to support multiple types of interfaces such as UMTS and WiFi [Ndi07].

As mentioned before, MIH standard provides three types of services; MIES, MICS and MIIS. NIST add-on modules in NS-2 supports only two services MIES and MICS. The MIIS is not supported. Some of the MIH events supported as MIES include; Link UP, Link Down, LGD, Link detected and Link handover complete, while MICS includes some events such as Link event subscribe, Link configure threshold, Link get parameters, MIH get status and MIH link scan. These services represent messages that pass between the wired, wireless infrastructure and the protocol stack of network entity to facilitate the handover process [Mar10].

2.5 Summary

An overview of the wireless access technologies were presented, focusing on the IEEE802.11b from 802 family of standards and UMTS from the 3G cellular networks. In this research, these two technologies were used as heterogeneous wireless technologies in vertical handover scenarios. The principal of vertical handover and challenges faced in its stages were defined. Some of these challenges were addressed by MIH standard. It is explained how the MIH standard facilitate handover by providing interworking mechanisms represented in MIH services between the lower and upper layers, showing also the major components of this standard. The researcher introduce the vertical handover evaluation tools used in the literature focusing on NS-2 that is used in this research and is considered as the most widely used simulator in vertical handover. The vertical handover scenarios were implemented based on the available add-on modules in NS-2 such as IEEE802.11b, UMTS and NIST mobility package that represents the MIH standard implementation in NS-2. In Chapter 3, the researcher will discuss in depth the simulation scenarios implementation. Simulation stages where the simulation parameters, execution and analysis tool will be presented. In addition, the performance evaluation metrics that will be measured in this thesis will be defined.

Chapter 3
Simulation Scenarios

3.1 Simulation Stages

The simulation tool used in this thesis is NS-2 version 2.29.3. This version was used because the 3rd draft of the NS-2.29 version was modified to contain an implementation of the MIH standard [Mac07]. IEEE802.21 and UMTS modules implemented in NS-2 were also used. Vertical handover scenarios between WiFi and UMTS were implemented using Tool command language (Tcl) in NS-2 and configuring specific simulation parameters. QoS evaluation was observed using performance evaluation metrics. The work is presented in three stages; pre simulation, simulation and post simulation as follows:

3.1.1 Pre Simulation

Table 3-1 shows the simulation parameters defined before running the simulation. These parameters include global parameters defined for all scenarios. Each wireless access network has its own technology dependent parameters. Mobile node speeds were selected in the range from 5 to 60 kilometers per hour (km/h). This range is realistic with respect to the defined technology dependent parameters. Applications bitrate used in these scenarios vary from 64 to 3840 Kilobits per second (kb/s) with Constant Bitrate (CBR). Most of the mobile applications work in these bitrates; such as voice, file transfer and video. The vertical handover scenarios were implemented using these parameters in order to figure out the impact of the mobile node speed and applications bitrate while the mobile node is moving from WiFi to UMTS and vice versa.

Table 3-1: Simulation Parameters for WiFi and UMTS [Mar10] [Vra10].

Global Parameters	
Propagation Model	TwoRayGround
Topology Range	3000 x 3000 m
Simulation Duration	40 sec
Mobile node speeds	5, 10, 15, 20, 25, 30, 40, 50, 60 km/h
Bitrate	CBR: 64, 256, 384, 480,960, 1920, 2880, 3840 kb/s
WiFi Parameters	
Coverage area	100 m
MAC Type	Mac/802_11
Frequency	2.41 GHz
Transmission Power	0.027 W 14.3 dBm
Bandwidth	11 Mb/s
RXThresh	2.64504e-10 W
CSThresh	90% of RXThresh
Weighted-Thresh	3.174048e-10 W
Antenna model	Omni Antenna
Pr_limit	1.2
UMTS Parameters	
Coverage area	1000 m
Frequency	2000 MHz
Bandwidth DL/UP	384 kb/s (outdoor)
Transmission Time Interval (TTI)	2 ms

3.1.2 Simulation

After configuring the scenarios, several executions with random seeds were done. In the first scenario, the mobile node moves from WiFi to UMTS network while in the second scenario, it moves from UMTS to WiFi. After monitoring the scenario and insuring that the vertical handover process was done successfully, the results of the evaluation metrics were extracted from the output files that were generated after every simulation run. These are structured data files that have specific formats. In the implemented scenarios the files are trace file format and new trace file format for wired and wireless networks. The trace files contain fields with useful information about all the events during simulation. Figure 3-1 shows two lines from a trace file format. Each line represents one WiFi sent packet. Figure 3-2 shows two lines each one represents UMTS sent packet.

```
+ 1.00 3 4 cbr 160 ------- 0 1.0.0.0 3.0.1.0 0 8
+ 1.02 3 4 cbr 160 ------- 0 1.0.0.0 3.0.1.0 1 9
```

Figure 3-1: Two WiFi sent packets logged in trace file.

```
+ 13.26 3 4 cbr 160 ------- 0 1.0.0.0 0.0.2.0 613 630
+ 13.28 3 4 cbr 160 ------- 0 1.0.0.0 0.0.2.0 614 631
```

Figure 3-2: Two UMTS sent packets logged in trace file.

Figure 3-3 shows the number of columns for WiFi and UMTS sent packets. It is noticed that this format has twelve columns, each represents useful information about the sent packet. For example; the first two rows start with event (+) in column 1 means the packets was sent at time 1.00 and 1.02 seconds from node 3 to node 4 with packet type CBR, flow ID = 0 and packet size 160 Bytes. The source address of these packets is the media server with interface 1.0.0.0 and the destination address of these packets is the mobile node WiFi interface 3.0.1.0. Column 11 shows the sequence id for each packet. Column 12 represents the packet id. The last two rows show two UMTS packets between media server and the mobile node UMTS interface with address 0.0.2.0.

Column ID	1	2	3	4	5	6	7	8	9	10	11	12
WiFi send packets	+	1.00	3	4	cbr	160	---	0	1.0.0.0	3.0.1.0	0	8
	+	1.02	3	4	cbr	160	---	0	1.0.0.0	3.0.1.0	1	9
UMTS send packets	+	13.26	3	4	cbr	160	---	0	1.0.0.0	0.0.2.0	613	630
	+	13.28	3	4	cbr	160	---	0	1.0.0.0	0.0.2.0	614	631

Figure 3-3: Columns of trace file format for WiFi and UMTS Sent Packets.

Figure 3-4 shows one line from new trace file format that presents one WiFi received packet with ID = 8, this packet was shown in the first row of Figure 3-1 as sent packet. As shown in Figure 3-4, this format has 51 columns as shown in Figure 3-5. Each column shows useful information about the packet. For example, column 1 is the event of this packet which is (r) means receive at time 1.045862287 seconds to node id = 7 (mobile node WiFi interface). Column 11 and 13 shows the X,Y coordinates of node id 7 in addition to the trace level in column 7 (MAC). This is a CBR packet, its ID equals 8 and the size of the packet is 160 Bytes received on the mobile node WiFi interface.

```
r -t 1.045862287 -Hs 7 -Hd 12582913 -Ni 7 -Nx 418.56 -Ny 100.00 -Nz 0.00
-Ne -1.000000 -Nl MAC -Nw --- -Ma d4 -Md 5 -Ms 4 -Mt 800 -Is 4194304.0
-Id 12582913.0 -It cbr -Il 160 -If 0 -Ii 8 -Iv 29 -Pn cbr -Pi 0 -Pf 1 -Po 0
```

Figure 3-4: One WiFi received packet logged in new trace format.

Column ID	1	2	3	4	5	6	7	8	9	10	11	12
WiFi received packet	r	-t	1.045862287	-Hs	7	-Hd	12582913	-Ni	7	-Nx	418.56	-Ny
	13	14	15	16	17	18	19	20	21	22	23	24
	100	-Nz	0.00	-Ne	-1.0	-Nl	MAC	-Nw	---	-Ma	d4	-Md
	25	26	27	28	29	30	31	32	33	34	35	36
	5	-Ms	4	-Mt	800	-Is	4194304.0	-Id	12582913.0	-It	cbr	-Il
	37	38	39	40	41	42	43	44	45	46	47	48
	160	-If	0	-Ii	8	-Iv	29	-Pn	cbr	-Pi	0	-Pf
	49	50	51									
	1	-Po	0									

Figure 3-5: Columns of new trace file format for WiFi received Packet.

Figure 3-6 shows that the first UMTS sent packet with ID = 630 and size = 160 Bytes was received on the mobile node UMTS interface (0.0.2.0) as four packets each one has size 40 Bytes.

```
r 13.314006 0 1 AM_Data 40 -------- 0 1.0.0.0 0.0.2.0 0 630 2
r 13.314007 0 1 AM_Data 40 -------- 0 1.0.0.0 0.0.2.0 0 630 3
r 13.314021 0 1 AM_Data 40 -------- 0 1.0.0.0 0.0.2.0 0 630 4
r 13.314029 0 1 AM_Data 40 -------- 0 1.0.0.0 0.0.2.0 0 630 5
```

Figure 3-6: One UMTS received packet logged in trace file.

3.1.3 Post Simulation

When the simulation is done successfully and without errors, the trace files for each experiment will be generated in specific directory. The evaluation metrics will be extracted from the data shown in the trace files above using data extraction scripts. Observing the effect of the pertinent input parameters such as mobile node speeds and application bitrates to evaluate the performance of the vertical handover process.

3.2 Vertical Handover Scenarios

The scenarios in this work consist of wired and wireless infrastructure as shown in Figure 3-7. The networks entities in the wired infrastructure are media server, gateway router and network links with 100 Mb/s bandwidth. The wireless infrastructure has UMTS BS and WiFi AP conceded to the gateway router via network links. WiFi power boundaries such as RX-Threshold and Weighted Threshold were identified in the implemented scenarios in order to observe the behaviour of the power RSS and how they affect the vertical handover process. The mobile node uses both infrastructures to establish a connection with the media server. Mobile node is implemented using the concept of multiFace node. Figure 3-8 shows the structure of the multiFace node. It is a node that is linked to other two nodes; WiFi and UMTS nodes that are considered as interfaces to the multiFace node. From the multiFace node point of view, WiFi interface is used to connect to the WiFi network and UMTS interface is used to connect to UMTS network. MAC layer events were triggered by the interface nodes while MIH commands were generated from the multiFace node [Mar10]. In this work, two vertical handover scenarios are implemented and described in the following sub sections:

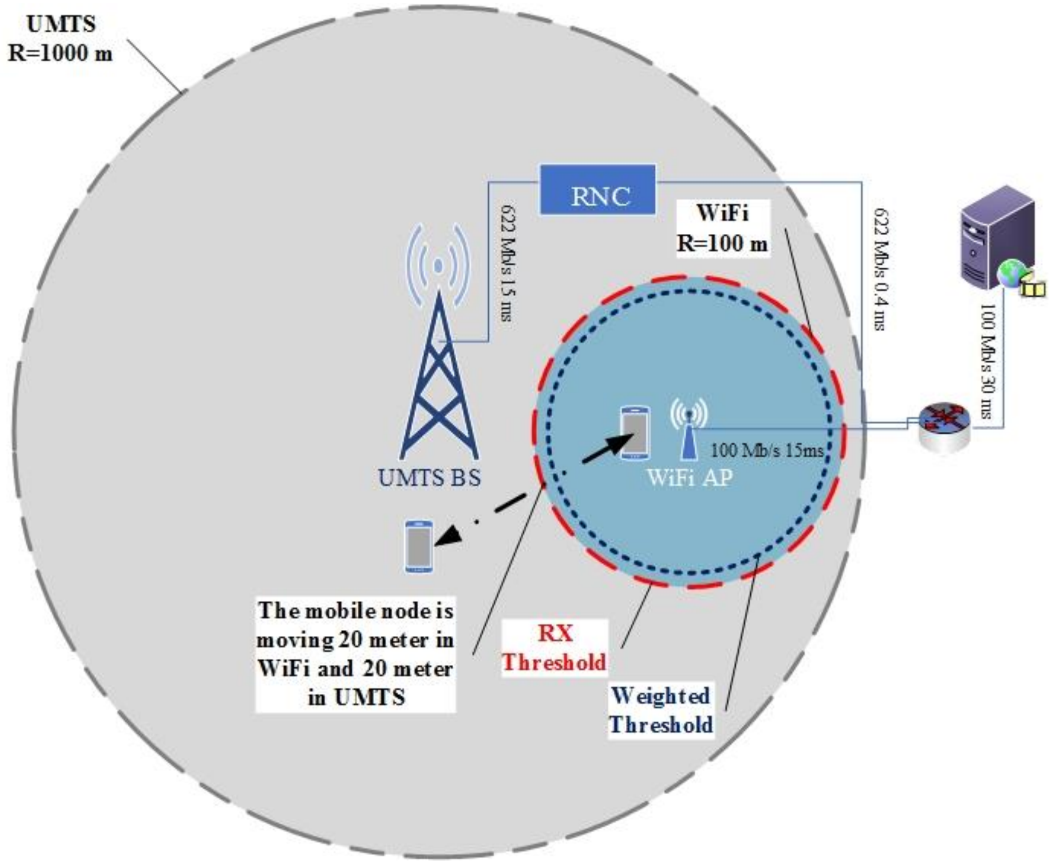

Figure 3-7: Simulation scenarios include wired, wireless infrastructure and mobile node movement.

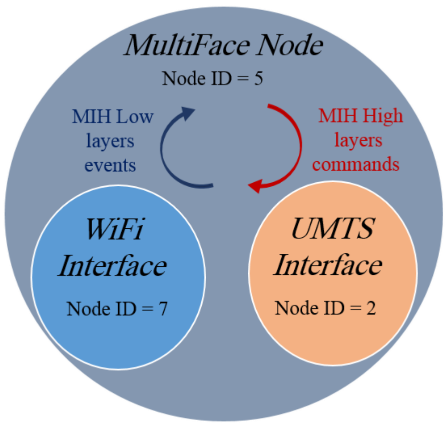

Figure 3-8: MultiFace node structure including WiFi and UMTS node interfaces [Mar10].

3.2.1 WiFi to UMTS

In this scenario, the mobile node is located in the coverage area of WiFi network. It connects to the WiFi and starts moving toward WiFi border going to the UMTS network. The mobile node stops inside the UMTS coverage area while it is connecting to it.

3.2.2 UMTS to WiFi

The mobile node in this scenario starts moving from the coverage area of the UMTS network toward WiFi network. While crossing the vertical handover area, the mobile node connects to the WiFi network and stops in its coverage area.

3.3 Performance Evaluation Metrics

The evaluation metrics were extracted from the trace files using AWK scripts. AWK stands for the names of its creators (Aho, Weinberger and Kernighan) [Ric06]. It is an interpreted programing language that is used as a tool for processing rows and columns in files. Linux based utilities generate matrix of information such as the trace files generated by NS-2, therefore filtering and reporting tools such as AWK are needed to extract the desired data from these files [Gry13]. AWK version 3.1.5 was installed on Fedora release 10 operating system. Shell scripts were also used for file manipulation. Linux shell is a command line interpreter that accepts commands in sequence one by one or grouped together in text file and executed from the shell, this is called shell scripting [Fre13]. These scripts were executed to extract the needed data from the generated trace files when the simulation stage is executed. Figure 3-9 shows how the vertical handover scenario is executed at speed 1.38 m/s (5 km/h) and after that the second statement present execution of awk file to calculate throughput between source node 3 (media server) and destination node 7 (mobile node WiFi interface) from the trace file (data1.38.tr) and write the results in the file (wifithru1.38.txt). The file scripts.sh contains sequence of commands that are executed on the trace files to calculate other evaluation metrics.

```
ns scenario.tcl 1.38
awk -f WiFi-Throu.awk src=3 dst=7 pkt=160 data1.38.tr > wifithru1.38.txt
sh scripts.sh
```

Figure 3-9: Executing vertical handover scenario at speed 5km/h, calculate throughput and other evaluation metrics using awk and shell scripting.

Figure 3-10 shows the simulation stages, evaluation metrics filtering and extraction. All the evaluation metrics were presented for the applications bitrates on different mobile node speeds. The following evaluation metrics were measured:

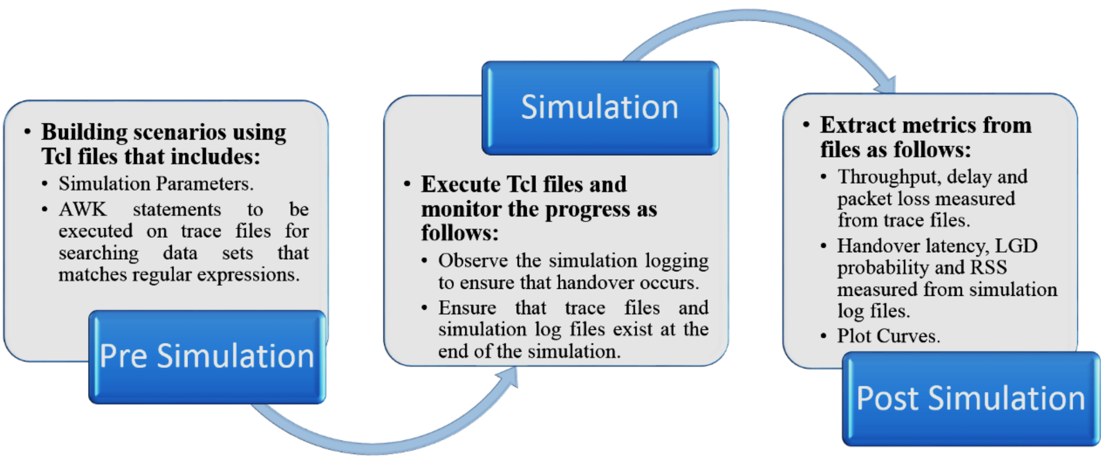

Figure 3-10: Simulation Stages, Evaluation metrics and filtering and extraction.

- *Average Throughput:* measured in kilo bit per second (kb/s), is the ratio of data packets delivered to the destination by time interval [IEEE09]. Equation (3.1) was used to study the impact of speed on throughput. Using equation (3.2) the average throughput was calculated. In order to study how the throughput for different bitrates was affected by speeds, the average throughput was normalized based on equation (3.3)

$$Speed = \frac{Distance\ (m)}{Time\ (s)}$$ (3.1) [Phy13]

$$Average\ Throughput = \frac{Total\ data\ delivered\ (kb)}{Time\ in\ access\ network\ (s)}$$ (3.2) [IEEE09]

$$Normalized\ Throughput = \frac{Average\ Throughput}{Bitrate}$$ (3.3)

- *Average end-to-end Delay (E2ED)*: measured in millisecond (ms), is the average time or one way latency a packet takes to reach the destination from a source node. E2E Delay includes processing delay, network delay prorogation, transmission and queuing delay [IEEE09].
- *Handover Latency:* measured in millisecond, is the amount of time that elapses between the first packet received on the mobile node interface in the destination or candidate network and the last packet received on the mobile node interface in the serving network [Rah13].
- *Packet Loss Ratio:* is the ratio of the amount of packets that were not delivered to a specific destination by the total number of sent packets during a defined time interval [Vig10].

$$Packet\ Loss\ Ratio = \frac{Sent\ Packets - Received\ Pacekts}{Sent\ Packets} * 100\%$$ (3.4) [Dje11]

3.4 Summary

In Chapter 3 the researcher explained the details of the simulation scenarios done in this research. Before running the simulation, the vertical handover scenarios were defined in pre simulation stage using specific parameters. In the simulation stage, the scenarios were executed and part of the results were generated. The analysis of these results were briefly discussed. The rest of the results and curves plotting took place in the post simulation stage. Mobile node movements, in addition to wired and wireless infrastructure details were also discussed. The performance evaluation metrics that were used in this research were also defined. In Chapter 4, the researcher will discuss in details the extracted results, showing in precise way the impact of the mobile node speed and application bitrate on the vertical handover scenario. Performance evaluation will be presented for each metric in both scenarios; WiFi to UMTS and UMTS to WiFi.

Chapter 4
Simulation Results

4.1 Performance Evaluation Mechanism

The evaluation metrics such as Throughput, End to End (E2E) delay, and Packet loss ratio were measured in the vertical handover scenarios shown in Figure 3-1 between the mobile node and the media server. The metrics were plotted as a function of mobile node speed for specific values of application bitrate. Handover latency was also measured by observing the last packet received before handover and the first packet received after handover. Power RSS was measured from the MIH events that were triggered during the scenarios. The evaluation mechanisms are also done based on the proposed scenarios in Figure 3-1, from WiFi to UMTS when WiFi is the serving Point of Attachment (PoA) and UMTS to WiFi when UMTS is the serving PoA and WiFi is the candidate network.

4.2 Normalized Throughput

4.2.1 WiFi to UMTS

To measure the throughput at specific bitrate, for example 960 kb/s; the bitrate value is set to 960 kb/s and create twelve scenarios using this bitrate but with changing the mobile speed in each scenario. This was done to observe the effect of speed when the mobile node is using application with 960 kb/s bitrate. In all scenarios, the starting and ending point of the mobile node movement are the same, which means the traveling distance of the mobile node is constant for all scenarios. To observe the effect of increasing the application bitrate; the process mentioned before was repeated for eight values of application bitrate. At specific speed the effect of using low and high bitrate application was figured out.

Figure 4-1, shows the normalized throughput for seven values of bitrate measured at different values of mobile node speed between the media server and the mobile node WiFi interface when the WiFi is the serving PoA. The throughput on the WiFi interface decreases with increasing mobile node speed. In addition, applications with high bitrate are affected more than low bitrate applications.

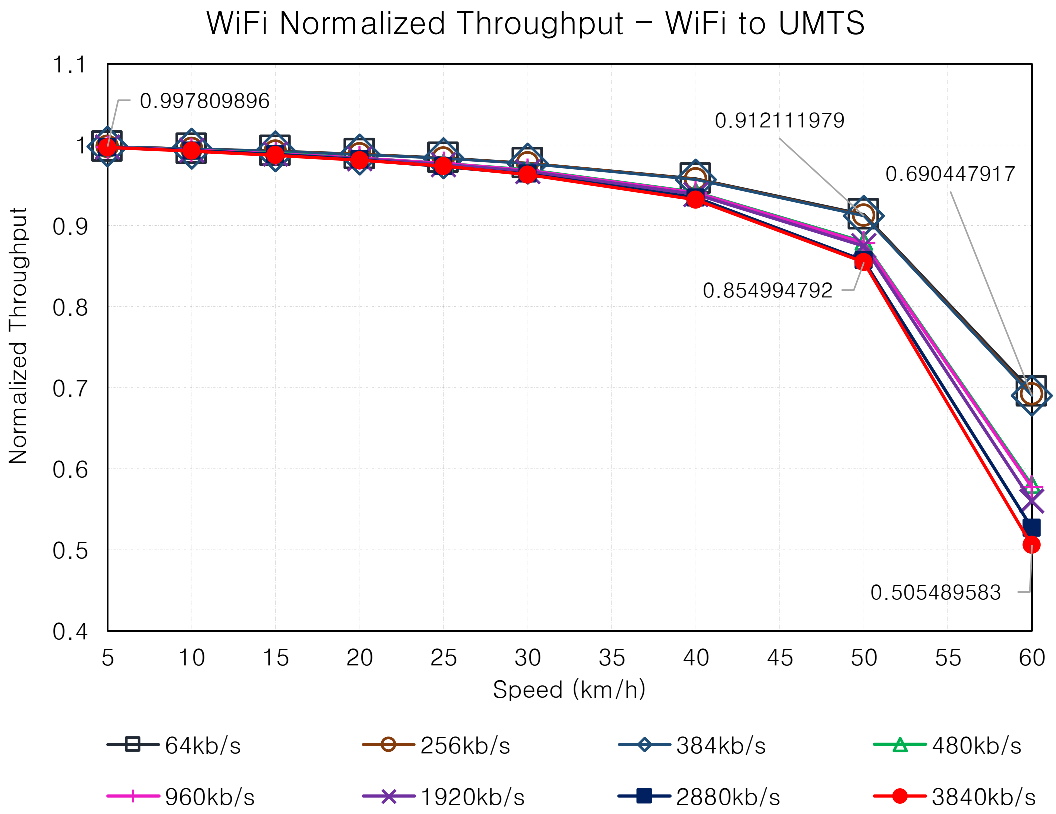

Figure 4-1: Normalized throughput for WiFi network in WiFi to UMTS scenario.

When the mobile node is approaching the border of the WiFi network with high speed, the total data received on the WiFi interface decreases accordingly, as shown in Figure 4-2, this occurs because the spent time in the WiFi network becomes shorter with increasing speed. In addition, WiFi RSS is degrading while the mobile node is moving far away from the WiFi AP.

From equation (3.1), at specific bitrate, for example 960 kb/s, and with increasing mobile node speed from 5 km/h to 60 km/h, the time in WiFi network becomes shorter accordingly because as it was mentioned before the distance from source to destination is constant, therefore the traveling distance inside the WiFi network is constant for all scenarios (WiFi coverage area). When the time spent inside WiFi network becomes shorter with increasing mobile speed, the connection time to the WiFi AP becomes shorter too, therefore the total amount of data received at the WiFi interface decreases accordingly as shown in Figure 4-2. Based on equation (3.2), decreasing the received data on WiFi interface will decrease the throughput values. Average throughput values were normalized based on equation (3.3) in order to observe how the different values of application bitrate were affected by increasing mobile node speed. As shown in Figure 4-2, it is observed that at low speed, for example 5 km/h, the higher the application bitrate, the greater number of received data measured on the WiFi interface. However, as speed increases the connection time in WiFi network becomes shorter because of its limited coverage area, therefore the total received data on WiFi interface will decrease accordingly and will highly effect the throughput on the WiFi interface.

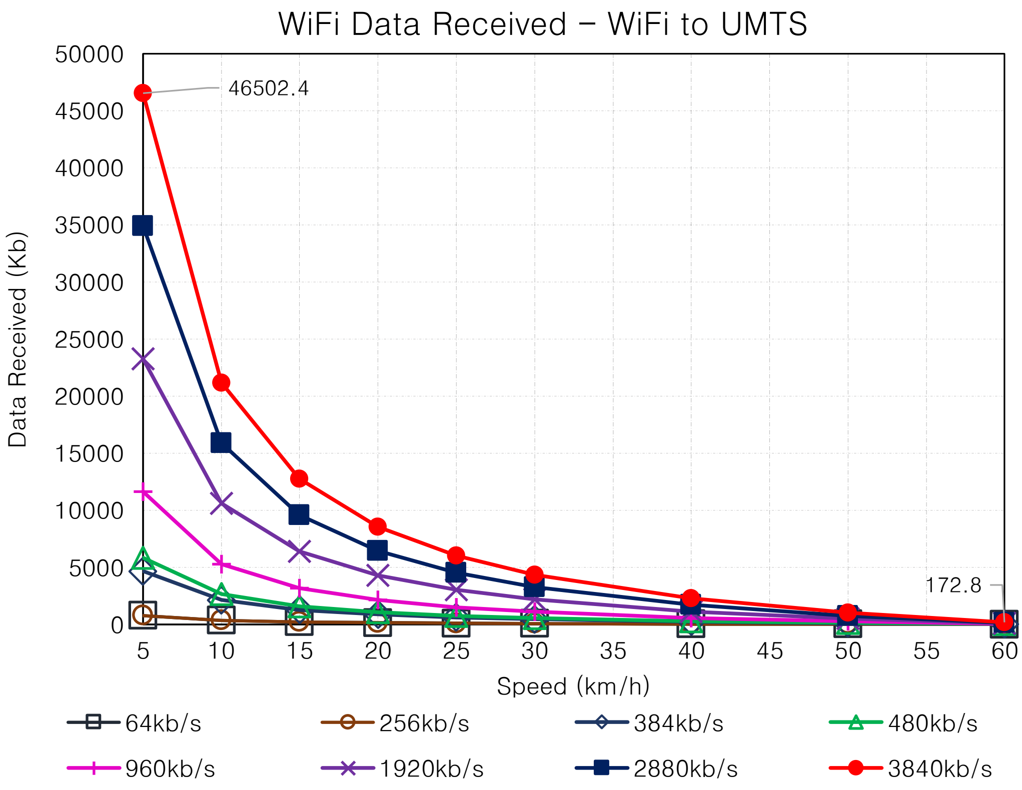

Figure 4-2: Total data received on mobile node WiFi interface in WiFi to UMTS scenario.

Figure 4-3 shows the degradation percentage in the throughput for WiFi network as function of mobile node speed. Result show that high degradation in throughput occurs when the mobile node approaches the intersection area between WiFi and UMTS networks with high speeds; meaning that when the mobile node speed is more than 50 km/h, the throughput degrades by 40% of the bitrate value when using bitrate 3840 kb/s, this value was calculated from the difference between the values of the normalized throughput for bitrate 3840 kb/s at speeds 50 km/h and 60 km/h divided by the value of the normalized throughput at speed 50 km/h multiplied by 100%. At speed above 60 km/h, no received data was delivered at the WiFi interface because of the vertical handover process to the UMTS network.

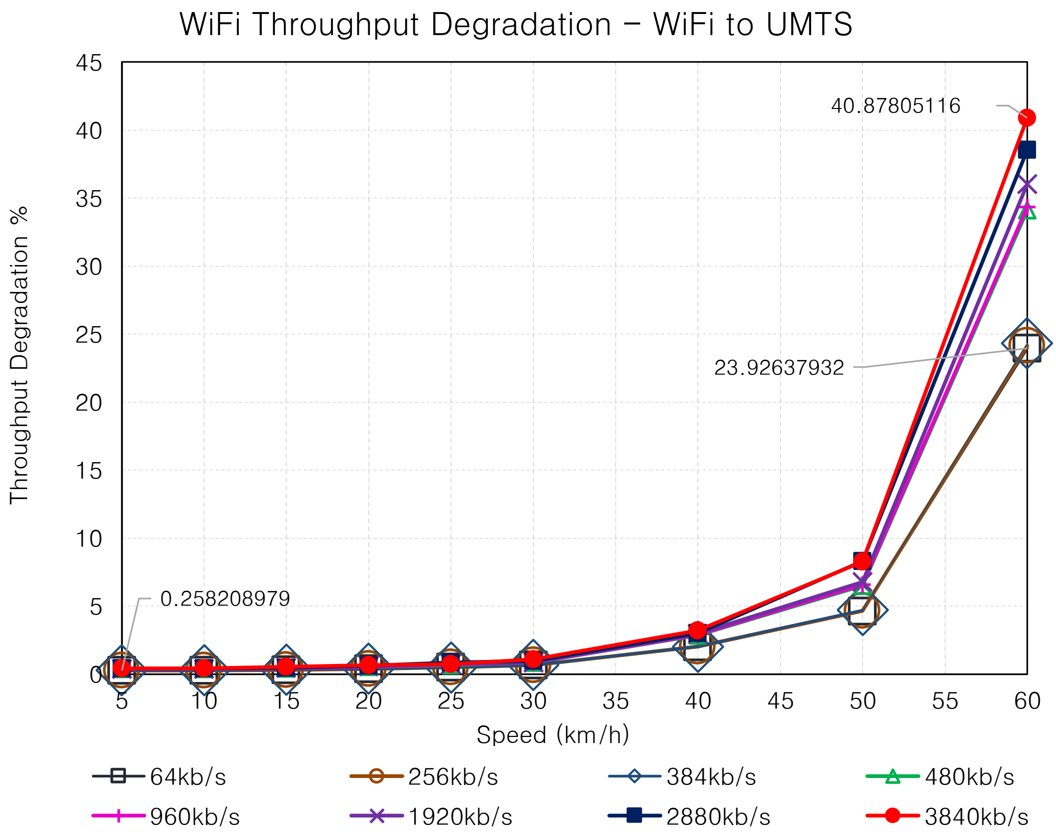

Figure 4-3: Throughput degradation in WiFi network in WiFi to UMTS scenario.

To measure the throughput in UMTS network, a similar set of simulation experiments were carried out again but this time between the media server and the mobile node UMTS interface. UMTS is the candidate network in WiFi to UMTS scenario. Figure 4-4 shows the normalized throughput measured on the mobile node UMTS interface on eight values of bitrate with different mobile node speeds. The results show that the throughput in UMTS is not affected by increasing mobile node speed because the mobile node in WiFi to UMTS scenario is entering the UMTS network without any degradation in the UMTS power RSS. The maximum bandwidth of UMTS is 384 kb/s which means that that the throughput will not be affected when the application bitrate is less than 384kb/s, showing 99% of the normalized throughput when using application bitrate less than 384 kb/s. For bitrate higher than 384 kb/s, average throughput became constant, it was measured 384 kb/s for all bitrates. This occurs because of the limited bandwidth of UMTS network which will limit the received data when using bitrate higher than 384 kb/s as shown in Figure 4-5.

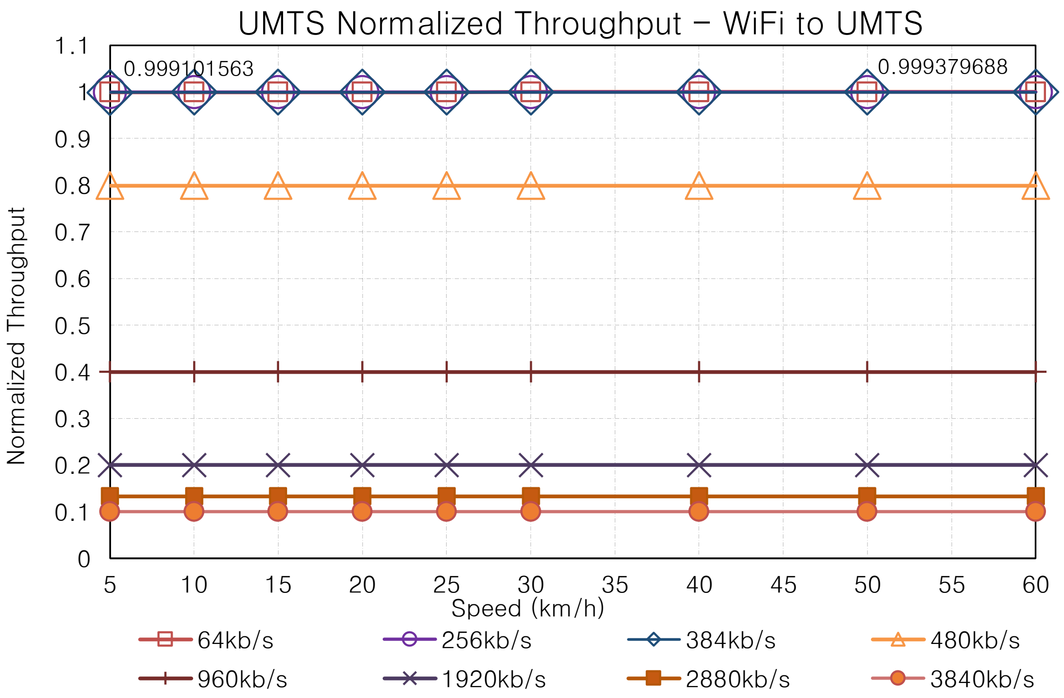

Figure 4-4: Normalized throughput for UMTS network in WiFi to UMTS scenario.

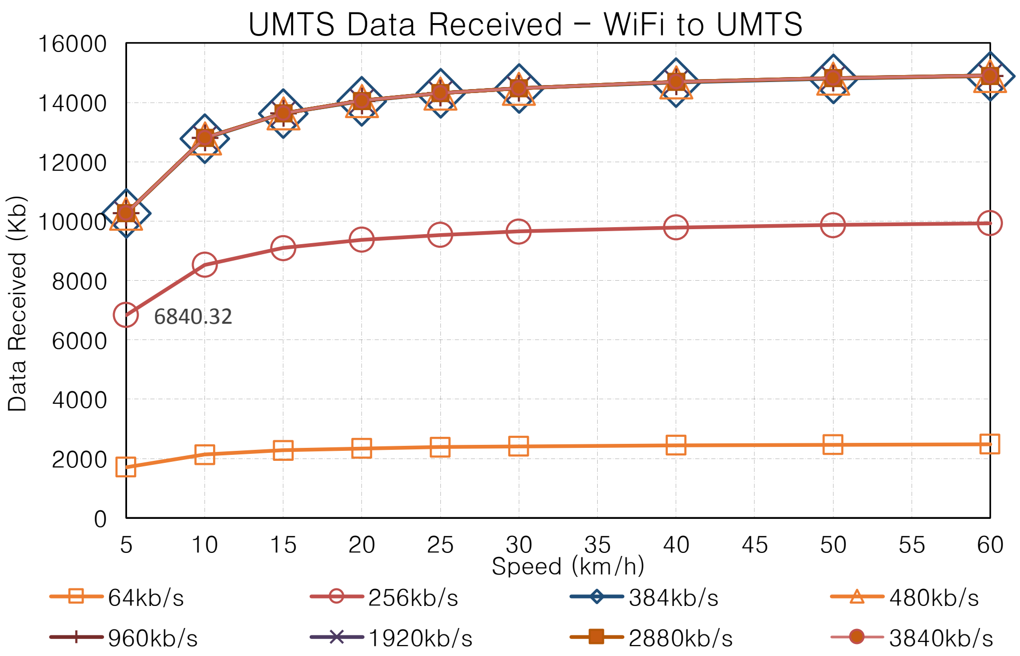

Figure 4-5: Total data received on mobile node UMTS interface in WiFi to UMTS scenario.

In WiFi to UMTS scenario, it is observed that the features of the access network affect the throughput values. The low mobility of WiFi network limits the mobile node speed to 50 km/h in the handover area and shows high throughput degradation (40%) when the mobile node left the WiFi network with speed more than 50 km/h. The limited bandwidth of UMTS started to affect the throughput values when using application bitrate higher than 384 kb/s. In order to achieve acceptable throughput values, and keep session continuity, bitrate application is preferable to be less than 384 kb/s and mobile node speed below 50 km/h.

4.2.2 UMTS to WiFi

Figure 4-6 shows the UMTS normalized throughput when the UMTS is the serving PoA. Throughput is not affected by increasing mobile node speeds. As a result of UMTS high coverage area since the UMTS signal is available wherever the mobile node moves in the vertical handover scenarios, therefore with increasing mobile node speed, the throughput degradation while leaving UMTS network will be low for bitrate lower than 384 kb/s. The throughput was highly affected when using application bitrate higher than 384 kb/s because this will exceed the maximum bandwidth of the UMTS network which is 384 kb/s, this limits the received data on the UMTS interface and therefore the throughput was highly decreased inside UMTS network when using application bitrate higher than 384 kb/s regardless of the mobile node speed.

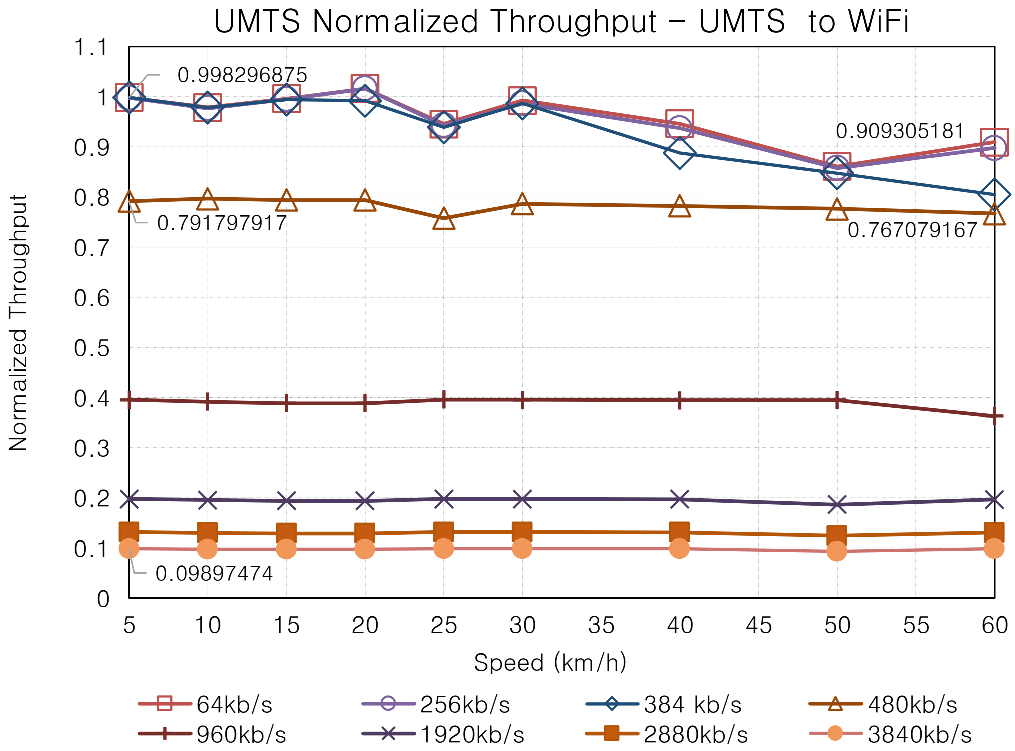

Figure 4-6: Normalized throughput for UMTS network in UMTS to WiFi scenario.

Figure 4-7 shows the data received on the UMTS interface as function of mobile node speed in UMTS to WiFi scenario. When the mobile node is leaving the UMTS network, the received data on the UMTS interface decreases with increasing mobile node speed, this occurs because the mobile node is leaving the UMTS network and the time spent inside the UMTS network becomes shorter as speed increases, which will shorten the connection time to the UMTS BS, therefore throughput values will decrease accordingly. For bitrate higher than 384 kb/s it is noticed that for all speeds the amount of data received becomes constant. The highest data received value was measured at speed 5 km/h.

At low speeds, it is supposed that received data increases with increasing bitrate, as the case in WiFi to UMTS scenario depicted in Figure 4-2 while the mobile node is leaving the WiFi network. This behaviour was only shown for bitrates lower than 384 kb/s depicted in Figure 4-7. But for bitrates higher than 384 kb/s, the low UMTS bandwidth limits the data received on the UMTS interface and high effect on the throughput values was observed, on the contrary the throughput values were slightly affected with increasing speed for bitrate lower than 384 kb/s. The slight effect of mobile node speed on the throughput was observed when using application bitrate lower than 384 kb/s, but the effect of application bitrate started to appear when using application bitrate higher than 384kb/s that will highly decrease the throughput.

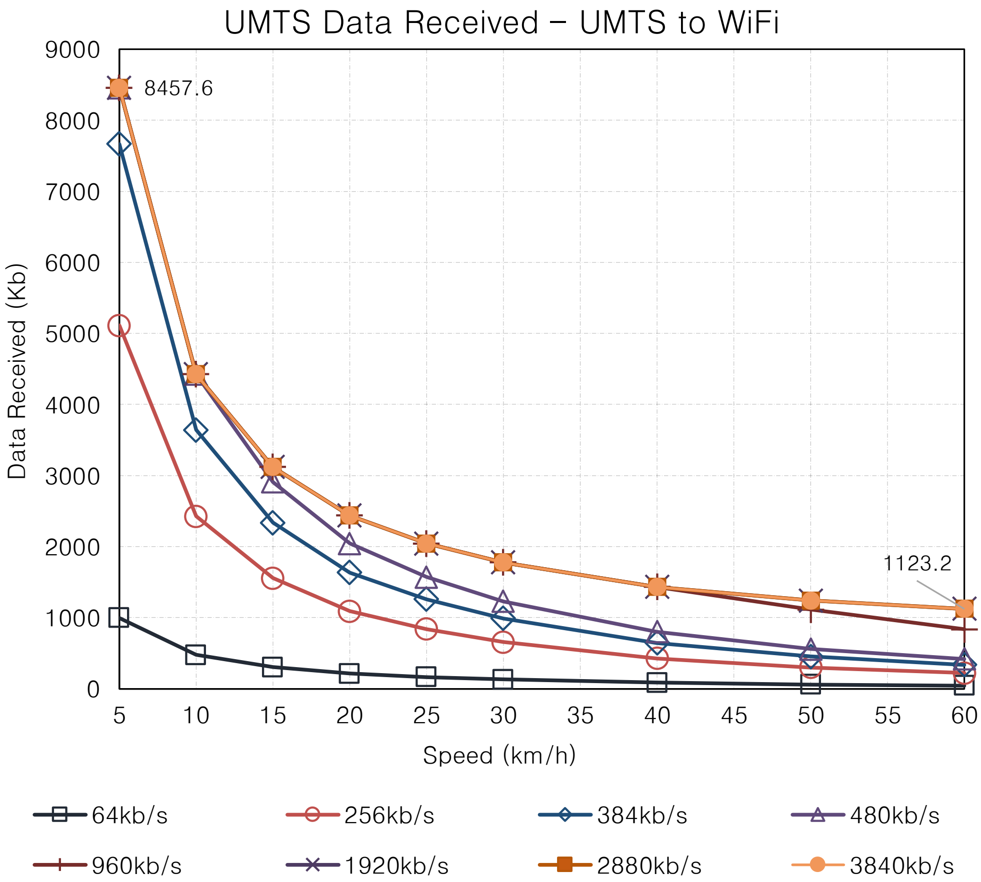

Figure 4-7: Total data received on mobile node UMTS interface in UMTS to WiFi scenario.

Figure 4-8 presents the behaviour of increasing throughput measured on the WiFi interface while the mobile node is entering the WiFi network, it is shown that, the faster the mobile node enters WiFi network the higher the throughput values. Using high bitrates slightly affect the throughput in WiFi. Figure 4-9 shows that the total received data increases with increasing mobile node speed. High data received at high bitrates was shown without any limitation on the bandwidth in WiFi within the range of bitrate used in the scenarios. This behaviour justifies the acceptable values of the normalized throughput for all used bitrates that were depicted in Figure 4-8

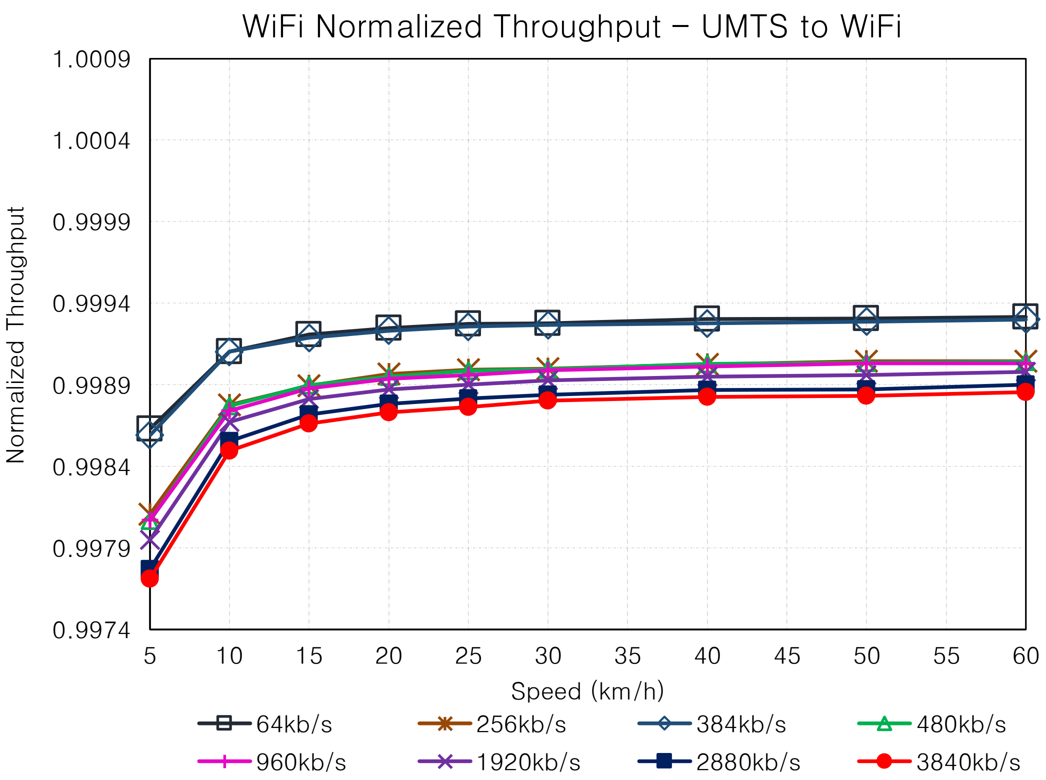

Figure 4-8: Normalized throughput for WiFi network in UMTS to WiFi scenario.

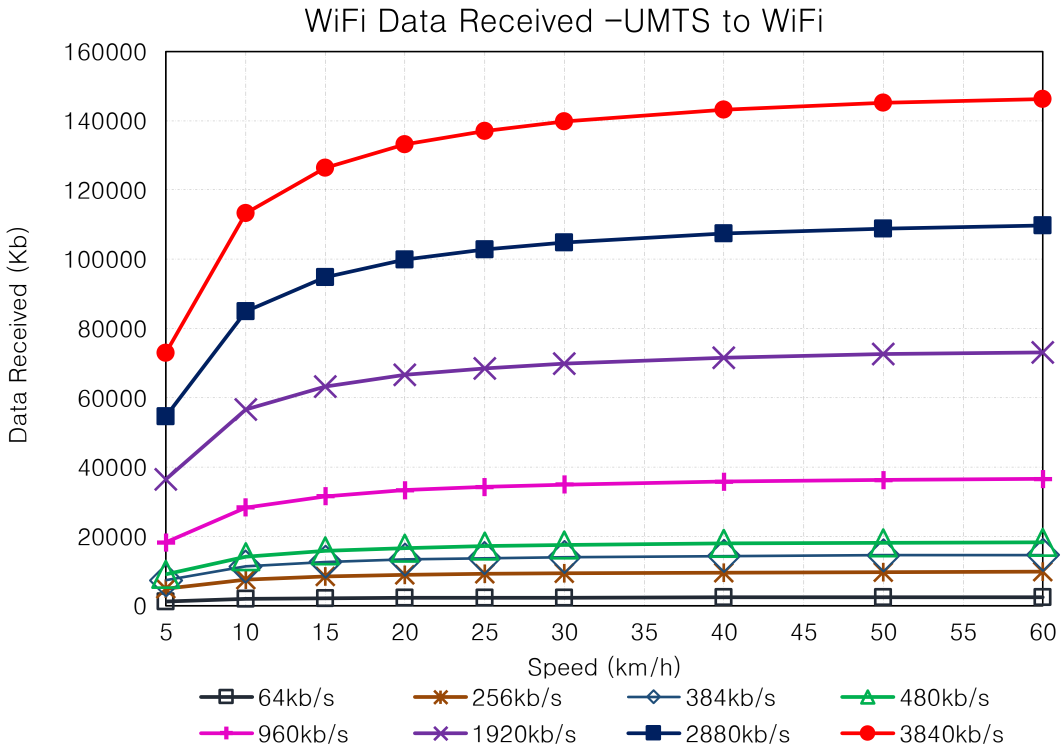

Figure 4-9: Total data received on mobile node WiFi interface in UMTS to WiFi scenario.

In UMTS to WiFi scenario, we can say that the UMTS high mobility feature allows the mobile node to increase its speed without affecting the throughput, on the contrary, the UMTS limited bandwidth started to appear when using application bitrate higher than 384 kb/s, and this will highly decrease the throughput values in UMTS. When the mobile node is entering the WiFi network, there are no limitations on the mobile node speed and application bitrate.

4.3 Packet Loss Ratio

4.3.1 WiFi to UMTS

Packet loss ratio was measured based on equation (3.4), Figure 4-10 shows the packet loss occurred while the mobile is leaving WiFi network. Packet loss increases with increasing mobile node speed in WiFi, for example when using application bitrate 384 kb/s, number of lost packets in WiFi is 7 packets; which is the difference between the sent and received packets, this number is constant for specific bitrate regardless of the mobile node speed. The lost in packets occurred because of the handover process latency. When the mobile node speed increases, the sent packets to the WiFi interface decreases and the packet loss value remains 7 packets, therefore at speed 5 km/h, 606 packets were received from 613 packets, the packet loss ratio is 1.1419%. At speed 60 km/h, 3 packets were received out of 10 packets, which means that the packet loss is 70%. This behaviour was observed for all values of bitrate.

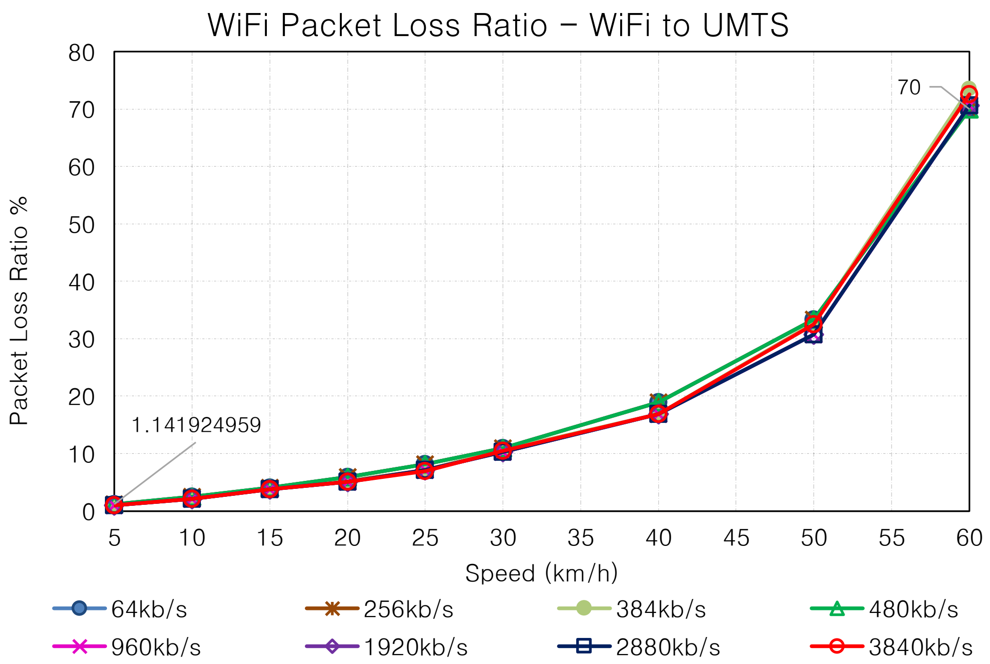

Figure 4-10: Packet loss ratio in WiFi network for WiFi to UMTS scenario.

Similar set of simulation experiments were carried out, but this time on the UMTS interface, Figure 4-11 shows that packet loss ratio is low when using application bitrate less than 384 kb/s. Packet loss ratio started to increase in UMTS when using application bitrate higher than 384 kb/s as a result of UMTS limited bandwidth. In this scenario, as the mobile node becomes faster, the connection time in UMTS becomes longer, this will increase the sent packets in UMTS network, In addition, increasing application bitrate will also increase the number of sent packets, but the limitation of the UMTS bandwidth will limit the number of received packets, therefore increasing the application bitrate more than 384 kb/s will lead to high packet loss ratio.

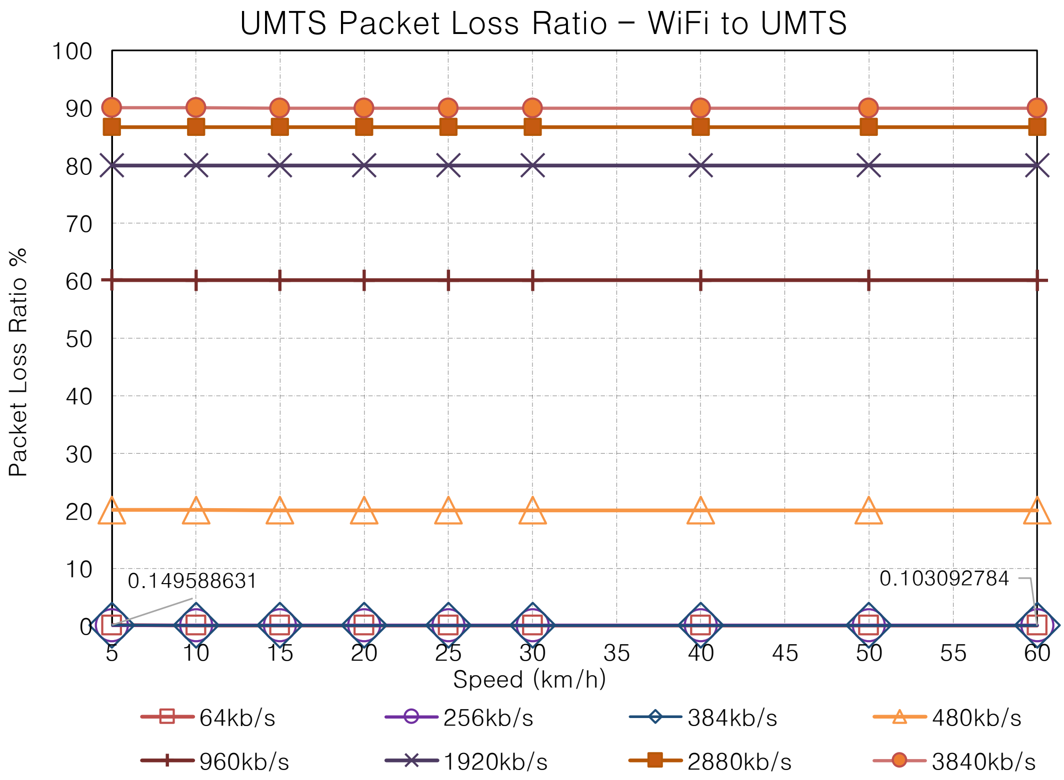

Figure 4-11: Packet loss ratio in WiFi network for WiFi to UMTS scenario.

In order to observe the behaviour of the packet loss ratio, total packet loss ratio during the whole scenario for both WiFi and UMTS was measured. Figure 4-12 shows the impact of mobile node speed and the application bitrate on the total packet loss that occurs in the vertical handover scenario. When using application bitrate less than 384 kb/s, packet loss ratio is very low (0.46%), it is also not affected by mobile node speed. This behaviour is due to the available bandwidth in both WiFi and UMTS network when using application bitrate less than 384 kb/s. The total packet loss ratio in this case occurred because of the behaviour mentioned above, in addition to the handover latency that took place when handover to UMTS network. The impact of using high bitrate started to appear when the application bitrate is more than 384 kb/s, what happened in this case is that the WiFi network will have an acceptable packet loss because of its high bandwidth, but for UMTS, the received data will be limited when using bitrate higher than 384 kb/s which equals to its bandwidth, this behaviour was shown in Figure 4-5; the total received data on UMTS interface will not increase when using application bitrate higher than 384 kb/s, therefore this scenario will suffer from high packet loss because of the UMTS limited bandwidth. In addition, increasing the mobile node speed will also increase the packet loss ratio, because when the mobile node enters the UMTS network faster, it will spend more time in UMTS and the data received on the UMTS interface will be more and thus packet loss will be higher with increasing mobile node speed.

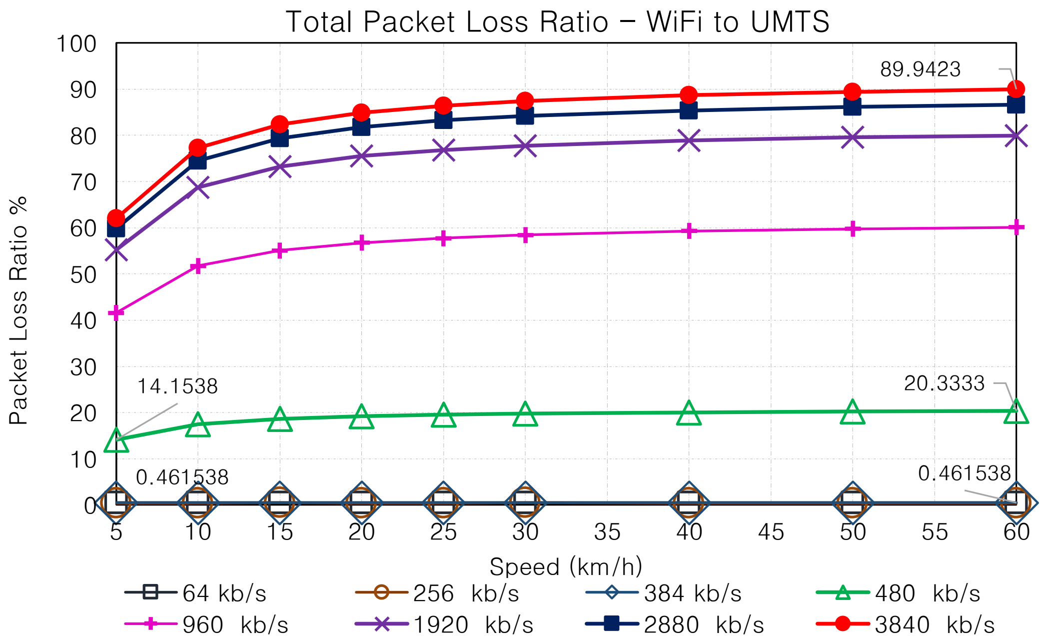

Figure 4-12: Total Packet Loss Ratio in WiFi to UMTS scenario.

4.3.2 UMTS to WiFi

In this scenario, the mobile node is leaving UMTS network towards WiFi network. Figure 4-13 shows packet loss ratio in UMTS network, no packets were lost when using application bitrate lower than 384 kb/s. For bitrate higher than 384 kb/s some packets were lost at low speeds. Packet loss decreases with increasing mobile node speed because the faster the mobile node leaves UMTS network, the lower the packet loss ratio.

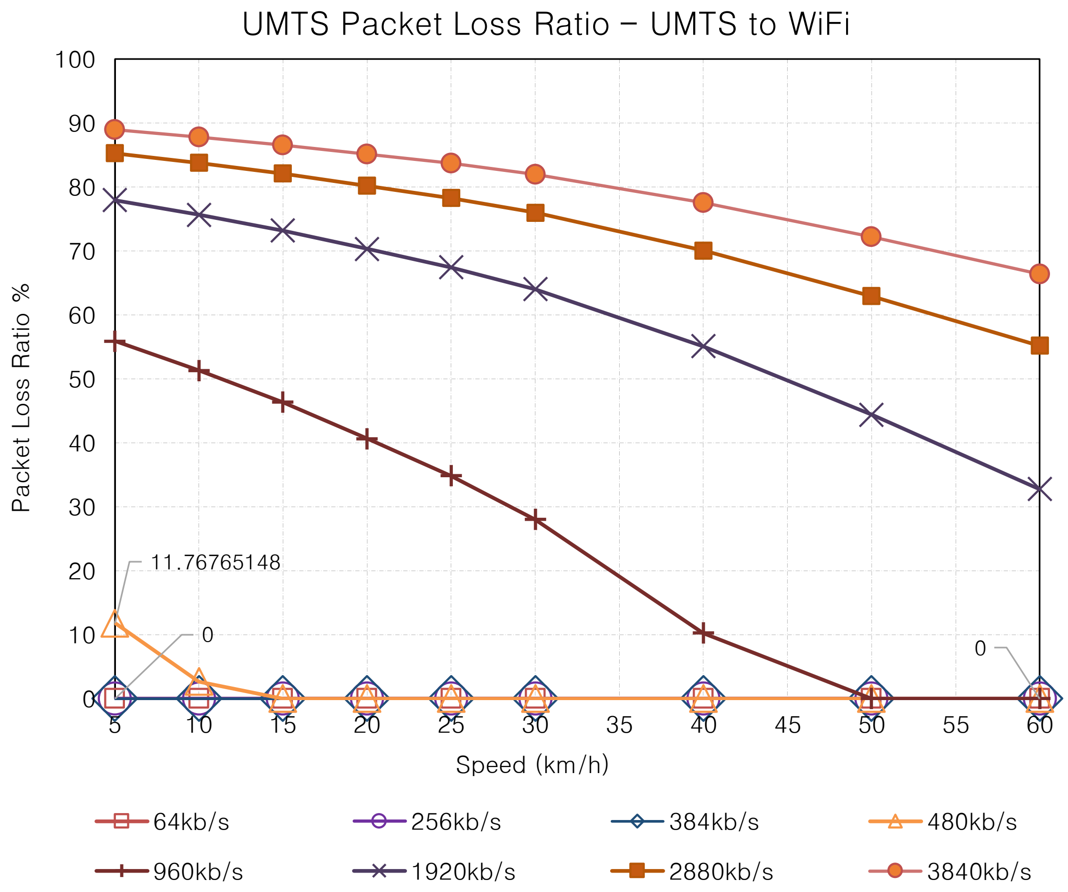

Figure 4-13: Packet loss ratio in UMTS network for UMTS to WiFi scenario.

Packet loss ratio in WiFi decreases when the mobile node speed increases, because when the mobile node moves with high speed in UMTS to WiFi scenario as shown in Figure 4-14, the connection time to WiFi network will be more than the connection time to UMTS network which will result in increasing the send and received packets in the WiFi network because the mobile node spent more time in WiFi network, it is also known from the results shown in Figure 4-10 that the number of lost packets in WiFi are constant at specific application bitrate regardless of mobile node speed, therefore, the packet loss ratio defined in equation (3.4) will decrease as a result of increasing the number of sent packets in WiFi while the number of lost packets at specific bitrate is constant which is defined as the difference between the sent and received packets in equation (3.4).

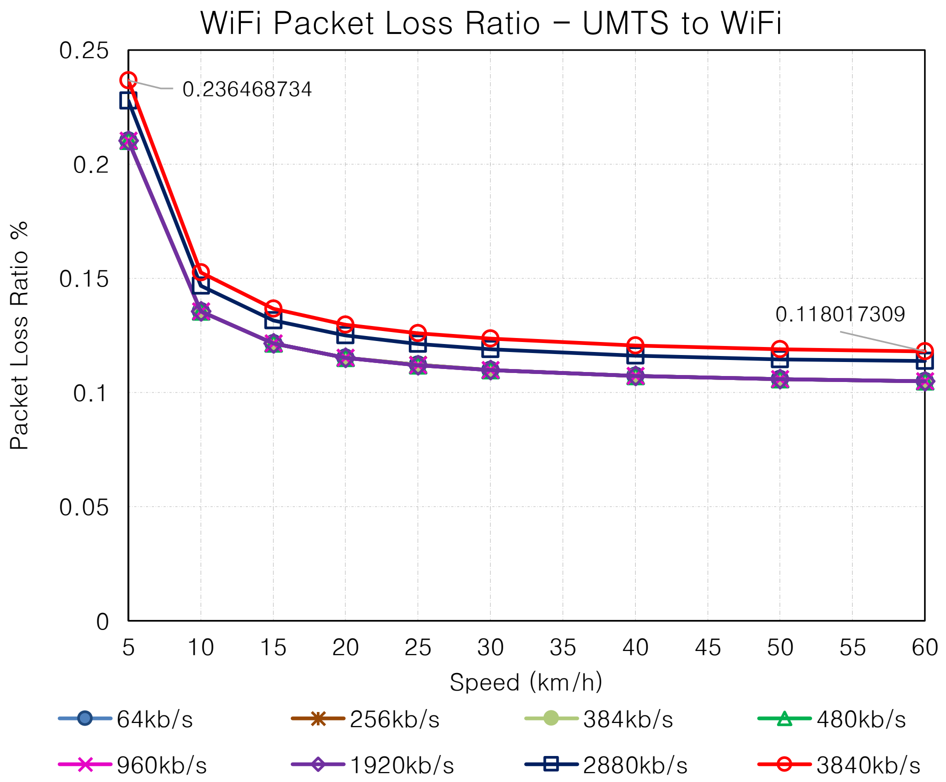

Figure 4-14: Packet loss ratio in WiFi network for UMTS to WiFi scenario.

For performance evaluation, total packet loss ratio in the UMTS to WiFi scenario was measured, Figure 4-15 shows that high packet loss occurred when the mobile node is moving in UMTS with low speed, which results in more packet loss for higher bitrate. In this scenario, packet loss occurs on low speeds in UMTS because the time spent in UMTS will be longer than the time spent when the mobile is moving with high speed, therefore number of packets will be more and the limited UMTS bandwidth will highly affect the number of received packets that will result in increasing the packet loss ratio. The faster the mobile node leaves UMTS network, the lower packet loss occurs. It is also observed that when using bitrate lower than 384 kb/s, packet loss ratio is acceptable.

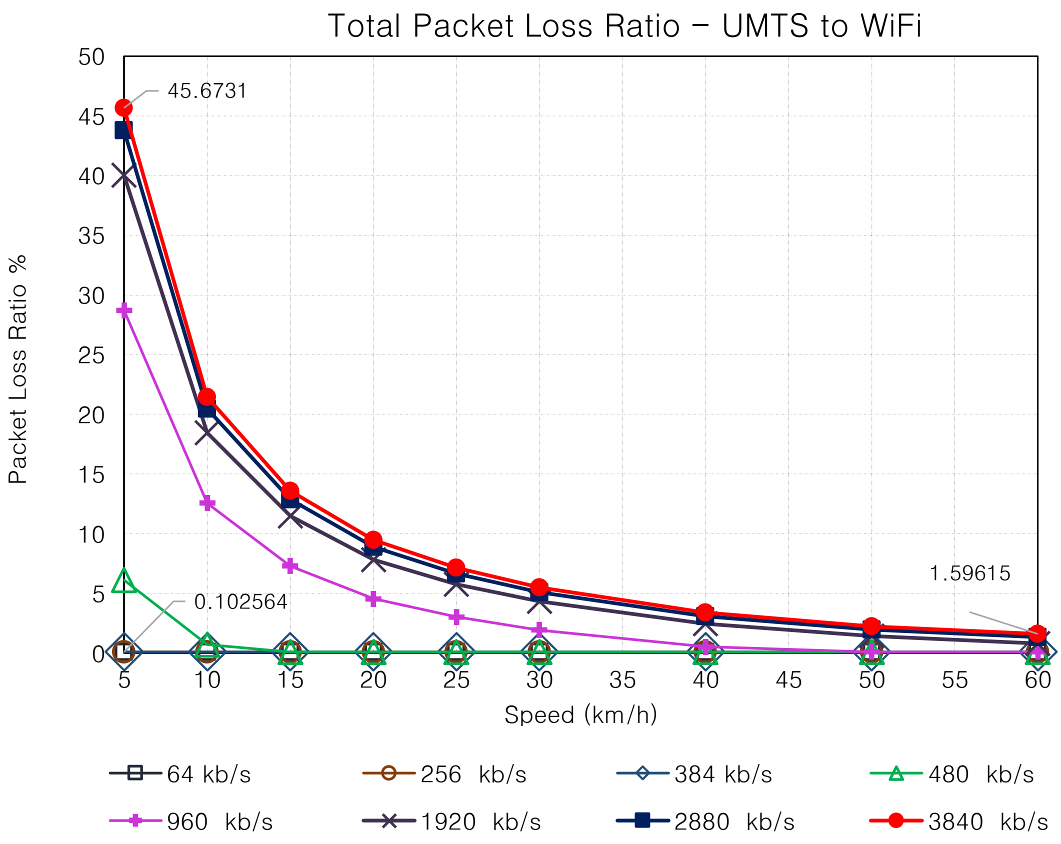

Figure 4-15: Total Packet Loss Ratio in UMTS to WiFi scenario.

In WiFi to UMTS scenario, It is noticed that the total packet loss started to increase when using application bitrate higher than 384 kb/s and when the mobile node spend more time in UMTS network as shown in Figure 4-12, however in UMTS to WiFi scenario, the faster the mobile node leaves UMTS network, the lower packet loss occurs as shown Figure 4-15.

4.4 Average End to End Delay

4.4.1 WiFi to UMTS

Based on the definition of the E2E delay in section 3.3, the time interval that starts when the packet was sent from its source until it reaches to the destination was measured. This time interval is called End to End delay or one way delay. The sum of these delay intervals divided by the number of received packets is the average E2E delay. In the implemented scenarios, the source of the packet is the network interface of the media server. The destination of the packet is the WiFi interface when the mobile node is connected to the WiFi network and UMTS interface when it is connected to the UMTS network because of the traffic redirection occurred during the handover process. Therefore, it is necessary to measure the average E2E delay when the packet was sent from the media server until it was received at the mobile node WiFi interface and UMTS interface. In between, there is handover latency that occurs only one time in each scenario (WiFi to UMTS and vice versa) and will be discussed in the next section. In this way, it is figured out which factors affect the delay in WiFi and UMTS network and to what limit the delay values are acceptable.

Figure 4-16 shows the average delay in WiFi network plotted as function of speed for various values of application bitrate. In this scenario, results show that the E2E delay in WiFi is not affected by mobile node speed, but it was slightly affected by increasing the application bitrate. The E2E delay increased from 46 ms to 50 ms when the application bitrate was increased from 64 kb/s to 3840 kb/s respectively. Figure 3-7 shows the links delay from the media server to the gateway router (30 ms), the link delay between the gateway router and the WiFi AP (15ms) in addition to the link delay between the gateway router and the UMTS BS (0.4ms +15ms = 15.4 ms). Therefore the minimum E2E delay for WiFi packet to reach WiFi AP will be (30 ms + 15 ms = 45 ms) and for UMTS packet to reach UMTS BS will be (30 ms + 15.4 ms = 45.4 ms).

We can say that the high bandwidth in WiFi network affect the E2E delay of the packets, acceptable delay values were measured. Furthermore, there are no constrains for the delay sensitive application in WiFi network. Good performance can be achieved for these applications in term of E2E delay.

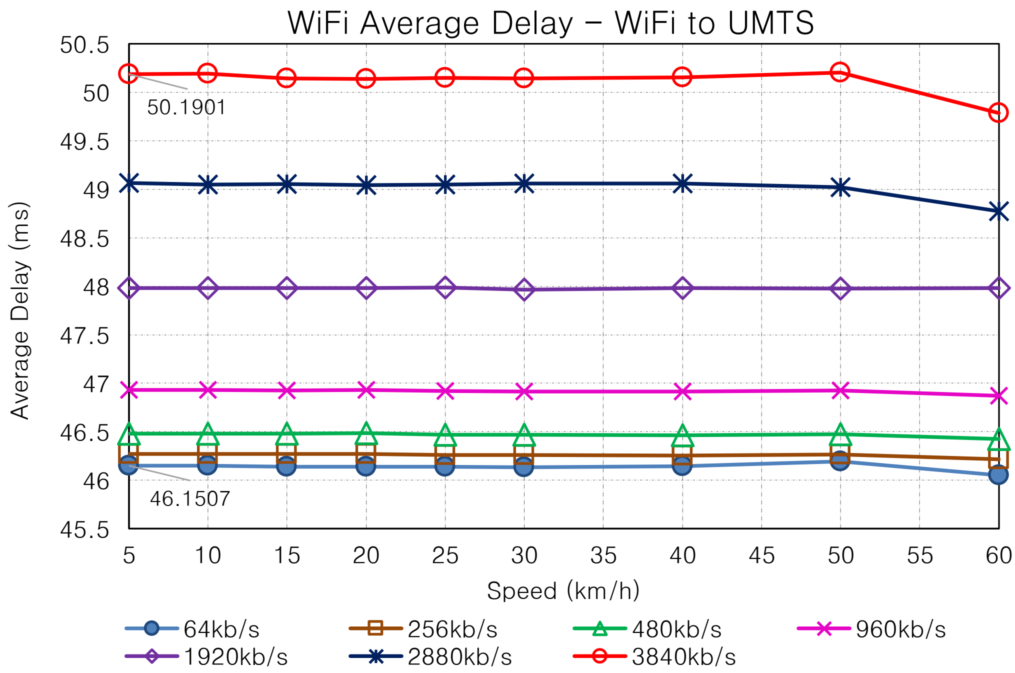

Figure 4-16: Average E2E Delay for WiFi packets in WiFi to UMTS scenario.

In UMTS network, Figure 4-17 shows the average E2E delay in UMTS network plotted as function of mobile node speed for different values of application bitrate. E2E delay is not affected by increasing the mobile node speed, on the contrary, it is affected by increasing the application bitrate. For bitrate lower than 384 kb/s, E2E delay is almost constant with acceptable values which is around 54 ms. Delay values increased dramatically when the application bitrate exceed the bandwidth of UMTS network, E2E delay values are around 1 second which is which is considered as very high value for delay sensitive applications.

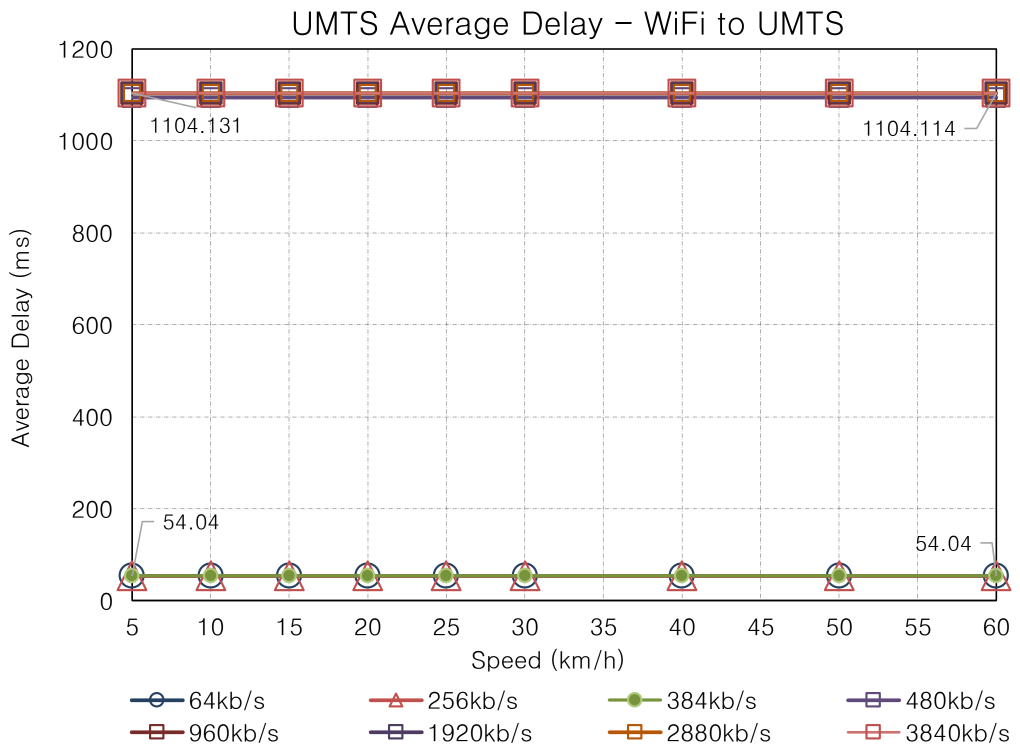

Figure 4-17: Average E2E Delay for UMTS packets in WiFi to UMTS scenario.

In WiFi to UMTS scenario, it was observed that the delay sensitive applications must operate with bitrate lower than 384 kb/s in UMTS network and accepting E2E delay of 54 ms. Applications with bitrate higher than 384 kb/s cannot operate because of the high E2E delay in UMTS.

4.4.2 UMTS to WiFi

In this scenario, E2E delay was measured for UMTS and WiFi packets, Figure 4-18 shows that the average E2E delay in UMTS network is not affected by the mobile node speed. Delay value is around 54 ms for bitrate lower than 384 kb/s. The high impact of the application bitrate becomes obvious when using application bitrate higher than 384 kb/s, showing high delay values - around 1. This occurs because of the limited bandwidth in the UMTS network that will affect the delay when increasing the traffic load by using application bitrate higher than 384 kb/s. It is concluded that bitrates lower than 384 kb/s has an acceptable E2E delay for both real time and non-real time applications.

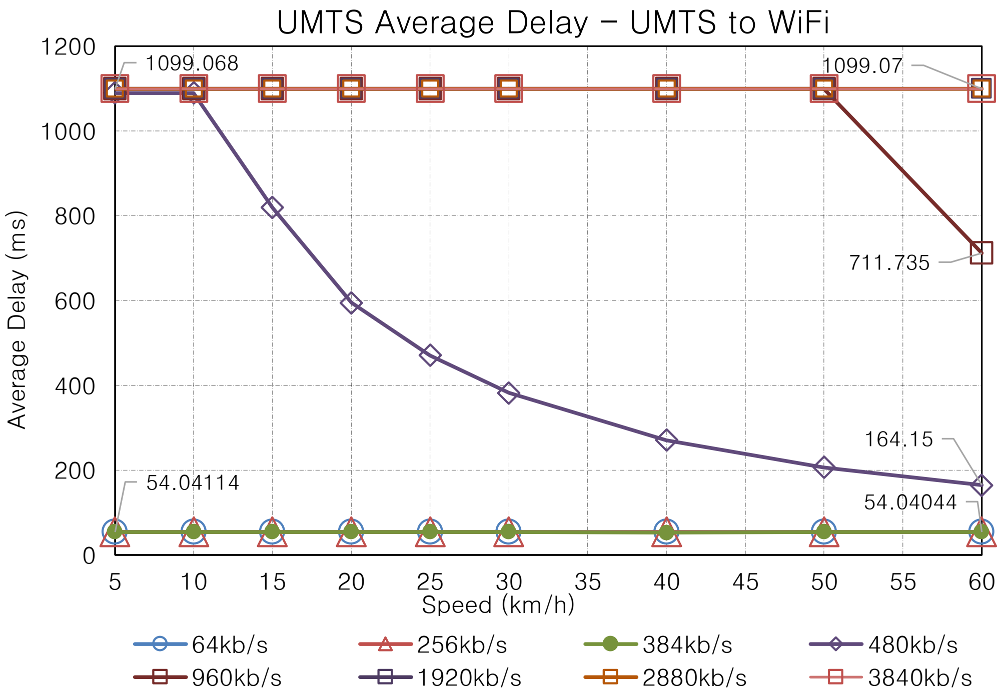

Figure 4-18: Average E2E Delay for UMTS packets in UMTS to WiFi scenario.

Figure 4-19 shows the average E2E delay for WiFi packets in UMTS to WiFi scenario, this result is similar to the obtained one for WiFi packets in WiFi to UMTS scenario depicted in Figure 4-16. This can be explained as, E2E delay in WiFi is affected by the links and network entities implemented in both scenarios. Increasing the application bitrates slightly affect the E2E delay but increasing mobile node speeds has no impact on the measured E2E delay in WiFi.

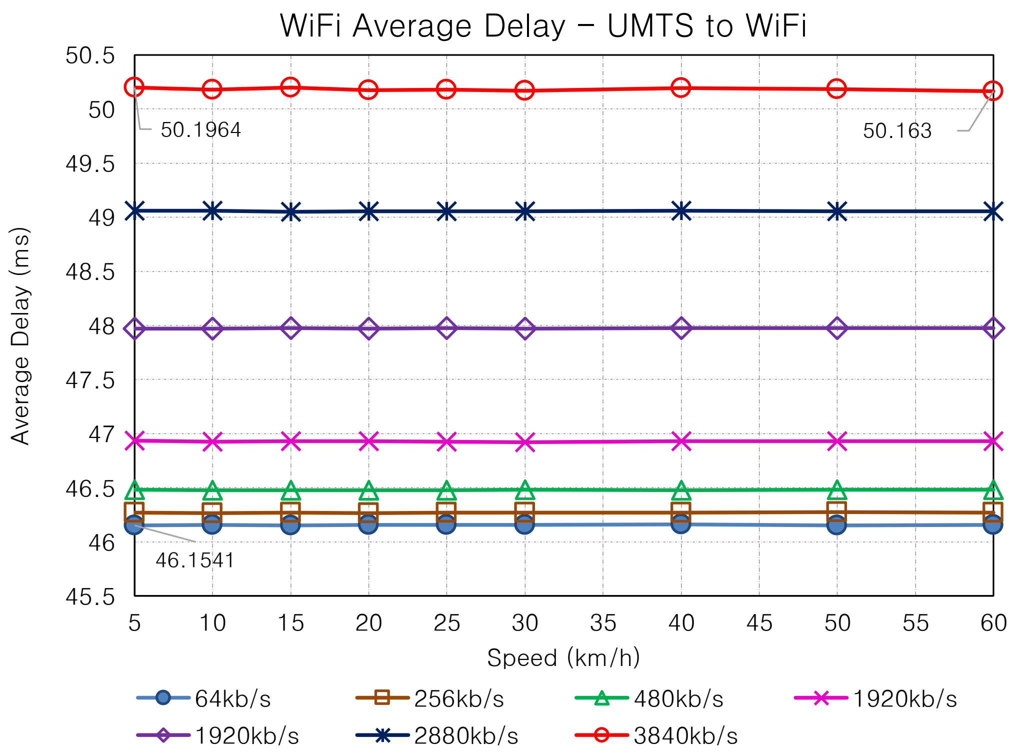

Figure 4-19: Average E2E Delay for WiFi packets in UMTS to WiFi scenario.

4.5 Handover Latency

4.5.1 WiFi to UMTS

Based on the definition of handover latency in section 3.3, the instant of time when the last packet was delivered to the WiFi interface of the mobile node was observed from the output files of the simulator. After that the packets were redirected to the mobile node UMTS interface and was observed in the output files of the simulator as well. During this time interval, no packets were delivered on both interfaces, therefore it is important to measure this latency to insure that it is reasonable for the delay sensitive applications.

It is noticed that the handover time in this scenario (WiFi to UMTS) varies between 142 ms and 167 ms for all bitrates and speeds used in the simulation scenarios.

Figure 4-21 shows the vertical handover latency as function of mobile node speed in WiFi to UMTS scenario. The behaviour shows limited effect for mobile node speed and slight effect for the application bitrate on the vertical handover latency.

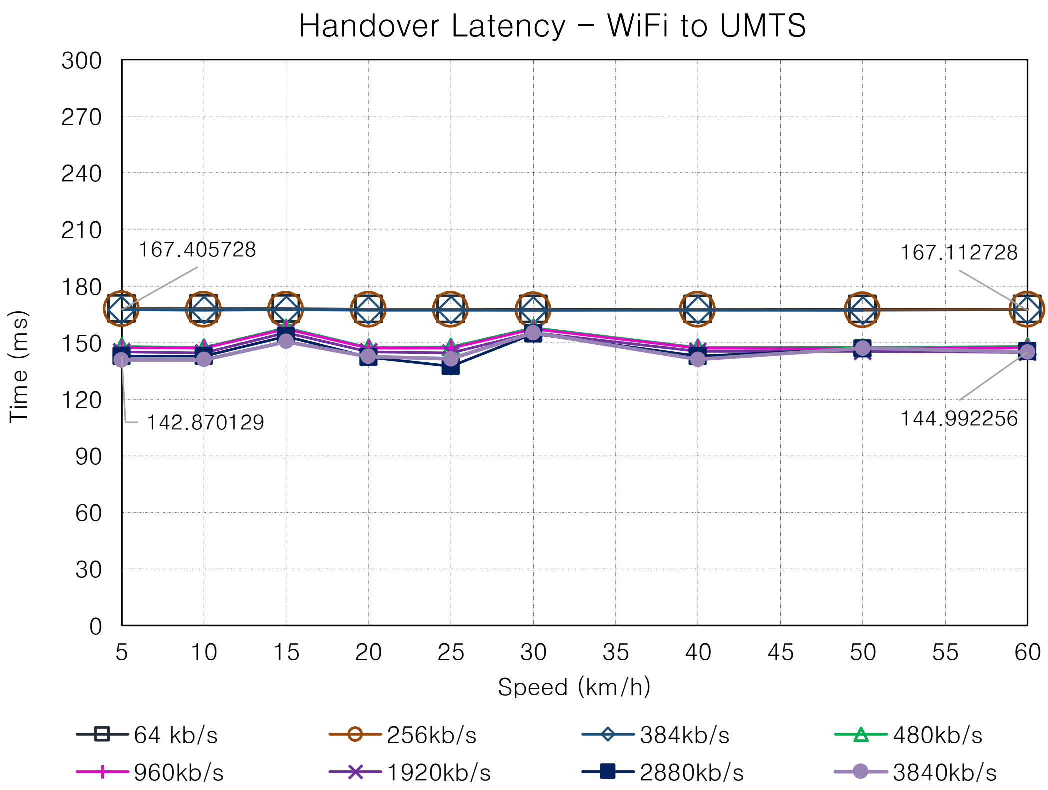

Figure 4-20: Handover latency measured in WiFi to UMTS scenario.

4.5.2 UMTS to WiFi

The handover latency in UMTS to WiFi was measured using the same method described in section 4.5.1, but this time the traffic will be redirected from the UMTS to

WiFi interface. Lower handover latency occurs when moving from UMTS to WiFi; around 11 ms regardless of the mobile node speed and for bitrates less than 384 kb/s as shown in Figure 4-22. Applications with bitrate higher than 384 kb/s will not work in this scenario because of the bandwidth limitation on the UMTS network that resulted in unacceptable values for throughput, delay and packet loss values as shown in Figure 4-6, Figure 4-13 and Figure 4-18.

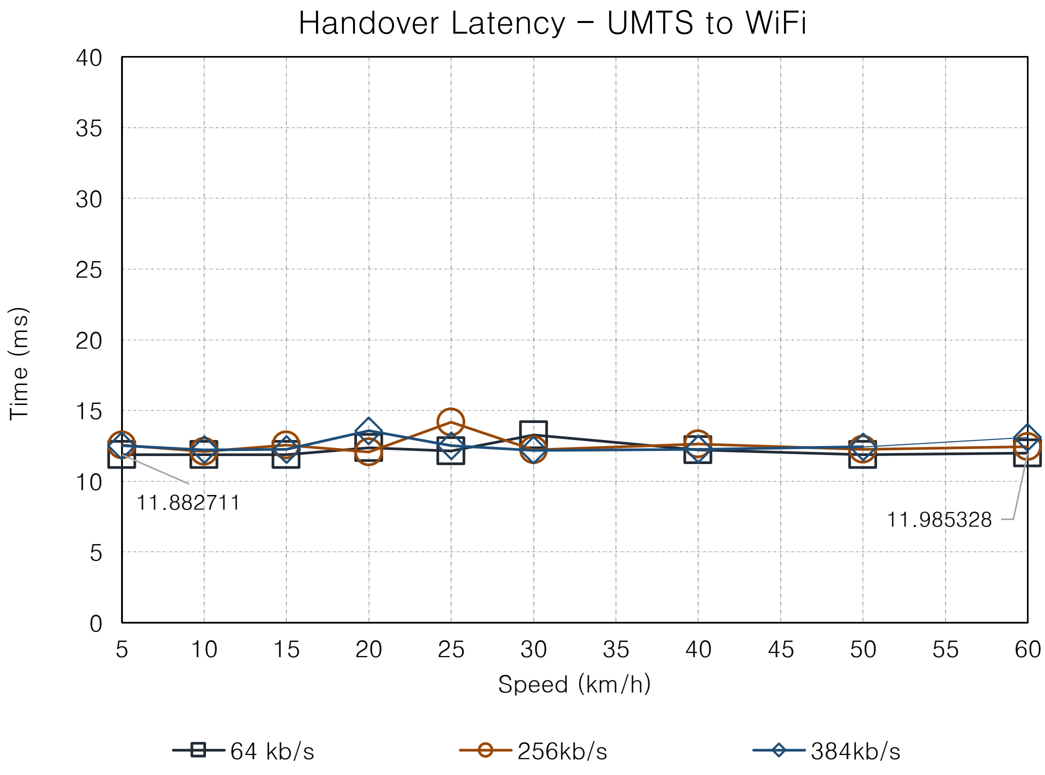

Figure 4-21: Handover latency measured in UMTS to WiFi scenario.

We can say that handover to WiFi shows lower latency values than handover to UMTS, the difference in behaviour is related to the wireless technology procedure for establishing a connection.

4.6 Power RSS

4.6.1 WiFi to UMTS

The power RSS values are directly related to the performance of some evaluation metrics such as throughput, packet loss ratio and MIH standard triggers. LGD trigger is one of the important services that is presented by MIH standard. The lower layers in the protocol stack PHY/MAC triggers this event as indication that power degradation is happening for the received signal. Figure 4-23 shows the power RSS measured on WiFi interface as a function of simulation time while the mobile node is moving from WiFi network to UMTS network. In this scenario, as the mobile node is approaching the WiFi border, the signal power degrades accordingly.

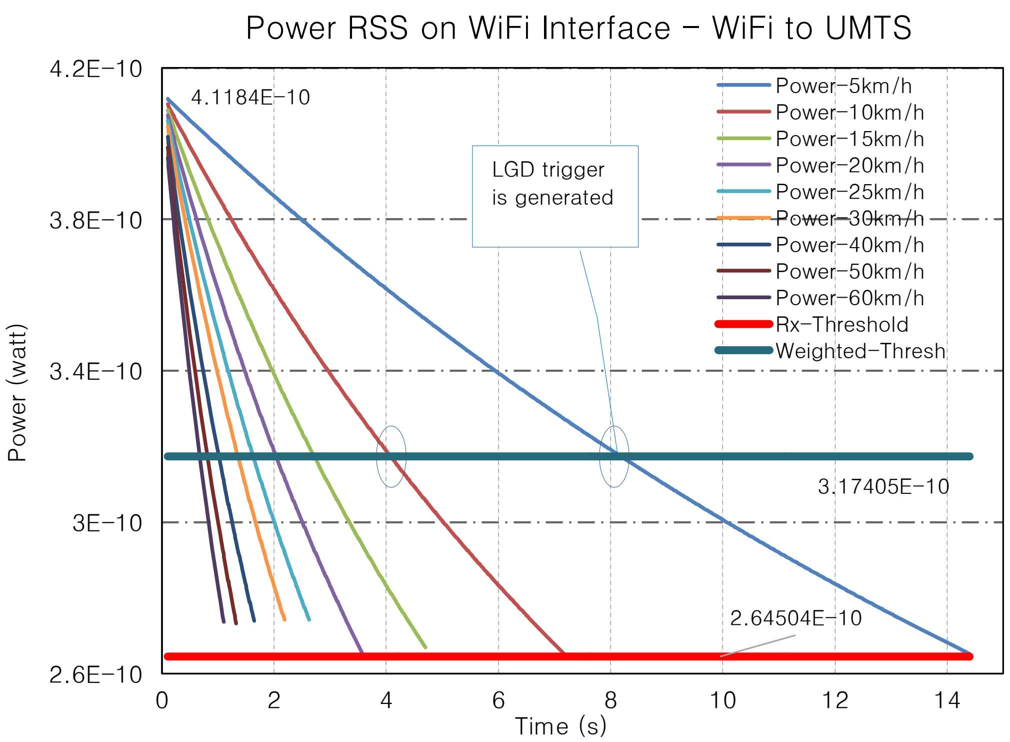

Figure 4-22: WiFi Power RSS measured in WiFi to UMTS scenario.

Figure 3-7 shows the two power thresholds of the WiFi network, they were measured to know the exact time for starting the handover initiation stage. The first threshold is RX-Threshold ($RXth$) which is the minimum power level for receiving error free packets. Weighted-Threshold (Wth) is measured using the Pr_limit factor multiplied by the RX-Threshold given by equation (4.1). The faster the mobile node moves toward the WiFi border, the sooner the weighted threshold power will be reached. The interval when LGD trigger comes out is given by equation (4.2). When the power RSS on the mobile node less than or equals the Weighted-Threshold, LGD trigger starts, during the interval given by equation (4.2).

LGD probability is given by equation (4.3) which is implemented in the MIH standard. When the mobile node approaches the WiFi network border, LGD probability increases and its value increases with increasing mobile node speed. Handover initiation and decision stages took place in this time interval. This technique results in service continuity, which prevents the RSS values from reaching the RX-Threshold. During handover initiation stage, WiFi signal degrades, the mobile node sense UMTS network signals and decide to handover to UMTS network accordingly, after that handover execution stage occurs using MIPv6.

$$Wth = \text{Pr\_limit} * RXth \qquad (4.1)$$ [Cha11] [Mar10]

$$Wth \geq RSS(t) > RXth \qquad (4.2)$$ [Cha11]

$$LGDprob(t) = \frac{Wth - RSS(t)}{Wth - RXth} * 100\% \qquad (4.3)$$ [Cha11]

Figure 4-24 was captured from the simulation logging of the scenario WiFi to UMTS when the mobile node is leaving the WiFi network with speed 5 km/h using application bitrate 64 kb/s. It shows the MIH events that were triggered during the WiFi to UMTS scenario. Power RSS (rxp) on WiFi interface at time 8.1857 s in addition to the Rx-Threshold (thresh) and Weighted Threshold (weighted-thresh) were shown in the first statement. LGD trigger were shown in the second statement. LGD probability was calculated based on equation (4.3) giving 0% and therefore no handover will take place at this instant.

```
At 8.185785050 Mac 5, rxp 3.173420e-10 thresh 2.645040e-10 weighted-thresh 3.174048e-10
At 8.185785 in 4.0.0 MIH Agent received LINK GOING DOWN trigger.
At 8.185785 in 4.0.0 Interface Manager received MIH event
At 8.185785 in 4.0.0 Handover1 received Link going down
          probability = 0%
         Do nothing
```

Figure 4-23: RSS on WiFi interface, MIH triggers and events on mobile multiFace node.

Handover will occurs after the statements in Figure 4-25 appears, because as observed the RSS value (rxp) is low and close to the value of the RX-Threshold (thresh). LGD probability was calculated by the decision algorithm in NS-2 based on equation (4.3) with very high value 98%, therefore handover process will start after this point.

```
At 14.396910053 Mac 5, rxp 2.652071e-10 thresh 2.645040e-10 weighted-thresh 3.174048e-10
At 14.396910 in 4.0.0 MIH Agent received LINK GOING DOWN trigger.
At 14.396910 in 4.0.0 Interface Manager received MIH event
At 14.396910 in 4.0.0 Handover1 received Link going down
          probability = 98%
         We fake a link down
```

Figure 4-24: Statements appear in simulation before the handover process occurs.

In UMTS to WiFi and when the mobile node is leaving the UMTS network, WiFi link detected trigger indicates that WiFi signal is available as shown in Figure 4-26.

```
At 20.900305 in 4.0.0 MIH Agent received LINK DETECTED trigger.
At 20.900305 in 4.0.0 Interface Manager received MIH event
At 20.900305 in 4.0.0 Handover1 link detected
        type 19, MacAddr=5, PoA=4
        The new interface is better...connect
        I launch the connection on the link
```

Figure 4-25: WiFi Link Detected trigger in UMTS to WiFi scenario.

While the mobile node is getting near to the WiFi network, the WiFi RSS increases and Link UP trigger occurs as shown in Figure 4-27. Figure 4-28 shows the traffic redirection from UMTS to WiFi procedure. The MIH in the MultiFace node sends capability discover request that checks the capabilities of local or remote MIHF support for MIH services such as commands, events and information. After that the decision algorithm decides to handover to better network (WiFi) and then the mobile node sends redirect request from its WiFi interface to the media server. The media server received the redirect message and send acknowledgment to the mobile node.

```
At 20.902051 in 4.0.0 MIH Agent received LINK UP trigger.
At 20.902051 in 4.0.0 Interface Manager received MIH event
At 20.902051 in 4.0.0 Handover1 received link up
        type 19, MacAddr=5, MacPoA=4
```

Figure 4-26: WiFi Link UP trigger in UMTS to WiFi scenario.

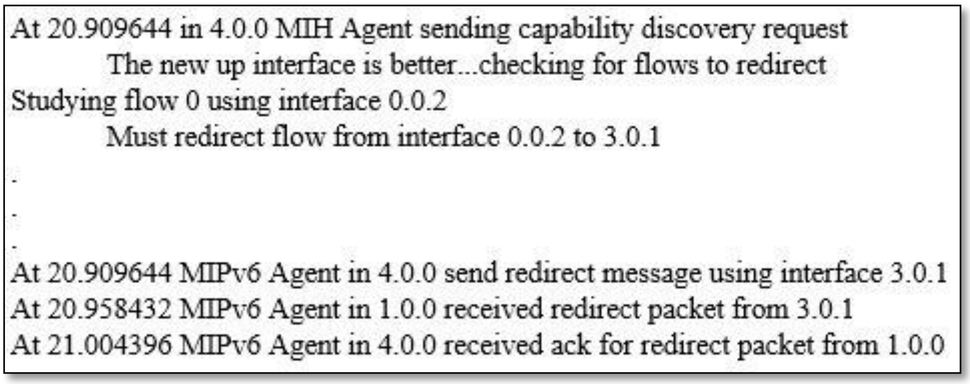
At 20.909644 in 4.0.0 MIH Agent sending capability discovery request
The new up interface is better...checking for flows to redirect
Studying flow 0 using interface 0.0.2
Must redirect flow from interface 0.0.2 to 3.0.1
.
.
.
At 20.909644 MIPv6 Agent in 4.0.0 send redirect message using interface 3.0.1
At 20.958432 MIPv6 Agent in 1.0.0 received redirect packet from 3.0.1
At 21.004396 MIPv6 Agent in 4.0.0 received ack for redirect packet from 1.0.0

Figure 4-27: MIH traffic redirection from UMTS to WiFi interface in UMTS to WiFi scenario.

4.7 Summary

In Chapter 4, the simulation results for both scenarios were presented; from WiFi to UMTS and vice versa. In each scenario, the evaluation metrics were plotted as function of mobile node speed using different values of application bitrates. The effect of the mobile node speed and application bitrate were analysed. The results were justified and the factors that affect the performance in the vertical handover scenarios were clearly mentioned. It was observed that some evaluation metrics were affected by increasing mobile node speed such as throughput, data received and packet loss, the behaviour of these metrics changed with respect to the mobile node direction; entering the access technology or leaving it. These metrics were highly affected when the mobile node speed exceeds 50 km/h. Other metrics such as delay and handover latency are not affected by mobile node speed. Application bitrate highly affect most of the evaluation metrics in UMTS network, using application bitrate higher than 384 kb/s has high effect on the throughput, data received, packet loss, delay and handover latency as well. Handover latency occurred once in each scenario, it was measured to be sure that the latency values are acceptable to the delay sensitive applications. In addition, it is noticed that handover to WiFi network is faster than handover to UMTS network.

Finally, we can say that the low mobility of WiFi and the limited bandwidth of UMTS affect the vertical handover scenarios, it is discussed how these features affect the performance metrics in the implemented scenarios. In Chapter 5, we are going to model some of the obtained results by fitting the curves of the evaluation metrics to present a functional description of the obtained results in the vertical handover scenarios. In addition, we will present the results by summarizing the effect of the mentioned factors such as mobile node speed and applications bitrate on the evaluation metrics and compare these results with the values defined by the ITU-T in order to evaluate the performance and to know to what extent these values are acceptable and to which type of applications. Results discussion will also compare the results in this thesis with other results in the related works proposed in the literature.

Chapter 5

Results' Modelling and Discussion

5.1 Results' Modelling

In order to obtain a functional description for the behaviour of the obtained results, curve fitting with various models was carried out. Curve Fitting Toolbox in MATLAB [Mat13] was used to select the best model that represents the behaviour of the results among the candidate models supported by this toolbox. After fitting the obtained results with the most suitable models, we assessed the goodness of fit using the following statistics measures:

1. **Sum of Squares due to Error (SSE):** It is also called the summed square of residuals, it measures the total deviation of the response values from the fit of the response values. The fit is considered useful for prediction when the SSE value is closer to zero, which indicates that the model has smaller random error components. [Mat13]

2. **Square of the multiple correlation coefficient (R-square):** It is the square of the correlation between the response values and the predicted response values. It measures successfulness of the fit in explaining the variation of the data. A greater proportion of variance is accounted by the model when the R-square value is closer to 1. For example a value of 0.998 means that the fit explains 99.8% of the total variations in the data about the average. [Mat13]

3. **Degree of freedom adjusted R-Square:** R-square is adjusted based on the residual degrees of freedom. The residual degrees of freedom is the difference between the number of response values and the number of fitted coefficients estimated from the response values. Value closer to 1 indicates a better fit. [Mat13]
4. **Root Mean Squared Error (RMSE):** It is an estimate of the standard deviation of the random component in the data. It measures the quality of the fit between the actual data and the predicted model. A fit is considered useful for prediction if the MSE value is closer to zero. [Mat13]

From the obtained results, some evaluation metrics were selected for modelling. Curve fitting was done for two curves in each evaluation metric, these two curves represent the minimum and maximum curves which is the 64 kb/s and 3840 kb/s bitrates. The best model with respect to the four statistics measures values (SSE, R-Square, Adjusted R-Square and RMSE) was selected to represent a functional description of the evaluation metrics behaviour. The four statistics measures values will be shown for the first evaluation metrics. R-Square and RMSE will be shown only for the rest of the evaluation metrics, in addition the model of one curve in each evaluation metric is also enough to represent the behaviour of all bitrates from (64 kb/s to 3840 kb/s) and mobile node speeds from (5 km/h to 60 km/h). Curve fitting for several evaluation metrics was carried out as follows:

5.1.1 WiFi to UMTS

In this scenario, six evaluation metrics were selected for modelling:

5.1.1.1 WiFi Normalized Throughput

The results of the WiFi Normalized Throughput in WiFi to UMTS scenario were shown in Figure 4-1. The minimum curve (3840 kb/s) and the maximum curve (64 kb/s) were selected for fitting. Figure 5-1 shows the actual data for each bitrate and the curves that fit with these data. The function of the fitted curves was of type exponential as shown in equation (5.1).

$$f(x) = a * e^{(b*x)} + c * e^{(d*x)} \tag{5.1}$$

The coefficients of equation (5.1) for each bitrate and the four statistics measures used to assess the goodness of fit were given by the toolbox in [Mat13] as follows:

Coefficients for 64 kb/s:

$a = -1.296 * 10^{-5}$
$b = 0.1651$
$c = 1.004$
$d = -0.0008415$

Goodness of fit for 64 kb/s:

$R^2 = 0.9997$
$SSE = 1.99 * 10^{-5}$
$Adjusted\ R^2 = 0.9996$
$RMSE = 0.001995$

Coefficients for 3840 kb/s:

$a = -3.465 * 10^{-5}$

$b = 0.1569$

$c = 1.006$

$d = -0.001307$

Goodness of fit for 3840 kb/s:

$SSE = 3.285 * 10^{-5}$

$R^2 = 0.9998$

Adjusted $R^2 = 0.9997$

$RMSE = 0.002563$

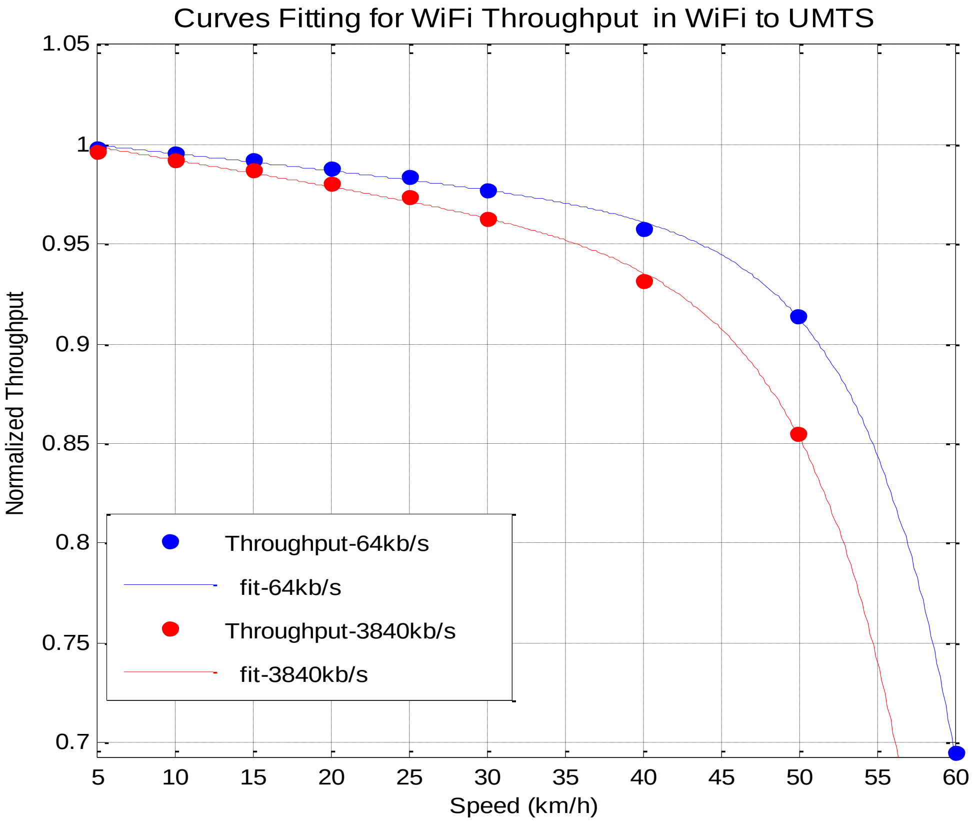

Figure 5-1: Curves Fitting for WiFi Normalized Throughput from WiFi to UMTS.

5.1.1.2 WiFi Throughput Degradation

The obtained results for WiFi Throughput Degradation were shown in Figure 4-3. The curves fitting for the lowest and highest bitrates is shown in Figure 5-2. The function of the fitted curves was of type exponential as shown in equation (5.2).

$$f(x) = a * e^{(b*x)} + c * e^{(d*x)} \tag{5.2}$$

Coefficients for 64 kb/s:

$a = 0.06166$
$b = 0.086$
$c = 1.924 * 10^{-13}$
$d = 0.531$

Goodness of fit for 64 kb/s:

$R^2 = 0.9998$
$RMSE = 0.1294$

Coefficients for 3840 kb/s:

$a = 0.1186$
$b = 0.08057$
$c = 1.518 * 10^{-6}$
$d = 0.2776$

Goodness of fit for 3840 kb/s:

$R^2 = 0.9999$
$RMSE = 0.2027$

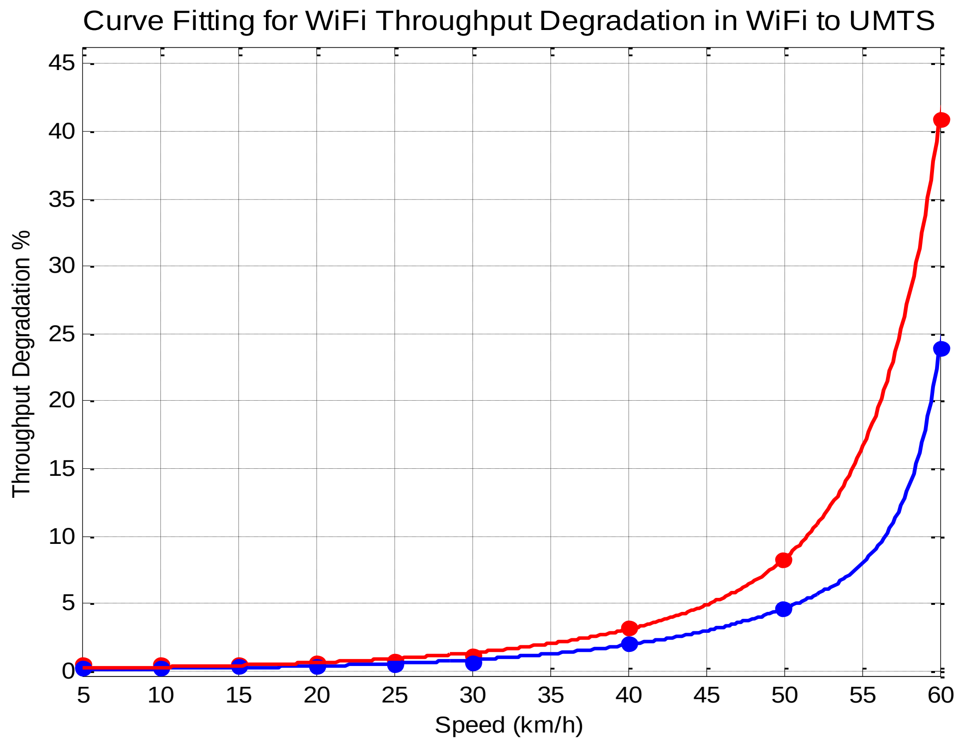

Figure 5-2: Curve Fitting for WiFi Throughput Degradation from WiFi to UMTS.

5.1.1.3 UMTS Normalized Throughput

The results in Figure 4-4 represent the UMTS Normalized Throughput in WiFi to UMTS scenario. As mentioned before, the UMTS throughput is not affected by increasing the mobile node speed but it is highly affected by increasing the application bitrate more than 384 kb/s. To observe the effect of the application bitrate on the UMTS throughput, it was plotted as function of bitrate as shown in Figure 5-3. Curve fitting for Figure 5-3 shows that the throughput in UMTS decreases exponentially when the application bitrate is higher than 384 kb/s as shown in Figure 5-4. The function of the fitted curves was of type exponential as shown in equation (5.3).

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

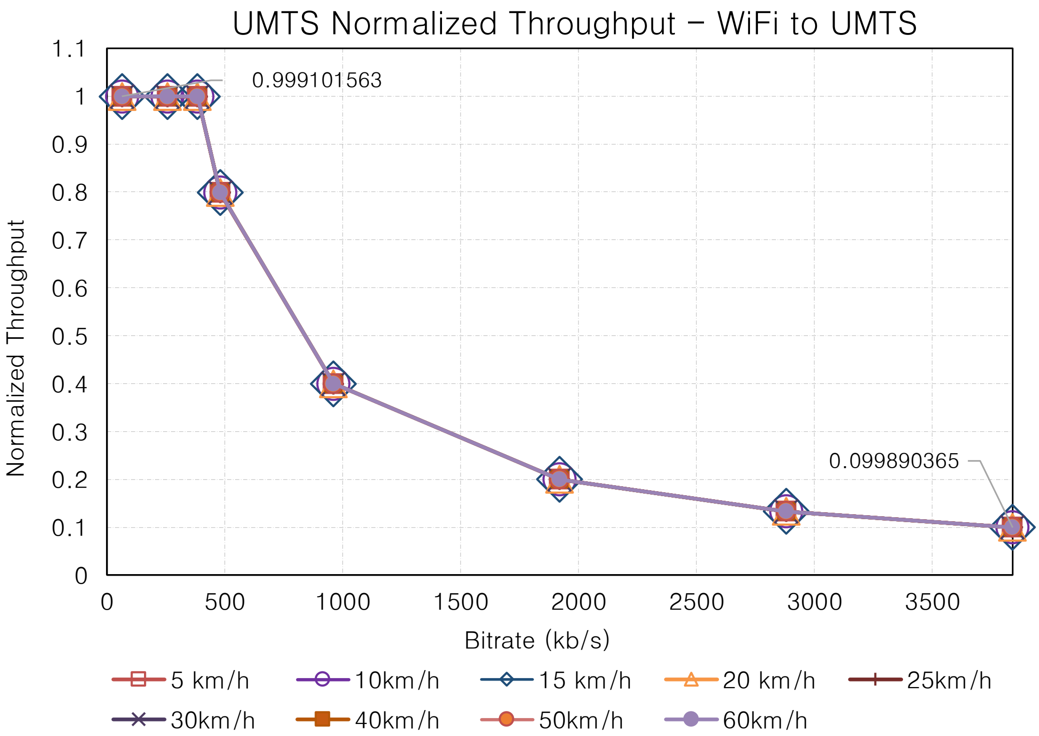

Figure 5-3: UMTS Normalized Throughput as function of Bitrate in WiFi to UMTS.

Coefficients for bitrate more than 384 kb/s:

$a = 2.237$

$b = -0.003405$

$c = 0.4549$

$d = -0.0004168$

Goodness of fit for bitrate more than 384 kb/s:

$R^2 = 0.9995$

$RMSE = 0.01357$

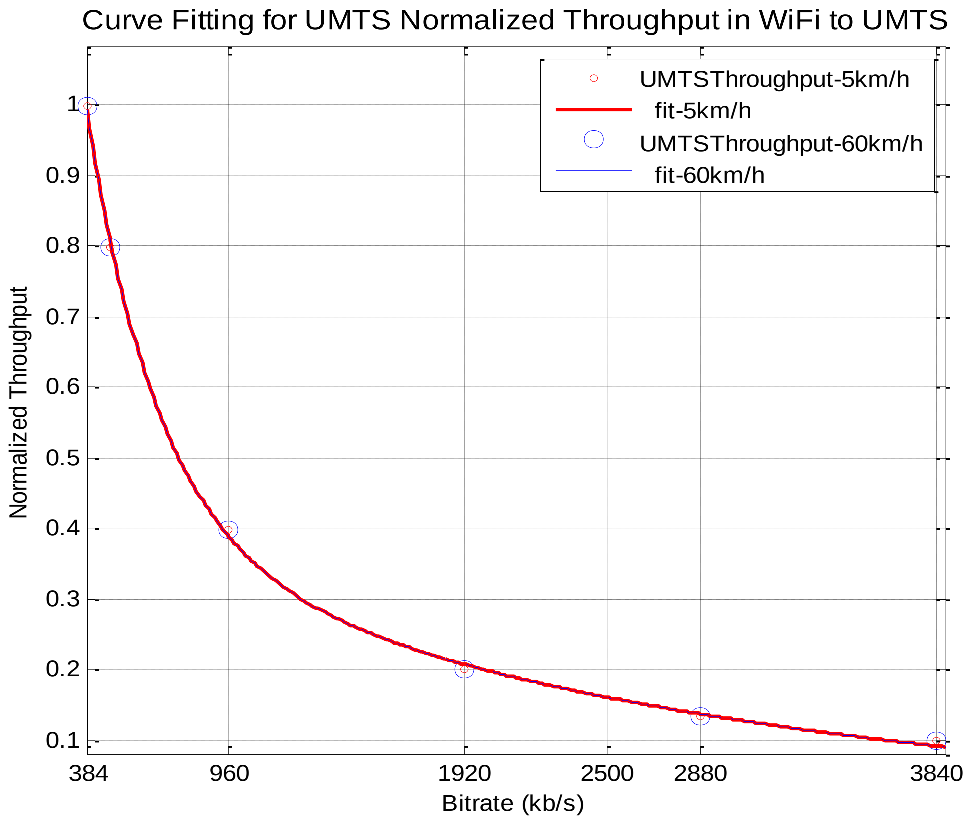

Figure 5-4: Curve Fitting for UMTS Normalized Throughput in WiFi to UMTS.

5.1.1.4 WiFi Packet Loss Ratio

The results of WiFi Packet Loss Ratio were shown in Figure 4-10. The curve fitting for the lowest and highest bitrates resulted in the same model as shown in Figure 5-5. The function of the fitted curves is of type polynomial of degree 4 as shown in equation (5.4).

The coefficients and statistics measures for 64 kb/s only is shown below.

$$f(x) = p1 * x^4 + p2 * x^3 + p3 * x^2 + p4 * x + p5 \quad (5.4)$$

Coefficients for 64 kb/s:

$p1 = \ 2.17 * 10^{-5}$

$p2 = -0.00196$

$p3 = 0.06773$

$p4 = -0.5799$

$p5 = \ 2.826$

Goodness of fit for 64 kb/s:

$R^2 = 0.9997$

$RMSE = 0.5857$

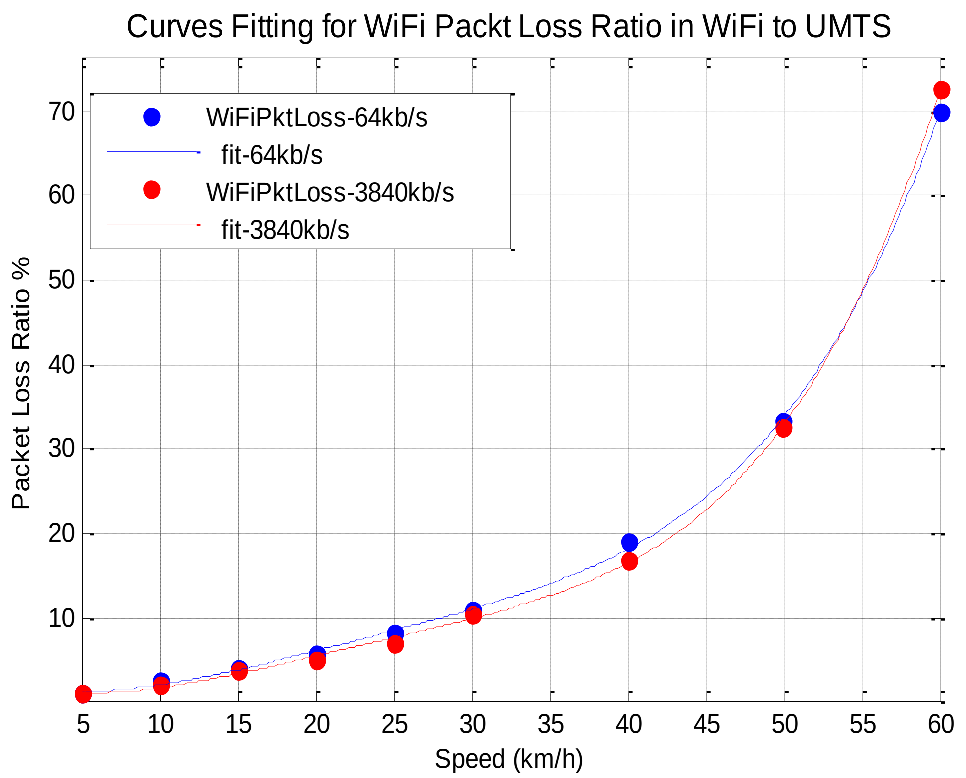

Figure 5-5 : Curve Fitting for WiFi Packet Loss Ratio in WiFi to UMTS.

5.1.1.5 Total Packet Loss Ratio

The results of the Total Packet Loss Ratio from WiFi to UMTS were shown in Figure 4-12. For bitrates less than 384 kb/s, total packet loss ratio is constant and is not affected by mobile node speed. For bitrate higher than 384 kb/s, the curve fitting for 3840 kb/s was shown in Figure 5-6. The function of the fitted curve is of type polynomial of degree 4 as shown in equation (5.5).

$$f(x) = p1 * x^4 + p2 * x^3 + p3 * x^2 + p4 * x + p5 \qquad (5.5)$$

Coefficients for 3840 kb/s:

$p1 = -2.698 * 10^{-7}$
$p2 = 4.117 * 10^{-5}$
$p3 = -0.002242$
$p4 = 0.05265$
$p5 = 0.4161$

Goodness of fit for 3840 kb/s:

$R^2 = 0.9906$
$RMSE = 0.01215$

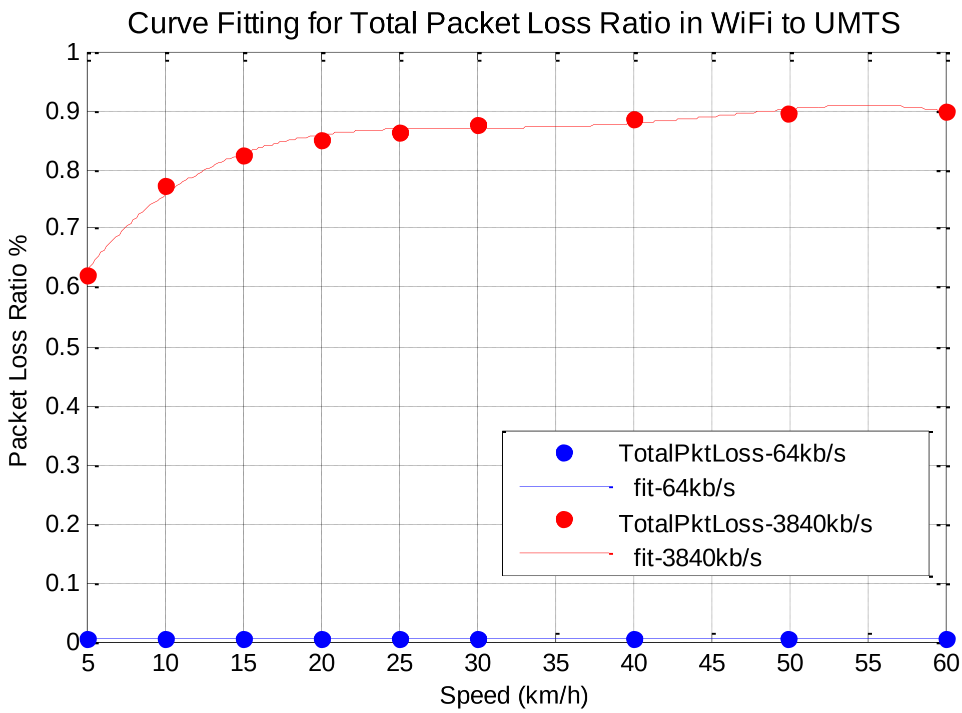

Figure 5-6: Curve Fitting for Total Packet Loss Ratio in WiFi to UMTS.

5.1.1.6 RSS on WiFi interface

Figure 4-23 shows the WiFi RSS on the mobile node WiFi interface while it is approaching the border of the WiFi network. The signal power degrades exponentially while the mobile node is moving far away from the WiFi AP, the function of this degradation is shown in equation (5.6). Figure 5-7 shows the fitting for the curve of Power RSS when the mobile node is moving with speed 5km/h and using application bitrate of 64 kb/s.

$$f(x) = a * e^{(b*x)} + c * e^{(d*x)} \qquad (5.6)$$

Coefficients for bitrate 64 kb/s and speed 5km/h:

$a = 9.697 * 10^{-11}$

$b = -0.07878$

$c = 3.163 * 10^{-10}$

$d = -0.02096$

Goodness of fit for bitrate 64 kb/s and speed 5km/h:

$R^2 = 0.9999$

$RMSE = 2.883 * 10^{-13}$

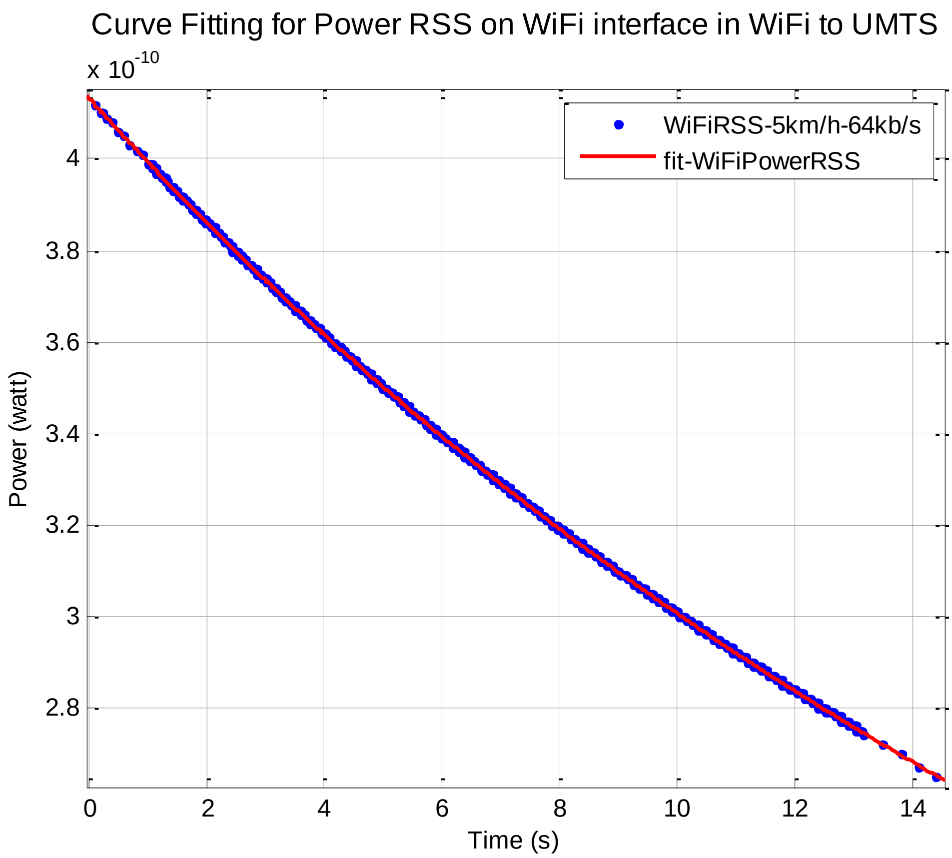

Figure 5-7: Curve Fitting for Power RSS on WiFi interface in WiFi to UMTS.

5.1.2 UMTS to WiFi

In this scenario, four evaluation metrics were selected for modelling:

5.1.2.1 WiFi Normalized Throughput

The obtained results for WiFi Normalized Throughput in UMTS to WiFi scenario were shown in Figure 4-8. The curve fitting for the lowest and highest bitrates is shown in

Figure 5-8. The function of the fitted curves is of type exponential as shown in equation(5.7).

$$f(x) = a * e^{(b*x)} + c * e^{(d*x)} \quad (5.7)$$

Coefficients for 64 kb/s:

$a = 0.9992$
$b = 1.718 * 10^{-6}$
$c = -0.002194$
$d = -0.2592$

Goodness of fit for 64 kb/s:

$R^2 = 0.9976$
$RMSE = 1.357 * 10^{-5}$

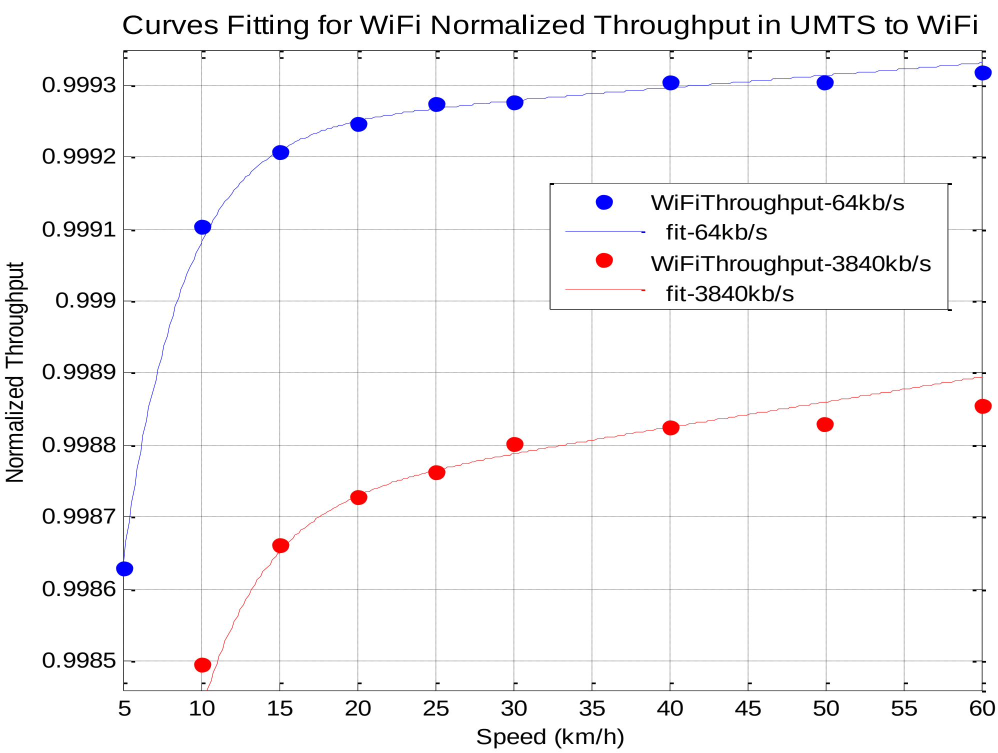

Figure 5-8 : Curve Fitting for WiFi Normalized Throughput in UMTS to WiFi.

5.1.2.2 UMTS Packet Loss Ratio

Figure 4-13 shows the results of the UMTS Packet Loss Ratio in UMTS to WiFi scenario. For bitrate less than 384 kb/s, packet loss ratio in UMTS is null. For bitrates higher than 384 kb/s, we have selected the maximum bitrate of 3840 kb/s for curve fitting and the results were shown in Figure 5-9. The function of the fitted curves is of type polynomial of degree 4 as shown in equation (5.8).

$$f(x) = p1 * x^4 + p2 * x^3 + p3 * x^2 + p4 * x + p5 \qquad (5.8)$$

Coefficients for 3840 kb/s:

$p1 = 1.785 * 10^{-6}$
$p2 = -0.0002336$
$p3 = 0.00579$
$p4 = -0.291$
$p5 = 90.33$

Goodness of fit for 3840 kb/s:

$R^2 = 1$
$RMSE = 0.05611$

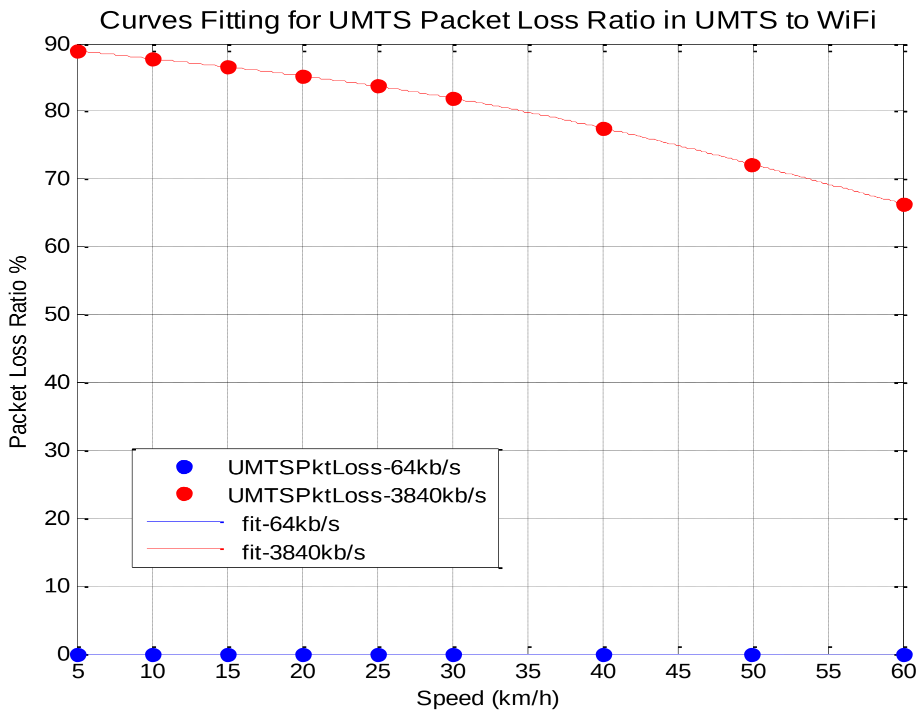

Figure 5-9: Curve Fitting for UMTS Packet Loss Ratio in UMTS to WiFi.

5.1.2.3 WiFi Packet Loss Ratio

WiFi Packet Loss Ratio in UMTS to WiFi scenario was shown in Figure 4-14. The highest and lowest bitrates were selected for curve fitting to model the decrease in the packet loss ratio when the mobile node moves toward the WiFi network. Figure 5-10 shows that the function of the fitted curves is of type exponential as shown in equation(5.9).

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

Coefficients for 3840 kb/s:

$a = 0.4196$
$b = -0.3025$
$c = 0.1189$
$d = -0.002288$

Goodness of fit for 3840 kb/s:

$R^2 = 0.9987$

$RMSE = 0.001508$

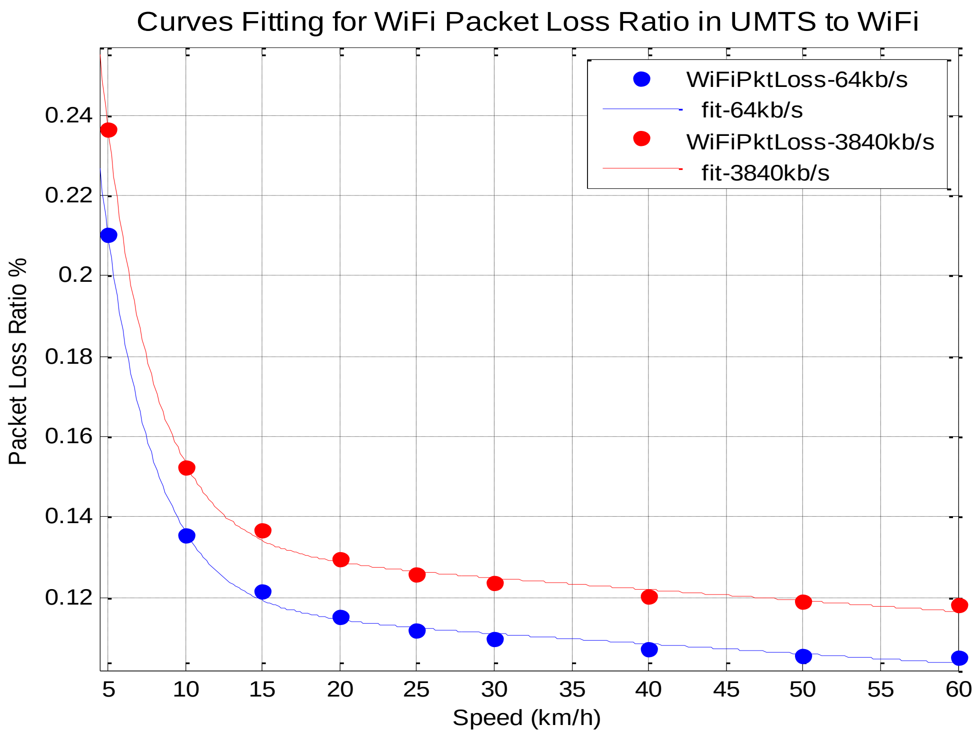

Figure 5-10: Curve Fitting for WiFi Packet Loss Ratio in UMTS to WiFi.

5.1.2.4 Total Packet Loss Ratio

Figure 4-15 shows the results of the total packet loss ratio in UMTS to WiFi scenario. For bitrates less than 384 kb/s, total packet loss ratio is constant and not affected by the mobile node speed. For bitrates higher than 384 kb/s, the packet loss ratio decreases as shown in Figure 5-11. The fitting of the 3840 kb/s curve shown in Figure 5-11 is represented by the exponential function shown in equation (5.10).

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

Coefficients for 3840 kb/s:

$a = 105.3$

$b = -0.2706$

$c = 23.38$

$d = -0.04752$

Goodness of fit for 3840 kb/s:

$R^2 = 0.9999$

$RMSE = 0.2041$

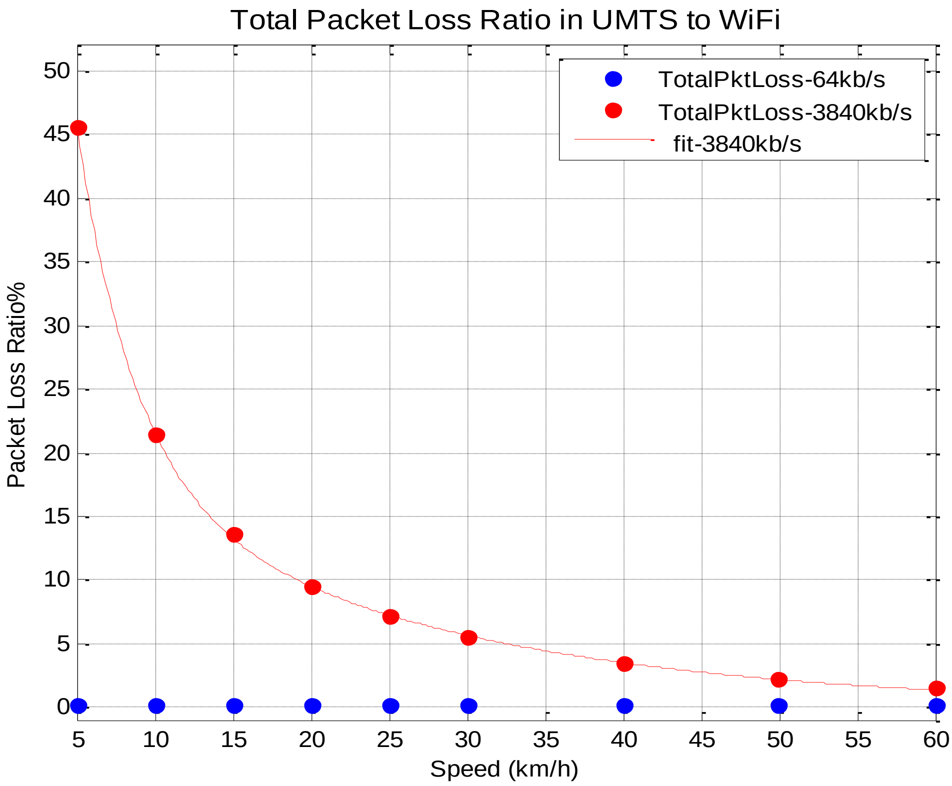

Figure 5-11: Curve Fitting for Total Packet Loss Ratio in UMTS to WiFi.

In order to summarize the modelling of the results, Table 5-1 and Table 5-2 present the fitting equations for the evaluation metrics with statistics measures to assess the goodness of fit in both directions, WiFi to UMTS and vice versa.

Table 5-1: Summary of Curve Fitting for five performance metrics in WiFi to UMTS scenario.

Direction of Mobility	Evaluation Metric		Fitting Equation
WiFi to UMTS	**Throughput**	WiFi Normalized Throughput	$\boldsymbol{f(x) = a * e^{(b*x)} + c * e^{(d*x)}}$ **Goodness of Fit for 64 kb/s:** $SSE = 1.99 * 10^{-5}$ $R^2 = 0.9997$ $Adjusted\ R^2 = 0.9996$ $RMSE = 0.001995$
		WiFi Throughput Degradation	$\boldsymbol{f(x) = a * e^{(b*x)} + c * e^{(d*x)}}$ **Goodness of Fit for 3840 kb/s:** $R^2 = 0.9999$ $RMSE = 0.1294$
		UMTS Normalized Throughput	$\boldsymbol{f(x) = a * e^{(b*x)} + c * e^{(d*x)}}$ **Goodness of Fit for bitrate > 384kb/s:** $R^2 = 0.9995$ $RMSE = 0.01357$
	Packet Loss	WiFi Packet Loss Ratio	$\boldsymbol{f(x) = p1 * x^4 + p2 * x^3 + p3 * x^2 + p4 * x + p5}$ **Goodness of Fit for 64 kb/s:** $R^2 = 0.9997$ $RMSE = 0.5857$
		Total Packet Loss	$\boldsymbol{f(x) = p1 * x^4 + p2 * x^3 + p3 * x^2 + p4 * x + p5}$ **Goodness of Fit for bitrate > 384kb/s:** $R^2 = 0.9906$ $RMSE = 0.01215$
	Power RSS	RSS on WiFi interface	$\boldsymbol{f(x) = a * e^{(b*x)} + c * e^{(d*x)}}$ **Goodness of Fit for 64 kb/s and 5 km/h:** $R^2 = 0.9999$ $RMSE = 2.883 * 10^{-13}$

Table 5-2: Summary of Curve Fitting for four performance metrics in UMTS to WiFi scenario.

Direction of Mobility	**Evaluation Metric**		**Fitting Equation**
UMTS to WiFi	**Throughput**	WiFi Normalized Throughput	$\boldsymbol{f(x) = a * e^{(b*x)} + c * e^{(d*x)}}$ **Goodness of Fit for 64 kb/s::** $R^2 = 0.9976$ $RMSE = 1.357 * 10^{-5}$
	Packet Loss	UMTS Packet Loss Ratio	$\boldsymbol{f(x) = p1 * x^4 + p2 * x^3 + p3 * x^2 + p4 * x + p5}$ **Goodness of Fit for bitrate > 384kb/s:** $R^2 = 1$ $RMSE = 0.05611$
		WiFi Packet Loss	$\boldsymbol{f(x) = a * e^{(b*x)} + c * e^{(d*x)}}$ **Goodness of Fit for 3840 kb/s:** $R^2 = 0.9987$ $RMSE = 0.001508$
		Total Packet Loss Ratio	$\boldsymbol{f(x) = a * e^{(b*x)} + c * e^{(d*x)}}$ **Goodness of Fit for bitrate > 384kb/s:** $R^2 = 0.9999$ $RMSE = 0.2041$

5.2 Results Comparison with ITU-T and IEEE802.20 Recommendations

In this research, the mobile node speed is considered as increasing when the values of mobile speed varies between 5 km/h and 60 km/h which is the lowest and highest values of speed respectively. The applications bitrate used varies between 64 kb/s and 3840 kb/s. The applications bitrate less than 384 kb/s are namely 64 kb/s, 256 kb/s while the bitrate values more than 384 kb/s are 480 kb/s, 960 kb/s 1920 kb/s, 2880 kb/s and 3840 kb/s.

The value of bitrate 384 kb/s represents the UMTS bandwidth. It is considered as important because the obtained results of some metrics were affected by increasing or decreasing the bitrate of the application above or below this value as well.

In order to evaluate the performance of the applications that are represented in the range of bitrates used in this research, the ITU-T and the IEEE802.20 working group recommendations are used as a reference to compare the obtained results and insure that the evaluation metrics are acceptable with respect to QoS and fulfill QoS requirements. The ITU-T defines recommendations regarding performance for the IP-based services whereas IEEE802.20 standard is the first IEEE standard that addressed of the mobile clients in vehicular mobility [Leh08].

In this research the obtained results for packet loss ratio, delay and handover latency in the vertical handover scenarios are compared to the ITU-T recommendations defined in Y.1541 [Itu11] and IEEE802.20 standard defined in [IEEE20]. Table 5-3 shows the acceptable E2E delay, Latency and packet loss values recommended by ITU-T and the obtained values of these evaluation metrics in this study. This will show how the proposed scenarios in this thesis are close to reality and to what extent they fulfil the QoS requirements.

Table 5-3 : Obtained results compared to ITU-T recommendations for different traffic types. [Mar10][Itu11].

Evaluation Metric	Application	Acceptable values recommended by ITU-T	Obtained Results
E2E one way Delay	Voice	150 ~ 200 ms	46 ~ 50 ms delay in WiFi for bitrates 64 ~ 3840 kb/s in both scenarios 54 ms delay in UMTS for bitrates 64 ~ 384 kb/s in both scenarios. 1 s delay in UMTS for bitrates > 384 kb/s 11 ms latency when handover to WiFi 144 ~ 168 ms latency when handover to UMTS
	Video	< 280 ms	
Total Packet Loss Ratio	Voice	< 2%	0.4% packet loss for bitrates < 384 kb/s when handover to UMTS No packet loss for bitrate < 384 kb/s when handover to WiFi Packet loss > 10% for bitrates > 384 kb/s in both directions
	Video	< 1%	

Table 5-4 summarizes the behaviour of the performance evaluation metrics under the effect of the mobile node speed, application bitrate and direction of mobility in both scenarios. The results are considered as acceptable, if the obtained value is within the range specified by the ITU-T standard shown in Table 5-3 regarding voice and video applications. The values that were not acceptable according to ITU-T recommendations will highly affect the performance of the applications, therefore the range of bitrate that covers these applications will not work in the vertical handover scenarios. The result of the unacceptable values occurred because they were affected by some factors such as low bandwidth in UMTS, low mobility in WiFi and the handover process which will affect the evaluation metrics as shown in Table 5-4.

Table 5-4: Summary of the evaluation metrics behavior and the obtained results values.

Scenario / **Metric**	**WiFi to UMTS**		**UMTS to WiFi**	
	WiFi	UMTS	UMTS	WiFi
Throughput	Exponentially Decreases with the increase of speed.	Not affected by increasing speed and bitrate for bitrate < 384 kb/s. Exponentially Decrease for bitrate > 384 kb/s.	Not affected by increasing speed and bitrate for bitrate < 384 kb/s. Exponentially Decrease for bitrate > 384 kb/s.	Exponentially Increases with increasing speed.
	Acceptable values for speed < 50 km/h	Acceptable values for bitrate < 384 kb/s	Acceptable values for bitrate < 384 kb/s	Acceptable values for all speeds and bitrates.
Data Received	Decreases with increasing speeds. Increase with increasing bitrate	Slightly Increases with increasing speed. Increase for bitrate < 384 kb/s Constant for bitrate > 384 b/s	Decreases with increasing speed. Constant for bitrate >384 kb/s.	Increases with increasing speed and bitrate
Total Packet Loss Ratio	Polynomially increases with increasing speed for bitrate > 384 kb/s Almost constant with increasing speed for bitrate < 384 kb/s		Exponentially Decrease with increasing speed for bitrate > 384 kb/s Not affected by speed for bitrate < 384 kb/s	
	Acceptable values only for bitrate < 384 kb/s		Acceptable values only for bitrate < 384 kb/s	
Average E2E Delay	Slightly increases with increasing bitrate. Not affected by speed.	Exponentially increase for bitrates > 384 kb/s Not affected by speed.	Exponentially increase for bitrates > 384 kb/s Not affected by speed.	Slightly increases with increasing bitrate. Not affected by speed.
	Acceptable values for all bitrates.	Acceptable value for bitrate < 384 kb/s Very high value for bitrate > 384 kb/s	Acceptable value for bitrate < 384 kb/s. Very high value for bitrate > 384 kb/s.	Acceptable values for all bitrates.
Handover Latency	Slightly affect with increasing bitrate. Not affected by increasing speed. Affected by the direction of mobility.		Not affected by increasing speed. Affected by the direction of mobility.	
	Acceptable values from 142 ms to 167 ms when handover to UMTS		Acceptable values only for bitrate < 384 kb/s. around 11 ms when handover to WiFi	

5.3 Results Discussion:

In this section, we will compare the results in total packet loss ratio and handover latency with other results proposed in the literature. In addition, the methodology used in this research will be compared. The research in [Rah13] and [Mar10] was selected from the literature because it addressed some of the metrics studied in this research. In addition, the methodology in simulating vertical handover scenarios used in these papers are the same methodology used in this research. Although these papers addressed the vertical handover between WiFi and WiMAX networks, we can still compare the results in this thesis to the results in their work to evaluate the performance in vertical handover scenarios between UMTS and WiFi using MIH standard and NIST mobility package in NS-2. The research in [Ast13] was selected because it proposed a vertical handover solution based on the open source implementation of the MIH standard (ODTONE) using real testbed for vertical handover scenarios. Therefore, the results in this research are compared to [Ast13] that proposed different methodology for vertical handover using MIH standard. The research in [So08] addressed the integration between WiFi and CDMA networks without using MIH standard. Results in handover latency will be compared to the results in [So08]. The research area of vertical handover addressed in the related works and compared to the one addressed in this research was shown in Figure 5-12.

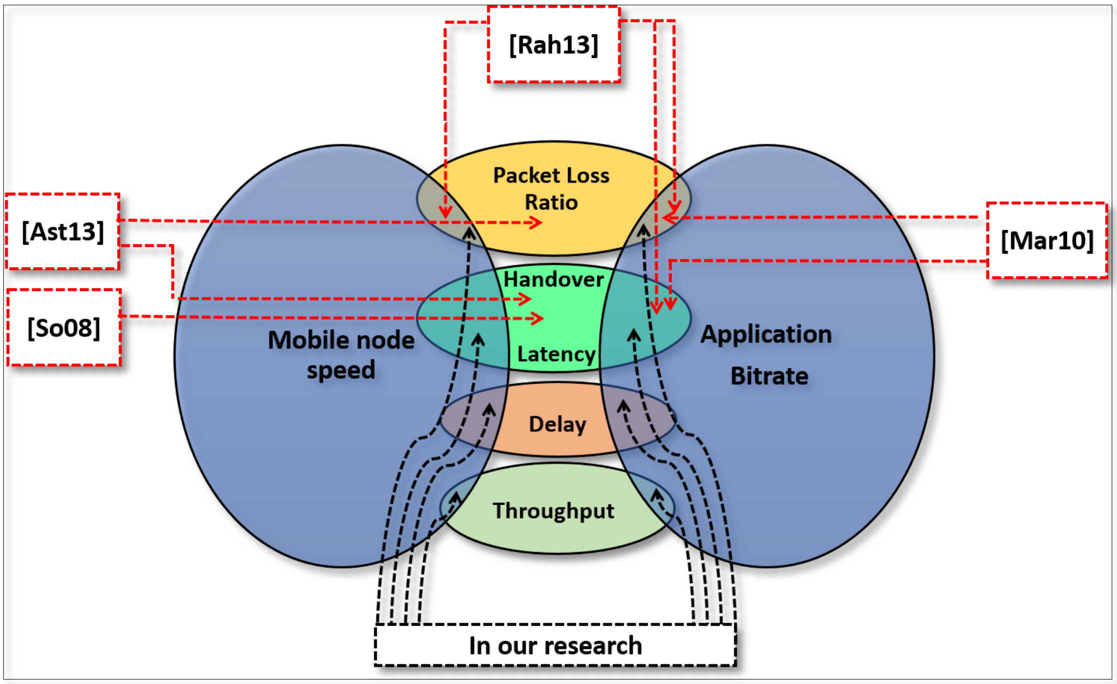

Figure 5-12 : Research area of the related works compared with the one in this research.

The obtained results in this research are related to other results proposed in the literature as shown in Table 5-5 and discussed as follows:

5.3.1 Total Packet Loss Ratio

Total packet loss ratio is considered high when its value is more than 2% for voice and 1% for video, these are the maximum acceptable packet loss values recommended by the ITU-T which are shown in Table 5-3.

In WiFi to UMTS scenario, the results of the total packet loss ratio are depicted in Figure 4-12 and Figure 5-6 and were affected as follows:

a) Polynomially increases with increasing mobile node speed for bitrates higher than the UMTS bandwidth (384 kb/s). This occurs because of the handover process and the bandwidth of the candidate network (UMTS) is insufficient for the application bitrate more than 384 kb/s and resulted in high packet loss; from 14% to 89% for bitrate 480 kb/s to 3840 kb/s respectively using speeds from 5 km/h to 60 km/h.

The results in (a) agree with results in [Rah13] and [Mar10]. The research in [Rah13] studied the impact of mobile node speed and concluded that packet loss ratio increases when the mobile node is leaving the WiFi network with high speed. In [Mar10] the research does not study the impact of the mobile node speed but it concludes that packets are lost mainly due to handover operation and the insufficient bandwidth of the access network. However, the functional description proposed in this research that shows a polynomially increase for packet loss ratio as function of mobile node speed was not addressed by [Rah13] and [Mar10].

b) Total packet loss ratio is not affected by increasing the mobile node speed from 5 km/h to 60 km/h and application bitrate when it is less than 384 kb/s. Packet loss ratio is 0.46% for application with bitrate less than 384 kb/s and for speed with range from 5 km/h to 60 km/h. These packets were lost because of the vertical handover latency when handover to UMTS network.

The results in (b) agree with the results in [Ast13] and disagree with [Rah13]. The vertical handover scenario in [Ast13] includes a car moving with speed between 30 – 40 km/h with a mobile node inside that has WiFi and WiMAX interfaces. The application bitrate used in [Ast13] is 265 kb/s and represent a video conference traffic using Skype application. The packet loss ratio measured in [Ast13] is less than 0.60% which is close to the obtained results in(b). The author in [Rah13] claimed that the RSS based algorithm in NS-2 failed to fulfil users' mobility and is limited to pedestrian mobility with speed 1m/s which disagree with results in (b).

In UMTS to WiFi scenario, the results of the total packet loss ratio are depicted in Figure 4-15 and Figure 5-11 and were affected as follows:

c) High packet loss ratio varies between 5% and 45.6% at low speeds (5 km/h to 10 km/h) for bitrate higher than 384 kb/s because of the UMTS insufficient bandwidth that will limit the received data on UMTS interface for bitrate more than 384 kb/s.

d) Packet loss ratio exponentially decreases with increasing mobile node speed from 45.6% at speed 5 km/h to 1.5% at speed 60 km/h for the highest bitrate (3840 kb/s). The faster the mobile node moves to a higher bandwidth network the lower the packet loss ratio measured.

Results in (c) agree with [Mar10] while results in (c) and (d) disagree with [Rah13]. In [Mar10] the researcher conclude that one of the factors that causes the packet loss ratio is the insufficient bandwidth of the access network which agrees with results in (c).

In [Rah13] the WiFi and WiMAX networks both have high bandwidth and therefore the results show only that the packet loss ratio increases with increasing mobile node speed while the mobile node is leaving the WiFi network. But in this research, the faster the mobile node leaves the UMTS network the lower packet loss ratio occurs (results in (c) and (d)) which disagree with [Rah13] because the UMTS network was not studied by [Rah13]. Functional description for total packet loss ratio as function of speed was not presented in [Mar10] and [Rah13].

e) Total packet loss ratio is 0.10% for application bitrate less than 384 kb/s and for speed values from 5 km/h to 60 km/h.

Results in (e) agree with [Ast13] and [Mar10] and disagree with [Rah13]. In [Ast13] packet loss ratio is less than 0.60% for bitrate 265 kb/s and speed from 30 – 40 km/h. In [Mar10], the packet loss ratio is less than 2% when the number of mobile nodes is less than 20 and the mobile node speed is 50 km/h.

The obtained results in (e) disagree with [Rah13] because the range of speeds used in this research is from 5 km/h to 60 km/h and packet loss ratio values were acceptable for bitrates less than 384 kb/s which contradicts with the claim in [Rah13] that the algorithm in NS-2 is suitable only for pedestrian speed (1 km/h).

f) Packet loss ratio in UMTS is null for applications bitrate less than 384 kb/s and mobile speed from 5 km/h to 60 km/h. This result is depicted in Figure 4-13.

Results in (f) agree with the results in [Rah13] that show null packet loss ratio in WiMAX because it supports high speed mobility users as the researcher in [Rah13] claimed.

5.3.2 Handover Latency

The handover latency in this research is based on the handover latency defined by [Rah13]. It is the time difference between the first packet delivered at the mobile node interface of the candidate network after handover and the last packet delivered at the interface of the serving network before handover. The handover latency is affected mainly by the type of candidate network and its procedure in establishing a connection. The value of the handover latency is considered as acceptable if it is less than 200 ms for voice application and less than 280 ms for video applications. The handover latency results in this research were compared to other results proposed in the literature as follows:

In WiFi to UMTS scenario, the results of the handover latency are depicted in Figure 4-21 and were affected as follows:

- **g)** Handover latency values when traffic is redirected to the UMTS network varies between 144 ms and 160 ms when using application bitrate from 64 kb/s to 3840 kb/s and mobile node speeds from 5 km/h to 60 km/h.

- **h)** Handover latency in WiFi to UMTS scenario is not affected by mobile node speed and slightly decreases with increasing the application bitrate more than 384 kb/s.

The results in (g) disagree with the results in [So08]. Handover latency to CDMA network varies between 270 ms and 350 ms. The difference in results is justified by the enhancement of the MIH standard in vertical handover process that was not considered in the implementation of [So08]. The results in (g) and (h) were not shown in [Mar10] and [Rah13] because the UMTS network was not addressed by their research.

In UMTS to WiFi scenario, the results of the handover latency are depicted in Figure 4-22 and were affected as follows:

i) Handover latency values when traffic is redirected to the WiFi network is around 11 ms when using application bitrate less than 384 kb/s and mobile node speeds from 5 km/h to 60 km/h.

j) Handover latency in UMTS to WiFi scenario is not affected by mobile node speed and application bitrate when the bitrate value is within the bandwidth of the UMTS network.

The results in (i) and (j) agree with [Mar10] and disagree with [Rah13]. The research in [Mar10] concludes that handover to WiFi took approximately 5 ms and is not affected by application bitrate when the number of mobile node is less than 20. The research in [Rah13] concludes that handover latency when connecting to WiFi decreases with increasing application bitrate. The values vary between 100 ms and 10 ms for bitrates from 120 kb/s to 1000 kb/s respectively. The research in [Ast13] did not study the range of bitrates, only one application bitrate of 256 kb/s was used, in addition the effect of the mobile node speed was mentioned in the future work of [Ast13].

k) Handover to WiFi needs less time than handover to UMTS.

Results in (k) agree with results in [Rah13], [Mar10] and [So08]. The researchers in [Rah13] and [Mar10] concluded that handover to WiFi took less time than handover to WiMAX. In [So08] the researchers concluded that handover to WiFi took less time than handover to CDMA. This behaviour is justified by the WiMAX and UMTS signal availability while the mobile node is moving inside the UMTS and the WiMAX networks (no degradation in the signal), therefore the connection to WiFi network will take place immediately when its signal is detected.

5.4 Summary

In this Chapter 5, the modelling for some evaluation metrics were presented. Curve fitting was done using Curve Fitting Toolbox in MATLAB. The functions of the fitted curves were shown with their coefficients. Four statistics measures were calculated to assess the goodness of fit; R-Square, RMSE, Adjusted R-Square and SSE. In the results discussion section we have mentioned the values from the obtained results in this research and compared them to the ITU-T recommendations to check if the values of the evaluation metrics are acceptable and fulfil the QoS requirements of the applications. In the results discussion section, we have summarized the results in this research and compared it to the results in the related works as shown in Table 5-5. We noticed that some of the obtained results agreed while others disagreed with the results proposed in the literature of the vertical handover. In Chapter 6, we will conclude the work in this thesis and suggest future work and recommendations within the same research area.

Table 5-5 : Results compared to the related works in the literature.

	WiFi to UMTS		**UMTS to WiFi**			
Result	**a**	**b**	**c**	**d**	**e**	**f**
Packet Loss Ratio	Agreed with [Rah13] and [Mar10]	Agreed with [Ast13] Disagrees with [Rah13]	Agreed with [Mar10] Disagrees with [Rah13]	Disagreed with [Rah13]	Agreed with [Ast13] and [Mar10] Disagrees with [Rah13]	Agreed with [Rah13]
Result	**g**	**h**	**i**	**j**	**K**	
Handover Latency	Disagreed with [So08]	Not addressed by related works	Agreed with [Mar10] Disagreed with [Rah13]		Agreed with [Rah13] [Mar10] and [So08]	

Chapter 6
Conclusions and Future Work

6.1 Conclusions

The integration between wireless heterogeneous networks are becoming an emerging issue. Recently, smart mobile phones have high computing capabilities and therefore the demand on seamless mobility with achieving QoS requirements has increased. Modern applications are developed to provide high quality service to mobile users, some of them are QoS aware applications such as voice and video services. Furthermore QoS requirements depends on the usability of the applications; acceptable values for QoS metrics were defined by ITU-T taking into consideration the quality of the applications. To fulfil the QoS requirements and ensure that mobile users have high mobility, wireless access technologies and their implemented interfaces on the mobiles must be highly utilized. WiFi and UMTS are the most widely implemented interfaces in the smart mobile phones, these interfaces suffer the lack of interworking mechanisms, and therefore the integration between UMTS and WiFi networks and interfaces will provide high mobility to users and fulfil most of the computing aspects. Vertical handover is considered as one of the main challenges in this integration. This challenge is addressed by the MIH standard that provides interworking mechanisms between link layer technologies and enhance the vertical handover process.

A key issue that is addressed in this thesis is to study the important factors that affect the performance during the vertical handover process using RSS based algorithm implemented in NS-2. Range of mobile node speeds are considered to evaluate user mobility. Various ranges of application bitrates were used to evaluate QoS metrics.

Wireless access technologies have some features such as high bandwidth supported by WiFi and high mobility in UMTS, they also have some constrains such as low coverage area of WiFi and low bandwidth of UMTS. These features highly affect the QoS and users mobility in addition to the vertical handover challenges faced in the WiFi – UMTS integration.

In order to study the above factors, two mobility scenarios were implemented using MIH module implemented in NS-2. Table 5.1 and Table 5.2 shows a functional description for some evaluation metrics in WiFi to UMTS and in UMTS to WiFi respectively.

Table 5-3 shows the values recommended by the ITU-T and compare it to the obtained results in this research. Table 5.4 summarizes the observations of the performance metrics and how they are affected by some factors showing this effect in WiFi to UMTS and UMTS to WiFi.

Regarding Throughput, it is highly affected by the access networks features. In WiFi to UMTS scenario, the throughput in WiFi exponentially decreases with increasing mobile node speed, limiting the mobile node speed to (50 km/h) in the handover area as a result of the WiFi limited coverage area and signal power degradation on the WiFi boundaries. In UMTS, and for bitrate more than 384 kb/s the throughput exponentially decreases as function of application bitrate regardless of the direction of mobility because of the UMTS limited bandwidth. In UMTS and for bitrate less than 384 kb/s, the throughput is not affected by speed and bitrate in both scenarios because of its high coverage area and signal power availability. It is concluded from the analysis that throughput sensitive applications will be affected by mobile node speed and application bitrate in WiFi to UMTS scenario; the difference in behaviour in WiFi and UMTS networks is related to the limited coverage area in WiFi and limited bandwidth of UMTS. Small WiFi coverage area limits the mobile node speed in the handover area to 50 km/h. Limited UMTS bandwidth adds some constrains on the application with bitrate higher than 384 kb/s. These applications will have maximum throughput of 384kb/s, but when using application bitrate higher than 384 kb/s, for example 3840 kb/s the throughput value will be 50% of the application bitrate at speeds higher than 50 km/h. In UMTS to WiFi scenario, there are no limitations on the mobile node speeds in the handover area. In addition, when using application bitrate higher than 384 kb/s, throughput degradation occurs in UMTS as a result of UMTS limited bandwidth.

Regarding total packet loss ratio, for bitrate less than 384 kb/s, packet loss is null when handover to WiFi and (0.4%) when handover to UMTS. For bitrate more than 384 kb/s, packet loss ratio polynomially increases as function of speed when handover to UMTS and exponentially decreases when handover to WiFi, therefore the measured values were more than (10%) in both directions which are unacceptable. On the contrary, packet loss ratio for bitrate less than 384 kb/s is acceptable in both scenarios according to the ITU-T recommendations. It is worth mentioning that these values present competitive results compared to the latest results of vertical handover proposed in the literature. Total packet loss ratio in WiFi to UMTS scenario polynomially increases with increasing mobile node speed. It was also observed that the packet loss ratio increases with increasing the application bitrate when it is more than 384 kb/s. Application bitrate must be kept under 384 kb/s in order to obtain acceptable results and meet the ITU-T recommendations shown in Table 5.3. In UMTS to WiFi scenario, packet loss occurs on low speeds in UMTS, the faster the mobile node leaves UMTS network, the lower packet loss occurs. Observing the obtained results in the proposed scenarios, ITU-T recommendations could be achieved for voice and video using bitrate lower than 384 kb/s. Applications with bitrate higher than 384 kb/s will suffer from packet loss that will lead to unacceptable quality.

Results of the E2E Delay show that it is not affected by the mobile node speed. In both scenarios, the delay value in WiFi varies between 46 ms to 50 ms for all the range of application bitrate and mobile node speed. In UMTS, for bitrate less than 384 kb/s, delay is (54 ms) in both scenarios. For bitrate more than 384 kb/s, delay exponentially increased as function of application bitrate. Delay value of (1 s) was measured which is unacceptable, whereas the obtained delay values in UMTS for bitrate less than 384 kb/s and in WiFi regardless of speed and bitrate are acceptable for voice and video according to the ITU-T recommendations. In WiFi to UMTS scenario, delay sensitive applications have no constrains in WiFi network. Acceptable delay values according to ITU-T were measured for all values of bitrate, it is also noticed that the mobile node speed does not affect the E2E delay in WiFi. In UMTS to WiFi scenario, application bitrate lower than 384 kb/s is recommended to work in UMTS network. In WiFi, delay slightly increases with increasing bitrate. To fulfil QoS requirements, delay sensitive applications must operate with bitrates under 384 kb/s in UMTS network in both scenarios.

In general, the obtained results are acceptable regarding E2E delay when using application bitrate lower than 384 kb/s and fulfil the QoS requirements tabulated in Table 5-3.

Handover latency occurred once in each scenario and no packets will be received during this time interval, therefore this latency was addressed. Results show that handover to WiFi (11 ms) takes less time than handover to UMTS (144 ms to 168 ms). In WiFi to UMTS scenario, handover latency slightly increases for bitrates less than 384 kb/s and is not affected by speed. In UMTS to WiFi scenario, only applications less than 384 kb/s are considered to work based on the obtained results in other metrics such as E2E delay and packet loss. After studying handover latency, we noticed that in UMTS to WiFi scenario and for bitrate less than 384 kb/s; the low handover latency value when establishing connection to WiFi, justifies the null packet loss measured in UMTS and low packet loss measured in WiFi (10%). Moreover, in WiFi to UMTS scenario, the higher packet loss ratio in UMTS (0.46%) is justified by the higher handover latency value to establish connection to UMTS. However, the obtained handover latency values are acceptable for voice and video in both scenarios according to ITU-T recommendations and competitive to other latest researches proposed in the literature.

Handover latency in WiFi to UMTS networks is higher than the values measured in UMTS to WiFi scenario. Mobile node speed does not affect the handover latency, it is affected by the direction of mobility depending on the type of the access network. Results show that handover to WiFi takes less time than handover to UMTS. According to ITU-T recommendations, the acceptable delay for voice packet is less than 200 ms. For video the acceptable delay is less than 280 ms. It is concluded that handover to UMTS network needs more time than handover to WiFi, this is related to the technology implementation and not affected by mobile node speed or application bitrates. However, the obtained handover latency values were acceptable in term of QoS requirements shown in Table 5-3

To achieve service continuity and fulfil QoS requirements the challenges faced when using application bitrate higher than 384 kb/s can be solved using variable bitrates encoders. The media servers can be configured with multiple profiles, each profile serves the users with different encoding bitrate, this technique is used to sense the bandwidth of the users' access network and serve them with bitrate lower than 384 kb/s when the mobile node moves in UMTS network.

Comprehensive analysis shows the impact of the application bitrate and the WiFi coverage area limitation on the obtained results that were presented in the evaluation metrics used. The results showed performance trade-offs; on the one hand WiFi is considered as preferred candidate network in terms of cost and bandwidth in the implemented algorithm in NS-2, but on the other hand UMTS is better than WiFi in terms of user's mobility since it has larger coverage area than WiFi networks. The impacts of moving between WiFi and UMTS networks are explained in details in this work. In addition, the important factors that affect the handover process were studied as well.

6.2 Future Work and Recommendations

Although MIH standard supports interworking mechanisms for vertical handover, it lacks of some features that are out of scope of the standard. MIH standard supports only static information server. Implementation of dynamic information server from networks entity could improve the vertical handover decision procedure [Ped11]. Security authentication and decision algorithms implementation are also left to the designers and out of the MIH scope [IEEE09].

It is important to address the multi criteria decision algorithms in vertical handover because the obtained results in this research showed that in addition to the RSS tradition criterion that is used in horizontal and vertical handover, the information about the mobile node speed and application bitrate will enhance the handover process and help improve the QoS. There are other important criteria that may be used, such as network cost, user preferences and power consumption. In order to consider these criteria in the vertical handover process, multi criteria decision algorithm is needed in the handover decision stage. It is also necessary to determine the information gathering technique that will be used to collect parameters about these criteria from the wireless access networks and present them to the decision algorithm. In the execution stage, several methods have been proposed in the literature to enhance the MIP protocol by reducing signalling overhead and enhance the security authentication protocols.

To handle the challenges mentioned above, special research and implementation environment are needed in order to test, evaluate and ensure the integrity of the proposed algorithms and methods in vertical handover. The performance and integrity of the vertical handover stages are important to ensure service continuity and high mobility. NS-2 is the most widely used simulator in the literature to propose vertical handover scenarios that use MIH standard because it has add-on modules for the wireless access networks and MIH standard, however it lacks of multi criteria decision algorithm and information server. In addition to the basic knowledge in NS-2, there are some challenges in modifying the modules that are related to vertical handover in NS-2, these challenges are presented in knowing the data structure of these modules such as NIST mobility package, WiFi and UMTS add-on modules in NS-2, in addition the parameters that are related to the multi criteria decision algorithm such as cost and user preferences should be available and acquired from the mobile node in the best possible way.

The real implementation of vertical handover scenarios faces some difficulties; the wireless access point in WiFi and UMTS do not support all the services of the MIH standard. Some primitives of MIH were added to the IEEE802.211u access points [IEEE11], but the availability to modify on the protocol stack of these units is limited for researchers, in addition, the smart phones network drivers were installed and updated by the manufacturers, therefore the real implementation that is related to the vertical handover and MIH standard is subject to the development of the wireless access technologies manufacturers.

Testbeds were also used rather than simulators to evaluate the vertical handover scenarios and trying to be closer to real mobility scenarios. As future work, it is recommend that the proposed scenarios in this thesis to be implemented using ODTONE [Cor11]. This tool is an open source implementation of the MIH standard. Mobile node could be implemented using multiple network interfaces for WiFi and UMTS on laptop. These interfaces must be capable for drivers' modifications in order to add MIH configuration. Adaptive bitrate media server can be used so as to optimize the application bitrates based on the bandwidth of the wireless access technology used. Successful implementation for the mentioned network entities in testbed may lead to realistic observations and performance evaluation.

Acronyms and Abbreviations

ABC	Always Best Connected
AP	Access Point
AWK	Aho, Weinberger and Kernighan
BS	Base Station
BSS	Basic Service Set
CBR	Constant Bitrate
CDMA	Code Division Multiple Access
DS	Distributed System
DSSS	Direct Sequence Spread Spectrum
E2E	End to End
ESS	Extended Service Set
EURANE	Enhanced UMTS Radio Access Network Extension
GGSN	Gateway GPRS Support Node
GPRS	General Packet Radio Service
IBSS	Independent Basic Service Set
ITU-T	International Telecommunication Union-Telecommunication
LAN	Local Area Network
LGD	Link Going Down
LTE	Long Term Evolution
MAC	Medium Access Control
MCDM	Multi Criteria Decision Making
MICS	Media Independent Command Service

MIES	Media Independent Event Service
MIH	Media Independent Handover
MIHF	Media Independent Handover Function
MIIS	Media Independent Information Service
MIP	Mobile IP
NIST	National Institute of Standards and Technology
NS-2	Network Simulator-2
ODTONE	Open Dot Twenty One
PHY	Physical
PoA	Point of Attachment
QoS	Quality of Service
RMSE	Root Mean Squared Error
RNC	Radio Network Controller
RSS	Received Signal Strength
SGSN	Serving GPRS Support Node
SSE	Sum of Squares Due to Error
STA	Station
TCL	Tool Command Language
TCP	Transmission Control Protocol
UMTS	Universal Mobile Telecommunications System
UTRAN	UMTS Terrestrial Radio Access Network
WCDMA	Wideband Code Division Multiple Access
WiFi	Wireless Fidelity
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless LAN

WMAN	Wireless Metropolitan Area Network
3G	3rd Generation
3GPP	3rd Generation Partnership Project

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Appendix A

Published Paper

Abedelaziz E. Khalil, Nasim Hamaydeh, Samer Bali and Labib Arafeh, “Tradeoff Analysis of Vertical Handover between UMTS-WiFi Enhanced by IEEE802.21” in proceeding of the 2013 IEEE International RF and Microwave Conference (RFM2013), Penang, Malaysia, pp.146-151, December 9-11, 2013.

Tradeoff Analysis for Vertical Handover Between UMTS-WiFi Enhanced by IEEE802.21

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***Abstract* — Mobile communication systems are equipped with multiple network interfaces. Wireless Fidelity (WiFi) and 3rd Generation (3G) are the most widely implemented interfaces in the latest mobile communication devices and therefore being able to fulfil most of the computing aspects. Nowadays, most modern mobile devices suffer from the interoperability between the WiFi and 3G interfaces, each access technology serves the user independently and therefore these technologies suffer the lack of interworking mechanisms and service continuity. In this paper, we carried out an intensive simulation analysis for the integration between WiFi from the 802 family of standards and UMTS as 3G cellular network. This integration is enhanced by IEEE802.21 standard that facilitates handover between heterogeneous networks by presenting media independent handover (MIH) reference models for different link layers technologies. The main objective is to study the impact of the mobile node speeds and applications bitrates on the key performance metrics in vertical handover scenarios. This study will present the importance of considering the mobile node speeds and applications bitrates in the vertical handover scenarios by observing the behavior of the performance metrics that affect the Quality of Service (QoS). In the proposed vertical handover scenarios, the recommended range of speeds and bitrates were precisely identified according to the acceptable values of the performance metrics defined by International Telecommunication Union – Telecommunication (ITU-T).**

Keywords—Vertical handover, QoS, MIH, IEEE802.21, WiFi, UMTS, Throughput, Delay, Handover Latency.

I. Introduction

Integration between heterogeneous wireless networks becomes a major issue to achieve service continuity and seamless mobility; enabling the mobile node to redirect traffic flow between network interfaces based on obtained features from mobile access networks, this process is called vertical handover, passing through three stages, preparation decision and execution. Vertical handover challenges are addressed by the Media Independent Handover (MIH) defined in IEEE802.21 standard. MIH defines extensible mechanisms for handover between implementations of IEEE802 family and Cellular networks [1]. The research trend of vertical handover is directed toward studying two major aspects; multi criteria decision making (MCDM) algorithms and mobility management techniques using Mobile IP (MIP) [2]. One of the earliest studies in vertical handover was presented in [3], the authors presented a tutorial on the design and performance issues, focusing on the vertical handover decision policies based on Power received signal strength (RSS) and cost function for network selection criteria. The study includes some possible architectures for exploiting the MIP in the 4G environment. Later studies focus on mobility management. Seamless handover between heterogeneous wireless networks was proposed in the literature using intermediate layers of the TCP/IP protocol stack such as MIPv4 [4] and MIPv6 [5], however these techniques have some challenges regarding security and session continuity. Decision making algorithms are responsible for completing the vertical handover decision stage. RSS based decision algorithms were proposed in the literature in order to enhance vertical handover process. These algorithms rely on determining signal power thresholds to trigger the handover process that took place in the handover preparation stage. In addition, handover decision stage took place based on these thresholds by selecting the candidate network with the highest RSS. MIH standard was combined with these algorithms to achieve seamless mobility. The research in [6] proposed a handover mechanism between WiFi and WiMAX networks using MIH standard. The impact of the LGD factor and probability confidence on the handover latency and packet loss were studied. However the impact of some key indicators in vertical handover were not considered such as mobile node speed, applications bitrates as inputs parameters and their effects on the average throughput, E2E delay, packet loss and handover latency. The work in [7] presents a cross-layer scheduling scheme based on exploiting the LGD trigger to predict handover requirements, in addition, the network traffic was categorized according to the QoS classes of services. Several evaluation metrics were studied to evaluate the performance of integrating UMTS and WiMAX, as well as WiFi and WiMAX networks. This study shows an enhancement in service continuity for the QoS sensitive applications, however the integration between WiFi and UMTS networks is not considered. The research in [8] proposed vertical handover decision algorithms for WiFi and CDMA networks, a roaming client software was implemented to enhance handover, the study does not consider the MIH standard in the implementation, thus the handover delay was high compared to the handover delay measured in MIH-assisted handover mechanisms.

In this research, we carried out a comprehensive simulation study for the key performance indicators that is affected by the vertical handover process between UMTS and WiFi networks. Two major scenarios were proposed based on the methodology used in [6]. Comprehensive analysis shows the impact of the mobile node speed and the applications bitrates on obtained results that were presented in the evaluation metrics used.

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The rest of the paper is organized as follows; Section II discusses the heterogeneous wireless access networks. Section III discusses the simulation environment including parameters and metrics. Section IV exhibits results and performance analysis. Section VI concludes the work and discusses some future work.

II. HETEROGENOUS WIRELESS 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. UMTS Networks:

3G systems represented in UMTS technology offers services such as voice, video and SMS transfer. The core network of the UMTS consists of circuit switched and packet switched network that supports the Serving GPRS Support Node (SGSN) and Gateway GPRS Support Node (GGSN). The Radio Access network; UMTS Terrestrial Radio Access Network (UTRAN) provides the air interface access method with the mobile node that is included in the Base station which is referred as (Node-B). Radio Network Controller (RNC) for Node-B in the UMTS access network is responsible for handover control. In our research we are going to use the packet switched network of the UMTS architecture.

III. SIMULATION SCENARIO

The scenario is implemented using the mobility environment for vertical handover in network simulator 2 (ns-2). Exploitation of two wireless modules implemented in ns-2; IEEE802.21 module contributed by the National Institute of Standards Technology (NIST) [9] and UMTS module contributed by EURANE [10]. The simulation scenarios parameters for UMTS and WiFi are shown in Table I.

Table I. Simulation Parameters for WiFi and UMTS [11] [12]

Global Parameters	
Propagation Model	TwoRayGround
Topology Range	3000 x 3000 m
Simulation Duration	40 sec
Mobile node speeds	5, 10, 15, 20, 25, 30, 40, 50, 60 km/h
Bitrate	CBR; 64, 480, 960, 1920, 2880, 3840 kb/s
WiFi Parameters	
Coverage area	100 m
MAC Type	Mac/802_11
Frequency	2.41 GHz
Transmission Power	0.027 W
Bandwidth	11 Mb/s
RXThresh	2.64504e-10 W
CSThresh	90% of RXThresh
Weighted-Thresh	3.174048e-10 W
Antenna model	Omni Antenna
Pr_limit	1.2
UMTS Parameters	
Coverage area	1000 m
Frequency	2000 MHz
Bandwidth DL/UP	384 kb/s (outdoor)
Transmission Time Interval (TTI)	2 ms

A. Handover Scenario

In this research, we have two mobility scenarios. In the first scenario, the wireless infrastructure consists of a mobile node connected to the WiFi network and moved toward the UMTS, and so the WiFi access point is the serving point of attachment (PoA) while UMTS base station is the candidate PoA in the WiFi to UMTS scenario. In UMTS to WiFi scenario, the mobile node is moving from the UMTS; the serving PoA to the WiFi network which represents the candidate PoA. Each node in the wireless infrastructure in addition to the mobile node has MIH components to facilitate handover.

The wired infrastructure consists of network router which connects WiFi and UMTS network using duplex links with bandwidth of 100 Mbit/s. The wired and wireless infrastructure connect the mobile node to media server as shown in Fig.1

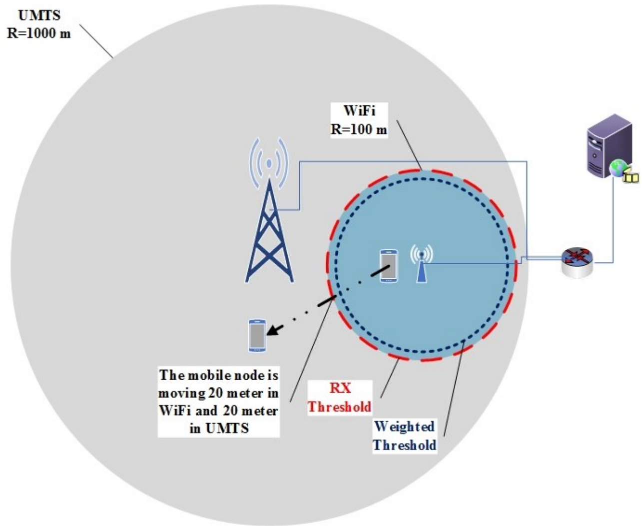

Fig. 1. Simulation Scenario

B. Performance Evaluation Metrics

After monitoring the scenario and insuring that the vertical handover process was successful, the impact of the pertinent input parameters - such as mobile node speeds and applications bitrates - were observed. All the evaluation metrics were presented for seven bitrates on different mobile node speeds. Several experiments with random seeds were configured to evaluate the performance metrics as follows:

- *Average Throughput:* measured in kilo bit per second (kb/s), it is the ratio of data packets delivered to the destination by time interval [1].
- *Average end-to-end Delay (E2ED)*: measured in millisecond (ms), is the average time or one way latency a packet takes to reach the destination from a source node. E2E Delay includes processing delay, network delay prorogation, transmission and queuing delay [1].
- *Handover Latency:* measured in millisecond, is the amount of time that elapses between an interface sending a MIPv6 redirect request to the media server and receiving the correspondent redirect acknowledgment from the media server [12].
- *Packet Loss Ratio:* is the ratio of the amount of packets that were not delivered to a specific destination by the total number of sent packets during the whole scenario.
- *LGD Probability and RSS:* It is the probability value of link going down trigger combined with the power RSS.

IV. PERFORMANCE ANALYSIS

After building a mobility scenario that includes the integration between WiFi and UTMS networks, this scenario must be harmonized with the vertical handover aspects; observing the behavior of the evaluation metrics in the area where the vertical handover took place. The observation of the behavior in this area shows the effect of the MIH standard services on the vertical handover process as follows:

A. Average Throughput

WiFi to UMTS: Figure 2, shows the normalized average throughput for seven bitrates measured in on different mobile node speeds. Average throughput on the WiFi interface decreases with increasing mobile node speeds. In addition, applications with high bitrates are affected more than lower bitrates applications. When the mobile node is approaching the border of the WiFi network with increasing speeds, the number of received packets on the WiFi interface decreases accordingly - as shown in Fig.3- This occurs because the travelling time in the WiFi network becomes shorter with increasing speed. Figure 4 shows the degradation percentage in the average throughput for WiFi network. Result shows that high degradation in throughput occurs when the mobile node approaches the intersection area between WiFi and UMTS networks with high speeds; meaning that when the mobile node speed is more than 50 km/h, the average throughput degrades by 40% of the bitrate value at speed 60 km/h, no received packets will be delivered at the WiFi interface when the mobile node speed is above 60 km/h because the vertical handover process will not have enough time to prepare and decide for handover to the target PoA (UMTS).

UMTS is the target PoA in WiFi to UMTS scenario. Figure 5 shows the normalized average throughput measured on the mobile node UMTS interface on seven bitrates with different mobile node speeds. The result shows that the average throughput in UMTS is not affected by increasing mobile node speed. In addition, the mobile node in WiFi to UMTS scenario is entering the UMTS network with increasing UMTS power RSS. The maximum bandwidth of UMTS is 384 kb/s meaning that that the average throughput will not be affected when the application bitrate is less than 384kb/s, showing 99% in the normalized throughput for bitrates 64kb/s and 256kb/s. For bitrates more than 384kb/s, average throughput is not increasing, giving 384 kb/s for all bitrates. This occurs because of the limited bandwidth of UMTS network which will keep the number of received packets constant when using bitrates higher than 384 kb/s.

UMTS to WiFi: Figure 6 shows the UMTS normalized average throughput. When the UMTS is the serving PoA, the average throughput is slightly affected with increasing mobile node speed. The high impact is for the applications bitrates as a result of the UMTS bandwidth bottleneck. Figure 7 presents the behavior of increasing throughput measured in on the WiFi interface while the mobile node is entering the WiFi network.

B. Packet loss Ratio

WiFi to UMTS: In order to observe the behavior of the packet loss ratio, total packet loss ratio during the whole scenario for both WiFi and UMTS was measured. Figure 8 shows the impact of mobile node speed and the application bitrate on the total packet loss that occurs in the vertical handover stage. We can say that the packet loss in WiFi increases as a result of increasing the mobile node speeds, but for UMTS, the packet loss is affected by the applications bitrate showing high packet loss for bitrates higher than 384 kb/s. By combining the effect of both speed and bitrate, total packet loss shows values between (1% – 60%) for bitrates lower than 960 kb/s and speed 60 km/h, on the contrary the packet loss for 3840 kb/s may reach to 89% on speed 60 km/h as a result of WiFi limited coverage area and the bandwidth limitation on UMTS.

UMTS to WiFi: Figure 9 shows that packet loss occurs on low speeds in UMTS and decreases while leaving it.

C. Average Delay

Figure 10 shows the average delay in WiFi network with mobile node speed and bitrates. Same behavior of WiFi E2E delay was depicted in both scenarios; WiFi to UMTS and UMTS to WiFi. Results shows that the E2E delay in WiFi slightly increase by increasing speed and bitrates. The E2E delay increased by 4 ms when increasing bitrate from 64kb/s to 3840kb/s showing a range of values from 46ms to 50ms. This occurs as a result of the available resources in WiFi network. We can say that constrains are limited for the delay sensitive application in WiFi network. Good performance can be achieved for these applications in term of E2E delay.

In UMTS network, Fig.11 shows the average E2E delay in UMTS network with mobile node speed for various bitrates. E2E delay is not affected by increasing mobile node speeds, on the contrary, it is affected by increasing bitrates. For bitrates lower than 384 kb/s, EDE delay is almost constant with acceptable values - around 54 ms - for most applications. Delay values increased dramatically when the application bitrates exceed the bandwidth of UMTS network showing unacceptable values – around 1s - for real time systems.

We conclude that delay sensitive applications must operate with bitrates under 384 kb/s in UMTS and accepting E2E delay of 54ms. Real time applications cannot operate with bitrates above 384 kb/s because of the high E2E delay in UMTS. To achieve service continuity, these challenges can be solved using variable bitrates encoders that will sense the bandwidth of the serving network and serve the mobile node with bitrates lower than 384 kb/s when the mobile node moves in UMTS network

In UTMS to WiFi scenario, E2E delay in WiFi does not change showing acceptable values as in WiFi to UMTS scenario. Figure 12 shows that the average E2E delay in UMTS network is not affected by the mobile node speeds showing value around 54 ms for bitrates lower than 384 kb/s. The impact of mobile node speeds occurs when the bitrate is 480 kb/s showing high value, around 1 s for 5 km/h and degrades to 164 ms for 60 km/h. For bitrates higher than 480 kb/s the E2E delay is very high, around 1s. We conclude that bitrates lower than 384 kb/s has an acceptable E2E delay for both real time and non-real time applications. For bitrate 480 kb/s, the faster the mobile node leave UMTS network, the lower the E2E delay, this occurs because the mobile node is moving to WiFi which provides high bandwidth and therefore delay decreases from 1 s on low speeds to 164 ms on high speeds. For bitrates above 480 kb/s, E2E delay value is high – around 1 s – because of the limitation on UMTS bandwidth that was clearly presented on bitrates higher than 480 kb/s in this scenario.

D. Handover Latency

WiFi to UMTS: Figure 13 shows the vertical handover latency with mobile node speeds in both scenarios. This latency is measured on layer 3 of the TCP/IP protocol stack. The behavior shows limited effect for speed and bitrates on the vertical handover latency. Values from 140 to 160ms were measured when going from WiFi to UMTS.

UMTS to WiFi: lower latency occurs when moving from UMTS to WiFi; around 95 ms regardless of the mobile node speeds and applications bitrates.

E. Power RSS and LGD Probability

WiFi to UMTS: The power RSS values are directly related to the performance of some evaluation metrics such as throughput packet loss ratio and MIH standard triggers. LGD trigger is one of the important services that is presented by MIH standard, the lower layers in the protocol stack PHY/MAC triggers this event as indication for power degradation is happening for the received signal. Figure 14 shows the simulation time with power RSS measured on WiFi interface while the mobile node is moving from WiFi to UMTS. In this scenario, the mobile node is approaching the WiFi boarder, the signal power degrades accordingly. Two power thresholds were measured in this stage in order to know the exact time for starting the handover initiation stage. The first threshold is RX-Threshold ($RXth$) which is the minimum power level for receiving error free packets. In Eq. 1, Weighted-Threshold (Wth) is measured using the Pr_limit factor multiplied by the RX-Threshold. The faster the mobile node, the sooner the weighted threshold power will be reached. Eq. 2, shows the interval when LGD trigger comes out. When the power RSS on the mobile node less than or equals the Weighted-Threshold, LGD trigger starts, during the interval defined in Eq. 2, LGD probability is calculated using Eq. 3 which is implemented in the MIH standard. When the mobile node approaches the WiFi network boarder, LGD probability increases until reaching 99% depending on the mobile node speeds, handover initiation and decision stages took place in this time interval. This technique results in service continuity, which prevents the RSS values from reaching the RX-Threshold. During handover initiation stage, WiFi signal degrades, the mobile node sense UMTS network signals and decide to handover for better network accordingly, after that handover execution stage occurs using MIPv6.

$$Wth = \text{Pr\_limit} * RXth \quad (1)$$

$$Wth \geq RSS \geq RXth \quad (2)$$

$$LGDprob = \frac{Wth - RSS}{Wth - RXth} * 100\% \quad (3)$$

UMTS to WiFi: When the mobile node is leaving UMTS network, link down trigger indicates degradation in UMTS signal power. Link detected trigger occurs when WiFi the mobile node sense WiFi carrier and decide to switch to WiFi accordingly.

V. CONCLUSION AND FUTURE WORK

Regarding Average throughput, we conclude from the analysis that throughput sensitive applications will be affected by mobile node speed and bitrates in WiFi to UMTS scenario; the difference in behavior in WiFi and UMTS networks is related to the limited coverage area in WiFi network and limited bandwidth of UMTS. Small WiFi coverage area limits the mobile node speed in the handover area to 50 km/h. Limited UMTS bandwidth puts some constrains on the applications with bitrates higher than 384 kb/s. These application will have maximum throughput of 384kb/s (i.e., the throughput value will be 40% of the applications that have bitrate 960 kb/s and 20% for the 1920 kb/s bitrate). In UMTS to WiFi scenario, there are no limitations on the mobile node speeds in the handover area. In addition, the applications that have high bitrates (more than 384kb/s) will suffer from throughput degradation in UMTS as a result of UMTS limited bandwidth.

Total packet loss ratio in WiFi to UMTS scenario increases with increasing speeds and bitrates. Packet loss in WiFi increases with increasing mobile node speed while packet loss in UMTS increases with increasing speeds and bitrates. Mobile node speed in the handover area must not exceed 50 km/h with bitrates lower than 480 kb/s. In UMTS to WiFi scenario, packet loss occurs on low speeds in UMTS, the faster the mobile node leaves UMTS network, the lower packet loss occurs.

In WiFi to UMTS scenario, delay sensitive applications have no constrains in WiFi network showing an acceptable delay values as a result of increasing application bitrates, mobile node speeds do not affect the E2E delay in WiFi. In UMTS, delay sensitive applications must operate with bitrates under 384 kb/s.

In UMTS to WiFi scenario, the faster the mobile node leaves UMTS network, the lower the E2E delay. Bitrates lower than 480 kb/s is recommended in this scenario. The mobile node speeds and bitrates were specified to keep the E2E delay under the acceptable delay recommended by ITU-T.

Handover latency in WiFi to UMTS is higher than the values measured in UMTS to WiFi scenario. Speeds and bitrates do not have any impact on handover latency, MIPv6 signaling in WiFi and UMTS causes this latency.

According to ITU-T, the acceptable latency for low to high quality voice is from 150 to 200ms. For non-interactive video the acceptable latency is 280 ms, but for interactive video the latency depends on the application QoS specification and on the category of class classification. We conclude that handover to UMTS network needs more time than handover to WiFi, this is related to the technology implementation and not affected by mobile node speed or application bitrates. Speeds and bitrates affect the key metrics in WiFi and UMTS integration. In general performance degradation occurs as a result of the limitations in WiFi and UMTS networks in terms of small coverage area and low bandwidth respectively.

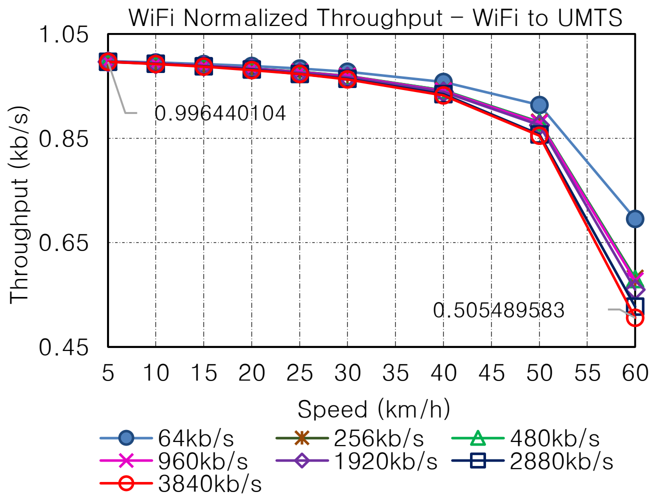

Fig. 2. Normalized average throughput measured between media server and mobile node WiFi interface for range of application bitrates when the WiFi is the serving PoA

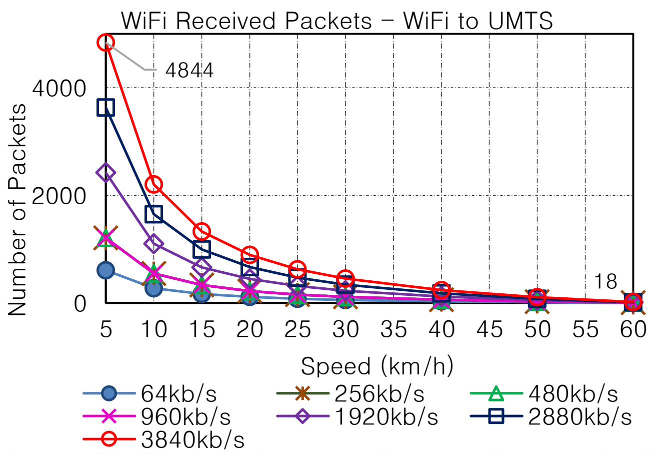

Fig. 3. Number of received packets measured between media server and mobile node WiFi interface for range of application bitrates when the WiFi is the serving PoA.

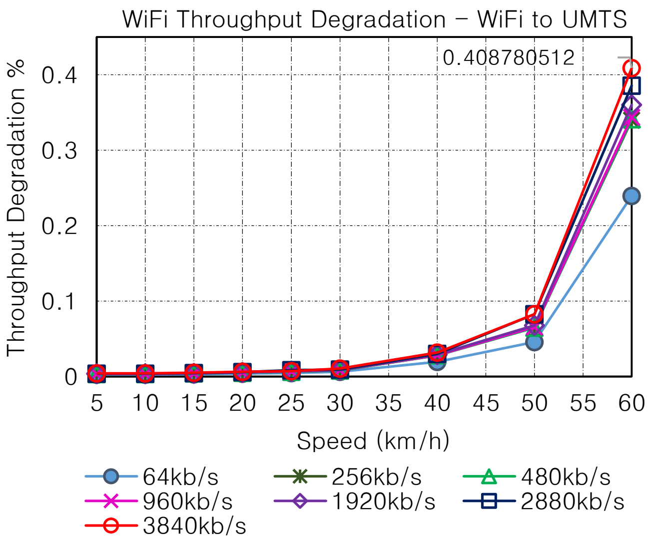

Fig. 4. Throughput degradation measured between media server and mobile node WiFi interface for range of application bitrates when the WiFi is the serving PoA.

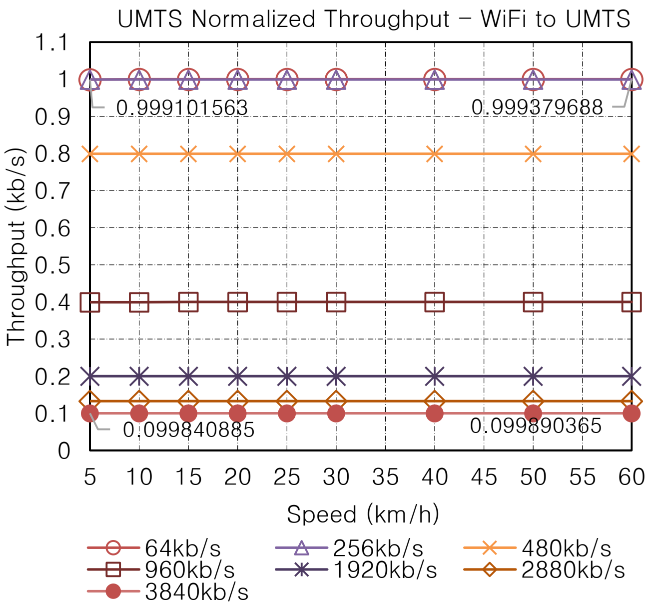

Fig. 5 Normalized average throughput measured between media server and mobile node UMTS interface for range of application bitrates when the WiFi is the serving PoA.

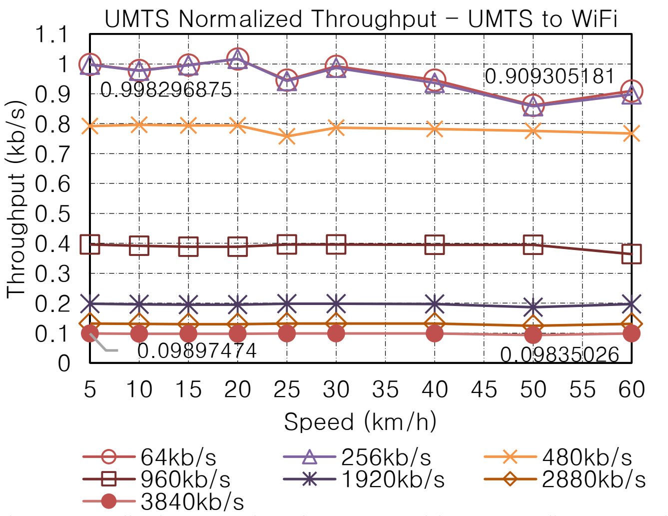

Fig. 6. Normalized average throughput measured between media server and mobile node UMTS interface for range of application bitrates when the UMTS is the serving PoA.

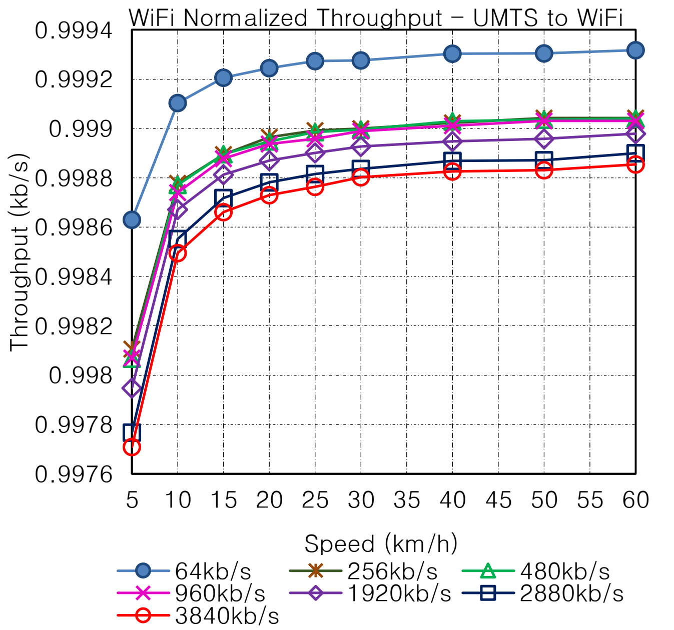

Fig. 7. Normalized average throughput measured between media server and mobile node WiFi interface for range of application bitrates when the UMTS is the serving PoA

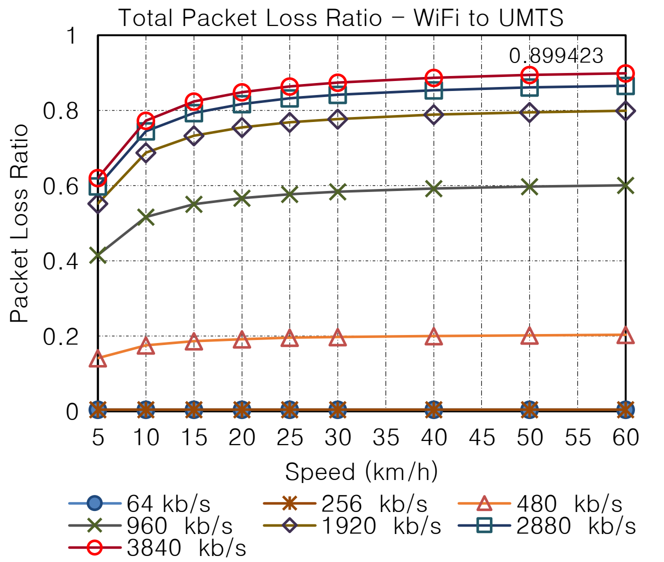

Fig. 8. Total packet loss ratio measured between media server and mobile node for range of application bitrates when the WiFi is the serving PoA.

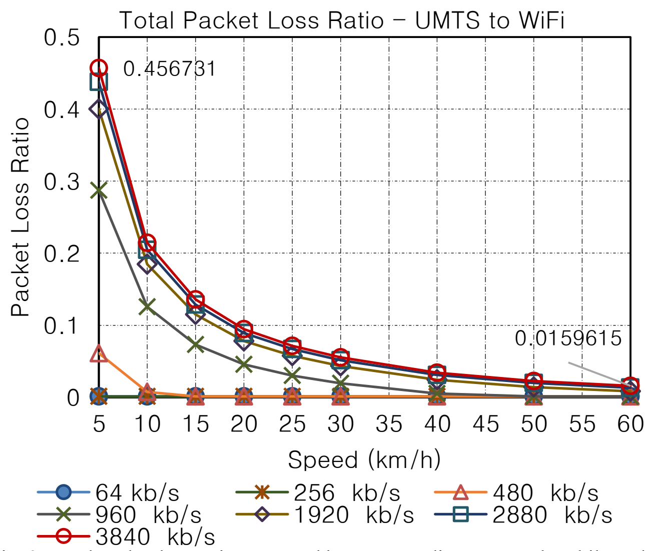

Fig. 9. Total packet loss ratio measured between media server and mobile node for range of application bitrates when the UMTS is the serving PoA

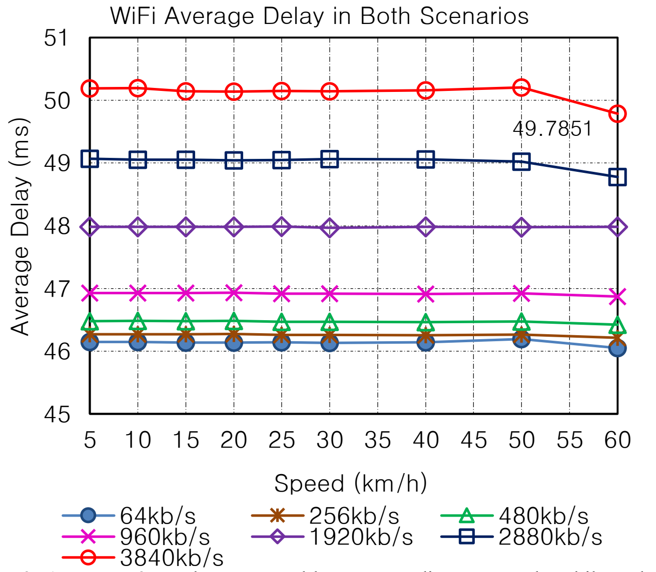

Fig. 9. Average E2E Delay measured between media server and mobile node WiFi interface for range of application bitrates in both scenarios.

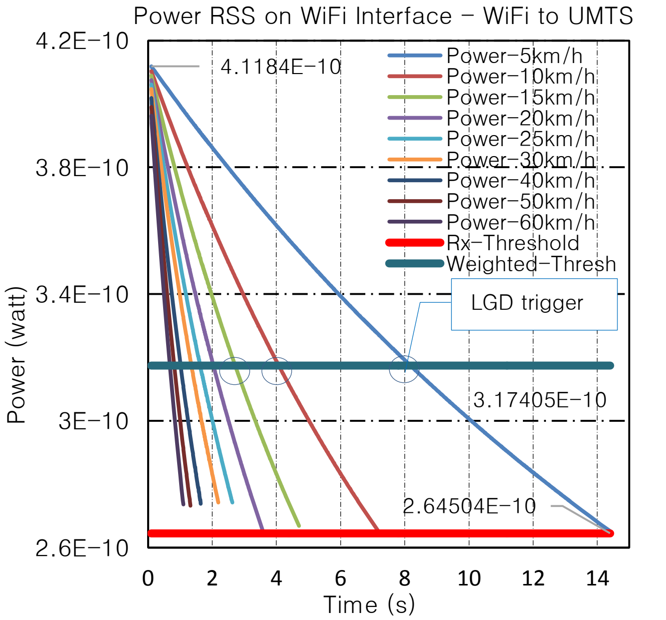

Fig. 10. Power RSS measured on the mobile node WiFi interface while it is leaving WiFi network when the WiFi is the serving PoA.

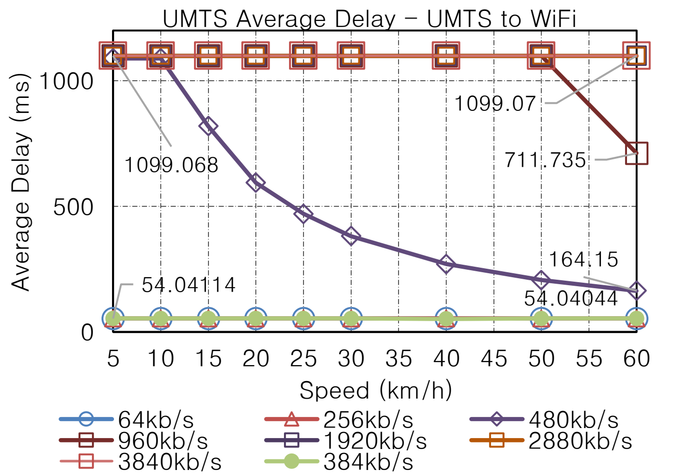

Fig. 11. Average E2E Delay measured between media server and mobile node UMTS interface when the UMTS is the serving PoA

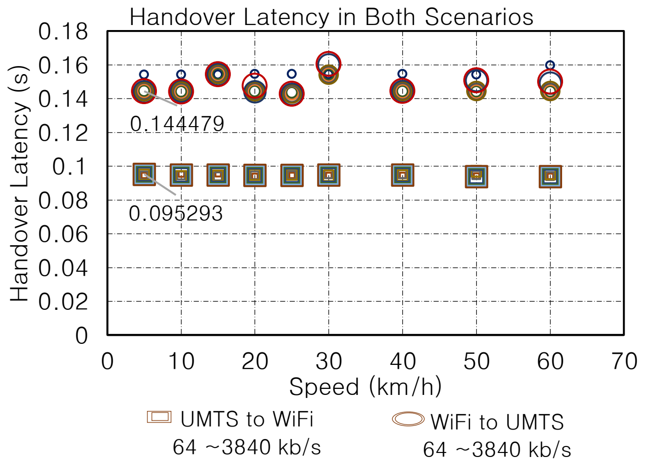

Fig. 12. Handover latency measured between media server and mobile node for range of application bitrates in both scenarios.

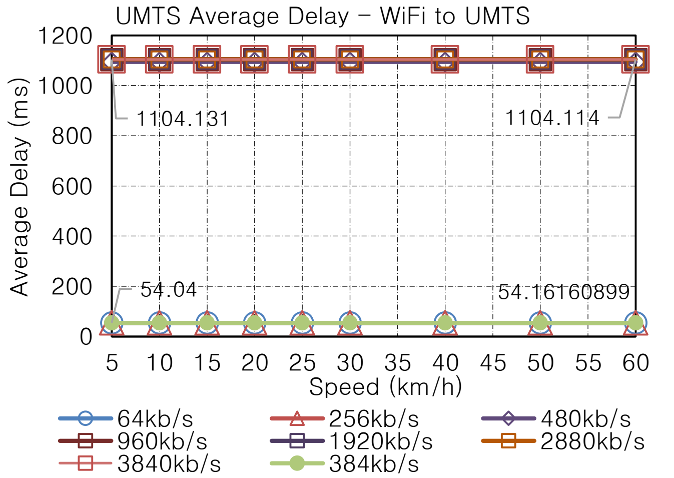

Fig.13. Average E2E Delay measured between media server and mobile node UMTS interface when the WiFi is the serving PoA

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