AN INTELLIGENT NETWORK SELECTION MECHANISM FOR VERTICAL HANDOVER DECISION IN VEHICULAR AD HOC WIRELESS NETWORKS

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Abstrak

Reka bentuk teknologi rangkaian ad-hoc kenderaan (VANET) adalah paradigma moden untuk komunikasi kenderaan mengenai pergerakan. Walau bagaimanapun, keputusan penyerahan menegak VANET dalam penyambungan lancar adalah cabaran besar yang disebabkan oleh kerumitan topologi rangkaian dan sebilangan besar nod mudah alih yang mempengaruhi lalu lintas rangkaian dari segi kecekapan penghantaran data dan penyebaran. Tambahan pula, skim konvensional hanya menggunakan kekuatan isyarat yang diterima sebagai nilai metric yang menunjukkan kekurangan metrik penyerahan yang lebih sesuai dalam penyerahan mendatar berbanding dengan penyerahan menegak. Keputusan penyerahan menegak yang tepat akan menghasilkan peningkatan kualiti perkhidmatan dari segi kelewatan, kependaman, dan kehilangan paket. Kajian ini bertujuan untuk merancang pemilihan rangkaian pintar bagi meminimumkan kelewatan, latensi penyerahan, dan kehilangan paket dalam rangkaian tanpa wayar kenderaan-ke-infrastruktur yang heterogen. Pemilihan rangkaian pintar yang dicadangkan dikenali sebagai skim penyerahan keputusan adatif (AHD) yang menggunakan algoritma logik kabur (FL) dan pemberat adatif mudah (SAW), dipanggil skim F-SAW. Skim AHD dirancang untuk memilih calon titik akses dan stesen pangkalan yang terbaik tanpa mengurangkan prestasi aplikasi yang sedang berjalan. Skim F-SAW diusulkan untuk mengembangkan mekanisme pemicu penyerahan yang menghasilkan beberapa atribut parameter dengan menggunakan konteks maklumat keputusan penyerahan menegak dalam rangkaian tanpa wayar heterogen kenderaan-ke-infrastruktur. Kajian ini menggunakan simulator rangkaian (NS-2) sebagai penjana rangkaian lalu lintas mobiliti dan lalu lintas mobiliti kenderaan (VANETMobiSim) untuk menerapkan scenario topologi mobiliti VANET yang realistik dalam teknologi rangkaian Wi-Fi, WiMAX, dan LTE. Skim AHD yang dicadangkan menunjukkan peningkatan dalam penyerahan kualiti perkhidmatan berbanding skim konvensional (RSS-based) dengan peningkatan purata kualiti perkhidmatan sebanyak 21%, 20%, dan 13% pada kelewatan, kependaman dan kehilangan paket manakala skim penyerahan bebas media (MIH-based) dengan masing-masing 12.2%, 11%, dan 7%. Skim yang dicadangkan ini membantu pengguna bergerak dalam memilih titik akses atau stesen pangkalan terbaik yang tersedia semasa pergerakan kenderaan tanpa merendahkan prestasi aplikasi yang sedang berjalan.

Kata Kunci: Kenderaan-ke-Infrastruktur, Logik kabur, Kekuatan isyarat yang diterima, Pemberat aditif mudah, Penyerahan bebas media.

Abstract

The design of the Vehicular Ad-hoc Network (VANET) technology is a modern paradigm for vehicular communication on movement. However, VANET's vertical handover (VHO) decision in seamless connectivity is a huge challenge caused by the network topology complexity and the large number of mobile nodes that affect the network traffic in terms of the data transmission and dissemination efficiency. Furthermore, the conventional scheme only uses a received signal strength as a metric value, which shows a lack of appropriate handover metrics that is more suitable in horizontal handover compared to VHO. Appropriate VHO decisions will result in an increase in the network quality of service (QoS) in terms of delay, latency, and packet loss. This study aims to design an intelligent network selection to minimize the handover delay and latency, and packet loss in the heterogeneous Vehicle-to-Infrastructure (V2I) wireless networks. The proposed intelligent network selection is known as the Adaptive Handover Decision (AHD) scheme that uses Fuzzy Logic (FL) and Simple Additive Weighting (SAW) algorithms, namely F-SAW scheme. The AHD scheme was designed to select the best-qualified access point (AP) and base station (BS) candidates without degrading the performance of ongoing applications. The F-SAW scheme is proposed to develop a handover triggering mechanism that generates multiple attributes parameters using the information context of vertical handover decision in the V2I heterogeneous wireless networks. This study uses a network simulator (NS-2) as the mobility traffic network and vehicular mobility traffic (VANETMobiSim) generator to implement a topology in a realistic VANET mobility scenario in Wi-Fi, WiMAX, and LTE networks technologies. The proposed AHD scheme shows an improvement in the QoS handover over the conventional (RSS-based) scheme with an average QoS increased of 21%, 20%, and 13% in delay, latency and packet loss, while Media Independent Handover based (MIH-based) scheme with 12.2%, 11%, and 7% respectively. The proposed scheme assists the mobile user in selecting the best available APs or BS during the vehicles' movement without degrading the performance of ongoing applications.

Keywords: Vehicle-to-Infrastructure, Fuzzy logic, Received signal strength, Simple additive weighting, Media independent handover.

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List of Abbreviations

3GPP	Third Generation Partnership Project
AHD	Adaptive Handover Decision
AMPS	Advanced Mobile Phone System
AP	Access Point
ABW	Available Bandwidth
BER	Bit Error Rate
BS	Base Station
CA	Context-Aware
CDMA	Code Division Multiple Access
CIR	Carrier-to-Interference Ratio
CN	Core Network
DL	Downlink
EDGE	Enhanced Data Rate for GSM Evolution
E-UTRA	Evolved UMTS Terrestrial Radio Access
E-UTRAN	Evolved UMTS Terrestrial Radio Access Network
ES	Event Service MIH
FL/NN	Fuzzy Logic and Neural Network-based
FIS	Fuzzy Inference System
F-SAW	Fuzzy Logic and Simple Additive Weighting
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communication
HO	Handover/Handoff
HSPA	High-Speed Packet Access
IEEE	International Electrical and Electronics Engineer
IMT	International Mobile Telecommunications
ISP	Internet Services Provider
ITU	International Telecommunication Union
IS	Information Services
LAN	Local Area Network
LTE	Long Term Evolution
LU	Link Up

LD	Link Down
LCU	Link Coming Up
LGD	Link Going Down
MAD	Multiple Attribute Decision
MADM	Multiple Attribute Decision Method
MEW	Multiplicative Exponential Weighted
Mf	Member Function
MIMO	Multi-Input Multi-Output
MIH	Media Independent Handover
MIHIS	Media Independent Handover Information Service
MIHES	Media Independent Handover Event Service
MN	Mobile Node
MT	Mobile Terminal
OFDM	Orthogonal Frequency Division Multiplexing
PoA	Point of Attachment
QoS	Quality of Service
RAN	Radio Access Network
RSRP	Reference Signal Received Power
RSRQ	Reference Symbols Received Quality
RSS	Received Signal Strength
RTT	Round-Trip Time
SAW	Simple Additive Weighted
SC-FDMA	Single Carrier FDMA
SINR	Signal-to-interference-plus-noise ratio
SIR	Signal-to-Interferences Ratio
TCP	Transmission Control Protocol
TDMA	Time Division Multiple Access
TOPSIS	Technique for Order Preference by Similarity to Ideal Situation
UE	User Equipment
UL	Uplink
UMTS	Universal Mobile Telecommunication System
VANET	Vehicular Ad Hoc Networks
VHO	Vertical Handover

VHOD	Vertical Handover Decisions
VoIP	Voice over IP
WAN	Wide Area Network
WLAN	Wireless Local Area Network
WiMAX	Worldwide Interoperability for Microwave Access

CHAPTER ONE
INTRODUCTION

In the year 2020, the fifth generation of the wireless communication system will be deployed in many countries. This technology provides more freedom to users in accessing the Internet and network applications with seamless communication through different wireless network technologies such as wireless fidelity (Wi-Fi), Worldwide Interoperability for Microwave Access (WiMAX), Universal Mobile Telecommunications Systems (UMTS), Long-Term Evolution (LTE), and 5G. The main intention is to allow a better connection with such applications, anywhere at any time without disconnection. Such enhanced connectivity is also referred to as "*Always Best Connected (ABC)*" network. On this context, this study proposes a strategy of vertical handover (VHO) decision making in heterogeneous vehicular ad hoc network (VANET), which focuses on vehicle-to-infrastructure (V2I) communication technology.

In the heterogeneous infrastructure, the network is built-up with few access points such as Wi-Fi, WiMAX, and a base station (LTE) in the roaming coverage of vehicles or Mobile Nodes (MN), which are called roadside units (RSUs). The RSUs have different technologies that provide various levels of link quality. Hence, the accuracy of the decision-making algorithm in the handover process is needed to choose the best candidate among the various link of the network.

The main challenge of the wireless communication management link is to ensure the successful delivery of available network resources especially when there is various accessibility of wireless link resources due to the high-speed mobility of MNs, which are carried by vehicles. Another issue is related to the instability of the wireless link quality, such as the multi-path fading, signal-to-noise ratio, and natural interference. The link instability usually occurs due to the high demand by users particularly when they access online using the wireless Internet such as Internet Protocol TV (IPTV) and high-speed Voice-over-IP (VoIP) services [1].

1.1 Evolution of Wireless Communication

The high demand for Internet access as well as anytime and anyplace network application contributes to the growth of wireless technologies in the open market. Figure 1.1 and Table 1.1 show the evolution of mobile communication technologies starting from the first to fifth generations in terms of specifications and features.

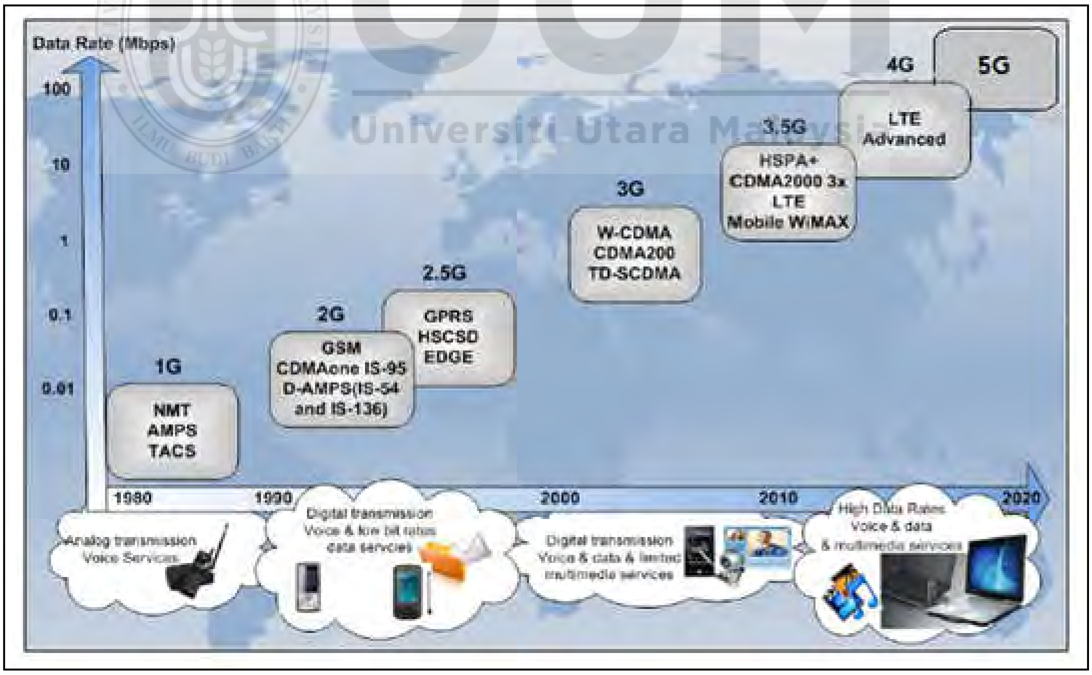


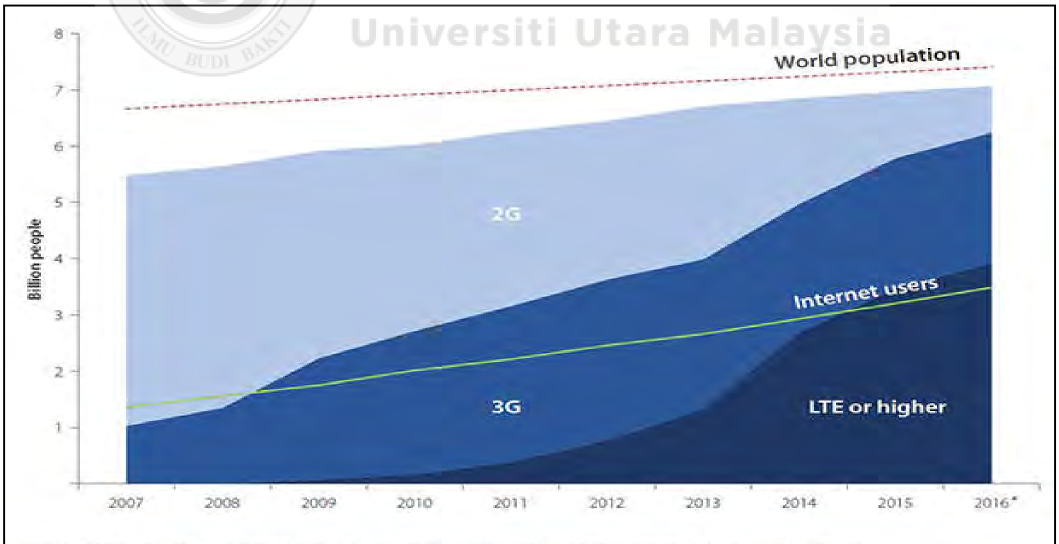
Figure 1.1 Evolution of Mobile Communications from 1G to 5G (adopted from [2])

Table 1.1

Mobile Communication Technology Generations from 1G to 5G

Generation	**1G**	**2G**	**2.5G**	**3G**	**4G**	**5G**
Technology	Analog signal	Digital signal (circuit switching)	Packet switching	Intelligent signal (connectionless)	Digital, Broadband Packet, All IP very high throughput	4G and WWWW
Multiplexing	AMPS	GSM	GPRS, TDMA, EDGE	IMT-2000(UMTS, WCMA,CDMA200)	OFDM, MC-CDMA, Network-LMPS, LTE	Not yet: Shall be supported by OFDM, MC-CDMA
Bandwidth	14.4 Kbps (peak)	9.6/14.4Kbps	171.2Kbps (peak), 20-40Kbps	Up to 2Mps	Full mobility: Up to 100Mbps, Low mobility: Up to 1Gbps	Probable gigabits (> 1Gbps)
Core network	PSTN	PSTN	PSTN	Packet Network	Internet	Internet
Services	Voice	Voice, short message service	Data service	Integrated high-quality audio, video, and data	Dynamic information access, variable devices	Dynamic information access, variable devices with all capabilities
Handoff	Horizontal	Horizontal	Horizontal	Horizontal & Vertical	Horizontal & Vertical	Horizontal & Vertical

The challenge of mobile network generations faced in the network environment is the competition between several service providers. These Internet providers offer various network access packages to numerous services available for different mobile devices. Network technologies are a combination of two or more types of similar networks in the field of telecommunications technology. However, the main problem is to choose the available networks access candidate with dissimilar wireless communication technologies in the same area. As reported by the International Telecommunication Union (ITU) [3], the statistical development in information and communication technology from 2007 to 2016 indicates that the analyzes of the ICT indicators or main telecommunication, including on Internet use, residence ICT access, mobile broadband, and fixed services, and mobile-cellular subscriptions have slightly increased in mobile networks technology coverage (2G, 3G, and LTE) against the population, as shown in Figure 1.2.



Note: * Estimates. Mobile network coverage refers to the population that is covered by a mobile network.

Figure 1.2 *The ICT Facts and Figures of Mobile Network Coverage and Evolving Technologies from 2007 until 2016 (adopted from [3])*

The proliferation of mobile and wireless communication technologies is a crucial factor in increasing the number of Internet access users. Besides, the characteristics (e.g. mobile, low price, and portable communication device) of nomadic devices also contribute to the increasing number of mobile-cellular subscriptions. Therefore, the most challenging issue is attaining the efficiency of the heterogeneous wireless networks by reducing the parameters (e.g. handover delay, packet loss, unnecessary handover, and handover latency) that can be influenced by the quality of service (QoS) during the handover process. However, the network overlay occurs because of the changes in the radio signal transmission between AP and BP in the heterogeneous networks. The network switching and seamlessness are two essential processes in the VHO management that require to be studied more by researchers. Thus, [4, 5, 6] states that the handover management approach should select the proper time of handover trigger and best access network among the available networks to maintain service continuity. The combination of various networks in the heterogeneous wireless networks will face challenges of the future generation research phases in mobility management and handover decision-making across multiple network technologies (Wi-Fi, WiMAX, UMTS, LTE, MANET, and VANET). There are to accomplish any location of network coverage [7, 8, 9, 10, 11, 12, 13].

1.2 Research Motivation

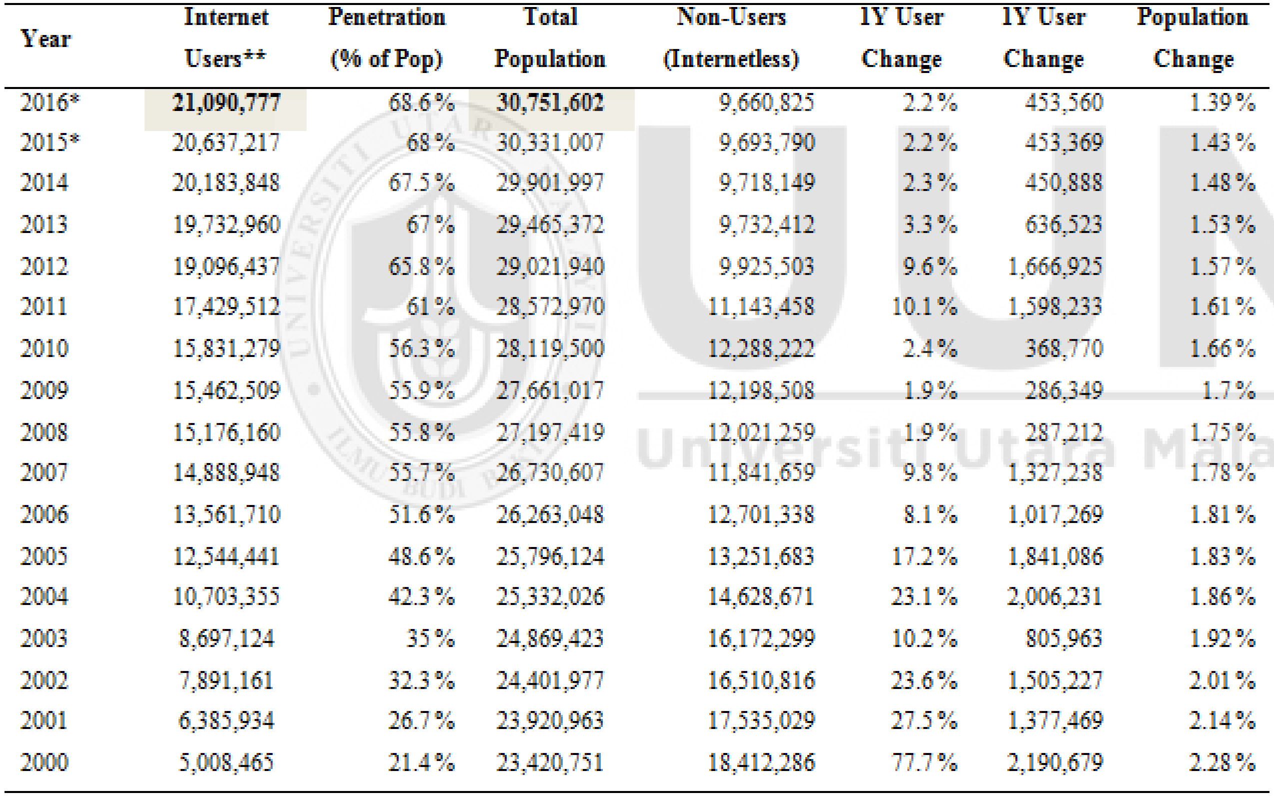
Integrating the heterogeneous wireless network in ensuring good QoS, service continuity and user satisfaction involves many technical challenges such as seamless vertical handover, good QoS, mobility management, authentication, security, resource management, and pricing.

Based on the Statistic of Internet Users in Malaysia [14], the penetration rates are rapidly increased to 68% from 2000 to 2016 (July) of 30,751,602 total population in Malaysia as shown in Table 1.2. The statistic signifies that more than 50% of Internet users are using the mobile networks through several wireless network technologies access. A most recent report by the Department of Statistic Malaysia (2018) [15] reveals that Malaysia's Internet penetration among users aged 15 years and above has increased by 0.9% to 80.1% in 2017, compared to 71.1% in 2015. Internet penetration increment is due to the increased of individuals using computers (1.1%) and mobile phones (0.2 %) in 2017.

The difficulties and high complexity of integrating the different network infrastructures with users' requirements or preferences are other challenges in fulfilling users' satisfaction. For instance, when the LTE (4G) technology was launched in 2013, the Malaysian telecommunication operators have expanded their speeds and network capacity with new technology, which allows them to deliver the 4G technology at the global average speeds of 13.5Mbps [16]. The report also highlighted that none of them had become the dominant 4G speed leader because the prevailing four operators in Malaysia such as Maxis, U-Mobile, Digi, and Celcom have closed the battle in terms of speed and coverage. Nevertheless, Maxis was the only company that able to hold an edge of coverage.

Table 1.2

Statistic of Internet Users in Malaysia in July 2016 (adopted from [14] *)*



Year	Internet Users**	Penetration (% of Pop)	Total Population	Non-Users (Internetless)	1Y User Change	1Y User Change	Population Change
2016*	**21,090,777**	68.6 %	**30,751,602**	9,660,825	2.2 %	453,560	1.39 %
2015*	20,637,217	68 %	30,331,007	9,693,790	2.2 %	453,369	1.43 %
2014	20,183,848	67.5 %	29,901,997	9,718,149	2.3 %	450,888	1.48 %
2013	19,732,960	67 %	29,465,372	9,732,412	3.3 %	636,523	1.53 %
2012	19,096,437	65.8 %	29,021,940	9,925,503	9.6 %	1,666,925	1.57 %
2011	17,429,512	61 %	28,572,970	11,143,458	10.1 %	1,598,233	1.61 %
2010	15,831,279	56.3 %	28,119,500	12,288,222	2.4 %	368,770	1.66 %
2009	15,462,509	55.9 %	27,661,017	12,198,508	1.9 %	286,349	1.7 %
2008	15,176,160	55.8 %	27,197,419	12,021,259	1.9 %	287,212	1.75 %
2007	14,888,948	55.7 %	26,730,607	11,841,659	9.8 %	1,327,238	1.78 %
2006	13,561,710	51.6 %	26,263,048	12,701,338	8.1 %	1,017,269	1.81 %
2005	12,544,441	48.6 %	25,796,124	13,251,683	17.2 %	1,841,086	1.83 %
2004	10,703,355	42.3 %	25,332,026	14,628,671	23.1 %	2,006,231	1.86 %
2003	8,697,124	35 %	24,869,423	16,172,299	10.2 %	805,963	1.92 %
2002	7,891,161	32.3 %	24,401,977	16,510,816	23.6 %	1,505,227	2.01 %
2001	6,385,934	26.7 %	23,920,963	17,535,029	27.5 %	1,377,469	2.14 %
2000	5,008,465	21.4 %	23,420,751	18,412,286	77.7 %	2,190,679	2.28 %

Using the time coverage metric in tracking the network availability, the author [17] has reported that Maxis has a 4G coverage of 70% in the Klang Valley. In contrast, Celcom, Digi, and U-Mobile only have 58% (Figure 1.3). Figure 1.4 depicts that U-mobile provides the highest 4G and 3G network speed as compared to the other operators in March 2016.

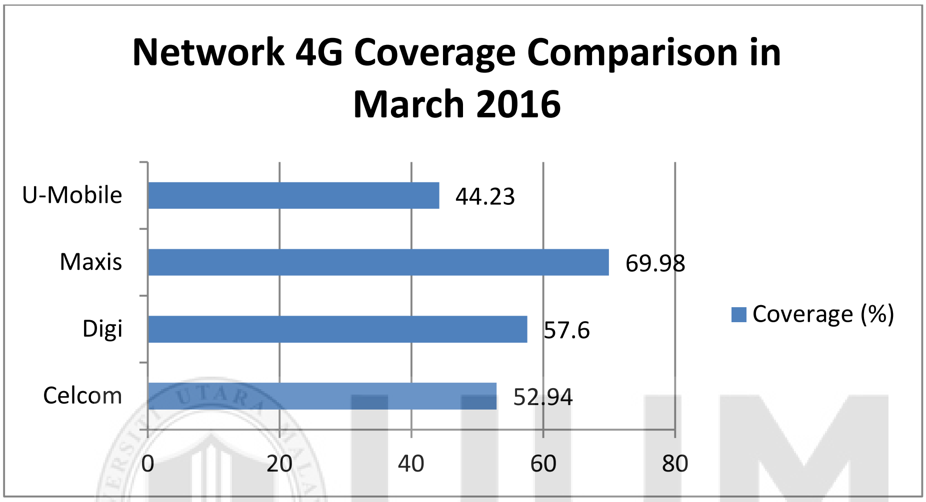


Figure 1.3 4G Network Coverage Comparison among Malaysian Operators in March 2016 (adopted from [17])

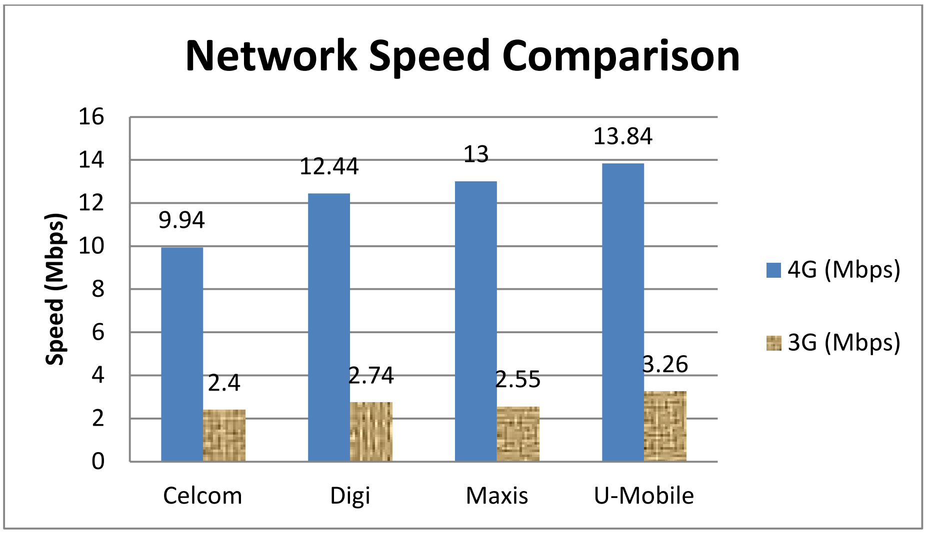


Figure 1.4 Network Speed Comparison between 4G and 3G among Malaysian Operators in March 2016 (adopted from [17])

Figure 1.5 shows the network latency comparison between 4G and 3G among the Malaysian operators. The measurement of the QoS performance in the network latency is obtained the time for data to create a round trip network. It is also significant to evaluate the reactive status of the 3G or 4G service. The network latency of the 4G technology of all the four operators is lower than the 3G.

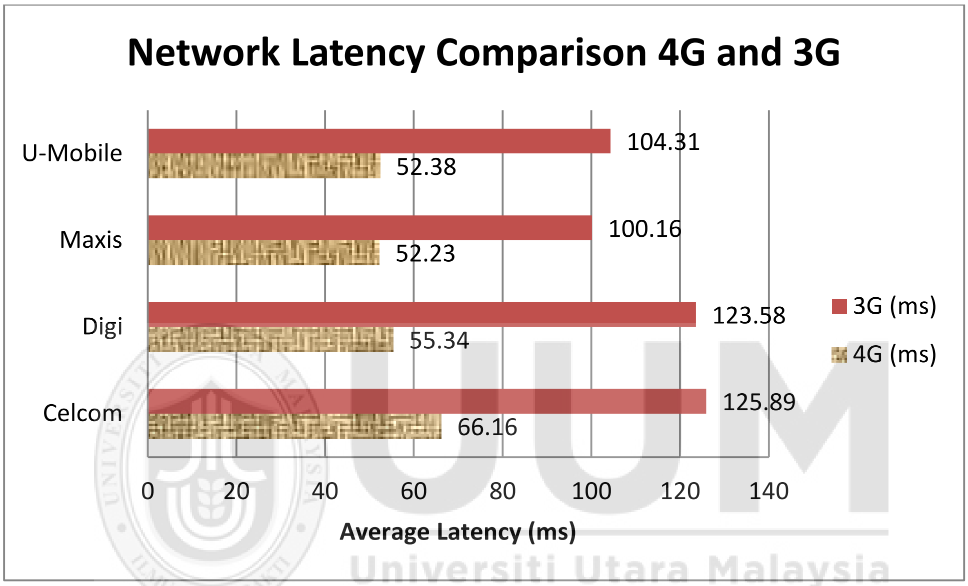


Figure 1.5 Network Latency Comparison between 4G and 3G among Malaysian Operators in March 2016 (adopted from [17])

Based on the above statistics, internet service providers in Malaysia are still competing among one another in providing the best QoS, especially in reducing the delay, packet loss, and handover latency. Most importantly, the providers or operators need to enhance the QoS to enable the delivery of the best service to consumers through faster data movement and no delays in the handover process.

1.3 Problem Statement

The interworking of heterogeneous wireless networks has been a challenge research and development issue in the past few years. VHO wireless networks will be leading in the future generation communication technology with the combination of different access wireless networks.

In metropolitan areas, most of the places have various network coverage across the same area. For instance, a busy hypermarket area in a city may have WLAN coverage, cellular networks like WiMAX, UMTS, LTE, and satellite networks. Having these multiple networks, when one of the access networks in a given area gets overloaded, other networks in the same area might persist loaded lightly. Consequently, the presence of multiple networks in the VHO wireless network overlaps with each other in coverage areas. Due to the inductive load throughout the various networks, which is caused by the inequality in radio resource allocation and low reliability which eventually increases packet loss, delay, and handover latency. Similarly, when AP is overloaded, features of VANET in terms of high speed, network size, active topology changes, and traffic density will affect the network performance [18].

The Radio Access Technology (RAT), usually based more on the Always Best Connected (ABC) standard which evaluated the existing attachment point of RSS with other available networks of RSS for handover decision making. As a consequence of the devices' availability and usability that required the RSS evaluation. The MNs are always aimed at the access networks which have the fastest or cheapest connection, the strongest and the smallest coverage. However, the different AP links are offered with different quality levels that are basically, achieved throughout MN’s roaming scanning procedures. Unfortunately, during the MN roaming process among the access points (APs) in WLAN, MN needs extra time to scan (passive and active) its wireless channel in looking for available APs to establish the connection. The connection may be lost due to its movement and changes in channel feature over the period when linking the MN to a specific AP. Therefore, MN has to transmit traffic flow to other APs to avoid connection breakdown. This could make a high variant between the load across multiple networks which congest the overloaded network and ultimately rises the dropping probabilities and call blocking. By reason of the various features and facilities of the different networks, the RSS parameter could not be revealed as a dependable trigger in the VHO wireless networks only. Thus, the prediction of the next wireless network connection with desirable quality attributes, which eventually supports low handover delay is highly required [19]. Furthermore, to accomplish end-to-end QoS assurance and seamless mobility for the clients, these matters must be cautiously addressed while the implementation of interworking and handover mechanisms of VANETs with different wireless networks by letting the RSUs in the VANET play an important role.

Consequently, the functionality of the 802.11 access point (AP) and 802.16 base station (BS), and LTE (4G) technology within different network coverage can be integrated by using the Media Independent Handover (MIH) IEEE 802.21. However, the MIH IEEE 802.21 only uses the interface type and signal strength for the interface selection. The majority of the existing studies have proposed the predefined threshold that uses RSS as the parameter to perform the handover selection. For example, [20] proposes a heuristic handover decision algorithm using a scheme based on the comparison between dynamic RSS-Threshold and current RSS from WLAN to 3G networks. At the same time, MN is linked to AP of the WLAN. As a result, dynamic RSS-Threshold can assist in decreasing unnecessary handover and handover failures. However, the dynamic RSS-Threshold method will reduce the network resources in terms of reliability because of the fluctuating RSS. Yan et al. [6] also used the heuristic method where the dynamic time threshold is estimated and evaluated the time between the cellular networks and WLAN. This approach minimizes handover failures and unnecessary handovers. However, the major drawback of this method is increased handover delay, which used the sampling and averaging of RSS points.

On the other hand, the traditional handover that only used the RSS as a single parameter is not adequate to create handover decision-making. Hence, the handover must use multi-criteria parameters such as RSS, available bandwidth, user preference, speed, and cost [21] [22][23]. However, the VHO may not take place only at the cell edge. But it can happen at any time depending on user preference and network conditions such as during the network congestion. In such a condition, the decision making about the triggering of a VHO referring to the QoS parameters and system performance becomes the integral concern. In other words, an efficient and effective VHO decision algorithm among of different access networks between Wi-Fi, WiMAX and LTE in VANET is required to increase resource utilization that can reduce delay, packet loss, and handover latency.

However, the handover mechanism is more complicated in various technology as the current systems are not adequate [24]. The RSS is not only a single parameter evaluate in VHO algorithms, but also other additional parameters are required such as monetary cost, interference power, network conditions, QoS, user preferences, and terminal capabilities that handover process can be increased significantly. Of this reason, the need to incorporate an adaptive predictive technique to find the most suitable AP is insistent. Through this research, an adaptive fuzzy logic approach was proposed to address the handover procedures issues across wireless networks.

1.4 Research Questions

Based on the above problem statement descriptions, three major research questions are highlighted in this research.

1. How to select the appropriate access point (AP) or base station (BS) networks during the vehicle movement through the available AP and BS in the heterogeneous network without degrading the performance of ongoing applications due to handover delay, packet loss, and handover latency?
2. What is the best vertical handover triggering mechanism that integrates multiple parameters in the information context of the handover decision algorithm? and
3. How to develop the intelligent network selection mechanism during the ongoing of the real-time applications to select the best access networks based on the vehicle-to-infrastructure (V2I) heterogeneous wireless networks?

1.5 Research Objectives

This research aims to design an intelligent network selection for minimizing handover delay, handover latency, and packet loss in the heterogeneous Vehicle-to-Infrastructure (V2I) wireless networks. The aim is followed by these objectives:

1. To design a new algorithm for candidate selection mechanism in a vertical handover decision algorithm to select the best qualified AP and BS candidates without degrading the performance of ongoing applications due to handover delay, packet loss, and handover latency.
2. To develop a handover triggering mechanism that integrates multiple attributes parameters using the information context of vertical handover decision in the vehicle-to-infrastructure (V2I) heterogeneous wireless networks.
3. To develop the performance evaluation of the intelligent network selection mechanism to select the best available access network in the vehicle-to-infrastructure (V2I) heterogeneous wireless networks.

1.6 Research Scope

This research focuses on developing the network selection mechanism for minimizing handover delay in the heterogeneous Vehicle-to-Infrastructure (V2I) wireless networks. Especially, the different generations of wireless communications such as WLAN-IEEE 802.11b, WiMAX, and LTE (4G), which are required a minimal number of handover latency, packet loss, and handover delay while maintaining maximum user satisfaction. Several requirement parameters handover mechanisms (e.g. handover latency, delay, packet loss, throughput, cost, user preferences, and velocity) then VHO decision algorithms will be utilized to evaluate and chooses the best access networks based on Vehicle-to-Infrastructure (V2I) heterogeneous wireless networks.

1.7 Research Steps

The following steps are taken to attain the aims of this research:

1. Review the existing research related to the handover mechanism requirements in the VHO wireless networks.
2. Conduct the comparative performance evaluation of the existing handover mechanisms in the VHO wireless networks to discover advantages and disadvantages.
3. Conduct the comparative performance of the handover decision mechanisms in VHO wireless networks.
4. Design the proposed performance model of the Vertical handover decision process in the Vehicle-to-Infrastructure (V2I) wireless networks.
5. Develop the proposed performance model of the vertical handover decision-making algorithm in the Vehicle-to-Infrastructure (V2I) wireless networks.
6. Evaluate the performance of the proposed network selection mechanism during the handover processing phases, delay, latency, and packet loss in the Vehicle-to-Infrastructure (V2I) wireless networks.

1.8 Significance of the Research

1. The review of the previous requirements of the handover wireless network will be utilized as a guideline for the following simulation experiments and VHO phases.
2. The appropriate performance model of the vertical handover decision for the Vehicle-to-Infrastructure (V2I) in the VHO wireless network is designed by integrating the network emulator traffic and simulation networks in three different access networks such as Wi-Fi, WiMAX, and LTE.
3. The Implementing and evaluating VHO decision within VANET multiple different access networks.
4. The comparative study of the proposed network selection mechanism uses handover decision algorithms such as fuzzy logic algorithm and multiple attribute decision making (MADM) algorithm to other decision-making algorithms.

1.9 Organization of the Thesis

This thesis is organized into seven chapters, as follows:

Chapter One provides an overview of the thesis as a whole. It begins by describing the related issues and highlighting the importance of the research. The problem statement and motivation in doing this research are also addressed in this chapter. Finally, the chapter ends by pointing out the research scope, objectives, steps, and significance.

Chapter Two consists of a literature review that analyzed the background resources on VANET and mobility management, which describes the framework for this study. It also describes the VANET characteristics and features like the essential keys for the VANET mobility Model and its main function in the VANET. The chapter reviews and classifies the current vertical handover decision mechanism in the handover decision of mobility management. The chapter concludes by comparing the different types of vehicular mobility models, VHO decision algorithms, and network simulation used for enhancing the VHO decision process in VANET.

Chapter Three presents the methodology which was undertaken in completing this research. The methodology comprises of three phases. The first phase reviews the preliminary studies that have been conducted to find suitable algorithms and techniques. The second phase discusses the design, development requirement, and criteria. This phase begins by introducing the two schemes which are used for designing the network selection mechanism, which are the Adaptive Handover Decision (AHD) and Fuzzy Logic and Simple Additive Weighting (F-SAW) Schemes. These two schemes are very important in a research experiment development where a simulation of VANET and Network Mobility traffic is used to conduct experiments on the traffic characteristics between Wi-Fi, WiMAX, and LTE technologies. The last phase covers the tests and results based on the problem, limitations, and assumptions of the research.

Chapter Four addresses the development of the Adaptive Handover Decision (AHD) scheme, which is a reflection of Chapter Three. The AHD scheme was implemented by using the Fuzzy logic algorithm which evaluates the handover process QoS performance and chooses the best among the AP or BS candidates based on several features. The results of the QoS handover from the experiment between AHD, RSS, and MIH-based schemes were analyzed and evaluated respectively to differentiate between Wi-Fi, WiMAX, and LTE wireless networks.

Chapter Five presents the sequence events handover link triggering the status process. This chapter elaborates on the detailed process of the link triggering the status event of VHO in VANET by using two algorithms; Fuzzy logic and SAW algorithms as known as the F-SAW scheme, which was then integrated with the MIH mechanism. It also discusses the evaluation of two different vertical handover decision schemes; F-SAW and RSS-Threshold schemes for reducing the time of handover link trigger process.

Chapter Six is about selecting the best network in the heterogeneous vehicular networks. This chapter explains the proposed F-SAW scheme, which was used to develop an intelligent network selection mechanism process for V2I wireless networks (LTE, WiMAX, and Wi-Fi). The results are then discussed and evaluated through the verification and validation by comparing the results of the F-SAW scheme with other existing schemes.

Chapter Seven concludes the thesis by summarizing the whole research and highlighting the contributions and limitations of the research and the possible future work.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

This chapter begins by presenting the overview of vehicular ad hoc network (VANET) and mobility management from several perspectives. For example, VANET focuses on the vehicle-to-infrastructure (V2I) to create a more realistic traffic mobility vehicle of a real-world scenario. The implementation of the real traffic light topology includes the development of network architecture, mobility model, routing protocols, and safety communication. The mobility management explains in detail about three phases of handover management, namely handover information gathering (initiation), handover decision, and handover execution. This is followed by analyses on the related works done by previous researchers. The discussions also cover various methods and strategies used to overcome the network selection mechanism in the handover decision problem.

2.2 Overview of the Vehicular Ad-Hoc Networks (VANETs)

VANETs are the subgroup of Mobile Ad-hoc Network (MANET), which represents networks-vehicles collaboration in a particular communication environment. VANETs can be classified into Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I). V2V allows direct communication among available cars, while V2I allows communication between vehicles and infrastructure (also known as a roadside unit-RSU) [25]. VANETs are also described as autonomous and self-configured ad-hoc networks. VANETs are the reliable establishment of vehicle networks used for communication purposes in highway or urban environments. Figure 2.1 illustrates the CAR 2 CAR Communication Consortium (C2C-CC) reference architecture and communication networks comprised of the ad-hoc, infrastructure, and in-vehicle.

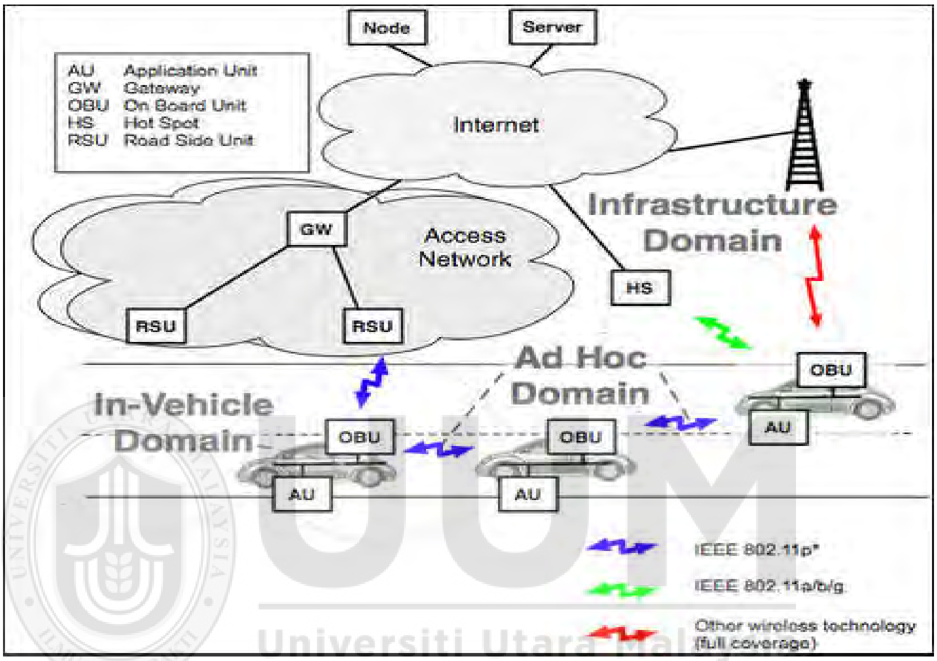


Figure 2.1 C2C-CC Reference Architecture and Communication Networks (adopted from [26])

Figure 2.1 depicts the types and characteristics of C2C-CC architecture and communication networks in VANET. There are three types of domains in connection with VANET, which are in-vehicle, ad hoc, infrastructure domains. Therefore, the vehicle domain is connected between the on-board unit (OBU) and roadside unit (RSU), while the ad hoc domain is linked using OBU of V2V. However, the infrastructure domain shown by links through OBU of vehicle and BS. This study focuses on the infrastructure domain.

VANETs are differentiated from MANET in terms of the node movement features, network architectures, and new application scenarios combination. Several features of VANETs are listed as follows;

1. High Mobility and Dynamic Topology

   Since the movement on highways is very fast, the communication range between each vehicle will always remain, while the connection is promptly established and disconnected. Therefore, in VANETs are not suitable the routing protocols in MANET, especially when the velocity of vehicles are low before the new routes can be rebuilt [26].

2. Mobility Modeling and Prediction

   Prediction on the future location of a vehicle should be made when the speed and street map are provided because vehicle nodes are typically restricted by pre-accumulated roads, streets, and highways. Vehicles move along pre-identified paths that offer an opportunity to evaluate how long the paths would last compared to the arbitrary motion patterns such as the random waypoint model used in MANETs.

3. Available Geographic Position

   Recently, hybrid and modern vehicles provide accurate geographic positioning systems (GPS) combined with electronic maps. This helps to prepare location information for routing purposes.

4. Hard Delay Constraints

Even without high data rates, the network in VANETs application has tough delay limits. The most significant highest delay is pre-crash sensing or collision warning.

5. Unlimited Battery Power and Storage

According to [27], the process cycle optimization is not equally related to sensor networks since the vehicles in VANETs do not have problems related to power and storage capacity restriction as experienced by the sensor networks.

2.2.1 Related works in VANETs

Since 1999, the Federal Communication Commission (FCC) provided the frequency spectrum for V2V and V2I in VANET. The Dedicated Short Range Communication (DSRC) service for V2V communication was then established in 2003. At this time, vehicles are recognized as computers on wheels or mobile nodes in the networks. Therefore, equipping the frequency spectrum and enabling services beacons for the vehicles and roadside in forming the VANETs are necessary to allow wireless linkages between all nodes without central access point [26]. In VANETs, the four main fields to be studied include mobility modeling, scalability issues, efficient channel utilization, and security and privacy.

1. Mobility Modeling

Mobility modeling is a difficult task in characterizing the motion of a vehicle on the road because the vehicular traffic flow can be divided into two parts; macroscopic and microscopic [28]. As reported by Harri and Bonnet (2006) in [29], the macroscopic method defines action limits such as traffic lights, crossroads, streets, and roads. In addition, the vehicular traffic of generation such as traffic flows, initial vehicle distributions, and traffic density is defined. In contrast, the microscopic represents the movement and behavior of each vehicle with respect to others. Moreover, the vehicular mobility model can be classified into dissimilar classes [30]. Tables 2.1 and Table 2.2 show the classification of vehicular mobility model and summary on related existing studies.

Table 2.1

Comparison of Vehicular Mobility Model Classes

Category Model	**Description**	**Example**
Synthetic	A mathematical model.	Stochastic, Traffic Stream, Car-Following, Queue, Behavioural Models.
Survey-Based	Macroscopic mobility information survey source.	Realistic human behavior – data collection on human activities.
Trace-Based	Mobility patterns are formed from traces of actual mobility.	Mobility traces
Traffic Simulator-Based	Vehicular mobility traces are extracted from detailed traffic simulator.	Corridor Simulation (CORSIM), Parallel Microscopic Simulation of Road Traffic (PARAMICS), Transportation Analysis and Simulation System TRANSIMS)
Urban Vehicular Mobility	The street is a key factor forcing nodes to confine their movements to well-defined paths regardless of destination.	Traffic Sign Model and Stop Sign Model
Street Random Waypoint (STRAW) Mobility	The street mobility model incorporates the use of a simple car according to the real traffic condition model.	Intra-segment & Inter-segment Mobility

Table 2.2

Summary of Existing Studies on Vehicular Mobility Models

Category	Feature	Objectives	Mobility Generator Model	Author(s)
Macro-Model	i) Road topology ii) Road characteristics iii) Movement Patterns Selection	i) User-defined graph, topology map extracted from Geographic Data File (GDF), TIGER map, and Voronoi graph clustered. ii) Several lanes or directed traffic movements speed limits or procedures for crossing intersections. iii) Trip generation module like the generation of random trip and activity sequences.	VANETMobiSim	[29][31][32] [33][34]
Micro-Model	i) Smooth speed variations ii) Vehicle queues iii) Traffic jams	i) In a deterministic way. ii) In a single lane situation, as a feature of nearby vehicle behavior. iii) In a multi-flow interaction like an urban scenario, as a function of nearby vehicle activity.	i) CanuMobiSim ii) VANETMobiSim iii) SUMO iv) CityMob v) STRAW vi) FreeSim	[35][36][37][38] [39][40][41] [42] [43][44][45][46]

On the other hand, the realistic vehicular mobility model in VANET plays an essential role in ensuring that the conclusion drawn from the simulation experiments will be carried out through the deployment of real scenarios [47]. For example, the used of traffic lights to regulate traffics flow that is moving in different directions, according to the driver's choice of route, and based on car overtaking behavior.

2. Scalability Issues

Scalability is a very crucial characteristic in handling large networks or distributed system. This includes the ability to cover additional nodes or objects without suffering from a noticeable loss of performance or increased complexity matters [48]. The main difficulty in VANETs is the operability process during deployment because of the highly overloaded networks such as traffic jams and major intersection roads. By right, VANETs must function in a very low density of road traffic conditions. The High-Density road traffic will be increased the number of active nodes (vehicles) and protocol designs which are given a great impact on scalability [49].

Moreover, securing the VANET from black hole attacks meant the malicious node drops the sender packet before transmitting to the receiver will give a negative impact on the scalability network performance [50]. Hence, the authors in [51] have proposed the upgrading of the VANET performance in high-density traffic scenarios by improving the connection time and data delivery ratio to enable reliable data dissemination. As mentioned by [52] that the network output under VANETs was affected by different routing protocols. As a result, shown OLSR performs better than DSDV and AODV routing protocols while the number density or nodes' velocity increases.

3. Efficient Channel Utilization

In VANET, seamless connectivity is necessary for better coverage and optimal use of the platform. Therefore, The high speed of vehicles and smaller gaps in coverage are significant challenges in ensuring a smooth transition from one RSU to another. In [53][54], the proactive handover technique of the performance evaluation was proposed with beacon frequency, vehicle velocity, and size. The results point out that there is a relationship between network dwelling time, velocity, and beaconing in understanding the cumulative effect of the beaconing as well as the probability of being affected by the vehicle velocity. Besides, the author in [55] has integrated the Agent Communication Model (IACM) with five predefined model agents that performed specific tasks to evaluate congestion-free, cooperative, effective channel usage, energy-conserving, and optimized connectivity across all VANET nodes. This study was investigated and analyzed the handover processes performance parameters like handover latency, delay, packet loss, and handover success ratio for increasing the QoS.

4. Security and Privacy

Security is vital in the VANET environment because an open service network needs to be available to the public on any road at any time. For instance, it is vital to ensure that an intruder or hacker is not targeting and manipulating the life-critical information. Nowadays, vehicles are not only just for transportation purposes but also are prepared with a wide variety of sensors with valuable data. Hence, VANETs allow vehicles to connect by enabling the sharing and collecting of data for decision-making and safe driving. However, most importantly, the vehicular networks need to be secured from any cyber-attack or hacker. Authors in [56] have discussed the significance of a variety of security and privacy challenges in the vehicular Internet. The important issue raised is regarding the method of sharing data by a voluntary person or sharing it after anonymizing, which has a higher risk. Another study by [57], introduces two authentication schemes in wireless LAN, proxy re-encryption, and new proxy re-encryption, to reduce the overhead process the roaming authentication. The result indicates that using the new authentication scheme is better than the previous in terms of reducing the basic overhead of privacy, security, and authentication during the roaming activities in a network.

The study by [58] presents generalized protection measures that are focused on methods of prevention and detection. Many VANET applications need stack-wide protection of support for detection-based mechanisms, rather than individual layer stacking of the network protocol. However, the study does not cover QoS security, especially for reducing the handover measurement metrics such as overhead signaling, delay, latency, and packet loss towards having more reliable and available vehicular networks.

2.3 Mobility Management Overview

Mobile communication networks have gone through many significant tests over the past several years in providing consumers with improved quality of cellular data and network services. Various ISPs have contributed and provided the medium to increase data rates and enhance communication QoS in fulfilling users' requirements. Due to the heavy use of heterogeneous networking technologies in providing more flexibility for mobile users, mobility is a significant problem in the management of wireless communication technologies. Besides, the multi-services network offers various range of services, particularly seamless connectivity that represents coverage and location-aware services as well as IP-based real-time multimedia [59].

Mobility management includes two types: localization and handover management, as shown in Figure 2.2. The Location Management (LM) administers the location update and call delivery that permits a network to identify the new Attachment Point (PoA)from a mobile node for making a call distribution. The location update (also known as registration), on the other hand, allows user's authentication by updating the location of the mobile user. During the process of system discovery, the mobile node (MN) will identify a new access network base station, permit user authentication, and update the user's location profile. The network can also monitor MN 's position at the same time. On the other hand, the call distribution is responsible for handling the terminal paging and database queries [60].

The handover management (HM) allocates MNs to connect to their network infrastructure and intends to use the MN throughout the switch from one single coverage area to another PoA. The HM is categorized into two parts: horizontal and vertical handovers. The horizontal handover (also known as homogeneous or intra-system handover) refers to the processes in the same network but performed in different cells, while the vertical handover (VHO) (also known as heterogeneous or inter-system handover) concerns about different network technologies.

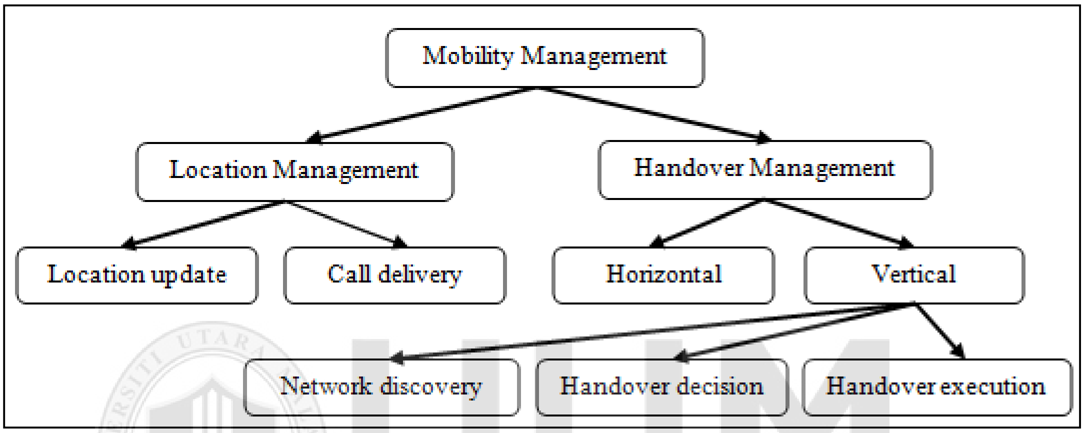


Figure 2.2 Mobility Management Process

A homogeneous network typically requires horizontal connectivity, whereas a router is not accessible due to the mobile terminal (MT) movement. For example, two horizontal transformation processes signify the change in the signal transmission MT from AP to other AP networks (e.g. IEEE 802.11 standard to the IEEE 802.11 geographic neighboring standard). Nevertheless, the vertical handover phase in the heterogeneous network refers to the transition in radio signal communication among WLAN AP and BS, which overlaid the cellular network. Seamlessness and network switching are critical handover management processes that should be investigated further. Hence, this research focuses on the three phases of the VHO process, which consist of handover information gathering, handover decision, and handover execution.

2.3.1 Vertical Handover Overview

The main concern of the VHO relates to the sustaining of the running services even when the IP addresses, network interfaces, and QoS characteristics are changing in various networks. Therefore, in discussing the related handover topics, the three main phases must be taken into consideration; handover information gathering and initiation, handover decision, and handover execution [59] [61] as depicted in Figure 2.3. The three phases are discussed in detail in the subsequent sections.

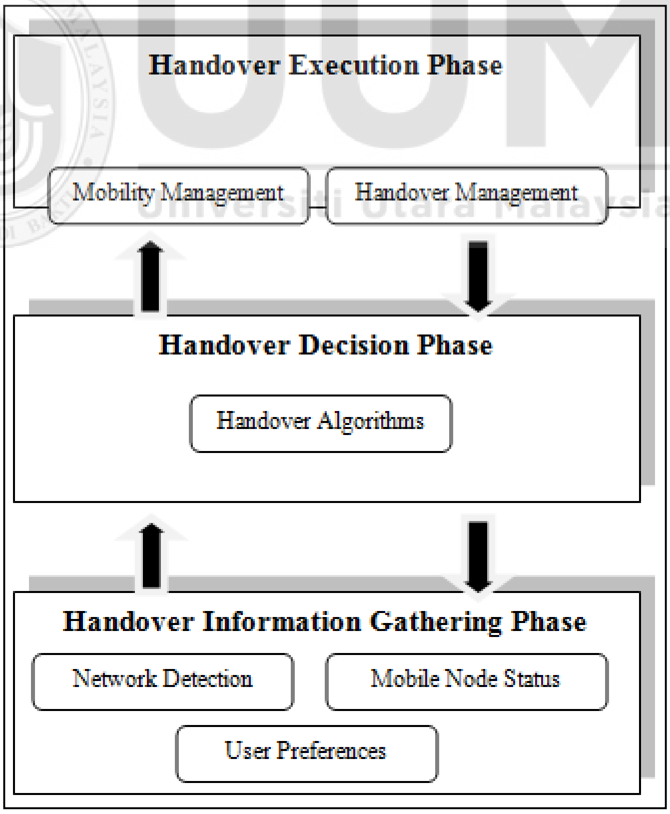


Figure 2.3 Handover Management Process

This research focuses on assessing the VHO of the QoS performance which related to the decision-making process in vehicular ad hoc heterogeneous wireless networks. The VHO may be affected by several issues such as handover and mobility protocols as represented in Figure 2.4.

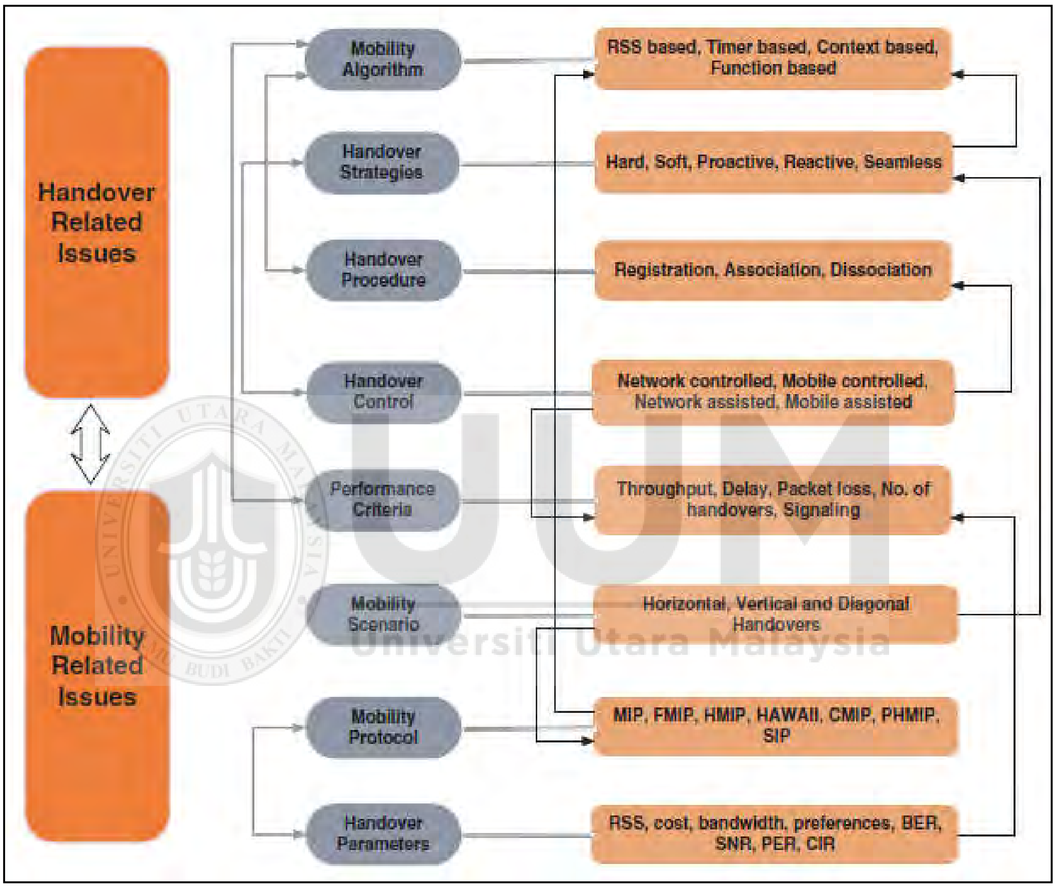


Figure 2.4 Mobility Management and Handover Related Issues (adopted from [59])

1. Handover Information Gathering (Initiation)

In the first phase, handover initiation, also known as system discovery. This is a detailed particular of the required information to assess the importance of a handover process. This comprised of both the network and system information such as mobile devices status, network attributes, access stages, and user preferences, as shown in Table 2.3. The information also represents the handover metrics, which refer to various measurable qualities in determining whether the handover initiation is required or not [62]. The information initiation is usually prepared based on the recommendation made by [55].

Table 2.3

Handover Information Gathering Classification

Data Information Collection	**Description**
Network detection in neighboring network	RSS, handover rate, cost, throughput, packet loss ratio, signal to interference ratio (SIR), noise signal ratio (NSR), bit error ratio (BER), carrier to interference ratio (CIR), location, distance, and QoS parameters.
Mobile node status	Resources, speed, battery status, and service category.
User preferences	Monetary cost, budget, and services

This first phase is crucial to collect adequate comprehensive information so that the handover process can achieve the “Always Best Connected” requirement. Thus, the handover decision phase can be performed to achieve accurate decision-making.

There are many pre-requisites and measures for an efficient handover found in the literature. Among the various handover parameters requirements and performance criteria are elaborated as follows:

a. Handover Parameters

1. Available bandwidth: The frequency forms (lower and upper) within a frequency continuity package. The bandwidth is typically estimated in kilobits per second (kbps) or megabits per second (Mbps).
2. Received Signal Strength (RSS): The most vital aspect that gives information about the power level obtained from the base station areas. The signal starts to reduce as users move away from the current access point (AP).
3. Signal Noise Ratio (SNR): SNR is a significant parameter that influences and reveals the QoS of a network.
4. Carrier to Interference Ratio (CIR or C/I): Also called the signal-to-interference ratio, which refers to the proportion between the average received modulated *carrier* power indicated as S or C and the average received co-channel *interference* power denoted as I (e.g., cross-talk).
5. Bit error rate (BER): This is the number of errors divided by the total number of bits transmitted over an interval of time.
6. User preference: The option of a user in choosing a particular network in the heterogeneous network circumstance.
7. Monetary cost: The cost of money that has been utilized to access the network.
8. Delay: It refers to how long it takes for a packet to switch from source to destination.

b. Handover Performance Criteria

i. Handover moment: Also known as handover location that provides a handover without degrading the QoS position. The handover moment should be carefully designed to obtain optimal values embracing an overlapped area of the old and new access point in the coverage network. The outside area might contain more noise and interference of the signal, which takes up the connection and slow down the handover movement.

ii. Unnecessary handovers: The most efficient mechanism should be able to decrease the value of unnecessary handovers. The signal strength algorithms will be used to decide on the handover moment and determine the distance to the access point. In one case, a mobile terminal moves near to the borderline of the coverage area when the algorithm starts determining the handover period. The measurement errors during this procedure can contribute to unnecessary handovers, which can contribute to higher energy use and possible degradation of the supported QoS.

iii. Handover delay: The delay is measured from the execution of the algorithm until its completion, while the MT is successfully connected to the other AP. If a handover takes too long, service disruption can occur, or connections can reach time out and will be lost.

iv. Handover Latency: This should be less for better seamless handover, which occurs when a mobile node accesses a new network without disconnecting the current network.

v. Throughput: The average data rate does travel successfully via the channel. The higher-throughput transfer is beneficial to the network.

vi. Handover failure probability: It happens because of the target network does not fulfil the requirement of resources during the initial of the handover process.

2. Handover Decision

Handover decision is a crucial and key step in each of the handover processes [59]. It is used to identify and determine the most suitable network access and communicate directives to the execution phase. The execution phase is also recognized as system selection. Based on the information initiation, this phase will determine the time and location based on the MN handover trigger. The precise timing of an effective handover is referred to similar the word 'When,' whereas 'Where' is the discovery of a suitable network that meets the mobile switching criteria. Several studies in the literature present related discussions on the categorization of VHO decision schemes [52, 53, 54, 55, 56, 57]. Based on the existing works, the author in [67] mentioned that The VHO decision-making schemes could be divided into five groups, referring to the decision-making criteria and methodologies used for processing the handover parameters as shown in Figure 2.5.

In a heterogeneous network, the HO decision policy must be measured using multiple criteria. The list of criteria can be static and dynamic based on the occurrence and the reasons for the changes. Static criteria are the monetary costing and user profile, while dynamic criteria are the number of mobile nodes, velocity, and RSS. Thus, the integration of each of these criteria with the dynamic process can increase conflict situation and complexity in the handover decision process. The conflict and complexity trouble can be overcome with a network selection algorithm, user-centric algorithm, context-aware algorithm, and multi-criteria algorithm.

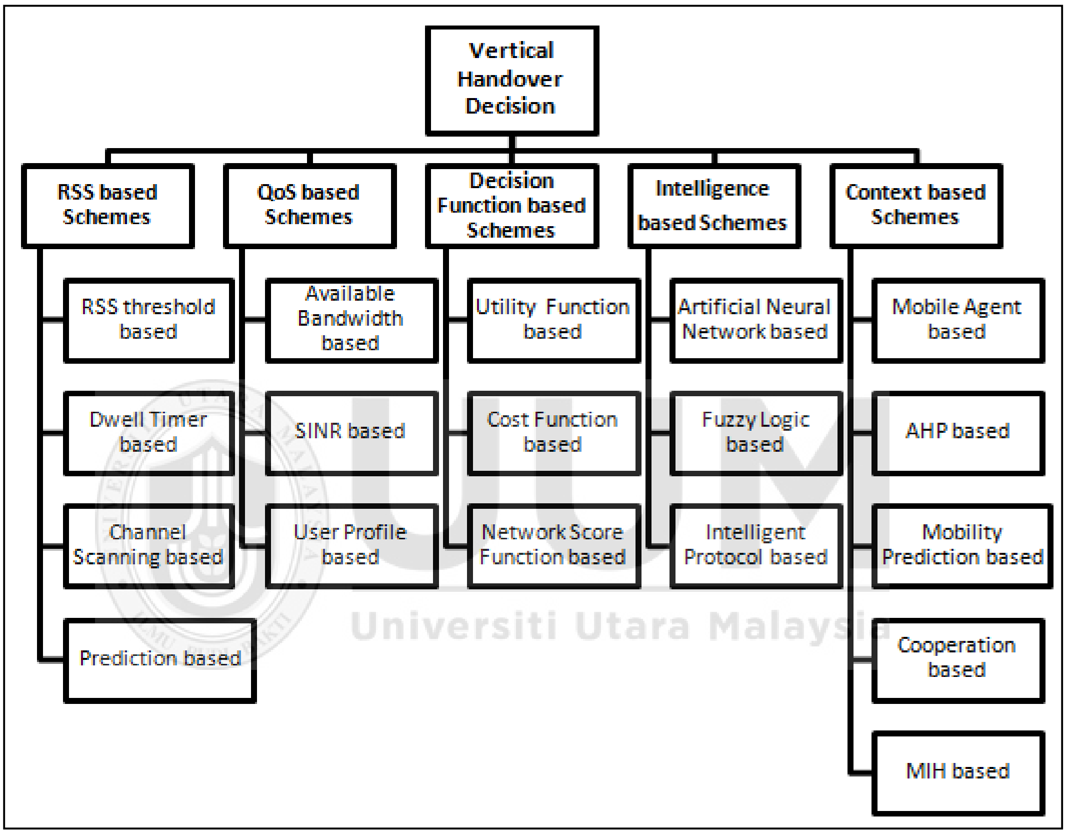


Figure 2.5 Categorization of Vertical Handover Decision Schemes (adopted from [59])

a. RSS-based Schemes

The four classifications of the RSS-based scheme are RSS-Threshold, dwell timer, channel scanning, and prediction based. During the past years, most of studies referred to this scheme because of its availability and the simplicity of hardware tools needed by the measurement. In this scheme, RSS value is the only criterion examined for decision making, while the others are only employed to support the handover procedure. Figure 2.6 shows the RSS-based scheme procedures.

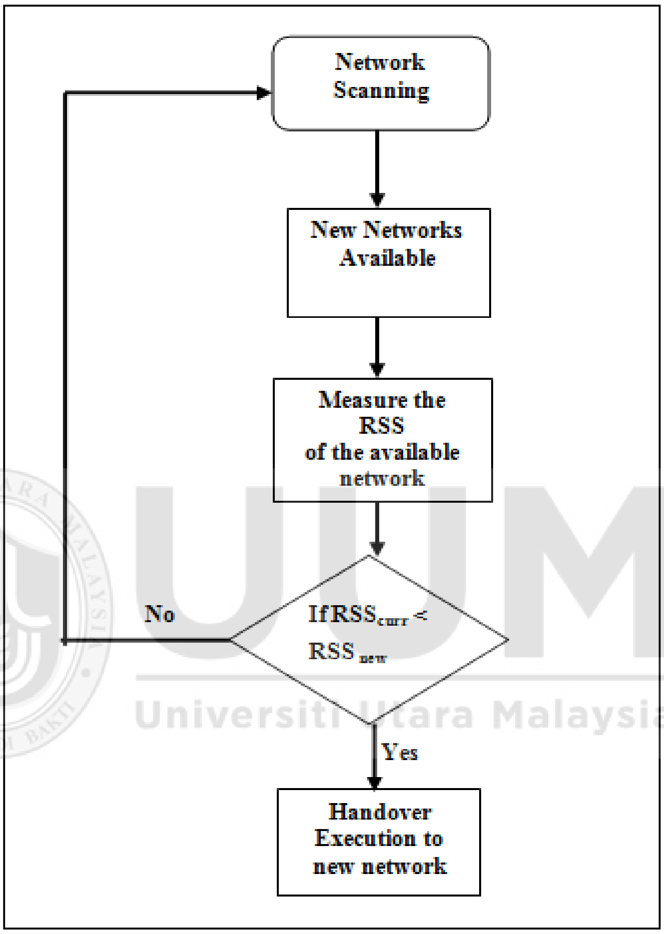


Figure 2.6 Flowchart of the RSS-based Scheme Procedure Process (adopted from [59])

The followings are detail descriptions of the four RSS-based schemes classifications:

i. RSS Threshold-based

RSS Threshold-based is a method used to dynamically receive only meaningful signal strength threshold (S_{dth}) by reducing false handover and controlling handover failures. Hence, Akyildiz and Mohanty in [20] proposed the combination of the WLAN and 3G to compare the dynamic RSS-Threshold and current RSS handover decision methods. As a result, it is evidenced that the method can reduce false handover and decrease the possibility of handover failure. Nonetheless, the method is found to cause wastage of network resources because of MN was triggered unnecessarily and wrongly. The dynamic RSS-Threshold (S_{dth}) method uses the calculation shown in Equation 2.1.

$$S_{dth} = RSS_{min} + 10\beta log10\left(\frac{d}{d-L_{BA}}\right) + \varepsilon \tag{2.1}$$

The RSS_{min} refers to the minimum level of RSS for the connection between a MN and WLAN AP. The β symbol represents the path loss coefficient. The length and shortest distance are represented by d and L_{BA} of the WLAN cell boundary, while ε represents a zero-mean Gaussian random variable.

In contrast, the author in [6] introduced the prediction traveling distance method to compare the handover decision threshold for minimizing the handover failures and unnecessary handover from a cellular network to a WLAN. The formula of this prediction method is represented by Equation 2.2.

$$t_{wlan} = \frac{R^2 - l_{os}^2 + V^2(t_s - t_{in})^2}{V^2(t_s - t_{in})} \tag{2.2}$$

R denotes the WLAN cell radius, while l_{os} is the distance from the RSS of point to WLAN AP. The MN velocity is *V,* the time taken by the RSS sample is t_s, and the time for a mobile node to get access to the WLAN coverage is t_{in}. Despite reducing handover failures and unnecessary handovers, the key problem of this approach is the increased in the handover delay because of the use of the RSS point sampling and averaging.

The author in [68] presented the survey results of the various vertical handover decision algorithms. From the analysis, the RSS-Threshold based algorithm is used to examine the optimal selection of networks. The $RSS_{Threshold}$ algorithm used to experiment with the handover initiation is stated as if the current RSS access network ($RSS_{serving}$) is lower than the handover threshold (*THO*) and the value of the RSS alternate network (RSS_{alt}). The RSS_{alt} gets high value rather than RSS current access network and hysteresis margin (H). The formula to represent the algorithm is stated in Equation 2.3.

$$RSS_{Threshold} = \left(RSS_{serving} < THO\right) \cap \left(RSS_{alt} > RSS_{Serving} + H\right) \qquad (2.3)$$

From the analysis, it reported that the RSS-Threshold based algorithm could only be enhanced in terms of the available bandwidth but not in terms of the major drawback, which is the increase in packet delay.

ii. Dwell-timer based

Dwell-timer based, one of the classes in this method, analyzes the effect of handover dwell time on the channel holding time and system performance to avoid the probability of new and handover call blockings that might affect the performance of the conventional holding time networks [69]. There are several numbers of research that looked into this dwell-timer based area. For instance, the authors in [70] have introduced a technique to estimate the appropriate timing initiation of the vertical handover that is important in reducing the probability of failure and unnecessary handovers.

In other words, to achieve the objectives of their study, three different techniques, such as signal trend detection, adaptive threshold fixing, and dwell timer for fast-moving terminals were generated together. However, the result indicates that the scheme has successfully achieved the aims of reducing failure and unnecessary handover, which is to increase the value of packet losses. As mentioned by Zaini et al. in [71], the comparative dwelling time prediction with a call holding time will allow MNs to decide on a suitable network by minimizing the VHO. The author in [72] also proposed a predictive fast handover technique design and protocol using a dwell time algorithm to reduce the handover delay. The technique was designed for IEEE 802.11.

iii. Channel Scanning based

The channel scanning scheme is a process of combining the RSS and estimated lifetime scanning for evaluating the handover time. This combination is usually used to perform the two conditions described in Equation 2.4.

$$(RSS_{current} < Threshold) \cap (Estimated\ lifetime\ \leq Handover\ Latency) \qquad (2.4)$$

The combination of the RSS, estimate lifetime, and available bandwidth parameters was established by [73] and [74] to generate the WLAN network candidate before entering the 3G network coverage. The evaluated average of the current RSS and lifetime parameter will be examined with the RSS change rates (new RSS) and other required QoS parameters using Equation 2.4. By using the lifetime parameter, this scheme can enhance the average throughput before the handover movement of the mobile node to 3G, while decreasing unnecessary handovers. However, the bad channel condition will be affected by the increased packet delay flow because of the lifetime metric utilization.

To overcome the handover performance reduction issues, [75] created an application-aware mechanism for generating efficient real-time multimedia services QoS. The simulation results revealed that the QoS degrading and power signaling overhead minimization can be avoided by using this mechanism. Unfortunately, active scanning involves a long process that will eventually increase the number of packet loss because of the interruption problem in the VoIP service.

iv. Prediction based

This scheme uses predictive RSS-Threshold to enable high-speed nodes to achieve service connection. The same handover technique was used by [76] to predict the signal quality between different accessible networks (WiMAX and LTE networks) in reducing the number of unnecessary handovers probability. This prediction uses a dynamic regressive integrated moving average (DRIMA) model for tracking the signal strength on the handover activities of the cross-layers 2 and 3. As a result, the total handover latency was reduced.

The handover predictive trigger method, another way of reducing the number of handover failures, was introduced by [77] to attain faster handover in a wireless LAN system. The investigation involved a different set of RSS values in time windows, which indicates the compensating prediction error can reduce the L2 handover triggers. However, this method might increase the handover delay because of the high overhead signaling.

Ghosh et al. [78] mentioned that it is needed to study at handover as MNs or vehicles travel between RSUs since various applications have seamless communication. Besides, the traditional handover models are not capable of handling the small coverage areas and high velocity of vehicles that have a similar presentation of a vehicular environment, as illustrated in Figure 2.7.

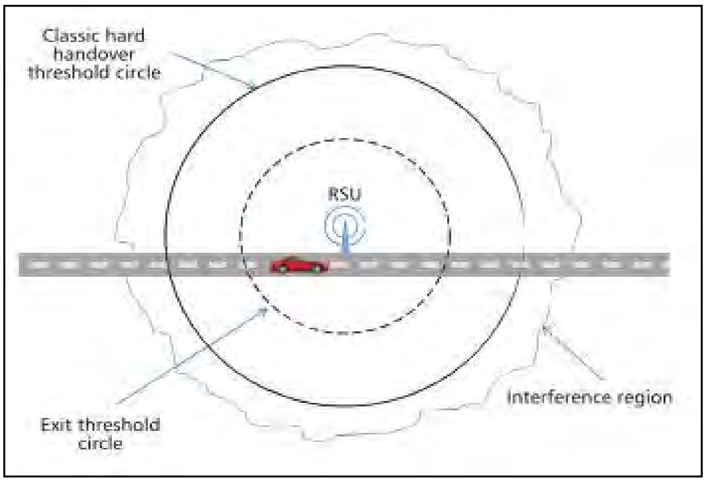


Figure 2.7 Hard Handover over Threshold Circle (adopted from [78])

Figure 2.7 shows the hard handover over the threshold circle in mobile communication illustrated by the hard barrier. The exit threshold is represented by the dotted around within the tough barrier. The way out of the threshold circle shows the boundary from which to begin the handover before hitting the hard barrier. Thus, for a successful soft handover, this might be needed. The disconnection in communication will happen if the handover is not successful. Currently, this model is being applied in mobile communications. However, it has been concerned with two obstacles in VANETs, which is a highly mobile situation. First, the release radius depends on the MN's velocity when a soft transition is not made at high velocities. Second, the hard handover circle determines the coverage area. The actual communication in the outside area is also complicated due to the likelihood of receiving error packets due to the poor signal-to-noise ratio (SNR). Thus, another algorithm is required to offer a rational boundary for handover to perform service continuity and high-performance QoS in a heterogeneous environment.

b. Quality of Services (QoS) Based Schemes

The author in [59] focused on the QoS based schemes by enhancing the QoS via several parameters such as user preferences, SINR, and ABW. Figure 2.8 illustrates the procedure of the QoS-based scheme.

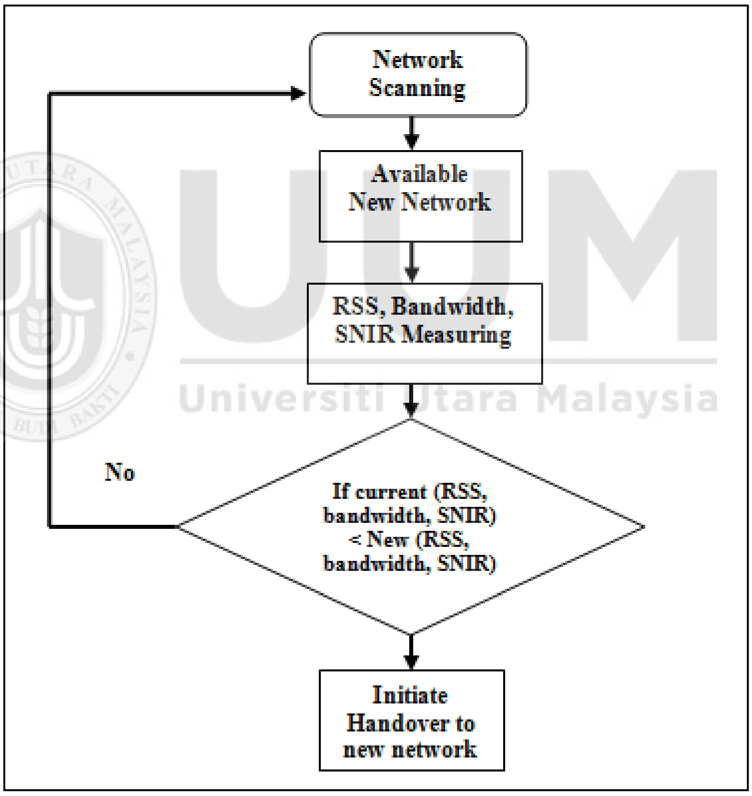


Figure 2.8 Flowchart of the QoS-based Scheme Procedure (adopted from [59])

i. Available bandwidth-based

Available bandwidth-based is examined for attaining the vertical handover upper throughput. In [79], the author has evaluated user preference and available bandwidth metrics for VHO decisions between different access networks. Based on the application type and ABW, which represent the key to the handover decision criterion, the proposed scheme reaches lower handover latency and higher throughput. However, the major drawback of this scheme reveals that the highest blocking rate for new incoming applications due to the idle state of the handover process.

Using a similar scheme, authors in [80] recommended the integration of the cellular networks system and WLAN for resource allocation and mobile management by using the RSS, coverage area, and ABW parameters for continuous handover mobility. This method helps in obtaining better load balancing and maximizing the battery life of the mobile nodes by limiting the switching processing (on/off). Hence, it can reduce the Ping-Pong effect and some unnecessary handovers.

ii. Signal-to-interference-plus-noise ratio (SINR) based

The SINR scheme concerns with maximizing the resource allocation and reservation during a handover. The author in [81] proposed the combination of SAW and AHP methods that were implemented with the SINR, considered as decision parameters. Most importantly, if all information were provided with traffic cost, network requirement, and available bandwidth, the accessible wireless network can still be achieved.

iii. Network Profile-based Scheme

This scheme focuses on optimizing the previous end-to-end QoS performance of the vertical handover process. Using the conventional QoS metric (e.g., RSS), the handover decision in choosing the best possible network cannot be carried out. Therefore, the authors in [82][83] emphasized the importance of monitoring several other technology-specific techniques that influence the vertical handover process. For instance, modulation, coding scheme, schedule mechanism, and power control. The authors have also identified two categories of the QoS handover procedure issues that relate to the cost mechanism function. Thus, they have modeled their research based on these two criteria. Firstly, it reduces the power strategy that manages a minimum level of QoS, such as a bit error rate. Secondly, the handover strategy decreases the ping-pong effect to minimize the number of handovers towards selecting the APs candidate. This scheme has improved in achieving the lowest level of QoS by reducing the valuable wireless resources, and the number of handovers as well as maintaining the battery level in choosing the best possible network for handover.

c. Decision Functions-based Schemes

The decision function-based method is also known as Multiple Attribute Decision Making (MADM). This method becomes more complex because of the multi-criteria decision-making problem and selection process. Moreover, it involves multiple parameters (e.g. QoS, cost function, and reliability) because of the contradiction criteria. The MADM method provides several algorithms such as Simple Additive Weighting (SAW), Techniques for Order Preference by Similarity to Ideal Solution (TOPSIS), Analytic Hierarchy Process (AHP), Grey Relational Analysis (GRA), and Multiplicative Exponential Weighting (MEW).

Based on the existing studies, most researchers used different methods to achieve the best network selection by utilizing various possible techniques and parameters. The following subsections describe the mathematical models used in the above mentioned formal techniques.

i. Simple Additive Weighting (SAW)

The SAW technique, also named as the weighted sum algorithm, is mostly used in the MADM method of the network selection related studies to calculate the multi-criteria parameters in the heterogeneous wireless network. This technique provides a weighted sum of normalization to each parameter of the overall available network coverage. There are comparative normalization scales among the parameters consisting of the highest or lowest score in targeting the most suitable network. For instance, let the list of the network candidates to consider several parameters represented by n. Then the score for each candidate i is defined as SAW_i as depicted in Equation 2.5. r_{ij} is utilized as the normalized performance rating of parameter j on network i, and w_j is the weight of parameter j. As a rule, the highest score signifies the most suitable target for a candidate in the network.

$$SAW_i = \sum_{j=1}^{n} w_j r_{ij} \tag{2.5}$$

ii. The Techniques for Order Preference by Similarity to Ideal Solution (TOPSIS)

The TOPSIS technique clarifies an approach of choosing the nearest network candidate to the best, whereas the farthest from the worst possible solution. This will result in recommending the best possible solution based on the appropriate possible values of each parameter. The score, $TOPSIS_i$, of every network candidate i is obtained from the highest value, as shown in Equation 2.6.

$$TOPSIS_i = \frac{D_{w,i}}{D_{b,i} + D_{w,i}} \tag{2.6}$$

$D_{w,i}$ and $D_{b,i}$ are defined in Equations 2.7 and 2.8, respectively. Both equations use the Mathematical Euclidean Distance as two points on the network i between the worst (w) and best (b) networks. The r_{ij} represents the normalization performance value of parameter j with the network i. However, r_w^j and r_b^j represent the worst and best of normalization ratings of parameter j within the available network candidates.

$$D_{w.i} = \sqrt{\sum_{j=1}^{n} w_j^2 \left(r_{ij} - r_j^{w}\right)^2} \tag{2.7}$$

$$D_{b.i} = \sqrt{\sum_{j=1}^{n} w_j^2 \left(r_{ij} - r_j^{b}\right)^2} \tag{2.8}$$

iii. Analytic Hierarchy Process (AHP)

AHP is a method of breaking down a dynamic, unstructured scenario, organized in a hierarchical order, and via individual parts or variables. The method also assigns quantitative values on the relative importance of each variable to the subjective decisions, which will then be synthesized to determine the highest priority variable in affecting the decision outcome.

The AHP method elaborates complex issues in the form of hierarchical structure so that it can easily overcome the sub-issues problems. This process is associated with four stages, namely problem structuring, pairwise comparison, pairwise comparison judgment matrix, and solution synthesizing.

iv. Grey Relational Analysis (GRA)

The GRA method ranks each of the network candidates before choosing the highest ranking. There are three processes which are normalization of information, ideal sequence definition, and grey relational coefficient (GRC) evaluation. The highest GRS score is regarded as the most suitable candidate, as shown in Equation 2.9.

$$GRC_i = \frac{1}{\sum_{j=1}^{n} w_j \left(r_{ij} - R_j\right) + 1} \tag{2.9}$$

r_{ij} represents the normalization performance rating of parameter j on network i, whereas w_j is the weight of parameter j, and R_j refers to the possible value of parameter j.

v. Multiplicative Exponential Weighting Method (MEW)

MEW, also recognized as the weighted product (WP), makes use of multiplication to communicate ranking parameters. For instance, the value acquired for every target of candidate network i is derived in Equation 2.10.

$$MEW_i = \prod_{j=1}^{n} r_{ij}^{w_j} \tag{2.10}$$

In Equation 2.10, r_{ij} denotes the normalized performance rating of parameter j on network i, whilst w_j is the weight of parameter j. The highest score value is the most suitable candidate among the networks.

Based on the existing studies, the authors in [84] have integrated two methods such as AHP and GPA in a heterogeneous system with UMTS and wireless LAN networks. The AHP algorithm is used to evaluate the weight of each metric, while GPA is to rate the available mesh networks and rank network alternatives. The AHP and GPA algorithms indicated the utilization of multi-criteria parameters and medium implementation complexity in a wireless network. In [85], the authors considered the use of multiple services with dissimilar priorities by proposing an online dynamic bandwidth reservation method.

By using the AHP to assign weights to the parameters, the three MADM methods, SAW, WPM, and Preference-Ranking Organization Methods for Enrichment Evaluation (PROMETHEE) are comparable. The PROMETHEE method is based upon the outranking theory. The authors in [86] revealed that the performance of PROMETHEE is the most accurate in selecting the best network in terms of reducing traffic delay and jitter.

d. Game theory-based Scheme

Game theory is designed to influence smart agents. Therefore, encounters among agents of different interests will be model. This theory is represented by a set of mathematical models and systematic tools for inspecting the possibility of field differences that have contradictory attentions. The theory can be classified with two-game theory approaches, namely cooperative and non-cooperative. The cooperative is a joined approach that takes into consideration of the other players. A non-cooperative approach, on the other hand, enables each player to choose its strategy individually by examining the plan decided from the interaction among participating players to develop utility or reduction costs [87].

Using the method, the players will categorize the accomplished solutions (e.g. Users vs Users, Users vs Networks, and Networks vs Networks) according to the cooperative and non-cooperative approaches. Table 2.4 presents the implementation of the game theory method in solving contradicts situations and other problems related to all telecommunications aspects. This theory is also used by other disciplines such as political, sociology, computer science, engineering, and biology. Recently, this model has been applied in various wireless communications and network technology domains (e.g., vehicular networks, power control games, wireless sensor networks, radio resource management, and economic approaches) [88].

Table 2.4

The Comparative Studies of the Game Theoretic Methods

Study	Players' Interaction	Models	Objectives	Strategies	Payoffs	Parameters
Salih et al. [88]	UMTS, WiMAX & Wi-Fi (Network vs network)	SAW Game (SAWG)	Network selection: choose the best network and optimize user's satisfaction	Available access network	Utility function	Monetary cost, available bandwidth, delay, and jitter
Radhika et al. [89]	Wi-Fi, WiMAX, & CDMA (Network vs network)	Bayesian evolutionary game	Network selection: choose the optimal network	Bayesian strategy	Utility function	Bandwidth (Mbps), packet delay (msec), supported velocity (Kmph), jitter (msec), and bit error rate
Khan et al. [7]	WCDMA, WLAN, & WiMAX (Network vs network)	Strategy game	Network selection: select the best access network	Service requests	Utility function	service type, user preferences, signal strength, speed of the user, battery level
R. Trestian et al. [90]	User and Networks (UMTS, WLAN1, & WLAN2) (User vs networks)	Repeated game	Strengthen the cooperation between users and networks - utility function attains a good trade-off	Network and user: cooperate	Utility function	Energy consumption, monetary cost, quality utility, and network load
M. Cesana et al. [91]	User and Access Point (User vs network)	Congestion game	Network selection: choose the network that reduces selection cost.	Available access point	Cost function	Congestion of the access points

Equilibrium is the best strategy for combining each participant (or player) to search for the maximum payoff. The Nash Equilibrium definition is formulated in Equation 2.11 [90].

$$f_i(s_i^*, s_{-i}^*) \le f_i(s_i, s_{-i}^*) : \forall 0 < i \le N, \forall s_i \in S_i \qquad (2.11)$$

N is the number of players in a game, while i is an index of a player, in which $0 < i \le N$. S_i indicates a set of available mixed strategies for player i with $s_i \in S_i$ being any possible strategy of player i. The Nash Equilibrium satisfies the condition where $f_i()$ is the payoff function of player i. s_i^* indicates a Nash Equilibrium strategy of player i and s_{i-1}^* is indicate the Nash Equilibrium strategies of all players other than player i. Therefore, some games might not have one or can have more than one Nash Equilibrium.

e. Intelligence-based Schemes

Network Intelligence-based can be classified as the Fuzzy logic (FL) and Neural Network (NN) methods. Lotfi A. Zadeh started FL in 1965 based on the theory of fuzzy sets [92]. FL based decision algorithm is a vague system, ambiguous and uncertainty with a correct arithmetic approach to overcome the sometimes irrelevant and difficult decision-making issues. For example, the vague data complexity can be measured using the pattern of RSS, network load, and Bit Error Rate (BER). However, fuzzy inference systems (FIS) based on fuzzy inference rules are applied to solve the complex algorithmic formations in the modeling of the system for achieving the best results. FIS is a computing structure process that relies on the input and output concepts, which are implemented in a linguistic arrangement with values of the low, medium, and high [93]. FIS rules are a set of *if-then* rules which enable decision selection referred to the provided input and output values, as shown in Figure 2.9.

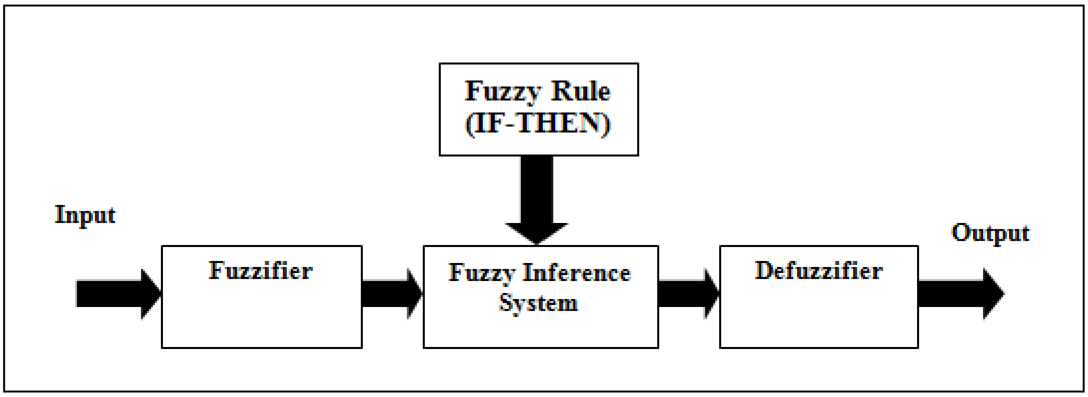


Figure 2.9 *Fuzzy Logic System (adopted from* [93]*)*

A fuzzy logic multi-criteria of the VHO algorithm, which can be assessed in the fuzzy logic control (FLC) system, takes into account various criteria of parameters such as RSS, network load, power consumption, and MN velocity [94]. It also deliberates on a set of predefined “if... then” rules that described the desired behavior of the FIS system. The FLC-based solution has been strengthened by a multi-layer Neural Network (NN) that looks into the correlation between the FLC parameters as well as the traffic variation and environmental fluctuation adjustment.

On the other hand, [95] introduced the integration of the FL system to manage vague data, multiple attributes to control decision making, and context-aware strategies to minimize unnecessary handover. The integration results indicate that the usage of the intelligent decision algorithm reduces the handover delay, call dropping and unnecessary handover in the vertical handover WLAN and 3G networks.

Also, Sadiq et al. [96] introduced an intelligent-based scheme to maximize the score value in evaluating the best candidate among the wireless networks. The proposed algorithm measures three parameters: connection lifetime, residual channel capacity, and faded signal-to-noise ratio. From the conducted experiments, the results show a decrease in the average of VoIP and video applications QoS in terms of end-to-end delay, packet loss, and handover delay.

The FL mechanism proposed by [97] enables the selection of the appropriate network of the VHO in vehicular networks by including various multi-criteria metrics such as network density, service cost, RSS, and vehicle speed. The proposed mechanism was able to decrease the number of VHO by solving the ‘ping-pong’ problem during the decision process. Moreover, the latency of the VoIP applications and streaming was reduced, while the downloading handover latency increased. Similarly, [98][99] have also introduced the FL approach for network selection in the realistic network measurements and implementations which used available parameters including signal strength, network load, distance direction, and velocity. Even though the data throughput was increased, the utilization of this model had reduced the time required to download different sizes of data files, call drop, call blocking, and user’s device energy consumption as well as increases the data throughput.

Unlike the other authors, [100] chose to combine the Kalman filtering and FL methods in reducing the handover initiation for attaining continuity of seamless communication. The Kalman filtering approach equalizes the technique of the propagation model, while the Mamdani FL relates to the handover decision process.

The combination of the two approaches will be supported by several parameters such as data rate, RSS, traffic load, and velocity vehicle. Despite the effective reduction in the handover initiation, the combination of the two methods increases system complexity and delay for the handover decision process.

f. Context-based Schemes

The context-based method is primarily influenced by all information that is relevant to a particular entity (e.g. people, objects, and place) that will be evaluated by a user and required services. This novel prediction algorithm proposed by [101] refers to the mobility using dynamic Link going down (LGD) to request the triggering of VHO through information server (IS) of the IEEE 802.21 MIH mechanism. The algorithm can predict the movement of participating in mobile terminals in the conflict area through the collection of basic mobility information such as velocity, position, movement detection, and coordinates. All this information can be collected through the MIH IS. The results of the algorithm revealed that the handover latency for MIPv6 and FMIPv6 could be minimized through the movement of the LGD trigger point. However, the algorithm faced a computational problem due to the implementation of complications.

Another model was the integration of created two modules protocol stack, generic virtual link layer (GVLL), and MIH in [102]. This model was set at the upper layer of the media access control (MAC) layer, which comprised of WLAN and WiMAX networks. The model showed that the effectiveness of GVLL on QoS was decreasing while the influence of the MIH helps to achieve seamless handover.

2.4 Comparison of the Vertical Handover Decision Schemes

The VHD schemes discussed by previous researchers highlight the advantages and disadvantages of handover decision algorithms. The following are the descriptions on the comparison of several features of these schemes [59]:

1. Domain Application – Most of the MNs have a single interface of the network that is accessible to link to other networks and terminals that used a single path for attaining seamless services such as RSS based scheme and QoS based. T Each mobile device's multi-mode terminals may connect to multiple networks at the same time. This approach is adopted because of its context-based and intelligence schemes that can assist a mobile user in selecting a suitable network based on the user's preference in the QoS.

2. Complexity and Network Selection- The parameters values of RSS and bandwidth are used by the RSS and QoS-based schemes to provide service continuity. However, for network selection, multiple parameters such as bandwidth, user preferences, RSS, power consumption, cost, security, and application requirements are implemented in the network intelligence, decision function, and context-based schemes.

2.5 Related Works

There are several related works on the vertical handover decision algorithms that were referred to by this research. The RSS-based algorithm used by [67] in assessing the complex system was not able to provide precise decisions. Nonetheless, the algorithms that used FL and cost functions are reliable to determine user satisfaction and accurate to be used in a complex system. Thus, the RSS-based algorithm is more proper to be developed in a simple design because in a complex system, the unnecessary handover and ping-pong effect increase. Moreover, the FL algorithm in a complex system achieved high handover user satisfaction and low delay [62]. Another study by Navale and Bhavani in [103] also found that the FL calculation reduces the blocking rate, high throughput with low latency, and security but increases the call drop rate.

Other studies have indicated that hybrid methods, the combination of Fuzzy TOPSIS, Fuzzy GRA, and Fuzzy AHP, can improve the QoS as compared to the MADM methods (TOPSIS, GRA, and AHP) in wireless networks [104][105][106][107][108]. Table 2.5 summarizes the comparison of the existing studies in the VHO decision methods based on the heterogeneous wireless networks. The proposed methods were compared in terms of the main features, the technique employed, advantages, weaknesses or drawbacks, and different technologies. From the comparison, some issues still need to be addressed, such as handover delay, packet loss, complexity in processing vertical handovers, signaling overhead, imprecise process to obtain network costs and some other challenges. Another comparison made involved the different VHO decision schemes, as shown in Table 2.6.

Another comparison made is the related VHO decision evaluation metrics, as presented in Table 2.7. Several evaluation metrics that were frequently evaluated and chosen by researchers are delay, packet loss, handover latency, throughput, jitter, cost, and velocity. However, in this research, the focus is on improving the QoS in the vehicular ad hoc network by emphasizing on these parameters; HO latency, HO delay, packet loss, and throughput.

Table 2.5

The Summary of Comparative Studies in Vertical handover Decision Method (Layer 3 + layer 2 Methods) based on Cross-Layer Design

Study	**Feature**	**Technique Employed**	**Advantages**	**Weaknesses**	**Applicable Area Technology**
Mir and Filali, in [109]	Studied the performance evaluation of IEEE 802.11p and LTE technologies networking by comparing standards such as reliability, delay, scalability, and mobile support in the context of various application requirements.	RSS based	Reduces handover delay	Increase network load and delay	WLAN (IEEE 802.11p) and LTE
Park, et al. in [110]	An application-aware scheme to raise multimedia streaming services' QoS to address issues of bad channel conditions that can increase delays in packet flow.	RSS Based	Reduces Ping-pong effect and handover delay	Reduce signaling and inappropriate for real-time applications	GPRS and WLAN
Mu, et al. in [111]	Integrates UMTS and WLAN network to evaluate the performance of QoS which access the MIH based VHO scheme and multimode node model implemented in NS-2.	RSS Based	Reduces handover latency and packet loss	Little effect on the throughput of vehicular user	WLAN and UMTS
Lee in [112]	A cross-layer hierarchical of network mobility framework with QoS handover for high-velocity vehicles.	RSS Based	Reduces packet loss	Increase handover delay and latency	WLAN and WiMAX

Sun in [113]	Decision making based on group vertical handover approach	RSS Based	Improve QoS and wireless connectivity of a group of vehicles	Unreliable probability distribution function and high complexity	WLAN, WiMAX and UMTS
Patil in [114]	Connectivity through the use of integrated technologies is a difficult problem as each network has its characteristics and characteristics, such as regional coverage area, data rate, frequency, latency, and bandwidth.	RSS Based	Better performance in terms of PDR, a total number of handover, the total time taken for handover, total packet loss, and channel utilization.	Increase handover latency	WLAN and UMTS
Lee et al. in [80]	Develop a VHO decision algorithm that helps a wireless access network not only to manage the total load across all connection points (e.g. base stations and access points) but also to optimize the mobile node 's cumulative battery life (MN).	RSS Based	The proposed algorithms work much better than the traditional optimization only used RSS metric based on the SSF method.	high unnecessary handover	WLAN, WiMAX and UMTS
Hendrixen in [115]	Focused on the efficiency of handovers between UMTS and the new 3GPP network technology LTE.	RSS Based	The inter-RAT handover mechanism is outperforming compared to the other handover mechanisms.	Increase unnecessary handover due to increase the power and consume battery	UMTS and LTE
Yan et al. in [6]	Time estimation method has been developed to predict the time duration that MN stay in each Wi-Fi-AP	RSS Based	Reduce the unnecessary HO from GSM network to a WLAN	More handover latency	WLAN and GPRS

Salih, et al. in [87]	Proposed a new model of network selection focused on the combination of simple additive weighting (SAW) methods and the analytic hierarchy cycle (AHP).	User-centric Based	-Reduce packet loss - Cross-layer based optimization is more valuable rather than single-layer based	High complexity	WLAN, WiMAX and UMTS
Vetrivelan, et al. in [116]	Implemented the optimal and sub-optimal decisions for selecting the network based on Nash-Equilibrium and ranking methods. The scheme enables QoS for different services according to vehicular priorities and provides group communication alongside vehicular collision avoidance.	User-centric Based	More effective and reduces handover delay	Does not measure the handover latency and packet loss	WLAN, WiMAX and LTE
Ong and Khan, in [117]	Introduces a novel network selection strategy focused on a calculation that offers a systematic way to obtain knowledge about QoS. It also increases the decision to move the current cost function approach by initiating the handover to provide an optimum outcome for network selection.	User-centric Based (Cost Function)	High user satisfaction	High complexity	WLAN and UMTS
Mahardhika, et al. in [118]	Proposed an enhanced VHO decision using multicriteria metrics in three network interfaces.	Decision Function Based (Multicriteria)	Decrease the number of handovers to 84.60%, blocking probability to 20.23%, and network load balance to 18.03%,	High complexity.	WLAN, WCDMA, and WiMAX

Anupama, et al. in [86]	Compares the performance of three MADM methods such as SAW, WPM, and PROMETHEE. Analytic Hierarchy Process (AHP) method is used to allocate weights to the criteria.	Decision Function Based (Multicriteria)	Reduced handover delay and jitter.	High complexity	WLAN, WiMAX and two UMTS (UMTS1 &2)
Malathy et al. .in [119]	Knapsack - TOPSIS technique in VHO of the heterogeneous wireless network, This technique is a modern and efficient vertical handover process adapted from the organizational research discipline using a dynamic programming system.	Decision Function Based (Multicriteria)	The approach proved to work better than TOPSIS. Unnecessary handover is reduced by 24% more compared to that of the existing TOPSIS model, while packet throughput is increased to 12% more.	Does not consider fuzzy logic based	WLAN, and WiMAX
Ning, et al. in [120]	Proposes solution for the terminal-controlled mobility across the heterogeneous network G1 and entropy method. This solution worked out in determining the handover decision policy.	Decision Function Based (Multicriteria)	Avoid unnecessary handovers.	Does not consider switching cost from the aspect of users.	WLAN and UMTS
Li, et al. in [121]	Proposes the Fuzzy Multiple Attribute Decision Routing (FMADR) scheme by characterizing the candidate vehicles with multiple attributes and selecting the candidates for the next-hop transmission using the multiple attribute Decision Making (MADM) method.	Decision Function Based (Multicriteria)	The delivery ratio of several hops without the rise of the delay.	Different scores must evaluate the high complexity of the direction attribute of the candidate.	WLAN (IEEE 802.11p)

Kathirvel and Loyd, in [122]	Optimizes the Hybrid Wireless Mesh Protocol using the Packet Loss Rate Algorithm Estimation for VANET such as Cluster, and Simple Adaptive Weighting (SAW) methods, as well as Real-Time Packet Loss Estimation algorithm (Gaussian Mixture Model)	Decision Function Based (Multicriteria)	Increases packet delivery ratio and decrease the packet drop ratio. High reliability.	High overhead UMTS in heavy traffic.	WLAN (IEEE 802.11p) and UMTS
Bisio et al. in [13]	A new selection using Dynamic-TOPSIS (D-TOPSIS) method. This method is performed similarly to the method of TOPSIS that will reduce the necessary computational load.	Decision Function Based (Multicriteria)	Reduction of the execution time of the D-TOPSIS in the computational load.	High overhead loading.	WLAN, WiMAX and UMTS
Mehbodniya, et al. in [123]	Presents the current VHO algorithm, completing two functions. The first task is to carry out the VHO Necessity Estimate (VHONE) using multiple parallel fuzzy logic controllers (FLCs) with reduced sets of rules to estimate the need for VHO. The second task is to pick the best network as the TOPSIS dependent goal for VHO.	Decision function Based (Multicriteria)	Improved around 30% of the RSS-load balancing algorithm and 25% of the average handover rate of TOPSIS based scheme.	High Complexity	WLAN, WMAN and WWAN
Alkhawlani, et al. in [124]	To tackle the VHO problem of a decision support system is developed. This program combines the algorithms FL, TOPSIS, and MADM to solve the VHO problem.	Decision function Based (Multicriteria)	Low handover failure	Not add an exponential complexity	WLAN, WMAN and WWAN

Savita and Chandrasekar in [125]	Proposes the vertical handover schemes using Multiple Attribute Decision Making (MADM) algorithms. SAW and TOPSIS were compared to reduce the handover delay.	Decision function Based (Multicriteria)	Reduces handover delay. TOPSIS is the best decision-making method to select the best network	It does not measure the handover latency and packet loss.	WLAN &WiMAX
Chandralekha and Bahera in [126]	Proposes the genetic algorithm in heterogeneous for decreasing the number of HO.	Decision function Based (Multicriteria)	Minimizes the number of handovers.	Not support the high complexity of network	WLAN, WMAN and WWAN
Tawil et al. in [5]	Network selection using a distributed Simple Additive Weighting (SAW) scheme	Decision function Based (Multicriteria)	Low handover failure rate due to the distribution of the decision calculation, delay decreased, and high throughput.	More load an AP due to the cost calculation process.	WLAN and WWAN
Zekri, et al. in [9]	Proposes an intelligent context-aware solution based on advanced decision approaches such as FL and AHP processes that consider both users and service requirements.	Context-aware (Context-Based)	High throughput.	An additional delay in the handover information gathering process.	WLAN and UMTS
Anantha et al. in [95]	The algorithm gains intelligence by combining the FL system to handle imprecise data, and MAADM to handle decision making and context-aware.	Network Intelligence-Based (FL)	Reduce unnecessary handover.	Not consider the reduction of the decision engine load by routing IP traffic based on the policy.	WLAN and UMTS

Sivakami and Shanmugavel in [12]	Focuses on the FL algorithm with dissimilar features to select the best network and discuss input factors for Network Selection Function (NSF).	Network Intelligence-Based (FL)	Reduces handover delay.	It does not consider packet loss and handover latency.	WLAN and WiMAX
Sadiq, et al. in [1]	Proposes an Intelligent Network Selection (INS) scheme focused on the maximization of scoring feature to efficiently target the rank of available candidates wireless network with the three input parameters such as Faded Signal-to-Noise Ratio, Residual Channel Capacity, and Connection Life Time.	Network Intelligence-Based (FL)	Decreases the average handover delay, as well as VoIP and Video applications packet E2E delays, and packet loss ratios for having a more efficient network selection process.	High complexity	WLAN and UMTS
Kang, et al. in [127]	Proposes the FL-based decision-making scheme that utilized a large number of parameters as context information to design the autonomous oriented approach such as QoS, battery level, user expectations cost, and type of service.	Network Intelligence-Based (FL)	-Removes access router discovery -Reduces information access time	Lack of target selection method	WLAN, WiMAX and CDMA
Drissi et al. in [106]	Proposes a network selection model based on the Fuzzy Analytic Hierarchy Process (FAHP) to determine on the weightage of the assessments. The Simple Additive Weighting (SAW) is used to rank out the networks available.	Network Intelligence-Based (FL)	The interactive traffic class has more improvement rather than the others: Reduces delay – 10% while Packet loss decreases – 25%	High overhead signaling	Wi-Fi and WiMAX.

Table 2.6

The Comparative Studies of Category in Vertical Handover Decision Schemes

Category of VHD Scheme	**Description**	**Advantages**	**Drawbacks**	**Author**
RSS-based Scheme	The handover decision is only based on the RSS value. Another metric is included to assist the handover procedures but not directly involved in the handover decision making.	Reduces handover delay, handover failure, and Ping-Pong effect.	Increases unnecessary handover and does not support the high complexty of network	[109], [110], [111], [112], [113], [114], [80], [115]
QoS based Scheme	To maximize the QoS using the available bandwidth, user preferences, and Signal-to-interference-plus-noise ratio (SINR) metrics for making an optimal handover decision.	High throughput, decreases handover latency, packet loss, and handover delay.	High Ping-Pong effect, but not applicable for high speed, higher resource consumption, and inefficient bandwidth calculation.	[87], [116], [117], [128],[129]
Decision Function-based Scheme	This handover decision making is used to select the best available network using the multi-criteria decision making (MCDM) method. The MCDM has included the cost, utility, score, and policy-based functions.	Cost-effective, low handover blocking rate, reduces the Ping-Pong effect, and ranks network selection.	Increases handover latency but not suitable for real-time application, and high communication delay.	[118], [86], [119], [120], [121], [122], [13], [123]
Intelligent based Scheme	This scheme is used to overcome the issues of handover performance that irreversible in real-time data delivery in terms of handover latency, throughput, and unnecessary handovers.	Reduces handover delay, latency, packet loss, successful handover, intelligent network selection, user satisfaction.	High complexity, decision processing delays, and signaling overhead.	[97], [106], [95], [96], [12], [127]
Context-based Scheme	The context is defined within any information that is relevant to the situation of an entity (person, place, or object.). In other words, it refers to the distribution of correct and accurate information to the end-users for decision making.	Optimal network selection reduces packet loss and high throughput.	Higher resource consumption, increased communication overhead, high signaling cost, security provision.	[9],[130],[102], [131],[132]

Table 2.7

The Comparative Studies of Vertical Handover Decision Algorithm Based on Evaluation Metrics

Study	**VHO Delay**	**VHO Packet Loss**	**VHO Latency**	**Number of VHO**	**Bandwidth**	**Throughput**	**Battery Consumption**	**Cost**	**Jitter**	**Respond Time**	**Velocity**
Drissi et al. in [106]	Low	Low									
Mahardhika, et al. in [118]				High							
Anupama, et al. in [86]	Low	Low							Low		
Malathy et al. in [119]	Low	Low				High					
Mir & Filali in [109]	Low					High					High
Salih, et al. in [87]	Low					High		Low	Low		
Park, et al. in [110]	Low					High					
Ning, et al. in [120]	Low				High						High
Li, et al. in [121]	Low										
Kathirvel & Loyd in [122]	Low		Low	High							
Anantha et al. in [95]	Low	Low				High					
Bisio et al. in [13]					High					Low	
Sivakami & Shanmugavel in [12]	Low					High					
Mu, et al. in [111]		Low	Low			High					
Sadiq, et al. in [96]	Low	Low									
Vetrivelan, et al. in [116]	Low										
Lee in [112]	Low	Low							Low		High

Mehbodniya, et al. in [123]				Low							
Sun in [113]	Low	Low									
Alkhawlani, et al in [11]	Low	Low									
Kang, et al. in [127]					High		High	Low		Low	
Savitha & Chandrasekar in [125]	Low										
Patil in [114]	Low	Low		High							
Zekri, et al. in [9]	Low							Low			
Ong and Khan, in [117]	Low	Low									
Chandralekha and Bahera in [126]	Low			Low							
Lee et al. in [80]						High					
Hendrixen in [115]	Low				High		Low				
Yan et al. in [6]	Low		High							Low	
Tawil et al. in [5]	Low				High						
Research Study focus	✓	✓	✓		✓			✓	✓		✓

Table 2.8 describes a comparison of the technique of VHO decision-making algorithms used by other researchers. Three algorithms that are given the most focused in their studies are RSS-based, decision function-based (Multi-criteria), and network intelligent-based (FL/NN). Table 2.9 displays the comparison of the related algorithms, which used the GPRS, WLANs, WiMAX, Wi-Fi, UMTS, and LTE networks from the year 2008 until 2016. Thus, most of the suggested approaches concentrate particularly on assessing the QoS performance of WLAN, WiMAX, and UMTS networks. Furthermore, Table 2.10 presents a comparative analysis of the VHO algorithms network selection using hybrid methods. The hybrid methods combine two or three VHO decision algorithms in wireless networks. For example, the FL based and AHP algorithm schemes. This research focuses on the FL and SAW algorithms for enhancing the QoS performance and network selection in different network access technologies.

Table 2.8

A Comparison of Existing Studies using the Technique of the Handover Decision-Making Algorithms from Years 2008 - 2016

Study	Decision-Making Algorithms				
	RSS-Based	User-Centric Based	Decision Function-Based	Context-Based	Network Intelligent-Based
Mir and Filali (2014)	✓				
Park et al. (2014)	✓				
Mu et al. (2013)	✓				
Lee (2013)	✓				
Sun (2012)	✓				
Patil(2011)	✓				
Lee et al. (2009)	✓				
Hendrixen (2009)	✓				
Yan et al. (2008)	✓				
Salih et al. (2014)		✓			
Vetrivelan et al. (2013)		✓			
Ong and Khan (2010)		✓			
Mahardhika et al. (2015)			✓		
Anupama et al. (2015)			✓		
Malathy et al. (2015)			✓		
Ning et al. (2014)			✓		
Li et al. (2014)			✓		
Kathirvel and Loyd (2014)			✓		

Bisio et al. (2014)	✓		
Mehbodniya et al. (2012)	✓		
Alkhawlani et al. (2011)	✓		
Savitha and Chandrasekar (2011)	✓		
Chandralekha and Bahera (2010)	✓		
Tawil et al. (2008)	✓		
Zekri et al. (2010)		✓	
Anantha et al. (2014)			✓
Sivakami and Shanmugavel (2013)			✓
Sadiq et al. (2013)			✓
Kang et al. (2011)			✓
Drissi et al. (2016)			✓

Table 2.9

The Network Technologies used by Different Mechanisms in the years 2008-2016

Study	**Applicable Area Technology**					
	GPRS	**WLANs**	**WiMAX**	**Wi-Fi**	**UMTS**	**LTE**
Mir and Filali (2014)		✓				✓
Park et al. (2014)	✓	✓				
Mu et al. (2013)		✓			✓	
Lee (2013)		✓	✓			
Sun (2012)		✓	✓		✓	
Patil(2011)		✓			✓	
Lee et al. (2009)		✓	✓		✓	
Hendrixen (2009)					✓	✓
Yan et al. (2008)	✓	✓				
Salih et al. (2014)						
Vetrivelan et al. (2013)		✓	✓			✓
Ong and Khan (2010)		✓			✓	
Mahardhika et al. (2015)		✓	✓		✓	
Anupama et al. (2015)		✓	✓		✓	
Malathy et al. (2015)		✓	✓			
Ning et al. (2014)		✓			✓	
Li et al. (2014)		✓		✓		
Kathirvel and Loyd (2014)		✓			✓	
Bisio et al. (2014)		✓	✓		✓	

Mehbodniya et al. (2012)	✓	✓		✓	
Alkhawlani et al. (2011)	✓	✓		✓	
Savitha and Chandrasekar (2011)	✓	✓			
Chandralekha and Bahera (2010)	✓	✓		✓	
Tawil et al. (2008)	✓	✓			
Zekri et al. (2010)	✓			✓	
Anantha et al. (2014)	✓			✓	
Sivakami and Shanmugavel (2013)	✓	✓			
Sadiq et al. (2013)	✓			✓	
Kang et al. (2011)	✓	✓		✓	
Drissi et al. (2016)		✓	✓		

Table 2.10

Comparative Analysis of the Vertical Handover Algorithms using Hybrid Methods

Method	Author	Objective	Parameter	Advantage	Disadvantage
Fuzzy MADM-TOPSIS	[133][134][135][136]	Network selection: uses the MADM-TOPSIS method with FL sets and rules to reduce the blocking probability and increase the HO probability performance of the heterogeneous vehicular network.	RSS, data rate, interference rate, velocity, and traffic rate.	Network selection. Increases handover probability percentage and reduces latency.	Connection lifetime is high and increases end-to-end delay and complexity.
Fuzzy GRA	[104][137][138]	Network selection: Compares the hybrid methods of Fuzzy TOPSIS and Fuzzy GRA to choose the best in the context of VHO.	Cost, delay, security, jitter, throughput, availability, packet loss, and energy consumption.	Fuzzy TOPSIS better than Fuzzy GRA because of choose networks that offer better QoS during the handover process.	High complexity level due to the integration of many network parameters in the algorithm.
SAW & Game Theory	[87][125][139]	Network selection: Integrates the SAW in a game theory framework and AHP methods to examine the weight of parameters.	Cost, available bandwidth, delay, and jitter.	Increases user satisfaction to perform better QoS.	More conflicts and negotiable processes with high complexity.
Fuzzy Utility Decision	[140][24][141]	Network selection: Combines the FL method and utility decision to select the best candidate among the access networks.	RSS, delay, SNR, available bandwidth, and network load.	Better performance of QoS when it increases the mobile speed.	Highly complexity.
Fuzzy AHP	[106][142][143]	Network selection: Integrates the FL and AHP approaches to determine the relative weights of the evaluation criteria. The SAW is used to determine network selection.	Throughput, delay, jitter, and BER.	FAHP is better than the AHP method in terms of delay and packet loss.	The study should be covered in multi-network environments, not only in a single network.

2.6 Summary

This chapter presents the overview of the vehicular mobility model, handover mechanism process, and HO decision algorithm in heterogeneous wireless networks by referring to the previous related works. This chapter is necessary to provide proper guidelines in designing and developing VHO decision making in VANET. Furthermore, the evaluation of the QoS performance in the VANET scenario and the selection of the best candidate for different network technologies are also described.

CHAPTER THREE
RESEARCH METHODOLOGY

This chapter outlines the research methodology as the elementary design phases of the Adaptive Handover Decision (AHD) and Fuzzy Logic with Simple Additive Weighting (F-SAW) schemes. The proposed AHD scheme supported by the Fuzzy logic algorithm is adaptively predicted to tackle the inefficiency of the IEEE 802.11b (Wi-Fi) prediction method which depends on the RSS-based scheme as an indicator for the quality of vertical handover (VHO) link based on a single value RSS parameter. The development of the F-SAW scheme for the network selection process in the heterogeneous vehicular to infrastructure (V2I) ad-hoc network helps to intelligently and exactly ranked the utility score of the wireless network candidates of the VHO between Wi-Fi, WiMAX, and LTE using multiple-criteria parameters. The performance evaluation and validation were performed to evaluate the proposed scheme is accurate and realistic infrastructure scenarios. The research approach, as depicted in Figure 3.1, details the methodology steps in Section 3.1. The research methodology is discussed briefly in Sections 3.2 to 3.5, while the summary is presented in Section 3.6 of this chapter.

3.1 Research Approach

The research approach used in this study is illustrated in Figure 3.1. The approach can be divided into four phases which comprised of the preliminary study on the VHO decision scheme in the VANET, design of VHO decision network performance in VANET, development of VHOD network performance in VANET, and evaluation and validation on the proposed VHOD scheme in VANET. The explanations of each phase are discussed in the later sections.

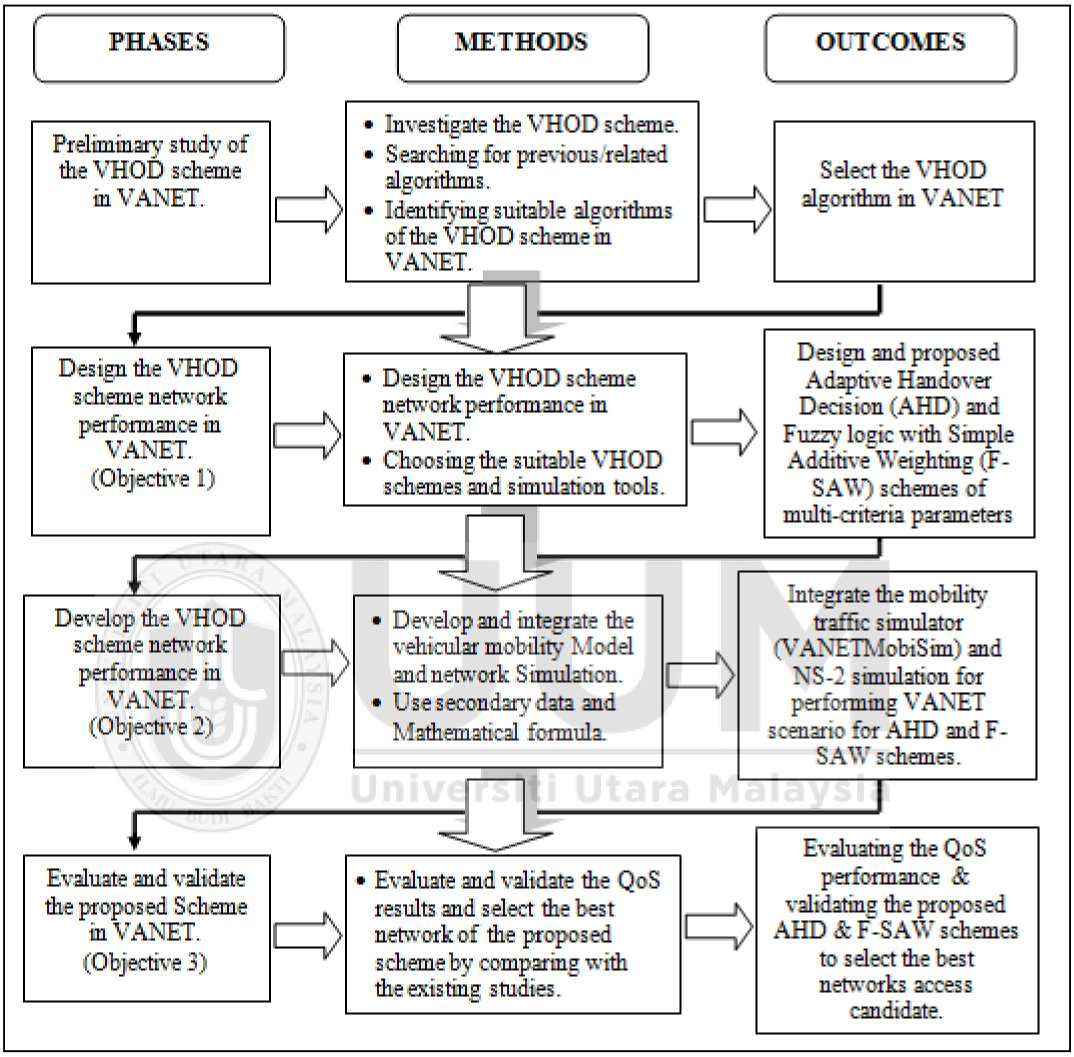


Figure 3.1 *Research Approach*

3.2 Preliminary Study of the Vertical Handover Decision in VANET

The preliminary study involved searching for related information on various sources. From the search, suitable algorithms of vertical handover decision scheme in VANET were chosen. This preliminary study was achieved by investigating the related information of the VHOD scheme, testing existing algorithms, and determining suitable algorithms. As stated in Table 2.6 in Section 2.4 of Chapter Two, the comparison of the existing studies in the vertical handover decision scheme shows that many researchers utilized intelligent-based, multiple attribute decision making (Decision function-based), context-aware, and RSS-based (traditional) schemes as the QoS performance calculation methods in different radio technologies network. The fuzzy logic algorithm of the intelligent scheme performs well in a decision-making system, including the control, evaluation, and prediction processes through the use of the coefficient that was designed using adaptive threshold and membership function range.

Most of the parameters used to measure the QoS performance in any network scenario include handover latency, handover delay, packet loss, throughput, cost functions, and velocity of the vehicle. The reference signal received power (RSRP) and signal-to-interference-plus-noise ratio (SINR) was employed as the multiple parameters in this research, as shown in Table 2.7 in Section 2.4 of Chapter 2.

This research proposed an intelligent network selection scheme of VHO decision in the traffic light topology of VANET. Detailed explanations are presented in Sections 3.3, 3.4, and 3.5 of this chapter. Figure 3.2 shows the vertical handover decision algorithm (VHDA) classification introduced by Sivakami et al. in [12]. In order to obtain the entire range of QoS in the heterogeneous network. It is important to efficiently feed input into the system based on the various aspects of the Fuzzy Logic and Decision Function (Multi-Criteria) algorithms to choose the best network.

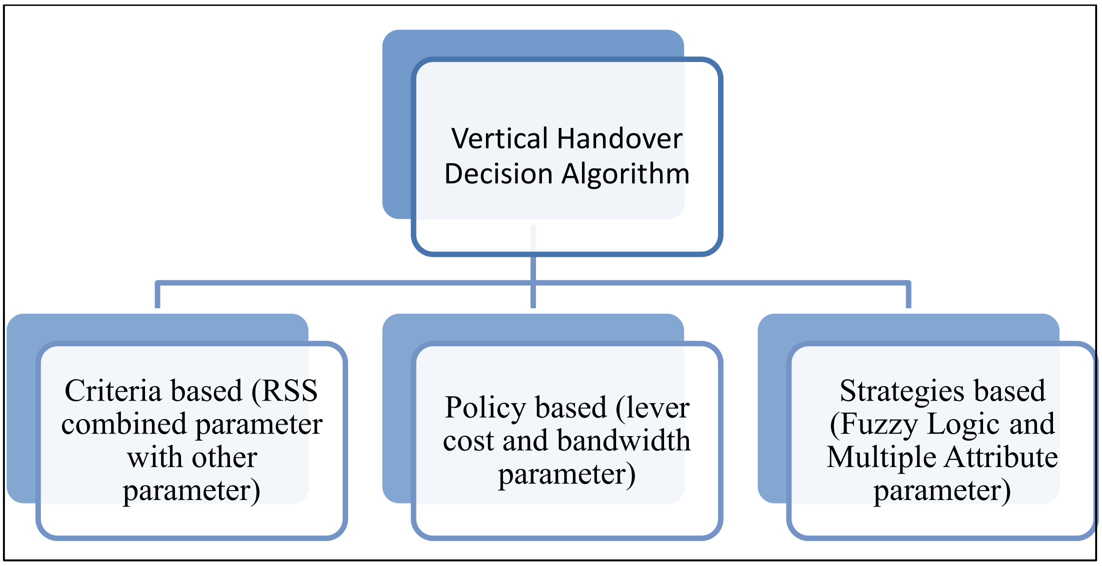


Figure 3.2 *Classification of the Vertical Handover Decision Method (VHDM) (adopted from* [12]*)*

Figure 3.3 illustrates the multiple parameters that define the RSS and ABW as dynamic parameters in real-time. The new network technology provides static information as the service type. Handover triggering occurs after the participating nodes discover a decreased link during the system discovery. The research used the dynamic and non-dynamic parameters, namely RSS, ABW, delay, jitter, monetary cost, vehicle velocity, and service type as simulation parameters. Fuzzy inference system (FIS) is a method that highlights the results of a specific complete set that utilizes a group of rules, as shown in Figure 2.9 of Chapter Two.

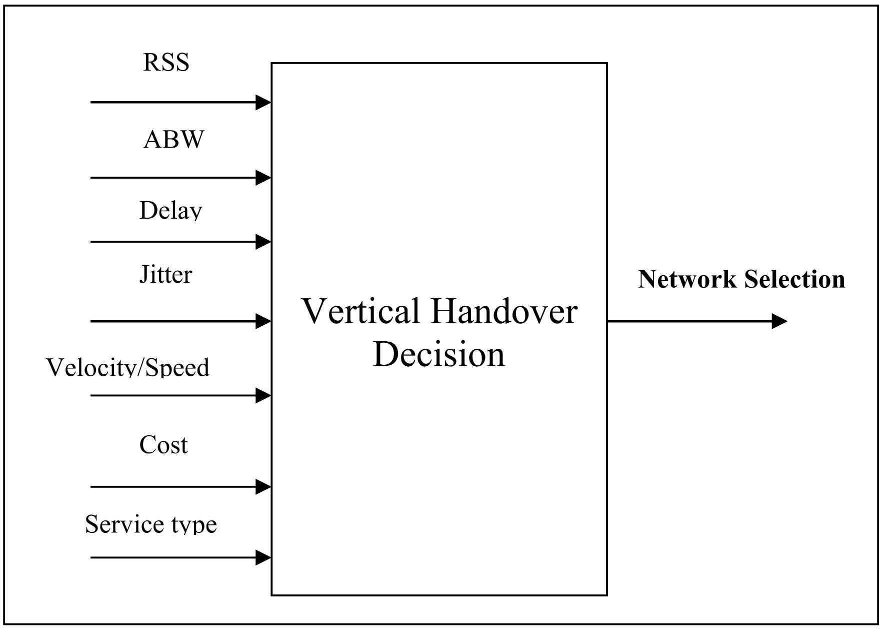


Figure 3.3 *Multiple Parameters*

3.3 Network Performance Design for Vertical Handover Decision Scheme in VANET

In the second phase, this research proposed the design of the simulation scenario of VANET for focusing on the VHDA algorithm from various aspects in deciding the best network access as suggested by previous studies. The AHD and F-SAW schemes were implemented to acquire similarity of the realistic simulation process to the real environment. The design was followed by the implementation of both proposed schemes using the VanetMobiSim and NS-2 simulators to get the actual results. Lastly, the results of the AHD and F-WAS schemes were compared to the VHOD schemes of the existing studies. The findings were then analyzed in the evaluation phase of this study.

3.3.1 Adaptive Handover Decision Scheme (AHD)

The AHD scheme process has begun by performing passive and active scans, followed by selecting among candidate access networks to deliver the handover. As reported by Saddiq in [96], the handover decision-making and link-layer process must be finished before the delay in the link layer. Figure 3.4 shows the flowchart of the proposed AHD scheme, which is divided into three phases; design, implementation, and evaluation. The design phase used a fuzzy logic algorithm to implement the handover initiation process for measuring the QoS of the handover performance as depicted by the dashed line in Figure 3.4. The implementation and evaluation phases generated the simulation set-up and parameters for evaluating the results.

The process of simulation started by generating the vehicular mobility model in the traffic light environment using the VanetMobiSim emulator to be performed similarly to that of the real environment. Hence, the scenario created a data set mobility VANET of the Canu Mobility Simulation Environment (CanuMobisim) produced by the Informatik University of Stuttgart. The traffic light topology created three lanes in each of the intersections. It included various technologies access networks such as IEEE802.11b, WiMAX, and LTE for VANET as illustrated in Figure 3.5 (assuming all traffic lights are in good conditions). The VANET simulation needs two types of simulators which are mobility model traffic and network simulators. The mobility model traffic used the VanetMobiSim simulator while the network simulation was developed using the NS-2 simulator. The two simulations were integrated due to their capabilities in achieving the objectives of this research. The traffic simulators were applied to estimate the VANET features and protocols performance, as well as to produce the location and movement information of vehicles. This simulation represents a real-world vehicular mobility model to determine a definite conclusion based on the conducted experiments.

The simulations created the routes of vehicle and mobility patterns by utilizing the real data set of the Canu Mobility Simulation Environment (CanuMobisim) Spatial Model provided by the Informatik University of Stuttgart. The real data set was then transformed into the VanetMobiSim emulator [31], as shown in Figure 3.5. Having implemented the real data set implemented into the VanetMobiSim for generating the mobility motion of the traffic light topology, the related mobility file (e.g. VANET.xml) was merged with the NS-2 simulation under the topology file. The XML format of the VANET file contained all the related particulars such as vehicle speed, acceleration or deceleration, simulation time, secure driving rules, number of vehicles, traffic light, and number of lanes as shown in Table 3.1. The VanetMobiSim simulator can generate all information in the VANET file for the mobility of vehicles and road features.

Furthermore, the integration of the mobility file into the NS-2 simulator requires the specification of the traffic light road design and vehicular user's mobility implementation through the topology and routing protocol in the NS-2 simulation. The integration can be configured and acquired based on the realistic mobility movement of vehicles and users' driving behavior patterns. Figure 3.6 reveals the process of integrating the VanetMobiSim and NS-2 simulation. The VanetMobiSim will focus on the traffic mobility of vehicles while NS-2 simulation will conduct the integration of three different networks, propagation model, Constant-bit-rate (CBR) traffic, and routing protocol. The traffic type of the data stream of the vehicle is CBR. The NS-2 will simulate together with the simulation parameters setting as in Table 3.2 to generate the simulation result of the output file as a log traces file. The traces file will analyze to get the graph plotting and comparison performance of QoS with other methods.

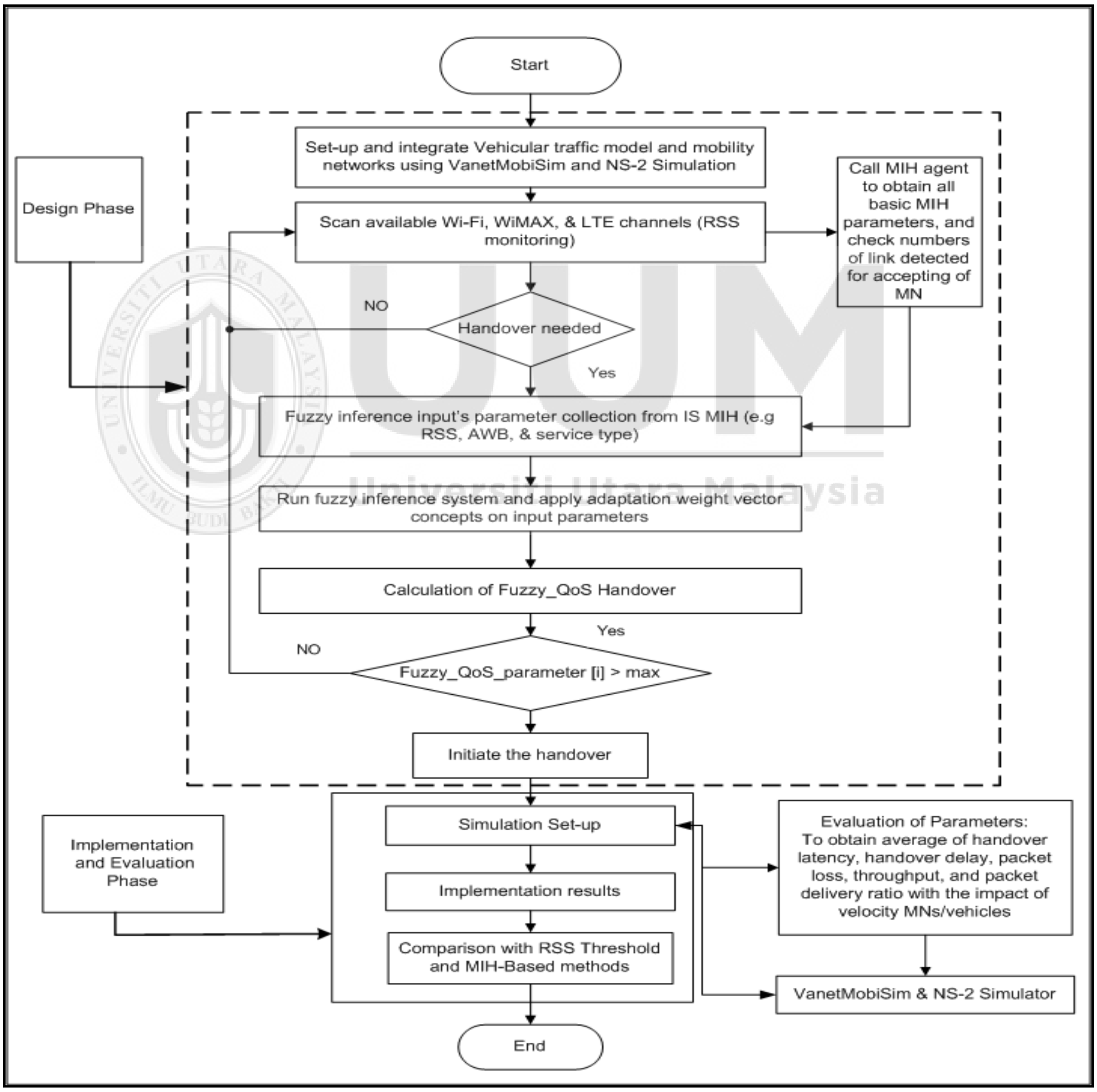


Figure 3.4 *The Systematic Architecture of Research Design, Implementation, and Evaluation Phases of the AHD Scheme*

The AHD scheme relied on an adaptive fuzzy inference system to improve QoS and prediction of the VHO process. Thus, it was designed using adaptive thresholds of membership functions range and calculated by employing the implemented piecewise linear equations. Therefore, the weight vector for each input parameter was proposed for ensuring the accuracy of the attained handover decision. Subsequently, the AHD scheme was chosen the final VHO decision if the AP or BS gained the highest QoS parameter (*Fuzzy_QoS_parameter*) to perform the handover process, for concerning the *max,* which is a threshold value that reduces unnecessary handover (the detail AHD scheme is elaborated in Chapter 4).

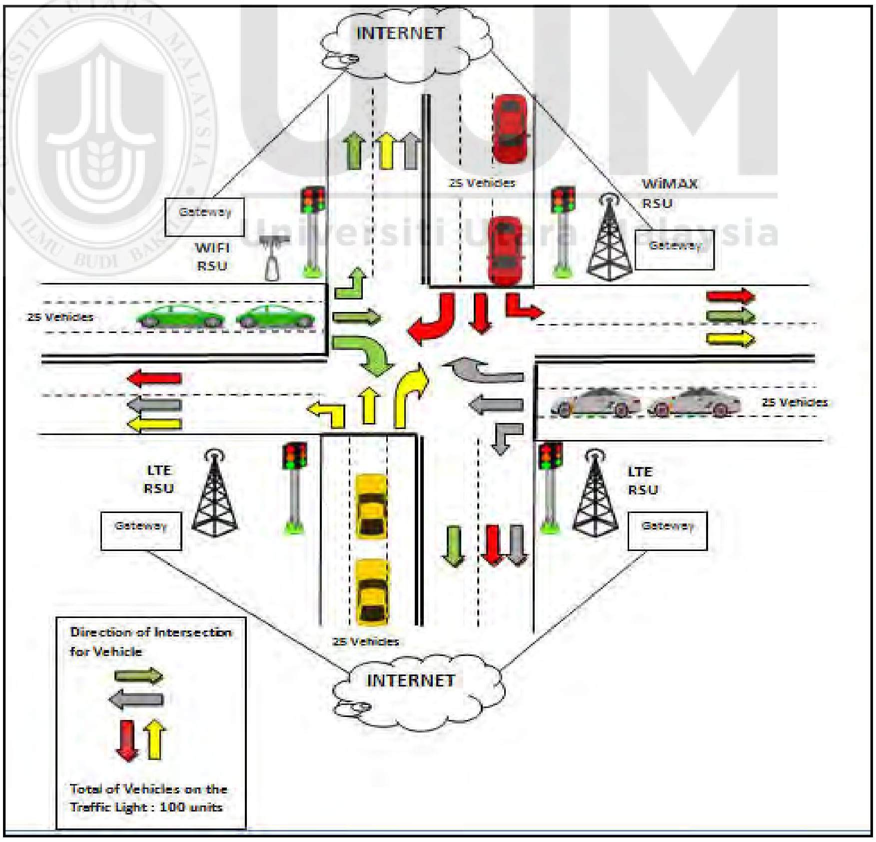


Figure 3.5 *Vehicular Networking Traffic Light Topology using IEEE 802.11, WiMAX, and LTE Technologies as Road Side Unit (RSU)*

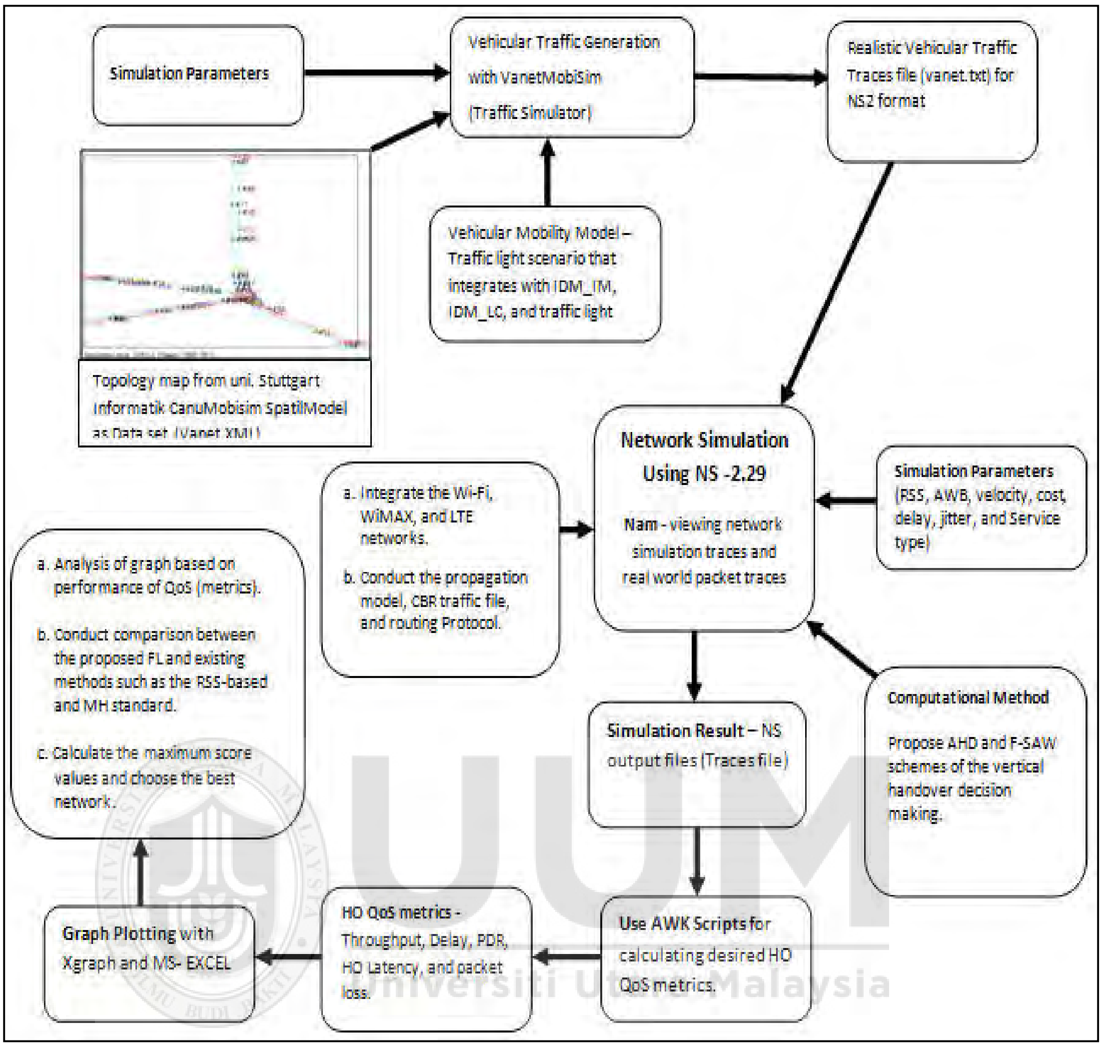


Figure 3.6 *Integrating VanetMobiSim with NS-2 Simulation*

In this research, the NS-2 simulator was applied for modeling and analyzing the handover of QoS in the VANET wireless network based on the simulation scenario and parameter settings. Two simulation parameter settings were developed in this research. The first was the traffic parameter settings in the VanetMobiSim and the second was set up the simulation parameter for three types of technologies IEEE 802.11, WiMAX, and LTE standards in the NS-2 as indicated in Tables 3.1 and 3.2. The performance of the IEEE 802.11, WiMAX, and LTE standards was measured by analyzing the impact of vehicle's average speeds (e.g. 20, 40, 60, 80, 100 / kmph) for three network standards. The performance of the QoS was evaluated in terms of throughput, delay, packet delivery ratio (PDR), handover latency, and packet loss based on the traffic parameters setting of the vehicular networks and simulation network parameter settings in the Wi-Fi, WiMAX, and LTE technologies.

Table 3.1

Traffic Parameter Setting in the VanetMobiSim (adopted from [111])

SIMULATION PARAMETERS	**VALUES**
Simulation range	1000m x 1000m
Speed of Vehicles (km/h)	1 - 100
Maximum Acceleration (m/s2)	4
Maximum Deceleration (m/s2)	4
No. of Vehicles	100
Number of Lanes	4
Road Direction	Two -way
Time Interval between traffic light changes (µs)	5000
Contain Traffic Lights	Yes
Safe Driving Rules	IDM_LC
Simulation Time (s)	300

Table 3.2

Simulation Parameters Setting in the NS-2 (adopted from [144])

SIMULATION PARAMETERS	VALUES
Simulation range	2000m x 2000m
Simulation duration	300 s
Frequency bandwidth of 802.11	2.4 GHz
Transmission radiuses of 802.11	20 m
Data rate of 802.11	11 Mbps
Propagation Model	TwoRayGround
Antenna	Omni antenna
Routing Protocol 802.11	DSDV
Max packet in if queue length 802.11	50
Frequency bandwidth of 802.16	3.5 GHz
Transmission radiuses of IEEE 802.16	500m
802.16 channel bandwidth	10 MHz
Propagation Model	TwoRayGround
802.16 modulation and coding	OFDM 16QAM 3/4
MAC/802.16 UCD (uplink channel descriptor) interval	5 s
MAC/802.16 DCD (downlink channel descriptor) interval	5 s
UMTS/LTE uplink bandwidth	384 kbps
UMTS/LTE downlink bandwidth	384 kbps
Link data rate	300 Mb/s
UDP Max packet size (byte)	1,024
UDP header size (bytes)	8
Mobility protocol	MIPv6
Vehicle speed	1~100 / kmph

Based on the results of the performance evaluation on the three technologies (e.g. IEEE 802.11, WiMAX, and LTE). The integration of the FL and SAW algorithms, which analyze the utility score (maximum score) for influencing the network selection mechanism process in the VANET wireless network was proposed as the handover decision algorithm in this research, as illustrated in Figure 3.7.

Figure 3.8 demonstrates the MIH process of the proposed FL model. The link trigger status of the MIH mechanism is divided into four services, namely link down (LD), link up (LU), link coming up (LCU), and link going down (LGD). These services represent the benchmark for events in the MIH mechanism. The proposed FL algorithm will receive the input data parameters such as ABW, RSS, and service types (assume as available) from MIH information Service (MIHIS) mechanism. Then the generated crisp inputs in the FL model will return information to the MIH event service (MIHES) action regarding the updated link status of LU, LCU, LD, and LGD as shown in Figure 3.8. The proposed FL and SAW algorithms are developed to select the best potential network candidate by solving the problems of handover latency, packet loss, handover delay, and throughput. The MIH can prepare significant particulars of the crisp inputs (e.g., ABW, RSS, and service types) through the MIHIS, which gathers data from among candidate networks (Wi-Fi, WiMAX, and LTE). The MIHIS adopted by the prediction method was executed into the FL model to rise above issues related to link quality. In the FL model of the event execution process will carry out the information for the MIHES, which is to handle the degree of link trigger.

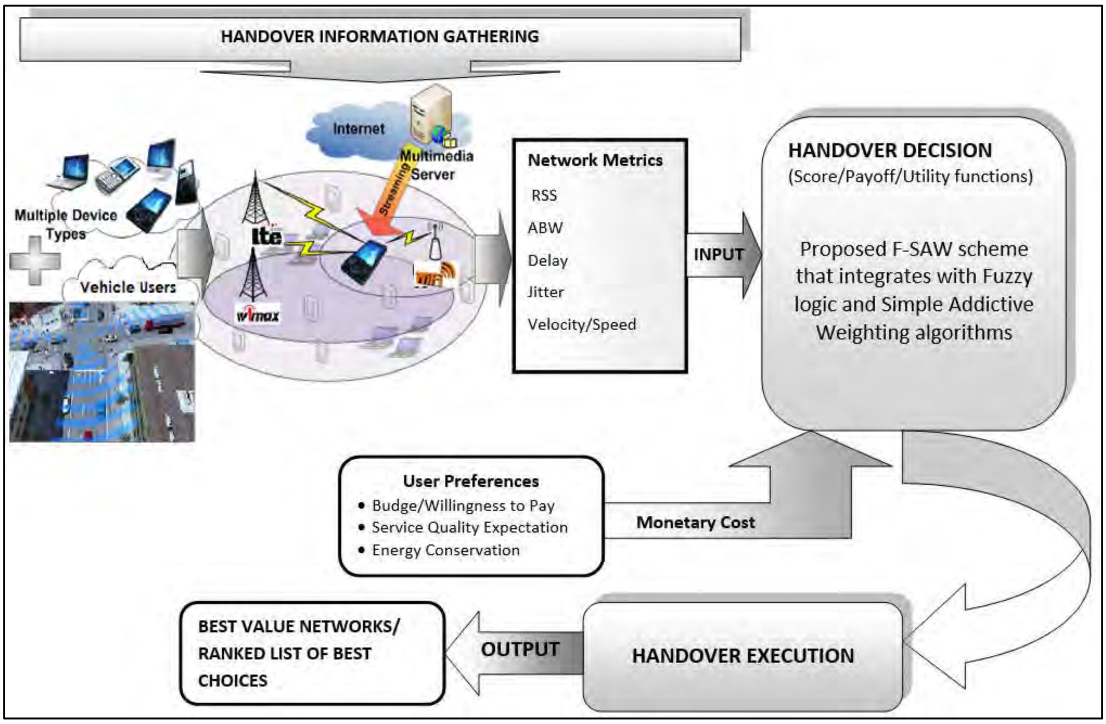


Figure 3.7 *Handover Decision-Making Processes*

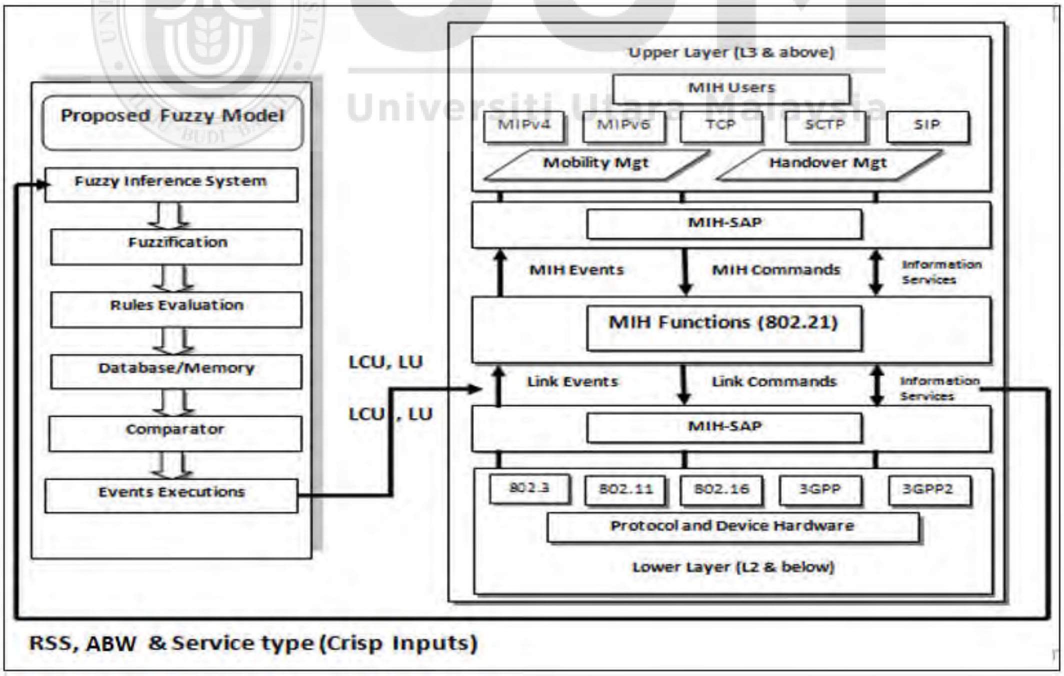


Figure 3.8 *Fuzzy Logic Model with MIH Process (adopted from* [144]*)*

The crisp outputs of the FIS will transmit the link trigger message to the MIHES mechanism for inquiring about the update message in the link status. The process began when the FIS gets values of the crisp inputs (e.g., ABW, RSS, and service type) from the MIHIS and then measure these inputs by referring to specific rules. The result was referred to as the regulation of calculation into de-fuzzified and crisp outputs. The fuzzifier with specific rule evaluation was adjusted to fulfil the user's interest. Further details on the FIS are elaborated in the succeeding sections.

Based on the FIS, the fuzzification process that consists of several steps will transform the value into membership function marking for the linguistic contribution of the fuzzy sets and define membership functions (MFs) to all parameters, as illustrated in Table 3.3. This table indicates that an unacceptable quality level is considered when the weak MFs represent the value is lower than the threshold. The Medium MFs is described as the value which is upper the threshold and considered as an acceptable quality level, while strong represents a guaranteed high-quality level. However, the available and unavailable MFs are defined based on the service type only.

Table 3.3

Values of the Membership Functions (adopted from [144])

Membership Functions (mfs)	**Weak**	**Medium**	**Strong**	**Available**	**Unavailable**
Value	1	2	3	4	5

The linguistic terms will be classified and used by the MFs, while the service type variable will be utilized as available (A) and unavailable (U) based on the MFs values. However, the RSS and ABW conditions are connected with weak, medium, and strong in MFs ranking. In contrast, the case of available (A) MFs in this study will assume all the service is available and not for unavailable (U), as demonstrated in Table 3.4. On the other hand, these MFs are used in the process to evaluate the event of link status in the MIH mechanism.

Table 3.4

Variables of the Membership Functions (adopted from [144])

Variable	**Weak**	**Medium**	**Strong**
RSS (- dbm)	RSS<60	60 ≤ RSS < 90	RSS ≥ 90
ABW(Mbps)	ABW< 0.2	0.2 < ABW < 0.37	ABW ≥ 0.37
Service type	**Unavailable (U)**		**Available (A)** **In our case assume all service is available**

The procedure of the evaluation stage revealed three fuzzy input variables which are ABW, RSS, and two fuzzy sets of service types. The possibility of having the maximum number of fuzzy rules is 18 (e.g. 3 × 3 ×2). The fuzzy rules are examined by using the AND and OR Boolean logic approaches, as shown in Table 3.5. For the composite of the three input variables, there are eighteen (18) possible rules, and the decision will pick only one of the eighteen (18) cases for every technology. Based on the assessment procedure, the table results obtained from each technology will be issued and kept in the memory for the next process. Then, the functional block evaluated from various networks through the database table kept in the memory as compared to acquire the best network connection. The output event was explained in terms of the LU, LD, LGD, and LCU of the MIH events process. This approach was practised for marking the events in the MIH functions. Therefore, if any of the assessed connections are preferable than the current connection, the leading algorithm will transmit mark from each technology to revise the decision making of the MIH event service. Table 3.5 shows that only three events triggered by the handover process are executed which include LCU, LU, and LGD. The LD event is not selected since the RSS, and QoS (e.g., ABW and service type) did not achieve the handover conditions.

Table 3.5

Possible Rules with Output Event Execution

		IF		**THEN**
Rule	**RSS**	**ABW**	**Service Type**	**Output Event**
1	1(Weak)	1(Weak)	5(U)	LD
2	1(Weak)	1(Weak)	4(A)	LD
3	1(Weak)	2(Medium)	5(U)	LD
4	1(Weak)	2(Medium)	4(A)	LD
5	1(Weak)	3(Strong)	5(U)	LD
6	1(Weak)	3(Strong)	4(A)	LD
7	2(Medium)	1(Weak)	5(U)	LD
8	2(Medium)	1(Weak)	4(A)	LD
9	2(Medium)	2(Medium)	5(U)	LD
10	2(Medium)	2(Medium)	4(A)	LGD
11	2(Medium)	3(Strong)	5(U)	LD
12	2(Medium)	3(Strong)	4(A)	LCU
13	3(Strong)	1(Weak)	5(U)	LD
14	3(Strong)	1(Weak)	4(A)	LD
15	3(Strong)	2(Medium)	5(U)	LD
16	3(Strong)	2(Medium)	4(A)	LCU
17	3(Strong)	3(Strong)	5(U)	LD
18	3(Strong)	3(Strong)	4(A)	LU

3.3.2 Integration of Fuzzy Logic and Simple Additive Weighting Scheme (F-SAW)

This research proposed the integration of two algorithms with different categories and features in the vertical handover decision scheme such as Fuzzy logic-based and Simple Additive Weighting algorithms also known as F-SAW. Figure 3.9 presents the system architecture of the proposed F-SAW scheme to achieve the essential objective of this research. The integration of the FL and SAW algorithms, highlighted in the dashed line border, can be implemented as the F-SAW scheme for the intelligent network selection mechanism to choose the best access networks. Firstly, the FL algorithm was implemented for initiating the handover process. Secondly, the SAW algorithm processes were defined through three steps of calculation; 1) calculate the cost value, bandwidth, delay and jitter for each network (e.g. Wi-Fi WiMAX, and LTE); 2) calculate the bandwidth normalization by dividing the bandwidth value of each network by the bandwidth value of the network that has the strongest bandwidth, but in the case of cost, delay and jitter the normalization is determined by dividing the value of the network that has the minimum value by the value of cost, delay, jitter for the LTE, WiMAX, Wi-Fi; 3) calculate the payoff which is the normalization powered by the weight of the parameter. After completed of the three steps calculation process in the SAW algorithm and then through the maximum scoring payoff will be chosen as the best network.

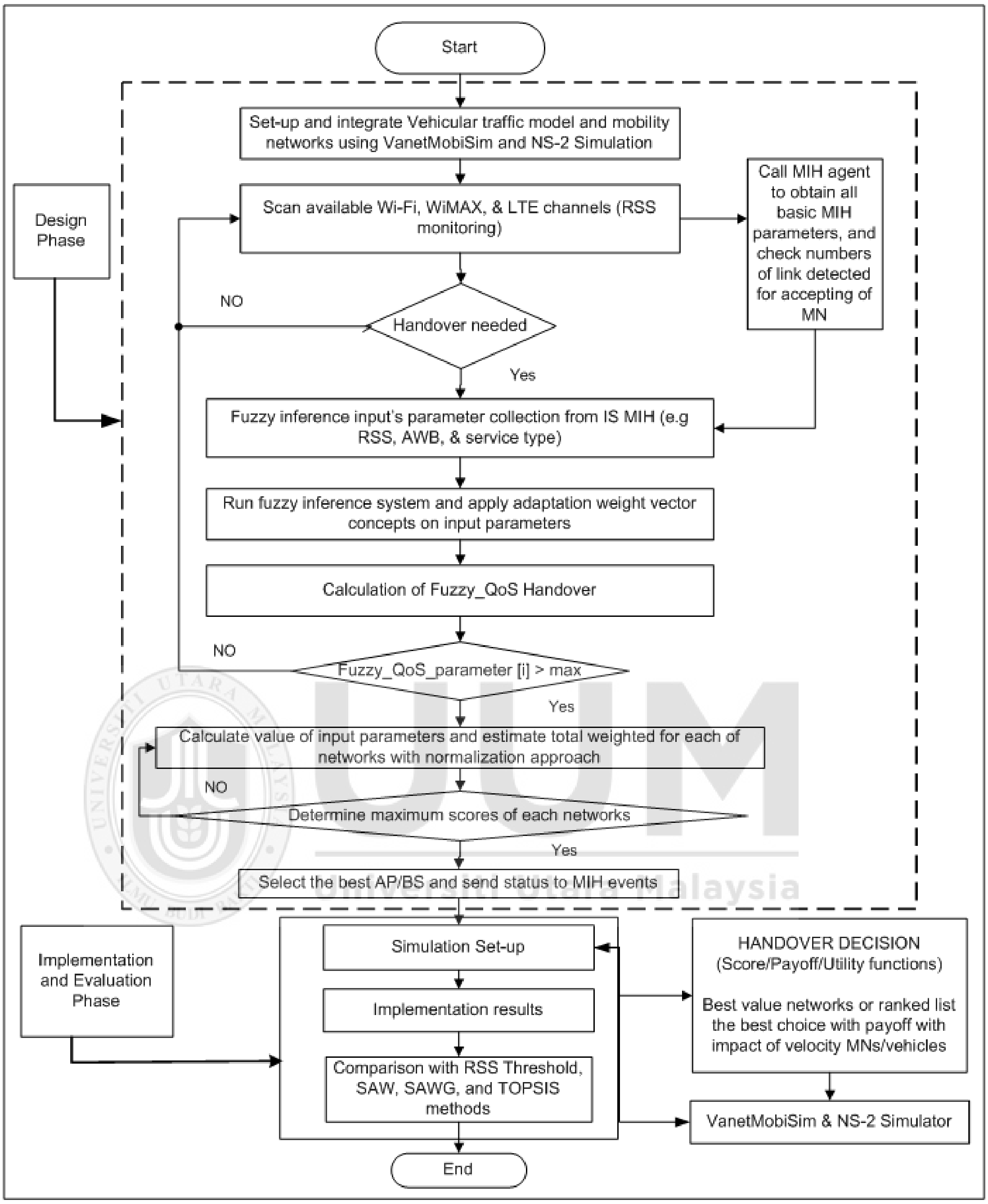


Figure 3.9 *The Systematic Architecture of the Research Design, Implementation, and Evaluation Phases of the F-SAW Scheme*

The mathematical formula for the algorithm selection using the SAW algorithm can also be described through the following steps [87]:

1. Acquiring normalized matrix theory based on the following procedures:

Its norm separates each metric, where *i* represent the LTE, Wi-Fi, and WiMAX networks and *j* represents ABW, jitter, delay, and monetary cost.

a. The ascending criteria are defined as benefit criteria meaning that the levels of the higher priority link will bear the higher value, such as the ABW (the greater value of x_j is the priority to choose the best). It can change the result x_{ij} to the one stated in Equation 3.1.

$$r_{ij} = \frac{x_{ij}}{max_i x_{ij}} = \frac{x_{ij}}{x_j^{max}} \tag{3.1}$$

b. The descending criteria consist of several variables, namely as cost, delay, and jitter. Therefore, a greater priority is defined by utilizing lower value. In this case, the result, represented as r_{ij}, is determined in Equation 3.2.

$$r_{ij} = \frac{min_i x_{ij}}{x_{ij}} = \frac{x_j^{min}}{x_{ij}} \tag{3.2}$$

Where r_{ij} has the same value of the delay and jitter in the network, which has the lowest value divided by the value of the delay and jitter in each network (e.g., LTE, WiMAX, and Wi-Fi).

Whereas, x_j^{min} represents the lowest value for delay and jitter in the network. However, the value of the monetary cost is constant for the three network technologies; LTE=0.7, WiMAX=0.5, and Wi-Fi=0.2.

2. The utility total scoring (utility value U^i) of the main offer for each option (network) can be acquired as formulated in Equation 3.3.

$$U_{primary}^{i} = \sum_{j=1}^{m} r_{ij} \tag{3.3}$$

3. Acquiring the utility total scoring (utility value U^i) for each option (network) can be acquired, as defined in Equations 3.4 and 3.5. For example, the parameters available bandwidth, Cost, Delay, and Jitter.

$$U^{i} = \prod_{j=1}^{m} r_{ij} w_j \tag{3.4}$$

Where the utility value U^i is also equal to total score with

$$U^{i} = \left(\sum\left(U_{cost}^{i} . U_{ABW}^{i} . U_{delay}^{i} . U_{jitter}^{i}\right)\right) \tag{3.5}$$

4. The score function is calculated for each network, and the network that acquired the highest scoring value will be decided as the best network. The one that includes alternative network N^* is chosen as depicted in Equation 3.6. The N^* is selected to determine the best network.

$$N^{*} = \left\{U^{i} \middle| max_{i} U^{i}\right\} \tag{3.6}$$

Therefore, this research proposed the network selection decision of VHO in the VANET situation referred to as the combination of the FL and SAW algorithms. This algorithm analyzes the weight of the parameters that influenced the network choice operation in VANET.

Furthermore, the network selection method may play a big role in finding and selecting the optimal cellular or wireless network for providing high-quality services to consumers.

From the literature, an intelligent scheme has been identified as the most used and adopted scheme when it comes to design a system architecture of the proposed scheme in this research.

3.4 Network Performance of Vertical Handover Decision Scheme Development in VANET

In the third phase, the VANET traffic scenario was implemented using the VanetMobiSim simulator to provide a realistic mobility traffic model similar to the real VANET network. The network performance model was developed using the Network Simulator 2 (NS-2.29), a simulation tool that integrates the IEEE802.21 standard (MIH) library produced by the National Institute of Standards and Technology (NIST). The integration of these two simulators was applied due to the high complexity of the communication systems and expensive infrastructures such as network-related devices and tools in this research for setting up the testbed or real network. The FL and SAW algorithms with the multi-criteria parameters were implemented by using the C++ program language. In contrast, both algorithm interfaces were established through the MIH library in the NS-2 simulation. The dynamic design simulation is very important for utilizing multiple technologies interface networks such as Wi-Fi, WiMAX, and LTE. The next stage is required to measure the performance of the handover decision method in terms of the handover QoS, link status trigger, and choose the best access network.

3.5 The Performance Evaluation and Validation of the Proposed Scheme in VANET

In the last phase, the performance evaluation and validation of the AHD and F-SAW schemes were managed to ensure process accuracy. In the evaluation process of the AHD scheme, the performance results were evaluated and analyzed based on the QoS of the handover process. The validation was conducted by comparing various schemes such as the RSS-Threshold algorithm as the indicator of link quality and MIH-based algorithm to determine the best QoS of the handover process.

In evaluating and validating the F-SAW scheme, the results were analyzed and compared based on the maximum utility score of other vertical handover algorithm methods which include RSS-Threshold, SAW, SAWG, and TOPSIS algorithms [87].

There are several metrics for performance QoS of handover decision mechanism as follows:

1. Throughput: The data rate provided for the subscribers, which can be obtained in available networks. In other words, it is a total of data moved from a sender to a receiver in a set of time. The measurement units usually used for this purpose are megabits per second (Mbps) and kilobits per second (kbps). Equation 3.7, as presented below, is used to evaluate the throughput.

$$Throughput = \frac{TransferFile}{TransferTime} \tag{3.7}$$

2. Delay: The total time takes for a bit of data to travel from one node to another across the network. It is measured in multiple fractions of seconds. It also consists of a total time of delay comprising of program processing, queuing delay, and propagation delays. The mean delay is measured using the formula in Equation 3.8. Where $\sum_{i=1}^{n} DelayofPacket$ is the length of the packet divided by the bandwidth of the outgoing link in the bits/seconds represented by (n).

$$AverageDelay = \frac{\sum_{i=1}^{n} DelayofPacket}{n} \tag{3.8}$$

3. End-to-end latency: This latency is the time needed to send a message packet from the source to destination nodes. It shows the totals of the network latencies (network response time) and handover latencies, as depicted in Equation 3.9.

$$Latency_{e2e} = Latency_{network} + Latency_{VHO} \tag{3.9}$$

4. Vertical Handover (VHO) latency: The VHO latency refers to the total time related to the VHO processes such as HO initiation, decision, and execution. The VHO metric is formulated, as shown in Equation 3.10.

$$Latency_{VHO} = Latency_{initiation} + Latency_{decision} + Latency_{execution} \quad (3.10)$$

5. Vertical Handover (VHO) packet loss: It refers to the total number of the packet that failed to be transmitted from a sender to receiver during the handover process. It must be evaluated only during the process of the mobile node triggered among candidate networks. This metric is described by Equation 3.11.

$$PacketLoss_{VHO} = \frac{1-Packet_{received}}{Packet_{send}} \quad (3.11)$$

The results of this research were compared to the other VHOD algorithms such as RSS-Threshold and MIH algorithms. This research presented the design and results of the simulation for the VHOD scheme in the VANET and prepared the performance of QoS executed in the NS-2 simulation. Most importantly, the novelty of the intelligent network selection mechanism allows selecting the best network technology that can achieve user satisfaction. The selected technology also should fulfil user requests by not only increasing the throughput, high signal strength, and high bandwidth but also decreasing the handover latency, packet loss, monetary cost, delay, and jitter. Finally, Figure 3.1 shows the applied research approach which is aligned to accomplish the objectives of this research.

3.6 Summary

This chapter describes the methodology phases utilized in this research towards achieving the stated objectives. The methodology highlights the overall related four phases starting from the preliminary study, design network performance, network performance development, and proposed scheme evaluation.

CHAPTER FOUR

THE DEVELOPMENT OF THE PROPOSED ADAPTIVE HANDOVER DECISION SCHEME

This chapter describes the issues related to the AP or BS prediction processes. Among the issues include the problems encountered in WLANs and advanced generation wireless technologies such as the quality of RSS link prediction, inaccurate handover decisions, and handover management, which have been specified as part of the main research questions of this research. In responding to the issues, the adaptive handover decision (AHD) scheme was proposed. The proposed scheme uses the FL algorithm, which evaluates the handover process QoS performance and selects the best candidate among several features of the AP or BS. The development of the proposed scheme was conducted in the design phase (refer to Figure 3.4 of subsection 3.3.1 in Chapter 3). After that, it is followed by the implementation phase that was conducted using the NS-2 simulator. Finally, in the evaluation phase, the proposed scheme was compared to the other existing schemes such as the RSS-Threshold and MIH-Based.

4.1 Overview of the Proposed Adaptive Handover Decision (AHD) Scheme

The AHD scheme is developed to achieve the first objective of this research, as listed in Section 1.5 of Chapter 1. The flowchart presents the related processes of the scheme development, as illustrated in Figure 4.1.

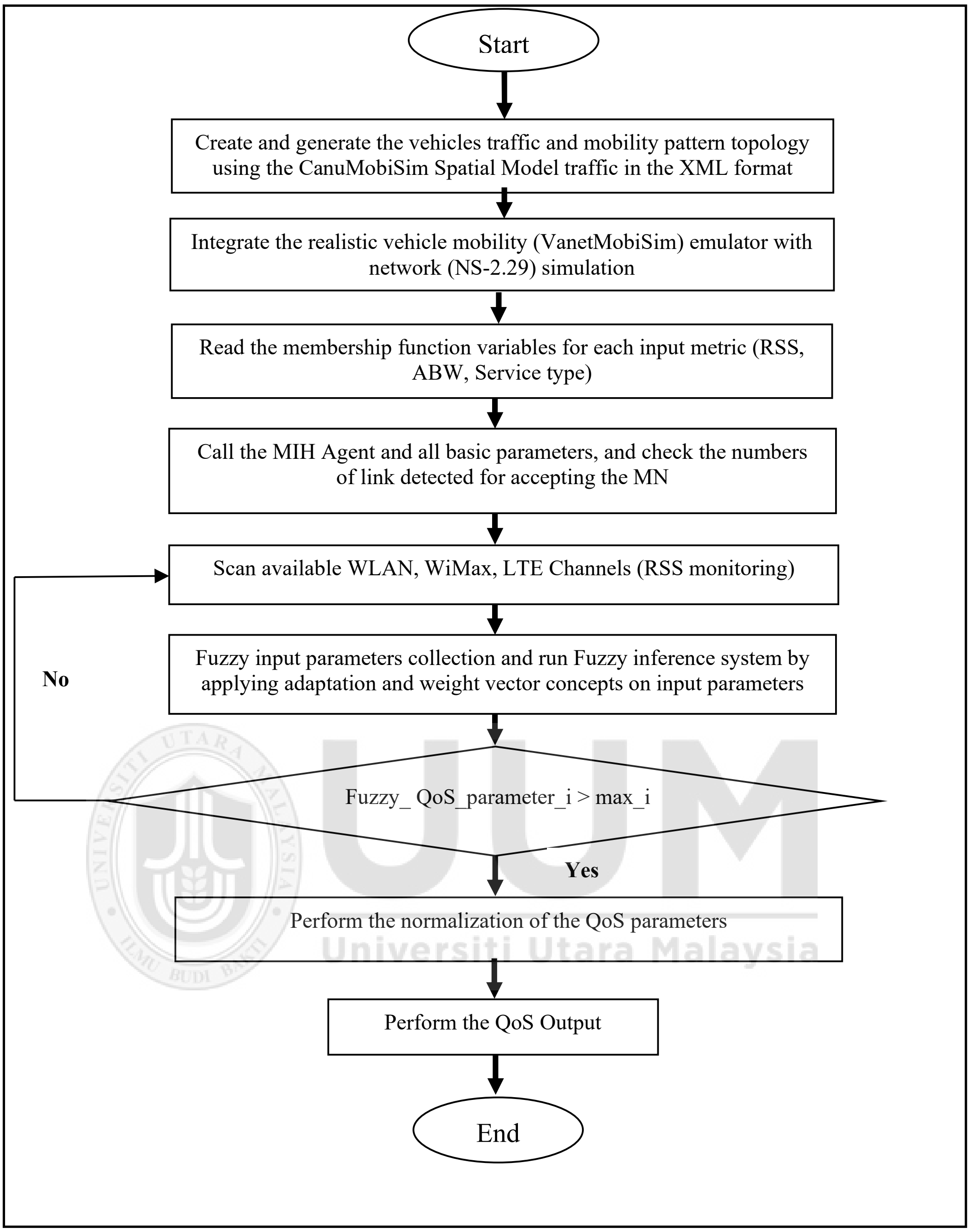


Figure 4.1 *The Flowchart of the AHD Scheme*

Figure 4.1 shows a flowchart of the proposed AHD scheme. The AHD scheme process began by generating the vehicle traffic and mobility pattern topology using the CanuMobiSim Spatial Model traffic in the VanetMobiSim generator. The vehicular spatial model created the spatial components (such as multi-lane roads or traffic lights) including their characteristics and associations to depict the vehicular area. The VanetMobiSim was used to generate the XML code for indicating the dissimilar simulations and providing the VANET scenario. Once generated, the mobility scenario XML file in VanetMobiSim (refer to Appendix A) was combined with the NS-2 open-source network simulator. The trace file was generated by the NS-2, as depicted in Figure 4.2.

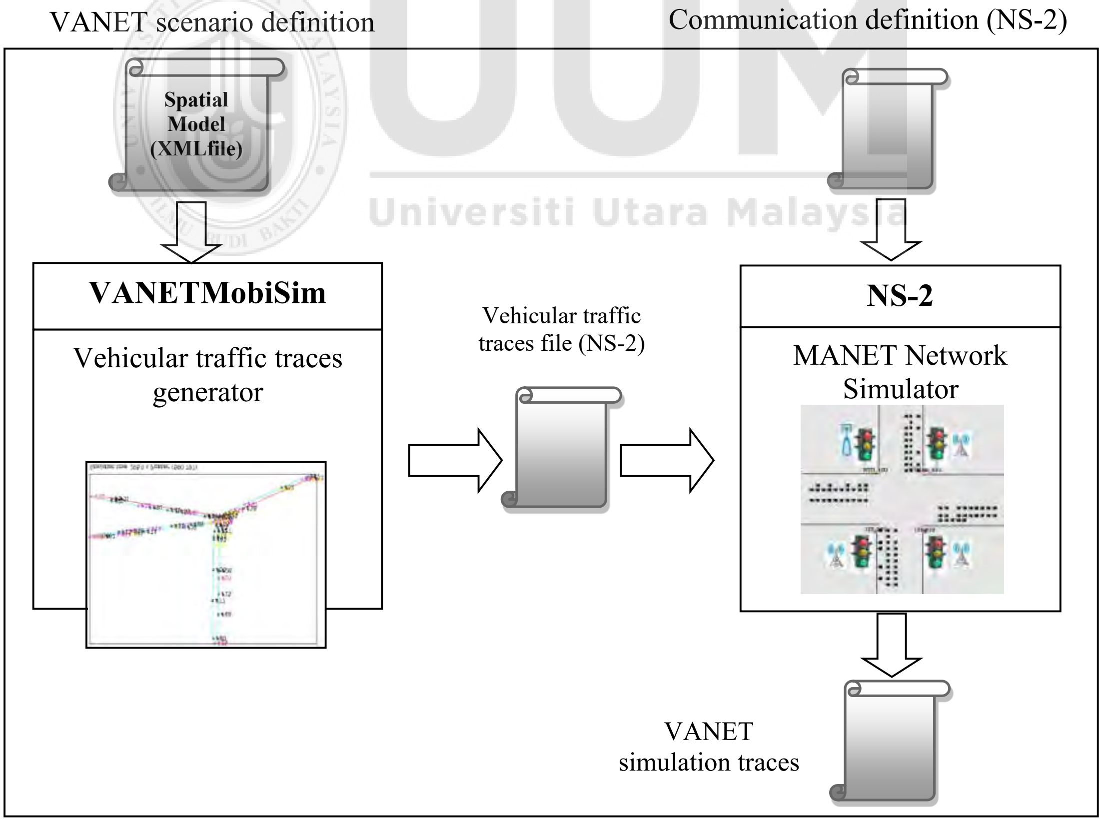


Figure 4.2 *VANET Simulator based on the Coupling of VanetMobiSim and NS-2*

The XML file generated in the VANETMobiSim framework is needed to generate the node of mobility trace file in NS-2 formats such as node identifier, position, time, and speed known as a vehicular traffic trace file. This file must be incorporated into the communication definition file (Wi-Fi, WiMAX & LTE technologies topology, propagation model, constant bit-rate (CBR) traffic file, and routing protocol) and executed by the tool command language (Tcl) of the scripting language in NS-2. In NS-2, the VANET simulation trace file was generated by viewing the Network Animator (NAM) visualization tool. The real-world packet traces were also revealed at this point. After running the NS-2, a trace file that provides results in the log trace (log.tr – refer to Appendix E) file for all routing events during the simulation was generated.

Before executing the NS-2, the AHD scheme gathered the fuzzy inference system (FIS) input metrics (RSS, ABW, and service type) from the Information Service (IS) MIH mechanism. The FIS required to measure the fuzzification process (e.g. *Fuzzy_Qos_parameter_i* > *max_i*) for calculating the total requested each parameter and recorded value in every node, as shown in Figure 4.1. After that, performing the normalization process and Output of the QoS handover. The integration of the fuzzy logic model and MIH mechanism to be able to achieve the performance of QoS handover. Therefore, the AHD scheme also can be chosen as the best available candidate for different network access.

4.1.1 Fuzzification of the Network Access Selection input Parameters and Output

The process of obtaining the three fuzzy interferences' input crisps (RSS, ABW, and service type) from the MIH information service (MIHIS) began by calling the MIH agent and all its basic parameters, as well as checking the numbers of link detected for accepting MNs. The required information will then be sent to the fuzzy inferences system for compiling the crisp inputs (e.g. ABW, RSS, and service types) with the MFs values. The detailed explanations are included in Subsection 4.1.2.

1. Received Signal Strength (RSS)

RSS is the key importance of the handover decision making parameters. To ensure the quality of RSS, the range of signals each AP is examined. The ping-pong movement occurred because the vehicle moves far away from the range of AP, which is the RSS either increases or decreases. Therefore, the RSS of the passive scanning process in the AHD scheme for among available AP is captured and entered into the FIS process. As a new contribution towards the handover prediction metric introduced in this section, the range of RSS membership functions (Mfs) is considered to be adaptive in FIS. On the other hand, to accomplish adaptive Mfs for the RSS input metrics, the RSS value is retrieved from the scanning process to be between two identified values: RSS_{Min} and RSS_{Max}. During the passive scanning process, the RSS value of each vehicle′s has been accumulated; the RSS values are normalized and categorized using Equations 4.1, 4.2, and 4.3 in [145].

$$Weak_{RSS^{V}} = \begin{cases} 1 & (RSS_{min} \leq RSS \leq M_{th}) \\ \left|\frac{RSS-M_{th}}{W_{max}-M_{th}}\right| & (M_{th} \leq RSS \leq W_{max}) \\ 0 & (RSS > W_{max}) \end{cases} \tag{4.1}$$

$$Medium_{RSS^{V}} = \begin{cases} 1 & (W_{max} \leq RSS \leq S_{th}) \\ \left|\frac{M_{th}-RSS}{M_{max}-M_{th}}\right| & (M_{th} \leq RSS \leq W_{max}) or\ (S_{th} \leq RSS \leq M_{max}) \\ 0 & (RSS > M_{max}) or\ (RSS < M_{th}) \end{cases} \tag{4.2}$$

$$Strong_{RSS^{V}} = \begin{cases} 0 & (RSS_{min} \leq RSS \leq S_{th}) \\ \left|\frac{S_{th}-RSS}{RSS_{max}-S_{th}}\right| & (S_{th} \leq RSS \leq M_{max}) \\ 1 & (M_{max} \leq RSS \leq RSS_{max}) \end{cases} \tag{4.3}$$

The adaptive member functions of the normalized RSS input parameters can be created, as shown in Figure 4.3.

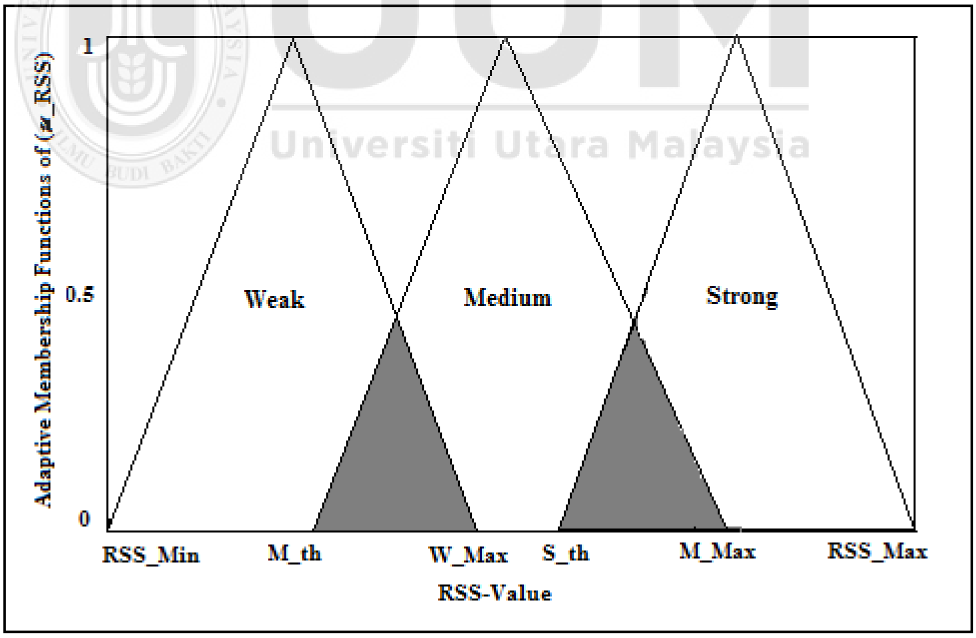


Figure 4.3 *The Adaptive Membership Functions of the Normalized RSS Input Parameter*

Figure 4.3 presents the adaptive Mfs for the RSS input metrics. The Mfs represented by three RSS quality levels recognized as Weak, Medium, and Strong. The range of the quality level based on new assumed variables. For example, the variables used to represent the quality levels are M_{th} threshold value for the Medium Mf, W_{Max} maximum value of the Weak Mf, S_{th} threshold value for the Strong Mf, and M_{Max} maximum value for the Medium Mf. Besides, the minimum and maximum values of RSS represented by RSS_{Min} and RSS_{Max}. The expanded piecewise linear Mfs could be achieved using the formula introduced in Equations 4.1, 4.2, and 4.3. By developing these equations, the points between (0 and 1) of RSS′s membership values in the vertical axis as depicted in Figure 4.3. By using the proposed adaptive FIS in the AHD scheme, Mfs have identified adaptively. The RSS_{Min}, M_{th}, W_{Max}, S_{th}, M_{Max}, and RSS_{Max} coefficients are devised to attain the adaptive Mfs based on the available features of the access network candidates. For instance, after classifying the value for each particular ratio by using equations 4.1, 4.2, and 4.3, (suppose: -130, -10, -85, -70, -50, and -40 dBm, respectively), the normalization process of each of the specific coefficient value should be obtained as -62 dBm which is allocated in the triangle with a rib of (M_{th}, W_{Max}).

On the other hand, when $M_{th} = -70$ dBm, $W_{Max} = -50$ dBm, ($-70 \leq -62 \leq -50$), Equation 4.1 is applied to the range between 0 and 1. The calculation value in $\left|\frac{RSS - M_{th}}{W_{max} - M_{th}}\right|$ will then be substituted numerically to $\left|\frac{(-62)-(-70)}{(-50)-(-70)}\right| = 0.40$. The obtained value of this calculation represents the degree of the weak signal. Moreover, by using Equation 4.1, the assembled RSS value of -62 dBm is apportioned in the weak Mf of the RSS input parameter. Since this value is disputed with the medium membership function, hence the point of weak rate is 0.40. The consideration of the membership rate is adaptively determined for the input values either based entirely on the inside or outside any particular Mf.

2. Available Bandwidth (ABW)

ABW is another fuzzy input parameter that relates to the closing movement of the MN or vehicle to each AP or BS. Usually, when MN starts to roaming throughout dissimilar AP or BS, a couple of APs with a high-quality RSS can be determined. In other words, MNs are free to access any of the APs or BSs with a high-quality RSS of various MNs directions or vehicle movements. ABW also is an essential parameter for measuring the reliable handover prediction to choose the best AP or BS candidate, which was considered by the proposed AHD scheme.

Therefore, the value is assigned to be between two identified values of ABW_{Min} and ABW_{Max} adaptively due to accomplish the fuzzy set process. While the ABW for each AP in the MN′s scanning has been gathered through the passive scanning process, the ABW rates are categorized and normalized using Equations 4.4, 4.5, and 4.6.

$$Weak_{ABW^V} = \begin{cases} 1 & (ABW_{min} \leq ABW \leq M_{th}) \\ \left|\frac{ABW-M_{th}}{W_{max}-M_{th}}\right| & (M_{th} \leq ABW \leq W_{max}) \\ 0 & (ABW > W_{max}) \end{cases} \tag{4.4}$$

$$Medium_{ABW^V} = \begin{cases} 1 & (W_{max} \leq ABW \leq S_{th}) \\ \left|\frac{M_{th}-ABW}{M_{max}-M_{th}}\right| & (M_{th} \leq ABW \leq W_{max}) or\ (S_{th} \leq ABW \leq M_{max}) \\ 0 & (ABW > M_{max}) or\ (ABW < M_{th}) \end{cases} \quad (4.5)$$

$$Strong_{ABW^V} = \begin{cases} 0 & (ABW_{min} \leq ABW \leq S_{th}) \\ \left|\frac{S_{th}-ABW}{AWB_{max}-S_{th}}\right| & (S_{th} \leq ABW \leq M_{max}) \\ 1 & (M_{max} \leq ABW \leq ABW_{max}) \end{cases} \quad (4.6)$$

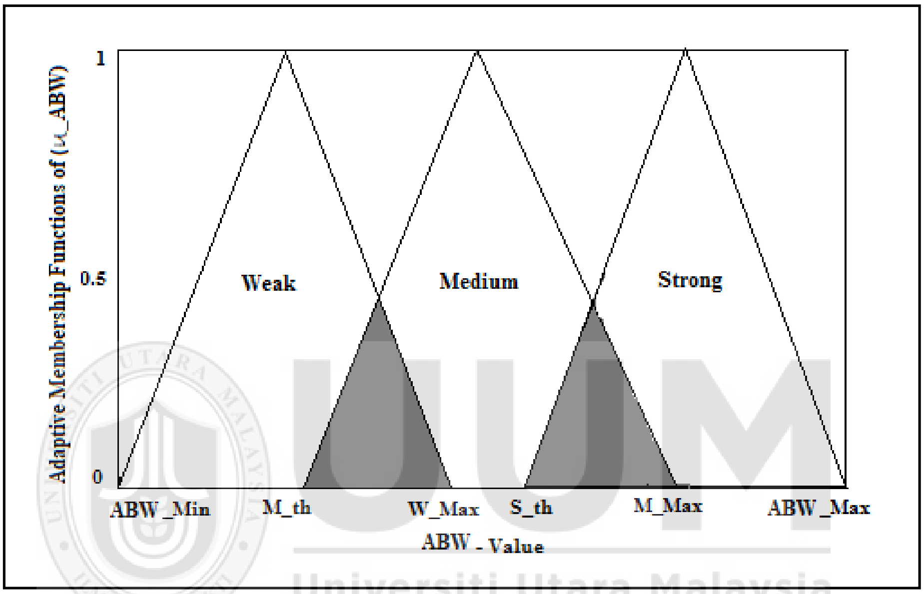


Figure 4.4 *The Adaptive Membership Functions of the Normalized ABW Input Parameter*

The developed Mf of the ABW input parameter is shown in Figure 4.4. This adaptive Mf for ABW has similar levels of quality, defined as Weak, Medium, and Strong. By using these variables, M_{th} threshold value of Medium Mf, W_{Max} maximum rate of Weak Mf, S_{th} threshold rate of Strong Mf, and M_{Max} maximum rate of Medium Mf in addition to minimum and maximum rates of ABW (ABW_{Min} and ABW_{Max}) the expanded piecewise linear Mfs could be achieved, as shown in Equations 4.4, 4.5 and

4.6. However, the equations could be developed through the range between 0 and 1 of ABW′s membership rates that are measured respectively, as depicted in the vertical axis in Figure 4.4. By using the proposed adaptive FIS in the AHD scheme, the adaptive Mf can be identified. The ABW_{Min}, M_{th}, W_{Max}, S_{th}, M_{Max}, and ABW_{Max} coefficients are plotted to attain adaptively based on the available networks access candidates' features.

3. Service Type

Service type, a vital input parameter of VHO, is provided by several technologies that have their services but do not support further technologies. However, it can share the same functions with other technologies. For instance, at some stage in the service change, transferring video-to-video is a better technology compared to the high data rate. Thus, the service type is a static input parameter that produces two membership functions, such as available (A) and unavailable (U). The available (A) membership functions represent performing the technology (A), which supports this service, while the unavailable (U) represents the technology that does not support this service.

4.1.2 The Design of the Adaptive Fuzzy Logic for the AHD Scheme with Media Independent Handover (MIH) Mechanism

This subsection explains the experiment and simulation topology of the proposed AHD scheme using the MIH mechanism. The MIH protocol represents the IEEE 802.21 standard that deployed information switch between peers for triggering a handover. The protocol also allows the payload of general information through different media technologies such as 802.3, 802.11, 802.16, and Cellular/UMTS/LTE [146]. The MIH prediction algorithm has four services that include link coming up (LCU), link up (LU), link going down (LGD), and link down (LD). Generally, Media Independent Handover Function (MIHF) is the logical entity to offer the specificities of different link-layer technologies from upper entities. MIHF also communicates with upper entities to obtain information from lower layers. MIHF provides three primary services: MIH Event Service (MIHES), MIH Command Service (MIHCS), and MIH information Service (MIHIS), as shown in Figure 4.5. The proposed AHD scheme in which the FL algorithm is designed to measure the performance of handover and select the best candidate networks that solved the QoS handover problem in terms of handover delay and packet loss. The MIH provides significant crisp inputs (e.g., RSS, ABW, and service types) through the Information Service (IS) by gathering related data from the available networks such as Wi-Fi, WiMAX, and LTE networks. The prediction method uses the crisp inputs obtained from the MIH IS as input parameters for the Fuzzy Logic algorithm to overcome connection quality issues. The event execution process in the Fuzzy Logic model transmits labeled information to the MIH event service that manages the degree of link trigger.

1. Adaptive Fuzzy Inference System

In the proposed AHD scheme, the adaptive Mf developed in the design of a FIS. The function separated into three categories, namely fuzzification, inference engine, and defuzzification. The fuzzy inference system (FIS) will start receiving crisp inputs (e.g., ABW, RSS, and service type) from the MIH, as depicted in Figure 3.8 of Subsection

3.3.1 in Chapter 3. The data of the parameters were further evaluated and highlighted as a standard or regulation. The fuzzifier with the rule assessment must be adjusted due to satisfy the user's interest. According to the FIS, the fuzzification process contains several steps to turn the value into membership function (MF) grading for the linguistic supply of fuzzy sets and constructed MFs to all parameters, as shown in Tables 3.3 and 3.4 of Subsection 3.3.1 in Chapter 3. The MFs utilized the procedures to estimate the link status of the MIH process.

The local MN will measure the obtained RSS and its path degree to each available AP or BS, which performed the handover prediction, as shown in Equation 4.7.

$$RSS_c < h \tag{4.7}$$

In addition to obtained AP RSS value, which is broadcast via each AP. The handover decision utilizing the proposed AHD when RSS from current serving AP, which is RSS_c rates lower than a threshold h as depicted in Equation 4.7)

Afterwards, the deciding factor, AHD_f based on the calculated $Fuzzy_{QoS\_parameter\_i}$ for all the AP or BS candidate is attained while the AP_i candidate is selected for handover initiation if the following in Equation 4.8 is fulfilled:

$$AHD_f = AP_{QoS} - Fuzzy_{QoS\_parameter\_i} > max \tag{4.8}$$

Where *max* is the threshold rate that supports to evade unnecessary handover refers to the condition of Table 3.4 in Chapter 3. The $\mathrm{Fuzzy}_{\mathrm{QoS\_parameter\_i}}$ is the final decision parameter of maximum QoS of AP_i candidate, AP_{QoS} is quality QoS of the recently helping AP or BS, and AHP_f is the variant among decision factor of the helping AP and the AP_i target.

The calculation process of the output event for determining the link status quality has the main impact on the whole performance of the FL process in APs and BS. For example, if the collected RSS for one AP or BS is strong, ABW is Medium, and the service type is available. The obtained output event using the AHD scheme for AP or BS is considered as a link coming up (LCU) as revealed in Table 3.5 of Subsection 3.3.1 in Chapter 3.

2. Defuzzification

In the process of defuzzification, the crisp value is removed from a fuzzy set value. This defuzzifier is based on Equation 4.9.

$$Fuzzy_{Qos^V} = \frac{\sum_{All\ Rules} \overline{U}_j \times \ \overline{W}}{\sum_{All\ Rules} \overline{U}_j} \tag{4.9}$$

Where, $Fuzzy_{Qos^V}$ is delineated as the degree value of decision making. $\overline{W}$ is the weight vector variable of input parameters (e.g., RSS, ABW, and service type) and $\overline{U}$ represents the adaptive degree of membership functions. The defuzzification method is used to change the output event to a crisp value.

However, the crisp output presented by the defuzzification process will be forwarded to the comparator part. The results received from the comparator will be produced by

Event Executions as link output status for the MIH link event, as illustrated in Figure 4.5.

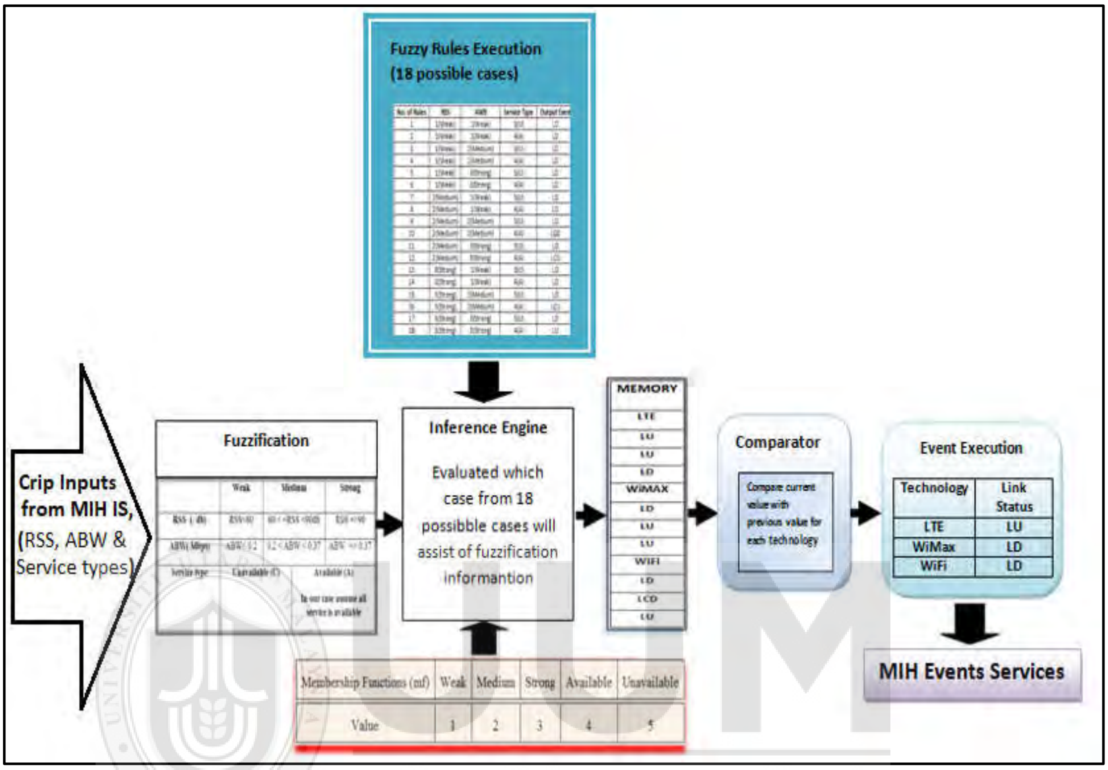


Figure 4.5 *Fuzzy Logic Components Process to Generate the Output Event of AP or BS*

4.2 The Experiment of AHD Scheme

This section explains in detail the two parts of the input and output for the vertical handover decision in VANET developed in the NS-2 network simulation. The input process describes the simulation (refer to Appendix B in module index 4.1 and 4.2) and parameters. At the same time, the analysis of output produces the simulation results (refer to Appendix C in module index 4.3), which are based on equations of 3.7, 3.8, 3.9, 3.10, and 3.11 of subsection 3.5 in Chapter 3.

4.2.1 Simulation and Parameters

The simulation conducted in this research uses the traffic light topology, as shown in Figure 3.5 of Subsection 3.3.1 in Chapter 3, involving three different radio technologies; Wi-Fi, WiMAX, and LTE in VANET. The simulation was implemented in the NS-2.29, which was integrated with the VanetMobiSim simulator. The simulation was developed in the NS-2.29, integrated with simulator VanetMobiSim. The simulation utilized various vehicular mobility models to get the movements of the realistic vehicles in the traffic light scenario such as VanetMobiSim[31], SUMO[40], CityMob[147], and FreeSim[43]. In this research, the CanuMobisim [35] Spatial Model traffic data provided by the Informatik University of Stuttgart was used to perform and generate in the VanetMobiSim simulator. The vehicle mobility models' macroscopic and microscopic features include road topology, road characteristics (e.g., multiple-lane or directional traffic flow, speed restriction, and intersection crossing rules), and variety of movement patterns. Once transformed into the XML file format, the traffic data was then integrated into the NS-2.29 simulation to evaluate the QoS VHO in VANET.

Table 3.1 and Table 3.2 of Subsection 3.3.1 in Chapter 3 show the list of the simulation parameters that will set-up in VanetMobiSim and NS-2.29, respectively. The Mobility Internet Protocol version 6 (MIPv6) was used as the mobility agent in the simulation, as shown in Table 3.2. Based on the simulation topology and parameters, the efficacy of the MIH mechanism with the FL algorithm for performing QoS handover was evaluated. The Fuzzy Logic algorithm was developed in C++ and used the available interfaces included in the MIH library of the NS-2.29. The vehicles were designed to use various wireless access technologies, such as Wi-Fi, WiMAX, and LTE networks, for simulation scenarios. The hundreds of vehicles will be used in the simulation as the amount of MNs available to access the different network coverage. For the simulation time, vehicles in the heterogeneous network were assumed to travel in 300 seconds through the traffic light road. The MN will use the interactive application as the traffic class. The traffic transmission began with LTE and Wi-Fi communication interfaces at the start of the simulation and then proceeded to connect to the WiMAX network interface. The traffic light was set up in three lanes to reflect the real situation of the traffic light. The movement of vehicles began at traffic light from the first lane of the road. The vehicle would then traverse and exit the traffic light until connected to the nearest communication network area AP or BS (e.g., LTE, Wi-Fi, and WiMAX). After that, the second lane vehicle must cross and exit the traffic light, followed by the third lane vehicle. The maximum interval time was set up in 5 seconds. Even the shorter synchronization time interval can be possible to demonstrate the maximum interval time of a seamless handover with higher efficiency.

After running the NS-2, the VANET traces file, which represents the network animator (NAM) output for displaying traces of real-world packets and traces of the network simulation. The VANET traces file also produces the entire events log during the simulation. Eventually, AWK scripts were needed to filter and measure the events trace file that performed all the essential data and estimation of the simulation scenario that examined the vertical handover of output QoS.

4.2.2 Simulation Results

This section presents the proposed AHD scheme results and QoS analysis in the heterogeneous vehicular ad-hoc network using the FL algorithm. The algorithm performed the simulation analysis in terms of the handover latency, end-to-end delay, packet loss, throughput, and packet delivery ratio using different vehicle speeds such as 20, 40, 60, 80, and 100 km/h.

1. Handover Latency

The handover latency describes the time required for the transmission of a data packet from the transmitter to the receiver nodes. It also defines the network total and the latency of a packet that travels from one node to another. Figure 4.6 presents the handover latency results of the proposed FL algorithm. The analysis results indicate that the average latency of FL is 10.6 millisecond when the speed of the vehicle increases from 20 to 100 km/h. Then, the speed between 20 and 100 km/h increased to 56.5% from 8.34 ms to 13.05 ms.

Therefore, this study is a significant accomplishment in our research design. Ndashimye et al. [148] mentioned that the increase in the speed of movement indicates the increase of handover latency. The situation occurs because of the growth in radio link failure (RLF), which may happen due to the point that the vehicle crosses the boundaries of the portion cell before finishing the handover movement to the target network.

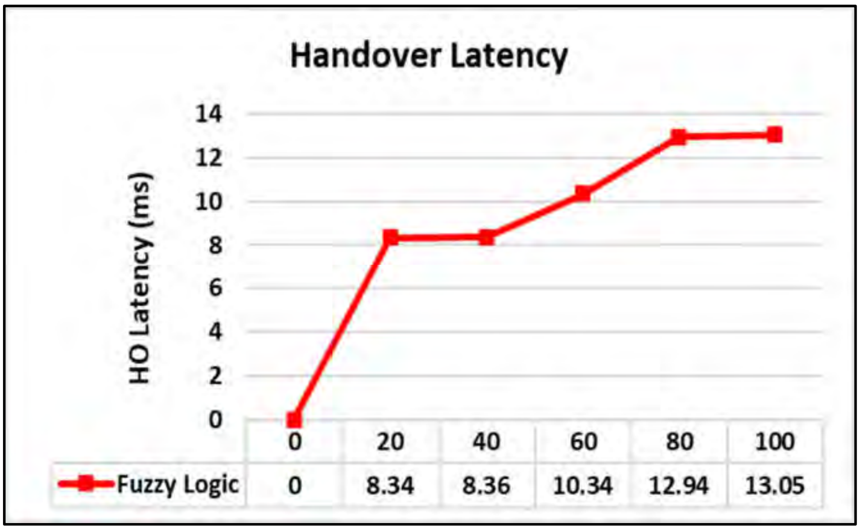


Figure 4.6 *Handover Latency vs Velocity in FL*

2. End-to-end Delay

The end-to-end delay is the time obtained for a packet to be transmitted across a network from the vehicle node to AP or BS. It is also known as a one-way delay. Figure 4.7 depicts the end-to-end delay simulation results of the FL algorithm. The average end-to-end delay is about 111.97 milliseconds when the speed of the vehicle increases from 20 to 100 km/h. Hence, the vehicle speed rapidly increased to 184%, when speed compared between 20 and 100 km/h.

However, the higher end-to-end delay will be affected by the QoS performance of delay-sensitive applications such as voice applications [148]. As a result of the analysis shown increasing of end-to-end delay due to high link quality of the trigger via vehicles and APs. Also, this study is implemented in passive scanning and the traffic light topology, which is the movement of the vehicles based on the reality of the traffic light direction system for triggering the potential of APs targeted.

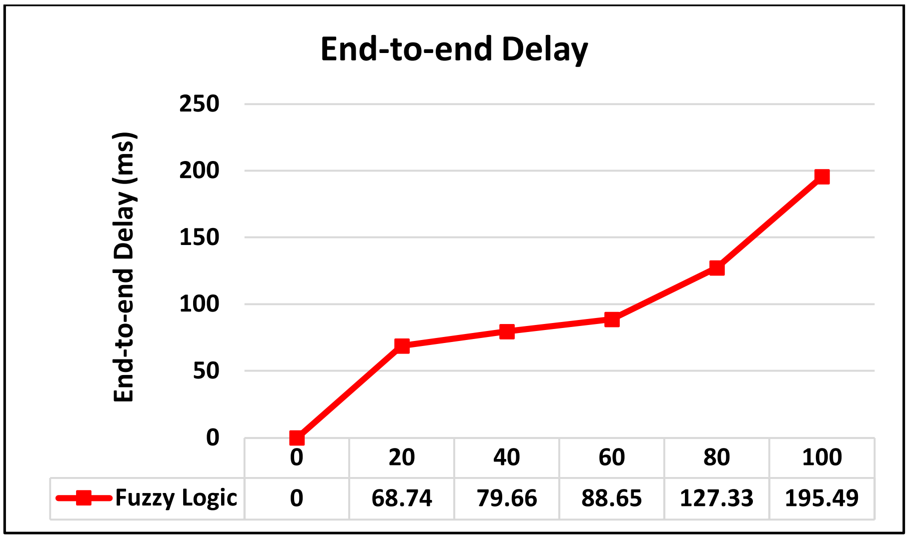


Figure 4.7 *End-to-end Delay vs Velocity in FL*

3. Packet Loss

Packet loss is the total number of packets that failed to reach the respective destination during the handover process. It was measured only during the handover triggering operation under several access networks coverage. Figure 4.8 shows the packet loss results using the FL algorithm. The packet loss increases approximately 41.1% when the speed of the vehicle increases from 20 to 100 km/h, while the average packet loss is 384 packets.

On the other hand, the increase of packet loss in this study due to the low link quality of connection via APs and packet congested during the transmission in the overloaded traffic network.

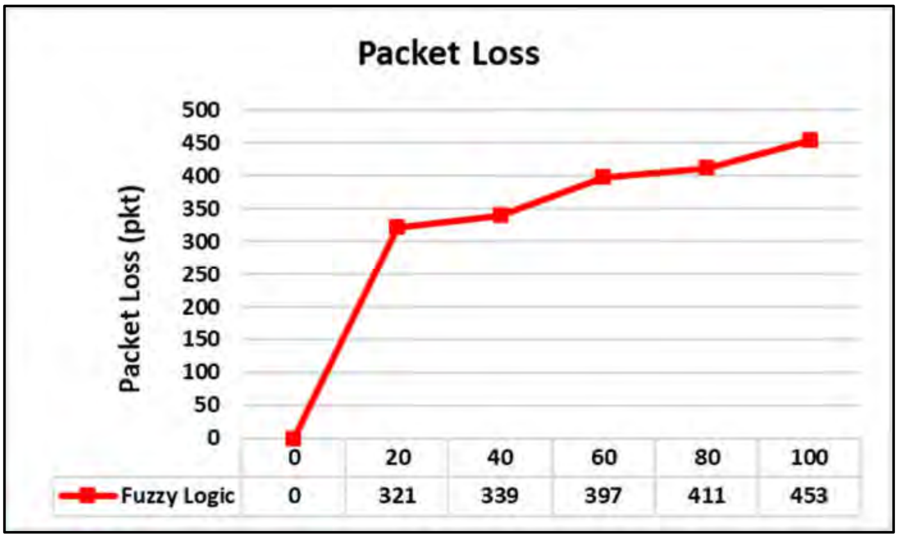


Figure 4.8 *Packet Loss vs Velocity in FL*

4. Throughput

The throughput is classified as the data rate offered for the subscribers, which can be obtained in available networks. In other words, it is a total of data moved from one sender to receiver nodes in a set of time. The units for measuring the throughput include megabits (Mbps) and kilobits per second (kbps). Figure 4.9 displays the throughput results in the FL algorithm. The average throughput is around 192,109.5 kbps when the vehicle's speed rises from 20 to 100 km /h, while the throughput rises to 22.9%.

As reported by [149] that the 4G-LTE network peak rate data at low mobility can be reached at 300Mbps and 1Gps for stationary in download and upload speeds. Therefore, as a result, showed the average throughput was 192.1Mbps in this study still significantly of the theoretical maximum 4G (LTE) range speeds higher at 300Mbps.

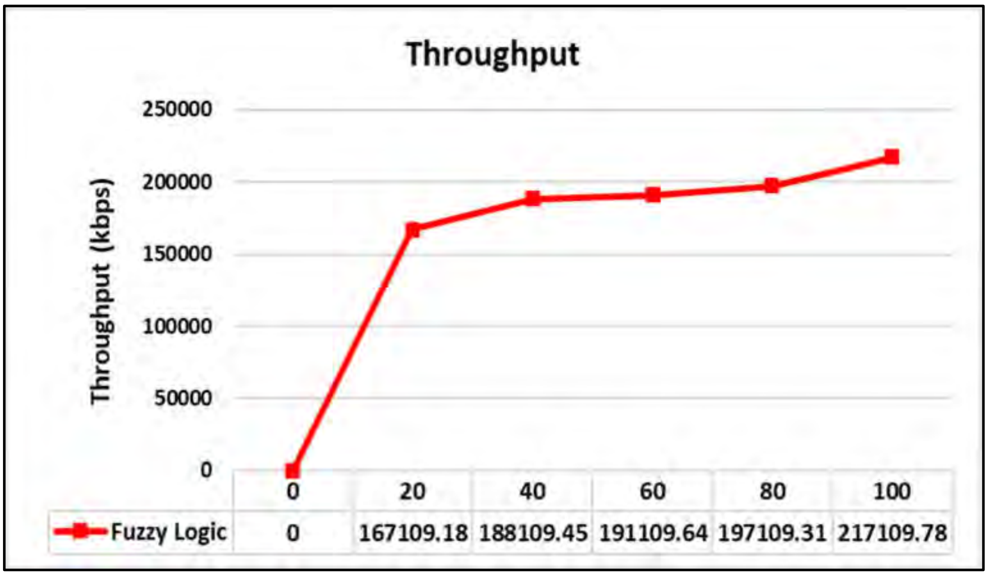


Figure 4.9 *Throughput vs Velocity in FL*

5. Packet Delivery Ratio (PDR)

PDR is defined as the ratio of the sender's packet delivery to the receiver's received packets. It is also known as the vertical handover success rate, which refers to the ratio of the successfully performed VHO events. Figure 4.10 depicts the average calculation of the packet delivery ratio results using the FL algorithm is 94.4% while the vehicle speed rises from 20 to 100 km/h. However, the handover success rate decreases to 10.1%, when the speed of the vehicle increases 20 to 100 km/h.

As a result, showed the AHD scheme supported by the fuzzy logic algorithm could avoid unnecessary handover and enhance the performance of VHO prediction, which the link quality in terms of RSS, ABW, and service type.

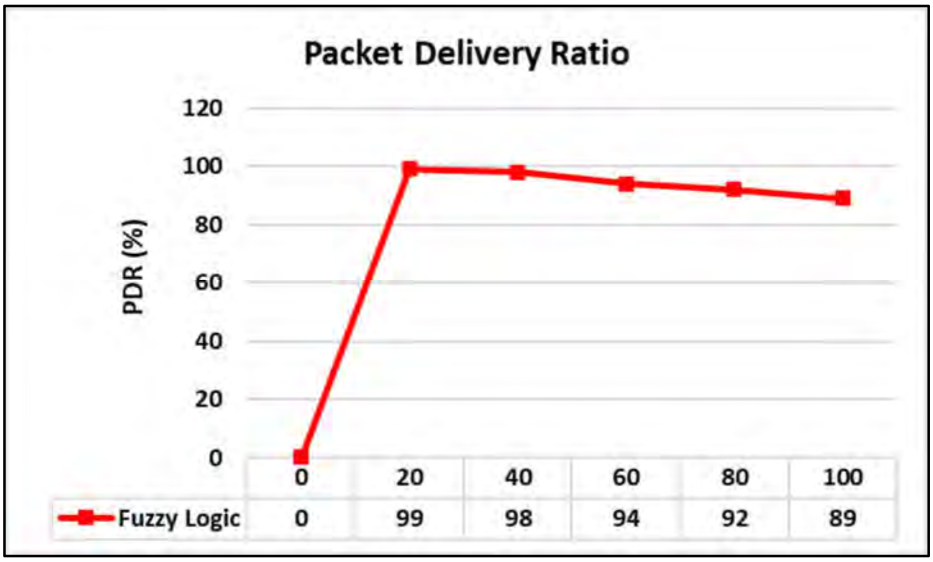


Figure 4.10 *Packet Delivery Ratio vs Velocity in FL*

4.3 Evaluation and Validation of Fuzzy Logic, RSS-Threshold, and MIH-Based Algorithms

This section discusses the evaluation and validation of the vertical handover decision QoS performance using the proposed FL, RSS-Threshold (RSS-T), and MIH-based algorithms. The proposed algorithms performed the simulation analysis in terms of the end-to-end delay, handover latency, throughput, packet loss, and packet delivery ratio (PDR) based on different vehicle speeds such as 20, 40, 60, 80, and 100 km/h. To validate the effectiveness of the proposed scheme. It compared the result of the AHD scheme with two techniques. The first scheme was used only RSS as an indicator of link quality for QoS handover as known as RSS-Threshold [150]. The second was a simple scheme that used only the MIH standard without any prediction algorithm. In other words, the performance of QoS handover will increase when the value of the parameter is reduced, especially the handover latency, delay, and packet loss.

4.3.1 RSS-based Algorithm Implementation with MIH Mechanism

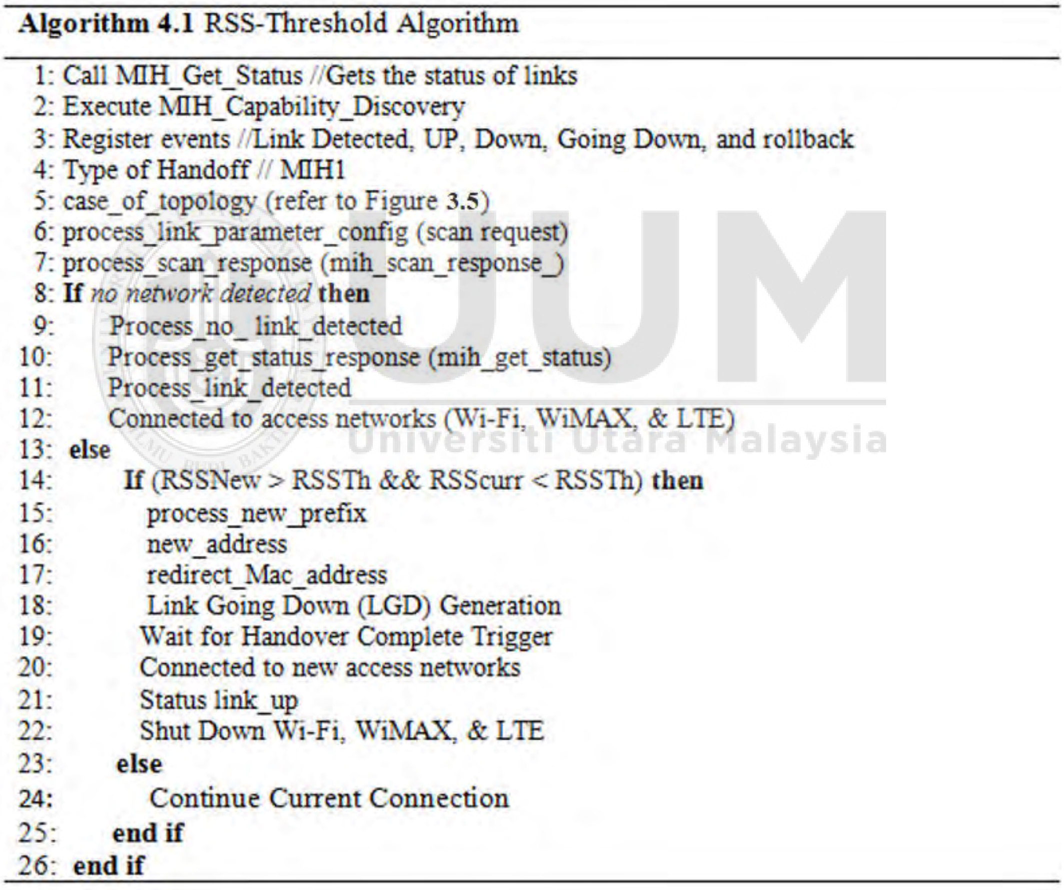
The MIH prediction algorithm has four services: link coming up (LCU), link up (LU), link going down (LGD), and link down (LD). The collected input data from the Information System (IS) MIH includes several parameters such as flow rate, received signal strength (RSS), available bandwidth (ABW), and service type (assume available). Then, a message regarding the link status of LD, LGD, LCU, and LU was sent to the MIH event service manager, as revealed in Table 3.5 (Refer to Subsection 3.2 of Chapter 3). The RSS-Threshold algorithm is designed to select the network which has the best signal strength proposed by authors in [150] and [151]. The MIH can access the RSS from respective layers of the different networks used (Wi-Fi, WiMAX, and LTE). RSS is only considered as a parameter value by a block diagram, which is similar to the fuzzy approach, as shown in Figure 4.5 of SubSection 4.1.2.1 in Chapter 4.

The following steps need to be conducted before triggering the handover from the current to a new network by using the RSS-Threshold algorithm:

1. RSS-A: The RSS of the mobile users from the BS or AP in which they are presently connected.
2. RSS-B: The RSS from the BS or AP where the mobile users are attempting to connect.
3. RSS-Threshold (A, B): The RSS-Threshold value for the handover from network A to B. The implemented RSS approach will trigger the handover based on Equation 4.8.

$$\textit{If, RSS-B} > \textit{RSS-Threshold (B, A)} \tag{4.8}$$

The equation 4.8 means that the handover will only occur if the RSS of the new network has higher signal strength than the current by considering the threshold. However, this does not mean that the algorithm will trigger the handover execution whenever the RSS has fallen below the current network. The details of the RSS-Threshold scheme processes are presented by Algorithm 4.1.

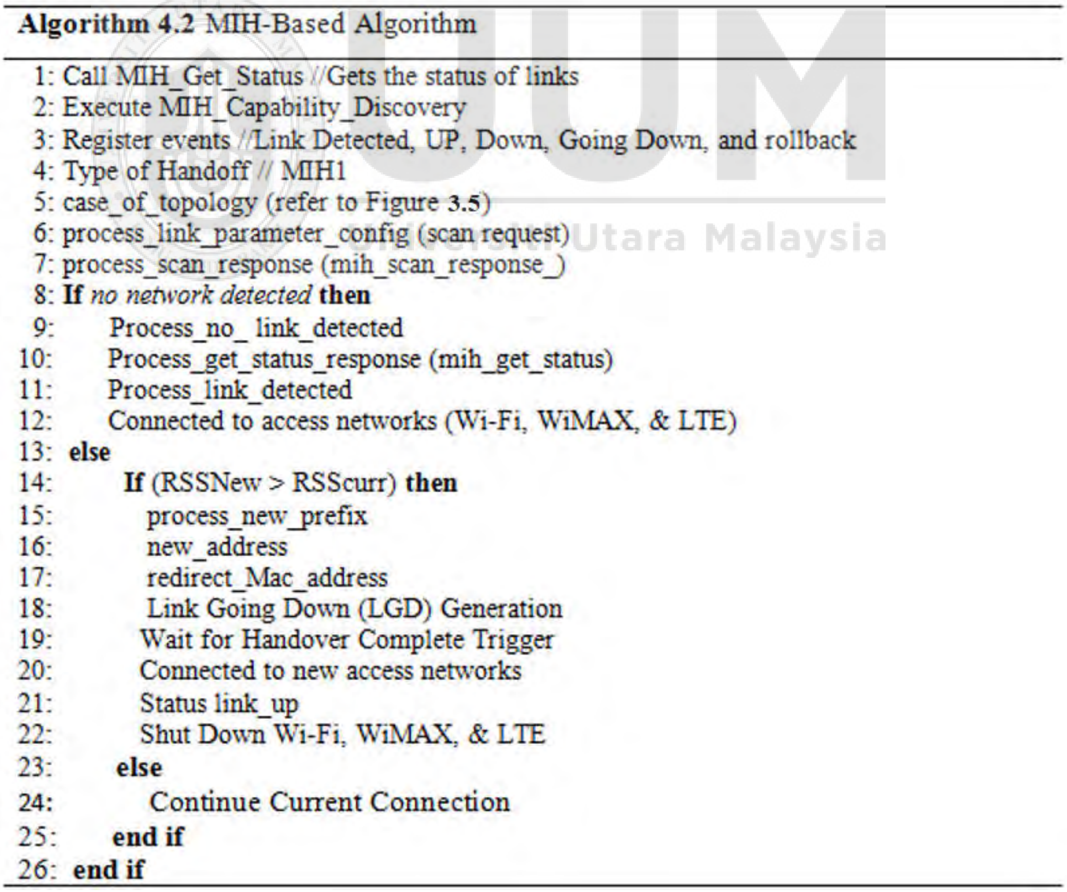


Algorithm 4.1 RSS-Threshold Algorithm

```
Call MIH_Get_Status //Gets the status of links
Execute MIH_Capability_Discovery
Register events //Link Detected, UP, Down, Going Down, and rollback
Type of Handoff // MIH1
case_of_topology (refer to Figure 3.5)
process_link_parameter_config (scan request)
process_scan_response (mih_scan_response_)
If no network detected then
    Process_no_ link_detected
    Process_get_status_response (mih_get_status)
    Process_link_detected
    Connected to access networks (Wi-Fi, WiMAX, & LTE)
else
    If (RSSNew > RSSTh && RSScurr < RSSTh) then
        process_new_prefix
        new_address
        redirect_Mac_address
        Link Going Down (LGD) Generation
        Wait for Handover Complete Trigger
        Connected to new access networks
        Status link_up
        Shut Down Wi-Fi, WiMAX, & LTE
    else
        Continue Current Connection
    end if
end if
```

4.3.2 The Implementation of the MIH-Based Algorithm

The MIH is utilizing the MIH-based scheme at the link layer of a network, which enables a network device to distribute decision making in the heterogeneous vehicular ad-hoc networks. The MIH can access the RSS from the respective layers for different networks (Wi-Fi, WiMAX, and LTE). The diagram in Figure 4.4 illustrated the MIH-based scheme process, which is similar to the fuzzy approach. However, the MIH-based scheme only considers RSS as the key value of the parameter. The detailed processes of the MIH-based algorithm are presented by Algorithm 4.2 proposed by Bhosale and Daruwala (2013) in [151].



Algorithm 4.2 MIH-Based Algorithm

```
Call MIH_Get_Status //Gets the status of links
Execute MIH_Capability_Discovery
Register events //Link Detected, UP, Down, Going Down, and rollback
Type of Handoff // MIH1
case_of_topology (refer to Figure 3.5)
process_link_parameter_config (scan request)
process_scan_response (mih_scan_response_)
If no network detected then
    Process_no_ link_detected
    Process_get_status_response (mih_get_status)
    Process_link_detected
    Connected to access networks (Wi-Fi, WiMAX, & LTE)
else
    If (RSSNew > RSScurr) then
        process_new_prefix
        new_address
        redirect_Mac_address
        Link Going Down (LGD) Generation
        Wait for Handover Complete Trigger
        Connected to new access networks
        Status link_up
        Shut Down Wi-Fi, WiMAX, & LTE
    else
        Continue Current Connection
    end if
end if
```

4.3.3 Simulation Analysis Results from Comparison between Fuzzy Logic, RSS-Threshold Based, and MIH-Based Algorithms

1. Handover Latency

Table 4.1 and Figure 4.11 indicate that the average of handover latency using the FL is less than the average handover latency of the MIH-based and RSS-T algorithms. The average latencies for the FL, MIH-based, and the RSS-T algorithms are 10.6, 11.90, and 13.2 milliseconds respectively. The comparison between the FL and RSS-T signifies a decrease of 19.58% of handover latency while the speed of vehicles increases from 20 /h to 100 km/h. However, the difference between FL and MIH-based is 10.92%, whereas MIH-based to RSS-T is 9.72%.

Therefore, as a result, showed the proposed AHD scheme is lower than MIH-based and RSS-T schemes. The reduction of the proposed method is outstanding to the decreased time that the vehicles connect for scanning only the potential target APs based on the direction of movement and the network load.

Table 4.1

The Average of Handover Latency for the RSS-Threshold, MIH-Based, and Fuzzy Logic

Velocity (km/h)	**RSS-T (ms)**	**MIH-Based (ms)**	**FL(ms)**	**RSS-T vs FL (%)**	**MIH vs FL (%)**	**RSS-T vs MIH (%)**
20	9.36	8.96	8.34	10.90	6.92	4.46
40	9.94	9.32	8.36	15.90	10.30	6.65
60	12.07	11.84	10.34	14.33	12.67	1.94
80	17.01	14.05	12.94	23.93	7.90	21.07
100	17.56	15.34	13.05	25.68	14.93	14.47
Average	13.18	11.90	10.60	**19.58**	**10.92**	**9.72**

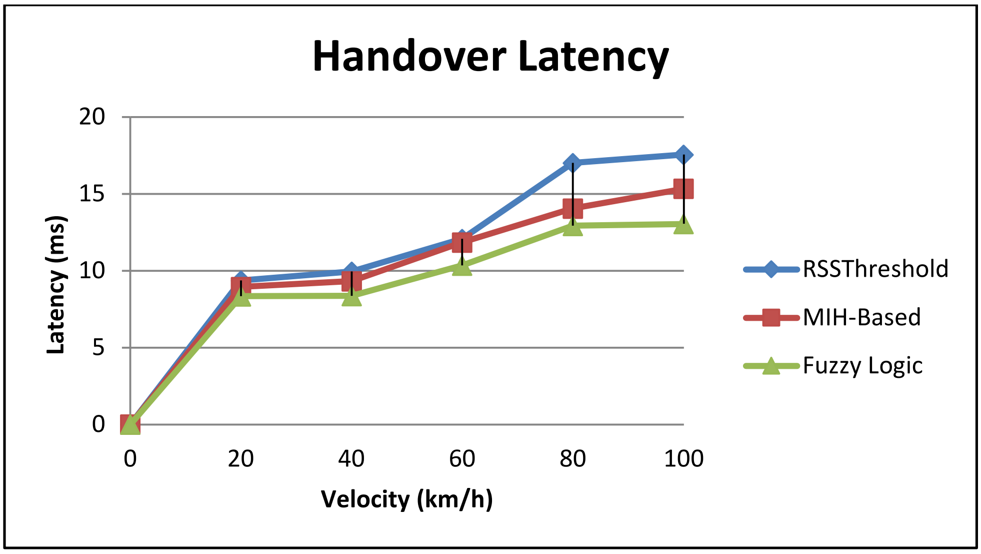


Figure 4.11 *Handover Latency vs Velocity in RSS-Threshold, MIH-Based, and FL*

2. End-to-end Delay

Table 4.2 and Figure 4.12 show the end-to-end delays results obtained from the simulation. The average end-to-end delay of the FL algorithm is much better than MIH-based and RSS-T algorithms of approximately 111.97, 133.83, and 141.41 milliseconds respectively. However, the FL average end-to-end delay is 20.82% when compared to the RSS-T algorithm. The FL algorithm also rapidly decreased the end-to-end delay by up to 29 milliseconds while the speed of vehicles increases from 20 to 100 km/h. Besides, the comparison of the end-to-end delay between the FL and MIH-based algorithm is 12.21%, while the difference between MIH-based and RSS-T is 6.46%.

The end-to-end delay of the proposed AHD scheme was relatively lower than others (MIH-based and RSS-T) schemes for the CBR traffic application. Due to the proposed scheme is concentrated on decreasing the network delay, which is attained by dropping the number of candidate APs to be shortlisted based on the proposed target network prediction method.

Table 4.2

The Average End-to-end Delay for the RSS-Threshold, MIH-Based, and Fuzzy Logic

Velocity (km/h)	RSS-T (ms)	MIH-Based (ms)	FL (ms)	RSS-T vs FL (%)	MIH vs FL (%)	RSS-T vs MIH (%)
20	76.99	72.40	68.74	10.72	5.06	6.34
40	90.99	86.68	79.66	12.45	8.11	4.96
60	103.78	95.09	88.66	14.58	6.77	9.14
80	163.48	149.19	127.33	22.11	14.66	9.57
100	271.80	265.78	195.50	28.08	26.45	2.26
Average	141.41	133.83	111.98	20.82	12.21	6.46

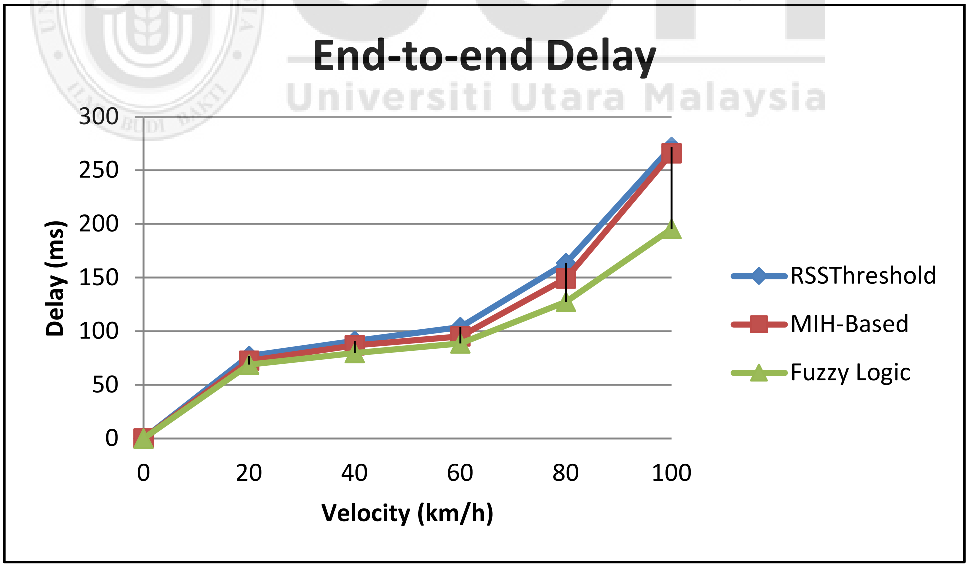


Figure 4.12 *End-to-end vs Velocity in RSS-Threshold, MIH-Based, and FL*

3. Packet Loss

Table 4.3 shows the average packet loss for the RSS-T, MIH-based, and FL algorithms, while Figure 4.13 portrays the graph of packet loss versus velocity obtained from the simulation. The average packet loss of the RSS-T, MIH-Based, and FL algorithms are 439, 413, and 384 packets, respectively. The average packet loss between FL and RSS-T is 12.48%, while the packet loss between FL and MIH-based is 6.90%. The average packet loss between RSS-T and MIH-Based algorithms is 6.34%. The number of packet loss usually decreases when the total number of handover latency decreases. From these results, the FL is found to be much better compared to the MIH-based and RSS-T algorithms.

Table 4.3

The Average of Packet loss for the RSS-Threshold, MIH-Based and Fuzzy Logic

Velocity (km/h)	RSS-Threshold (pkt)	MIH-Based (pkt)	Fuzzy Logic(pkt)	RSS-T vs FL (%)	MIH vs FL (%)	RSS-T vs MIH (%)
20	355	342	321	9.58	6.14	3.80
40	401	369	339	15.46	8.13	8.67
60	448	422	397	11.38	5.92	6.16
80	474	449	411	13.29	8.46	5.57
100	517	481	453	12.38	5.82	7.48
Average	439	413	384	12.48	6.90	6.34

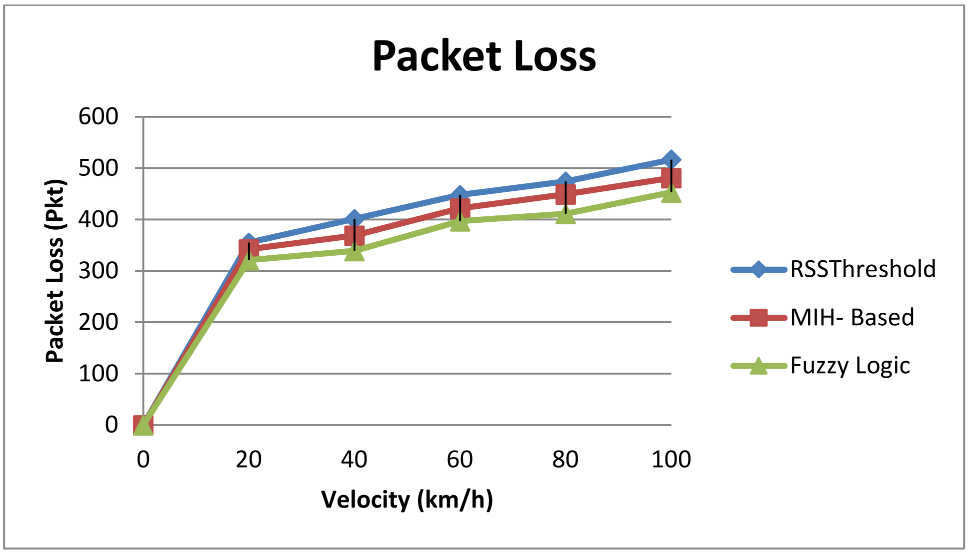


Figure 4.13 *Packet Loss vs Velocity in RSS-Threshold, MIH-Based, and FL*

4. Throughput

Table 4.4 presents the average throughput for the RSS-T, MIH-based, and FL algorithms. Figure 4.14 illustrates the graph of simulation throughput versus velocity. The average throughput for the RSS-T, MIH-based, and FL algorithms are 188128.26, 186146.07, and 192109.47 kbps, respectively. The analysis shows that, relative to the RSS-T and MIH-based, the FL average throughput steadily increases to 2.2% and 3.31%. These means that the average RSS-T throughput is much better than the MIH-based by 0.98%. In other words, the FL algorithm has shown an improvement in the QoS throughput as compared to the RSS-T and MIH-based algorithms.

However, as a result, showed the throughput gradually increased with increasing vehicle speed. The situation occurred because of the increase in the number of unsuccessful handovers and incomplete handover signaling messages between the vehicle OBU and the selected target networks caused by high vehicle speed [148].

Table 4.4

The Average Throughput for RSS-Threshold, MIH-Based, and Fuzzy Logic

Velocity (km/h)	RSS-Threshold (kbps)	MIH-Based (kbps)	Fuzzy Logic (kbps)	RSS-T vs FL (%)	MIH vs FL (%)	RSS-T vs MIH (%)
20	160642.34	162490.18	167109.18	4.03	2.84	(1.14)
40	187636.48	185395.45	188109.45	0.25	1.46	1.21
60	189036.60	188723.64	191109.64	1.10	1.26	0.17
80	196651.37	193253.31	197109.31	0.23	2.00	1.76
100	206674.53	200867.78	217109.78	5.05	8.09	2.89
Average	188128.26	186146.07	192109.47	2.12	3.13	0.98

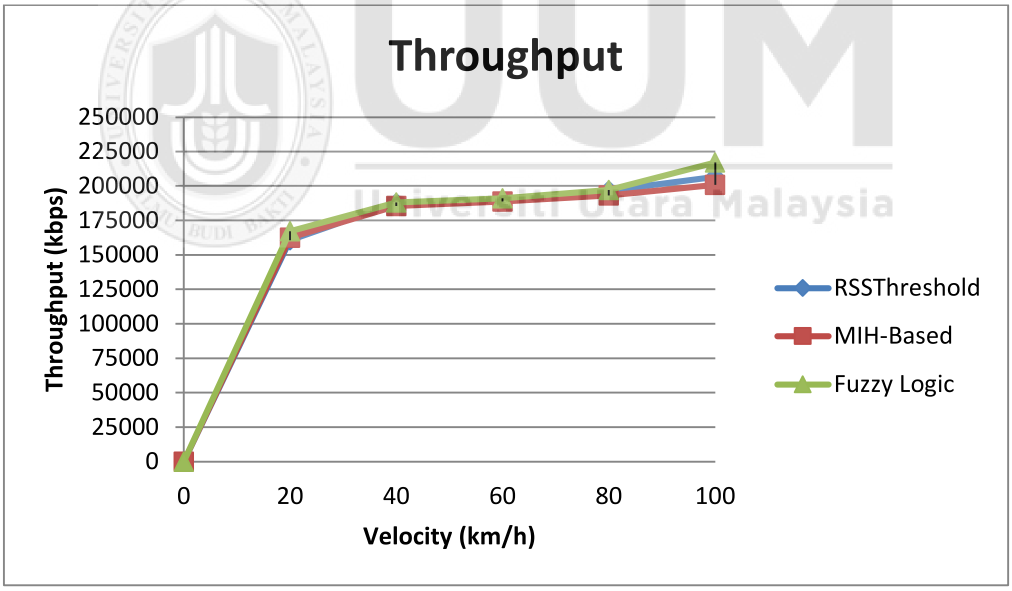


Figure 4.14 *Throughput vs Velocity in RSS-Threshold, MIH-Based, and FL*

5. Packet Delivery Ratio (PDR)

Table 4.5 and Figure 4.15 list the corresponding PDR average between the RSS-T, MIH-based, and FL algorithms. The PDR average of the FL is much better than the MIH-based and RSS-T algorithms of approximately 94.4 %, 92.6%, and 92.2% respectively. The highest average of PDR among the three algorithms is 2.2% while the speed of vehicles increases from 20 to 100 km/h when compared to FL and RSS-T. Also, the average PDR between the FL and MIH-based is 1.8%, while between MIH-based and RSS-T is 0.4%.

In other words, as a result, showed the average PDR is gradually decreased when increasing vehicle speed. Therefore, is because the proposed AHD scheme deliberates the accessibility of suitable network resources at the target network before beginning the handover activities.

Table 4.5

The Average PDR for RSS-Threshold, MIH-Based, and Fuzzy Logic

Velocity (km/h)	**RSS-Threshold (%)**	**MIH-Based (%)**	**Fuzzy Logic (%)**	**FL vs RSS-T (%)**	**FL vs MIH (%)**	**MIH vs RSS-T (%)**
20	99	99	99	0	0	0
40	97	97	98	1	1	0
60	92	93	94	2	1	1
80	88	89	92	4	3	1
100	85	85	89	4	4	0
Average	92.2	92.6	94.4	2.2	1.8	0.4

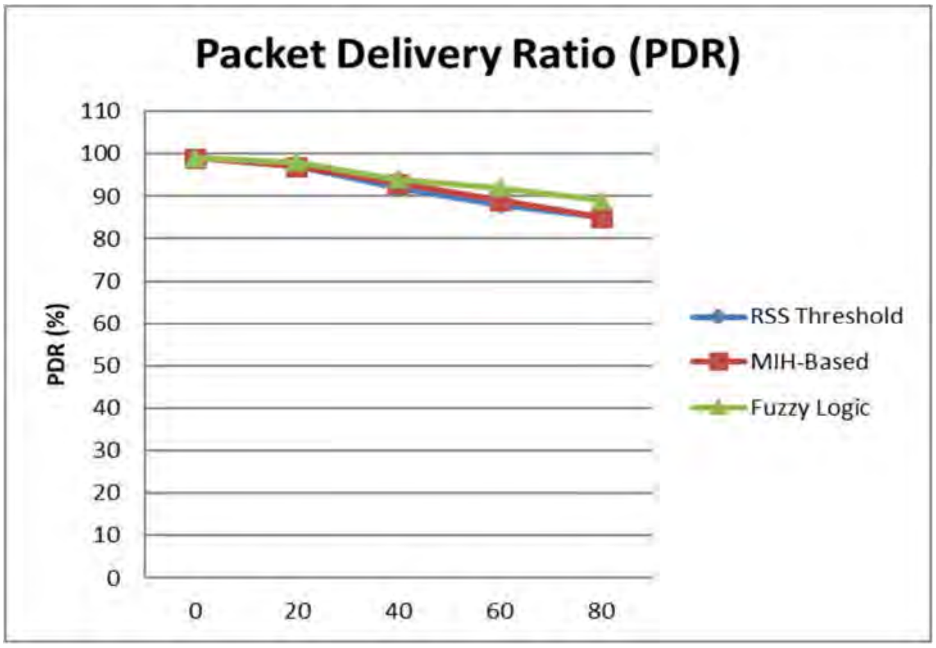


Figure 4.15 *PDR vs Velocity in RSS-Threshold, MIH-Based, and FL*

4.4 Summary

Currently, the uses of multi-technology enabled terminals are becoming popular. However, in the future, the vehicular heterogeneous wireless networks, network detection, and handover decision procedures will play a significant role in accomplishing efficient mobility solutions for the Internet connection. However, accomplishing seamless service using vertical handover between vehicular ad-hoc heterogeneous networks is complicated. Therefore, this research proposes an AHD scheme that was implemented by using the fuzzy logic algorithm to tackle the QoS problem of VHOD in the VANET. The analysis results show that the proposed scheme offers QoS enhancement for the vertical handover decision making between the Wi-Fi, WiMAX, and LTE networks in VANET. The results indicate the proposed scheme achieved better QoS performance as compared to the RSS-Threshold and MIH-based algorithms in the VANET by reducing the handover latency, end-to-end delay, and packet loss and increasing the throughput and packet delivery ratio performance. Even though considered as an uncertain, ambiguous, and vague system, the FL algorithm, embedded with the accurate mathematical method, can handle the complexity or somewhat irrelevant decision-making process in solving the vertical handover problem.

CHAPTER FIVE

DEVELOPING VERTICAL HANDOVER TRIGGERING IN VEHICULAR AD-HOC NETWORKS

This chapter highlights the vertical handover triggering a process in the Vehicular Ad-hoc networks by using the proposed F-SAW scheme, which is integrated with the MIH mechanism. Section 5.1 addresses the design and implementation of the proposed scheme, while Section 5.2 provides a comparison of the reliability and scalability between the NS-2 and several existing algorithms. Finally, Section 5.3 discusses the summary of this chapter.

5.1 Overview of Vertical Handover in NS-2

Since NS-2.29 released by NIST, the mobility package was developed in collaboration with IEEE 802.21 and IETF, which has been used in numerous studies. That module was used to measure the performance of the MIH authentication process, considering the impact of using the IEEE 802.21 link triggers and intelligent-based scheme in achieving seamless mobility as well as in choosing the best network access (e.g., Wi-Fi, WiMAX, or LTE).

5.1.1 Media Independent Handover IEEE 802.21 Support in NS-2

As explained in subsection 4.1.2 of Chapter 4, the F-SAW scheme was integrated with the IEEE 802.21 MIH add-on modules comprised of Media-independent handover function (MIHF) implementation based on draft 3 of the IEEE 802.21 specification. Figure 5.1 presents an overview of the MIHF relations to the different elements of the mobile node (MN).

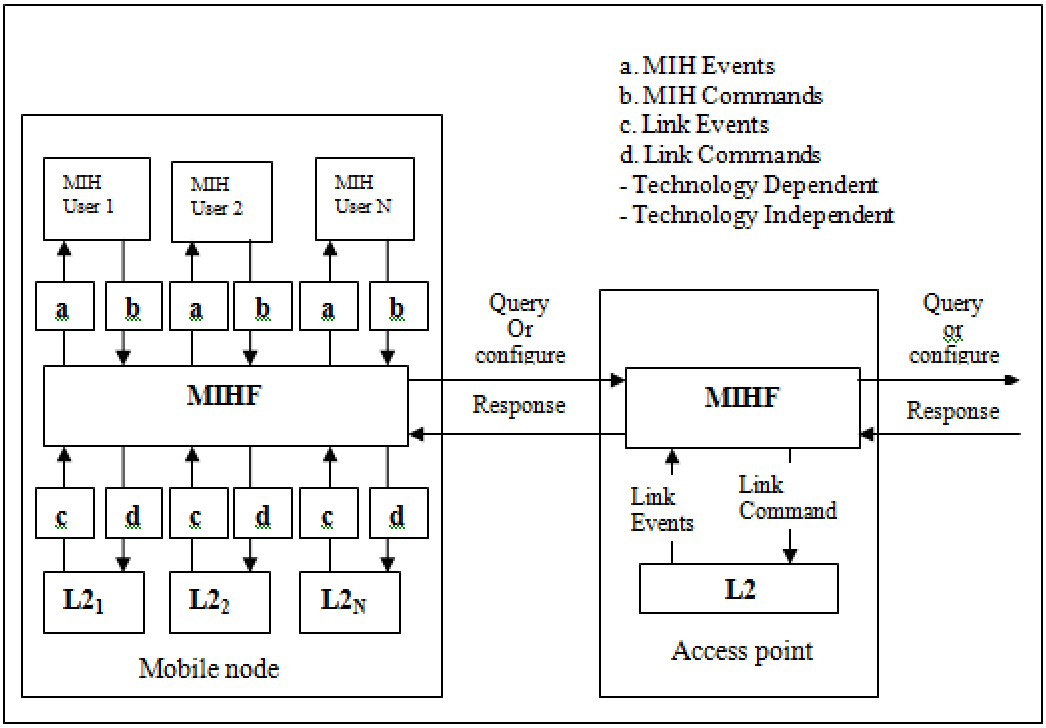


Figure 5.1 *Overview of the MIH Implementation in NS-2 (adopted from* [152]*)*

Based on Figure 5.1, it is clearly understood that the MIHF fully supports users in optimizing the handover process. The scenario created in this research refers to the traffic light environment consisting of 100 vehicles or MNs that are available to access all their network coverage. Each of the mobile nodes should access the AP or BS based on the parameters condition and cases established for the user's convenience. Figure 5.2 illustrates the screenshot of the integrated design of the VANET traffic light topology in the VanetMobiSim and NS-2 simulation.

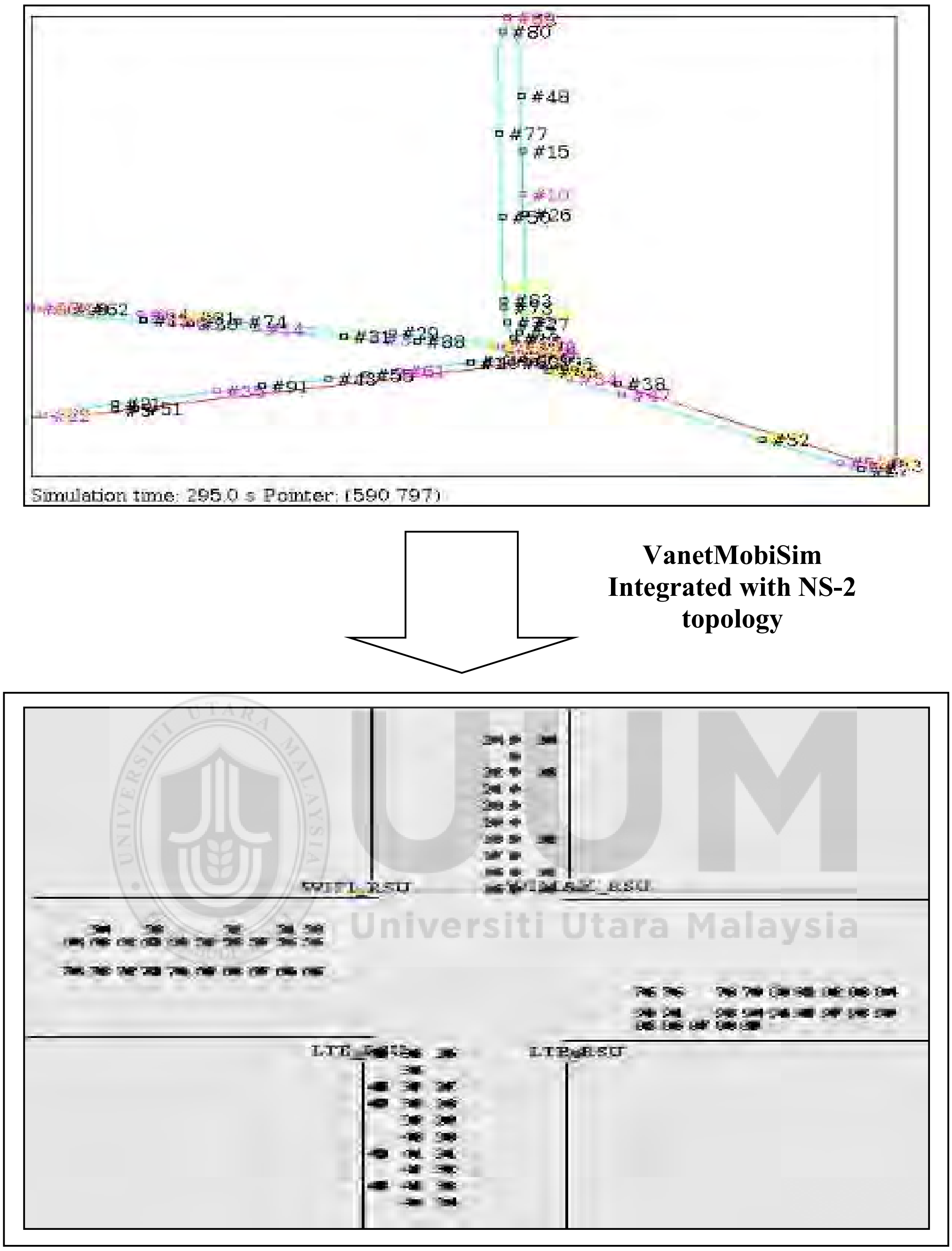


Figure 5.2 *Screenshot of the Integrated Traffic Light of VANET Topology Design in VANETMobiSim and NS-2 simulation (NAM)*

5.1.2 Direction and Instruction of Vehicles

The MIH IEEE802.21 mechanism must support a VANET traffic light handover trigger with more functionalities. The handling of the handover triggering process involves several movement directions and detections for various vehicles or MNs set up. For example, Figure 5.2 demonstrates that in the NS-2 (NAM) topology, the traffic light lane is divided into four (4) intersections (IntSec). Each of the intersections is provided with three (3) lanes. The first lane is near to the AP or BS network, followed by the second lane. The third lane is the farthest from the AP or BS network at its intersection.

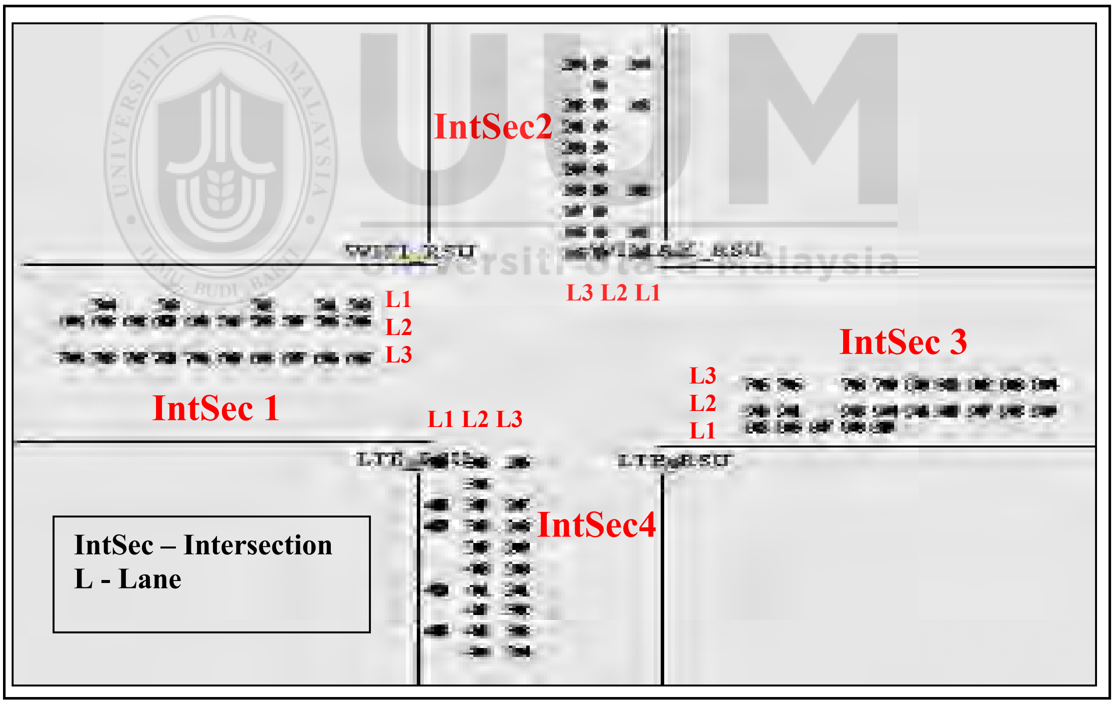


Figure 5.3 *Screenshot of the VANET Traffic Light Topology Overview in NS-2 involving the Vehicle Movement Direction and Instruction*

Figure 5.3 exhibits an overview of the vehicles' directions in the VANET traffic light topology in NS-2. The set up of the movement of vehicles or mobile nodes is shown in Table 5.1.

Table 5.1

The Movement of Vehicles or Mobile Nodes

Time	**Direction /Instruction**	**Description**
0s	None	No movement
5s	IntSec 1 (L1) & IntSec 3 of L1 (Point A)	Start detecting and moving vehicles from the L1.
50s	IntSec 1, 2, 3, & 4 of L2 (Point B)	Second lane (L2) of Intersections 1, 2, 3, & 4 will move to different directions.
100s	IntSec 1, 2, 3, & 4 of L3 (Point C)	Third lane (L3) of Intersections 1, 2, 3, & 4 will move to different directions.

Traffic on vehicle or MN will start on the LTE and Wi-Fi interfaces in 5s at intersections 1 and 3 through the first lane (IntSec1 and IntSec 3 - L1). In the 50s, the intersections 1, 2, 3, and 4 of the second lane will start moving towards different directions. After reaching 100s, the third lane on the intersections 1, 2, 3, and 4 will move to different directions until all the vehicles completed their tasks (refer to the screenshot of log.nam in NS-2). All vehicles will move and not overtake each other by following the Intelligent Driving Model with Intersection Management (IDM-IM). The IDM-IM has correctly described the car-to-car movement and intersection management to ensure smooth performance. Thus, it is essential to recognize that the *multi-Face* node concept generated by the NIST model, which enables the occurrence of the descriptions of the events, also allows the connection between nodes as depicted in Figure 5.4.

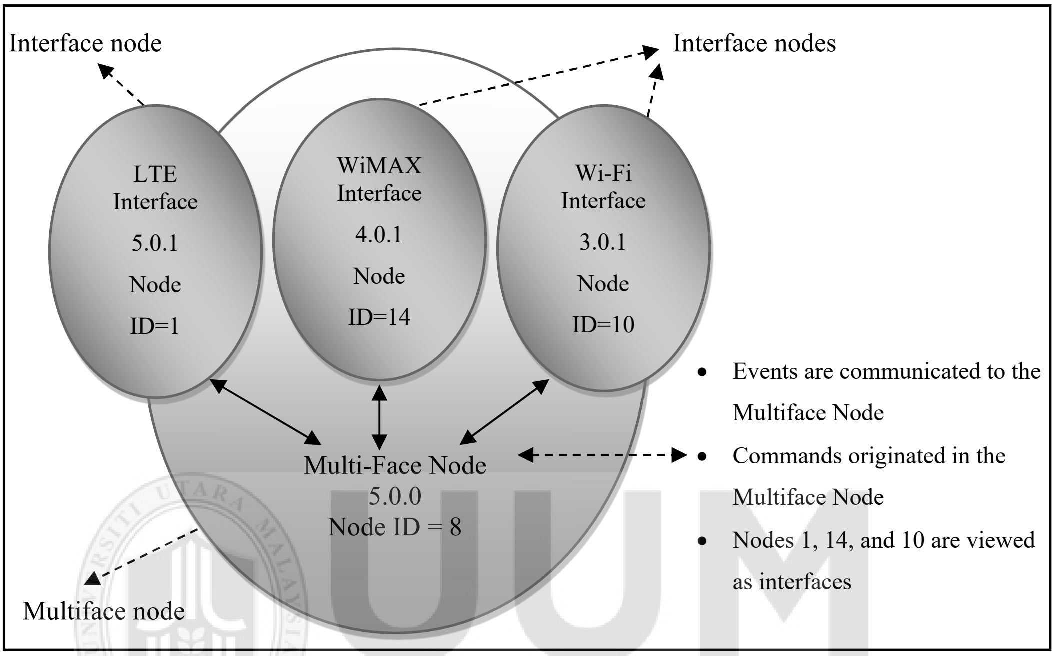


Figure 5.4 *Overview of the Multiface Node*

Figure 5.4 shows the high level of multi-face node functions that allow the communication between three different network interfaces; LTE, WiMAX, and Wi-Fi. The multi-face node of the MIH user is also known as a supernode, which received trigger events from the interface nodes, especially the RSS parameter. In this study, the setup of the network address, node ID, and Mac address for the multi-face node, as well as the LTE, WiMAX, and Wi-Fi interfaces is depicted in Figure 5.4. The multi-face node links the three different interfaces of the LTE, WiMAX, and Wi-Fi access networks that establish the direction of movement as illustrated in Figure 5.5.

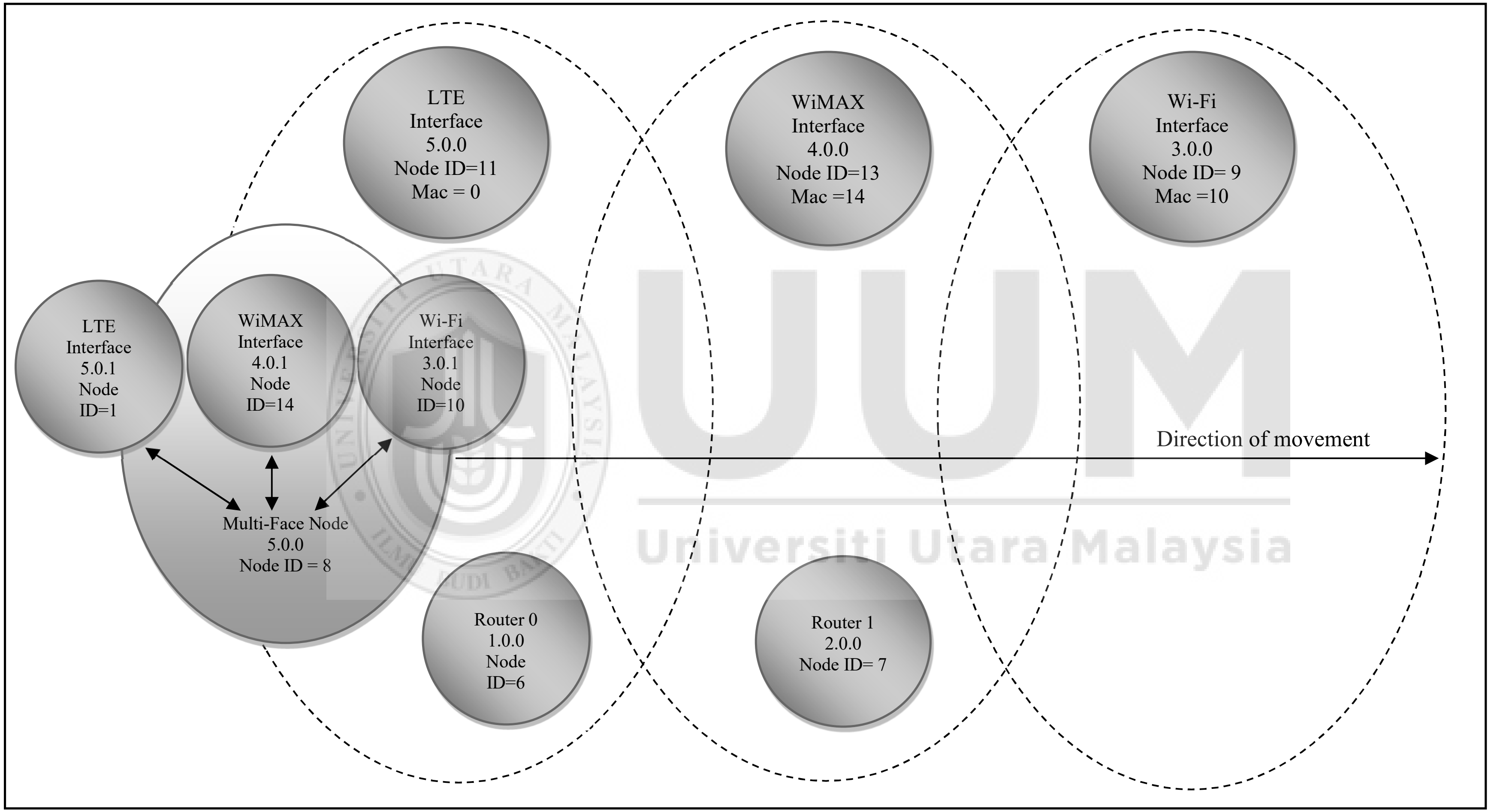


Figure 5.5 *Multiface Node Links with Three Different Interfaces (LTE, WiMAX, and Wi-Fi)*

5.2 The Evaluation of the Proposed F-SAW and RSS-Threshold Algorithms in the Handover Triggering of Sequence Events Description between LTE, WiMAX, and Wi-Fi Access Networks

This section defines the handover triggering of the MN and network execution sequence events to create an accomplishment of HO. This section is divided into two subsections to describe the proposed F-SAW and RSS based algorithms for the vertical handover in the Vehicular ad-hoc networks.

5.2.1 General Description of Handover between LTE, WiMAX, and Wi-Fi Access Networks using F-SAW Algorithm

The short descriptions of the sequence of the events are as follow:

1. Figure 5.6(a) shows the simulation that starts with a MIH user on the MN sending a MIH *Get Status Request* to the MN's MIHF.
2. The MN MIHF responds with the MIH *Get Status Response*, stating the three available interfaces. First is the MIH of the MN obtained from the LTE interface through link type 23. Second and third are the Wi-Fi and WiMax interfaces acquired from link types 19 and 27, accordingly. All the interfaces support the related commands and events, as shown in Figure 5.6(a).
3. The MIH user subscribes to the event on the MN interfaces.
4. The MN MIHF confirmed the three interface subscriptions (LTE, WiMAX, and Wi-Fi) from the MIH user.
5. The MN WiMAX interface receives a *Download and Upload Context Descriptors (DCD and UCD)* from the BS and triggers a *Link Detected* event as depicted in Figure 5.6(a).

6. Figures 5.6(a) and 5.6(b) show that the MN MIH user agent receives *Link Detected* in which only one interface was detected as a possible PoA. The command of the MN WiMAX interface will be connected to the BS through link type 27, MacAddr: 15, and PoA: 14. The MIH user will connect to the WiMAX interface because of the better network performance compared to the others. For example, the best utility WiMAX interface is 1 or probability around 0.450000s at 0.006314s until 0.018581s.
7. Figure 5.6 (c) shows the connection between the MN WiMAX interface and BS that triggers a *Link Up* event received by the MN MIHF that will then command the MN's MIPv6 Agent to request the Neighbor Discovery (ND) to send a Router Solicitation (RS) at 0.018581s.
8. After receiving, BS will send the MIH Capability Discovery Request, including the MIHF identification. The MIH Agent will now be aware of the identification of the remote (PoA) MIHF as depicted in Figure 5.6(c).
9. At t=0.025414s, CN starts to send CBR traffic to the MN. The traffic is received through the WiMAX interface.
10. At t=0.066739s, the MN MIH user Agent receives the *Link Detected* from the LTE interface. This link enables the detection of possible LTE PoA from the BS, as shown in Figure 5.6(c).
11. Figure 5.6(c) indicates that the MIH user realizes that LTE is the best interface to access network compared to the others. Hence, the MIH Agent made a connection to the LTE PoA through the LTE interface.

12. At t=1.000000s, MN starts to move towards the LTE cell. The MN user connects to the LTE because it is the best utility interface of 2 (LTE) with a probability of approximately 0.950000. The MN LTE interface connects to the BS and triggers a *Link Up* event that is received by the MN MIHF. The MN MIPv6 Agent will request the ND Agent to send an RS.
13. Figure 5.6(c) points out that the new neighbor of the handover event, which is the MN LTE interface, sends an RS. Upon detecting the new neighbor, the BS sends a Router Advertisement (RA) including router lifetime (1800s), prefix valid-lifetime (5s), network prefix (ex 4.0.0), and advertisement interval (600000ms) at t=3.163050s.
14. Having received the RA, the MN LTE interface will reconfigure its address according to the received prefix (i.e., interface address = 4.0.1). Once being informed, the MN MIH Agent will request the LTE interface to send an MIH Capability Request to the BS.
15. When the MN LTE interface sent the RS, BS will detect a lifetime update. After that, BS will send a Router Advertisement (RA) including the router lifetime (1800s), prefix valid-lifetime (5s), network prefix (ex 4.0.0), and advertisement interval (600000ms) at t=3.215050s as shown in Figure 5.6(d). The BS detected the first-lifetime update.
16. BS obtains the MIH Capability Request and replies to MIH Capability Response, including its MIHF identification. The MIH Agent will then know the identity of the remote (PoA).

17. At t=3.276881s, MN MIH Agent is informed and commands the LTE interface to send an *MIH Capability Request* to the BS. BS receives the *MIH Capability Request* and sends an *MIH Capability Response* including its MIHF identification. The MIH Agent will then know the identity of the remote (PoA) MIHF identification at Interface 2.
18. At t=3.278783s, the MN MIH Agent sends the *MIH Send Registration Request* to the LTE interface. The Agent will then received back the *MIH Received Registration Request* from the LTE interface at t= 3.281103s.
19. MN LTE interface sends an RS; BS detects a lifetime update. After that BS sends a Router Advertisement (RA) including: router lifetime (1800s), prefix valid-lifetime (5s), network prefix (ex 4.0.0), and advertisement interval (600000ms) at t=3.479050 s as shown in Figure 5.6(d). The BS detected the second-lifetime update.
20. Figures 5.6(d) and 5.6(e) indicate that at approximately t= 4.280836s, the MIH Agent user on the MN receives the *MIH Received Registration Request* from the LTE interface, which was set up with 100 nodes. The MIH Agent user will again receive the *MIH Received Registration Request* from the LTE interface at t=4.780836s. After that, the MIH Agent will receive a message from the Correspondent Node (CN) that got the packet lacking Acknowledgement (ACK) at 28.022739s and 52.022738s. At the same time, the MN MIH Agent has been notified of the MN new address and redirects the reception of the CBR traffic from the WiMAX interface (4.0.1) to the LTE interface. The arrived traffic will utilize the link between the LTE interface and BS.

21. At both the times of 100.022738s and the 196.022738s, the MIH Agent received the packet missing ACK alert, which influenced the total of packet losses as shown in Figure 5.6(e).

22. Figure 5.6(e) shows the MIH Agent on the MN sends the *MIH Neighbor Discovery Send* process that used *Internet Control Message Protocol* (ICMP) message and solicited-node multicast address to decide the link-layer address of a neighbor on the same network (local link) at the time approximately of 207.6835s. It sends the RA through a network prefix (interface address 3.0.0) that linked the Wi-Fi interface. The Wi-Fi interface triggers a *Link going down* event (based on the obtained power of the beacon frames); due to the MN's speed with the probability that the Wi-Fi will increase the establishment of the link goes down. Instead, it achieves an explicated rate of 90% in this case. Means that the MN's LTE interface is still active. Then, the MN MIPv6 Agent commands the LTE interface to send a redirect message to the CN to inform the CN of the new MN location network prefix address 4.0.0. At the same time, the MN's Wi-Fi interface triggers a *Link Down* event, and then the MNs are disconnected (Wi-Fi signal lost) from the Wi-Fi cell.

23. Figure 5.6(e) presents that at t=238.371050s, BS detects a lifetime update. After that, BS sends a Router Advertisement (RA) to the MN MIH Agent including router lifetime (1800s), prefix valid-lifetime (5s), network prefix (ex 4.0.0), and ad interval (600000ms). The BS updated the third-lifetime.

24. The MIH Agent receives the *Link Down* trigger through the MN WiMAX interface type of 27 and Mac Address of 15 at t=249.910491s. The MIH Agent

will then notice that the MN interface has been disconnected (WiMAX signal lost) from the WiMAX cell, as shown in Figure 5.6(e).

25. Figure 5.6(f) shows that the MN's MIPv6 Agent redirects message using interface address 0.0.2 before it flows to the interface 3.0.1. Finally, almost at the same time, the MN's LTE interface is still active connections to the BS until its received *Link Down* event at t=249.910491s, which is the best utility interface of 2 (probability= 0.950000).
26. While receiving the *Link Down* event, the MN's MIH Agent also commands the LTE interface to execute a link scan using *Link Action Request* to search for other nearby LTE networks. Then, it received no other networks found at t=249.96046s by *Link Action Confirm* command. The simulation experiment ends at approximately t=250s, as depicted in Figure 5.6(f).

Figure 5.6 shows the sequence of events triggered by the LTE, WiMAX, and Wi-Fi handover using the NIST modules in the NS-2 simulation and the proposed F-SAW algorithm.

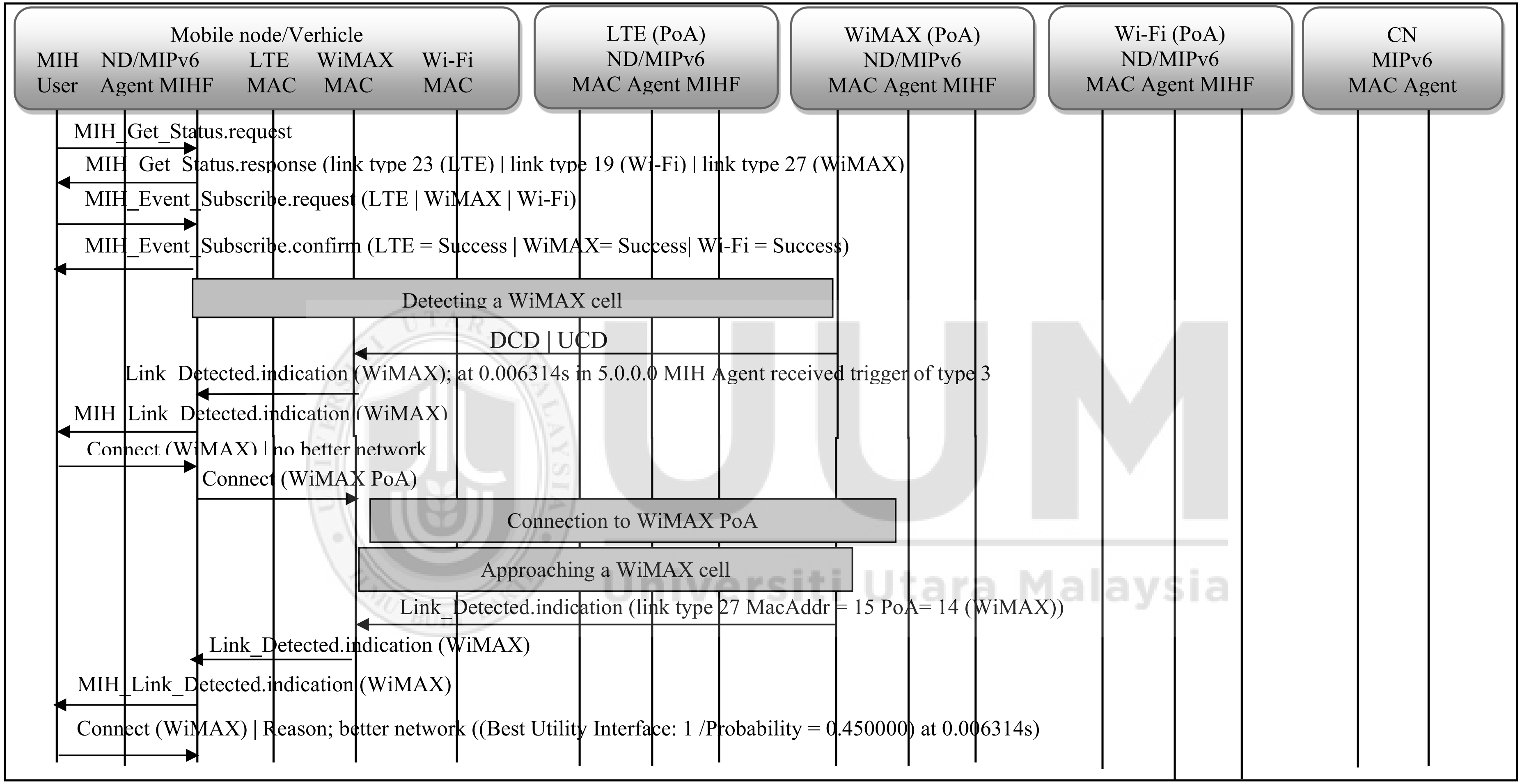


Figure 5.6(a) *Sequence of Events Triggered by LTE, WiMAX, and Wi-Fi Handover using F-SAW Algorithm*

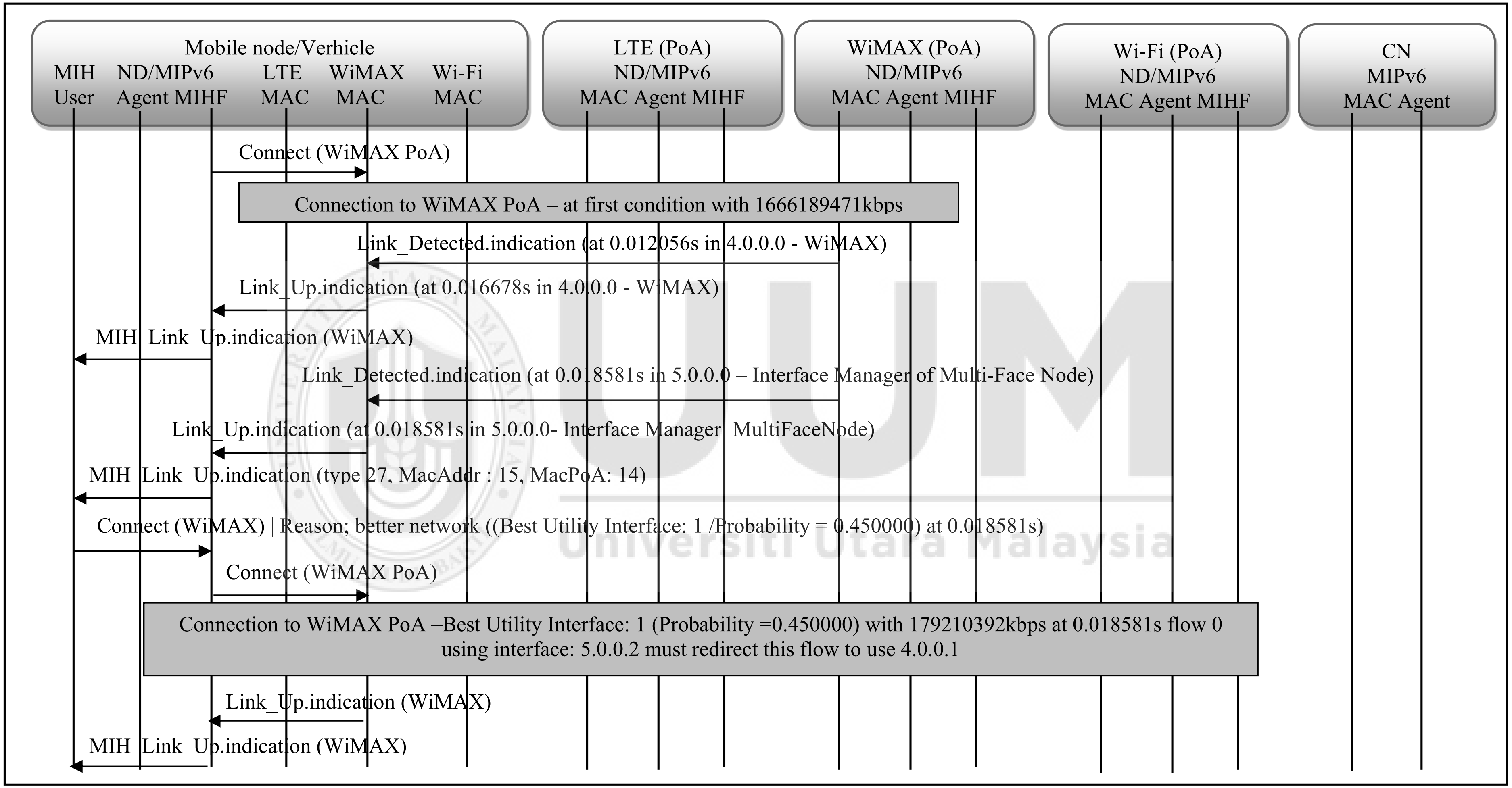


Figure 5.6(b) *Sequence of Events Triggered by LTE, WiMAX, and Wi-Fi Handover using F-SAW Algorithm*

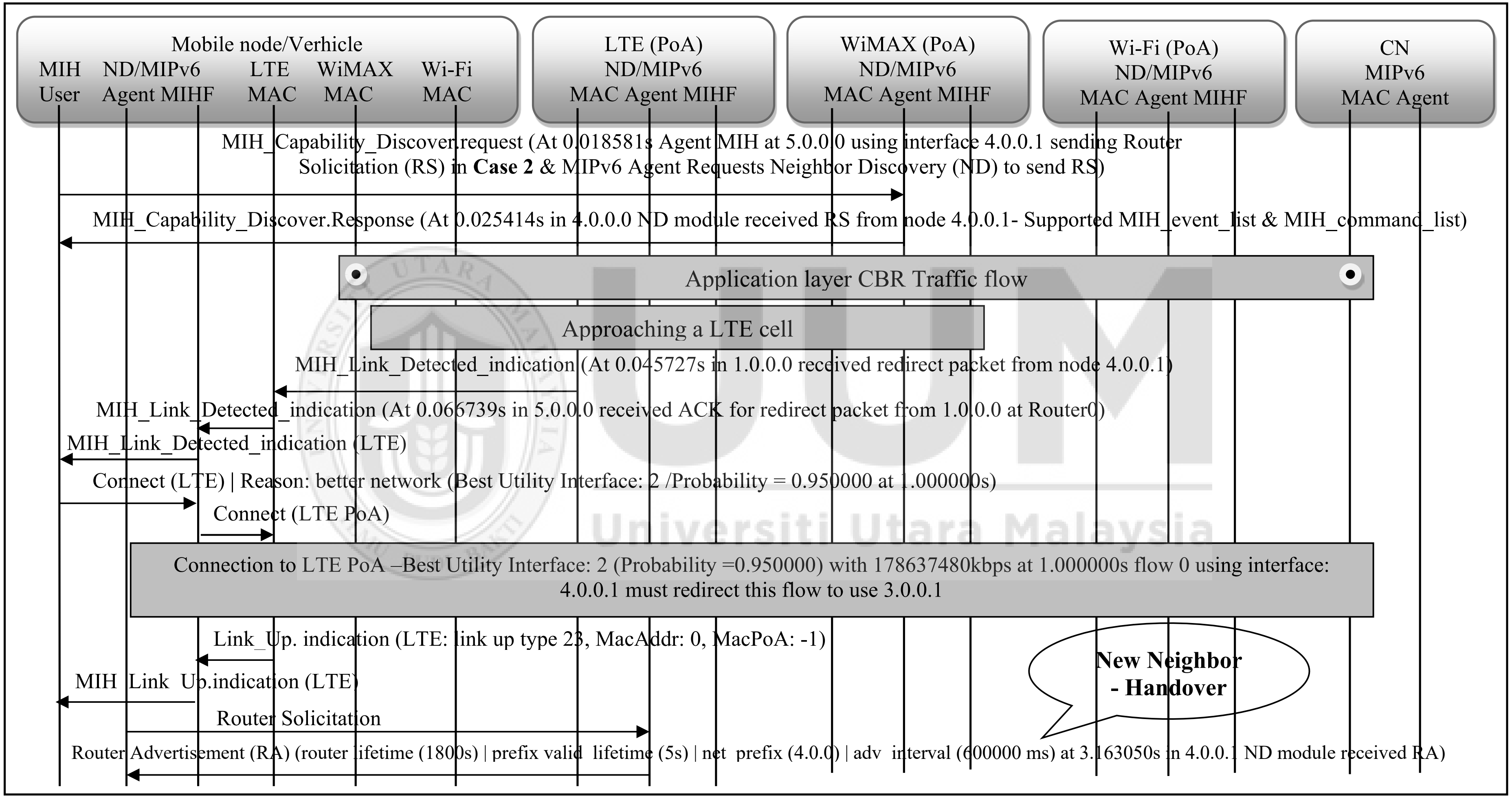


Figure 5.6(c) *Sequence of Events Triggered by LTE, WiMAX, and Wi-Fi Handover using F-SAW Algorithm*

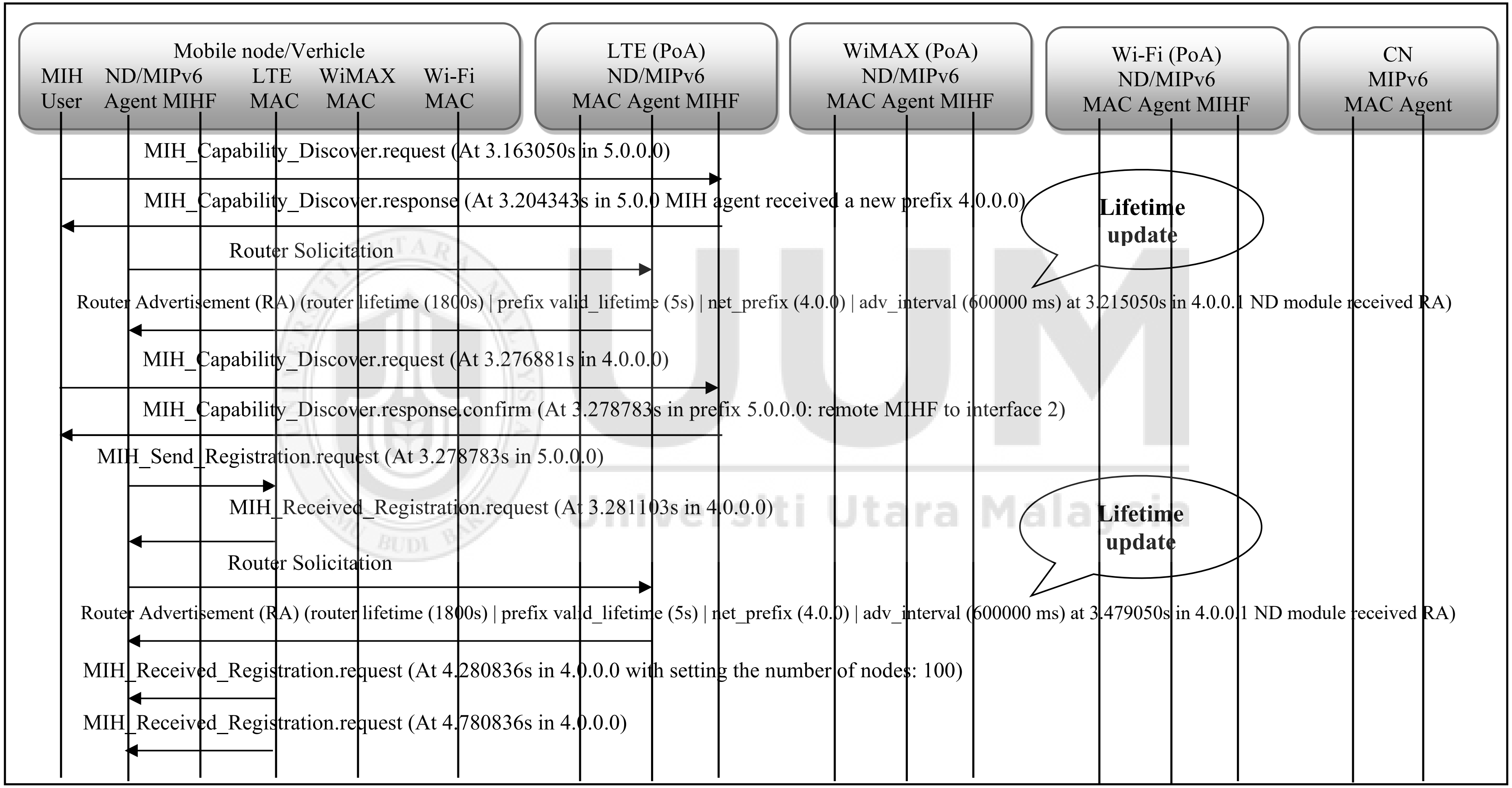


Figure 5.6(d) *Sequence of Events Triggered by LTE, WiMAX, and Wi-Fi Handover using F-SAW Algorithm*

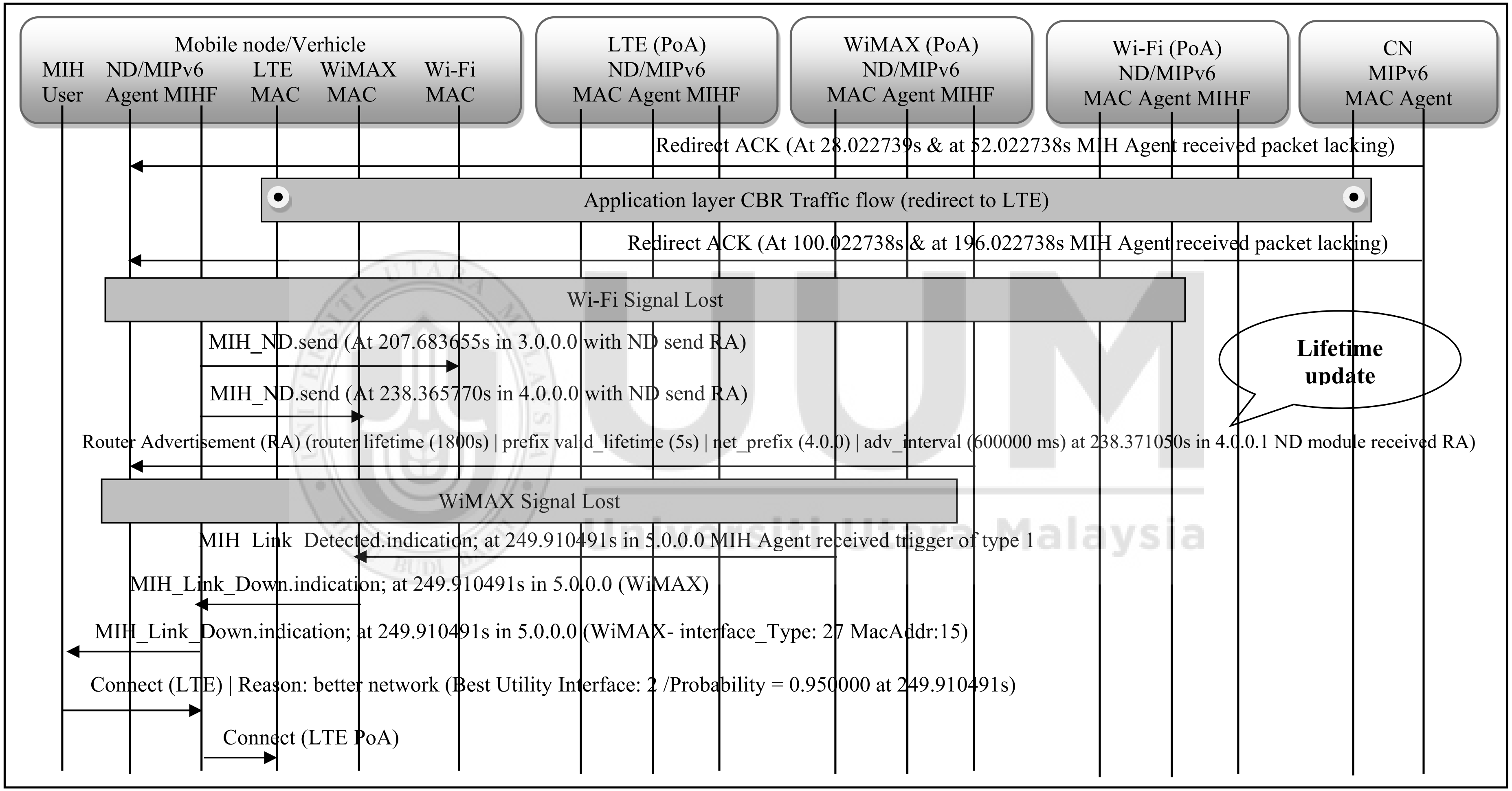


Figure 5.6(e) *Sequence of Events Triggered by LTE, WiMAX, and Wi-Fi Handover using F-SAW Algorithm*

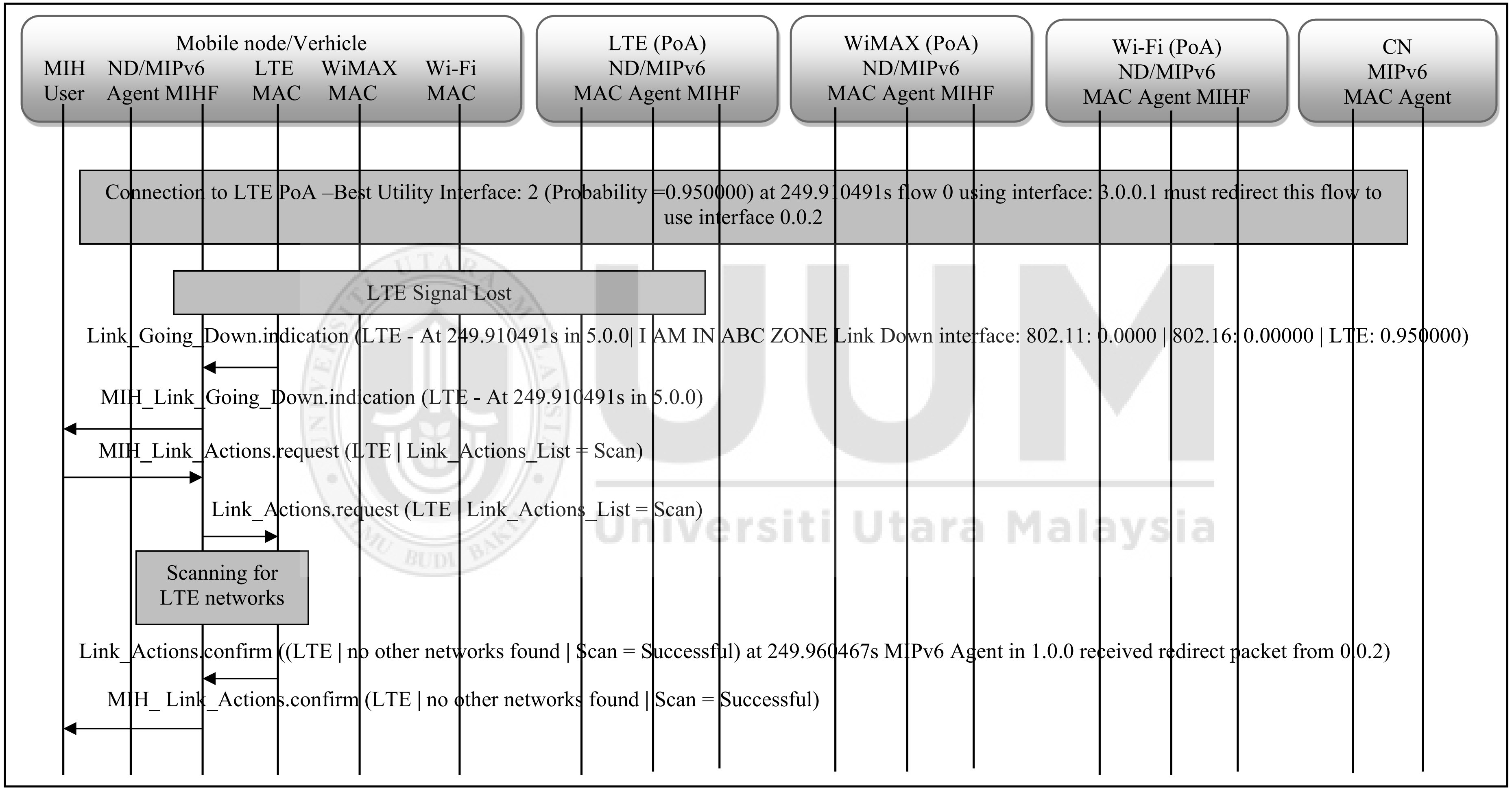


Figure 5.6(f) *Sequence of Events Triggered by LTE, WiMAX, and Wi-Fi Handover using F-SAW Algorithm*

5.2.2 General Description of Handover between LTE, WiMAX, and Wi-Fi Access Networks using RSS-Threshold Algorithm

The short descriptions of the sequence of events are as follow:

1. Figure 5.7(a) presents the simulation that starts with the MIH user on the MN sending the MIH *Get Status Request* to the MN's MIHF.
2. The MN's MIHF responds with an MIH *Get Status Response*, stating that three interfaces are available: 1) linked type 23 (LTE), 2) link type 19 (Wi-Fi), and 3) link type 27 (WiMAX). All the interfaces support the related commands and events, as shown in Figure 5.7(a).
3. The MIH user subscribes to the event on the MN's interfaces.
4. The MN's MIHF subscribes the confirmation on MIH users from the three interfaces; LTE, WiMAX, and Wi-Fi.
5. The MN's WiMAX interface receives a Download and an Upload Context Descriptor (DCD and UCD) from the BS and triggers a *Link Detected* event as depicted in Figure 5.7(a).
6. Figure 5.7(a) presents the receiving of the *Link Detected* the MIH User Agent of the MN. The possible PoA is detected by only one interface. The command of the MN's WiMAX interface will connect to the BS through link type 27, MacAddr: 15, and PoA: 14. The MIH user connects to the WiMAX interface because of the better network performance compared to the others. For example, the best utility WiMAX interface is one (1) or probability of around 0.430000 at 0.006642s until 0.021478s.

7. The MN's WiMAX interface connects to BS and triggers a *Link Up* event that is received by the MN's MIHF, which then commands the MN's MIPv6 Agent to request the Neighbor Discovery (ND) to send a Router Solicitation (RS) at 0.021478s as shown in Figure 5.7(b).
8. Figure 5.7(c) depicts the receiving of the *MIH Capability Discovery Request* (MCDR) by the BS, which will then send a MCDR, including its MIHF identification. By this time, the MIH Agent is aware of the identification of the remote (PoA) MIHF identification.
9. At t=0.029546s, CN starts to send CBR traffic, which was received through the WiMAX interface to the MN, as presented in Figure 5.7(c).
10. At t=0.076356s, the MIH user Agent in the MN receives the *Link Detected* from the LTE interface that has detected possible LTE PoA from BS, as shown in Figure 5.7(c).
11. The MIH user of MN recognizes that LTE is the best interface to access network compared to the others. Hence, the MIH Agent will make a connection to the LTE PoA through the LTE interface.
12. However, at t=1.250000s, the MN starts moving towards the LTE cell. The MN user connects to the LTE interface because it provides the best utility of 2 (LTE) and the probability of approximately 0.911000. The MN's LTE interface connects to BS and triggers a *Link Up* event that was received by the MN's MIHF. The commands MN's MIPv6 Agent will request the ND Agent to send the RS, as shown in Figure 5.7(c).

13. Figure 5.7(c) indicates the new neighbor of the handover event, which the MN's LTE interface sends the RS. Once this new neighbor is being detected BS will send a Router Advertisement (RA) including router lifetime (1800s), prefix valid-lifetime (5s), network prefix (ex 4.0.0), and advertisement interval (600000ms) at t=3.674543s.
14. After receiving the RA, the MN's LTE interface will reconfigure its address according to the received prefix (e.g., interface address = 4.0.1). Once informed, the MN's MIH Agent will command the LTE interface to send an MIH Capability Request to the BS, as shown in Figure 5.7(d).
15. Once the MN's LTE interface sent an RS, BS will detect a lifetime update. After that, BS will send a Router Advertisement (RA) consisting of router lifetime (1800s), valid-lifetime prefix (5s), network prefix (ex 4.0.0), and advertising interval (600000ms) at t=3.99754s, as shown in Figure 5.7(d). The BS detected the first-lifetime update from BS.
16. BS receives the *MIH Capability Request* and sends an *MIH Capability Response,* including the MIHF identification. The MIH Agent recognizes the MIHF identification as the identity of the remote (PoA), as illustrated in Figure 5.7(d).
17. At t=4.457857s, MN's MIH Agent is informed and commands the LTE interface to send an *MIH Capability Request* to the BS. The BS will then send the *MIH Capability Response,* including its MIHF identification. This identification is recognized by the MIH Agent as the identity of the remote (PoA) at Interface 2, as depicted in Figure 5.7(d).

18. After sending the *MIH Send Registration Request* to the LTE interface, the MIH Agent on the MN will receive the *MIH Received Registration Request*.
19. Once the MN's LTE interface sent the RS, BS will detect a lifetime update. After that, BS delivers a Router Advertisement (RA) including router lifetime (1800s), prefix valid-lifetime (5s), network prefix (ex 4.0.0), and advertising interval (600000ms) at t=4.876654s, as shown in Figure 5.7(d). The BS updated the second-lifetime.
20. Figures 5.7(d) and 5.7(e) points out that at approximately t= 5.124678s, the MIH Agent user on the MN will receive the *MIH Received Registration Request* from the LTE interface which was set to 100 nodes. The MIH Agent user will again receive the *MIH Received Registration Request* from the LTE interface at t=5.345757s. After that, the MIH Agent will receive a message from the Correspondent Node (CN) that has a packet lacking Acknowledgement (ACK) at 33.358053s and 59.135677s. At the same time, the MN's MIH Agent has been notified of the MN's new address and will redirect the reception of the CBR traffic from the WiMAX (4.0.1) to the LTE interface. The arrived traffic arrives utilized the link between the LTE interface and BS.
21. At these two points of time, 119.945664s and 211.342434s, the MIH Agent will again receive the message about the packet lacking ACK, which affected the number of packet loss, handover latency, and delay as shown in Figure 5.7(e).
22. Figure 5.7(e) indicates that at approximately of t= 223.093576s, the MIH Agent on MN will send the *MIH Neighbor Discovery Send* process using the *Internet Control Message Protocol* (ICMP) message and solicited-node multicast address

to decide the link-layer address of a neighbor on the same network (local link). It sends the RA through network prefix (interface address 3.0.0) that linked to the Wi-Fi interface. This interface triggers a *Link going down* event (based on the obtained power of the beacon frames) due to the MN's speed with the probability of increasing the establishment of the Wi-Fi link goes down. However, in this case, the speed achieves an explicated rate of 90%. Means that the MN's LTE interface is still active, whereby the MN MIPv6 Agent will give the command for the LTE interface to send a redirect message to the CN to inform about the new MN location network prefix address of 4.0.0. At the same time, the MN's Wi-Fi interface will trigger a *Link Down* event, and the MN's will be disconnected (Wi-Fi signal lost) from the Wi-Fi cell.

23. At t=271.343435s, BS detects a lifetime update. After that, BS delivers a Router Advertisement (RA) including router lifetime (1800s), prefix valid-lifetime (5s), network prefix (ex 4.0.0), and advertising interval (600000ms), as shown in Figure 5.7(e). The third-lifetime update from BS.
24. Figure 5.7(e) shows that the MIH Agent received the *Link Down* trigger through the MN WiMAX interface type of 27 and Mac Address of 15 at t=274.963434s. The MIH Agent will then notice that the MN's WiMAX interface has been disconnected (WiMAX signal lost) from the WiMAX cell.
25. The MN's MIPv6 Agent redirects the message using the interface address of 0.0.2 before that it flows to the 3.0.1. Finally, almost at the same time, that MN's LTE interface that is still active will be connected to the BS until its received

Link Down event at t=274.963434s which is the best utility interface of 2 (probability= 0.920000) as shown in Figures 5.7(e) and 5.7(f).

26. During the receiving of the *Link Down* event, the MN's MIH Agent will instruct the LTE interface to execute a link scan using the *Link Action Request* to search for other nearby LTE networks. However, no other networks were found at t=274.963456s by the *Link Action Confirm* command. The experiment of simulation ended at approximately t=250s, as presented in Figure 5.7(f).

Figure 5.7 shows the sequence of events triggered by the LTE, WiMAX, and Wi-Fi handover using the NIST modules in the NS-2 and RSS-Threshold algorithm.

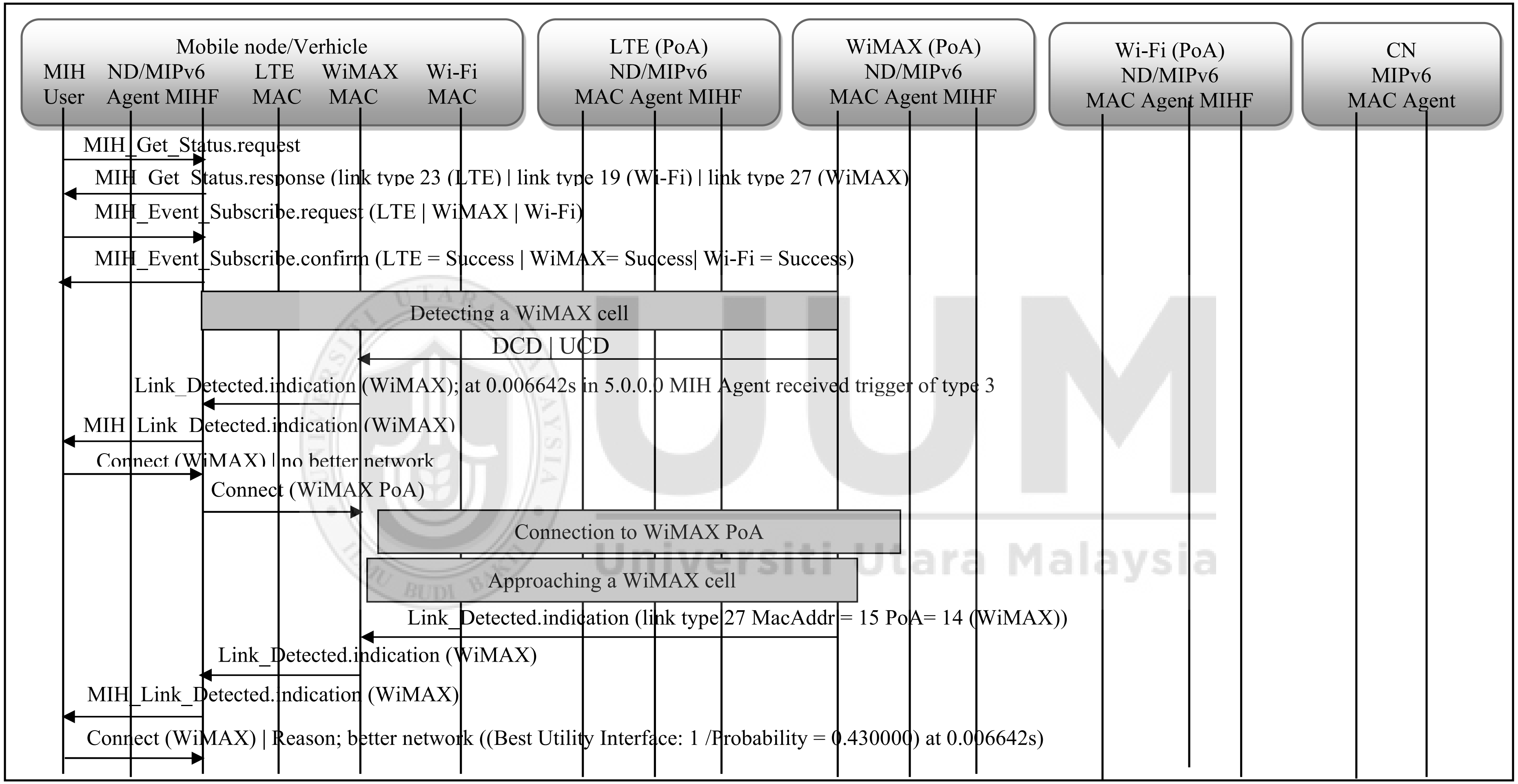


Figure 5.7(a) *The Sequence of Events Triggered by LTE, WiMAX, and Wi-Fi Handover using RSS-Threshold Algorithm*

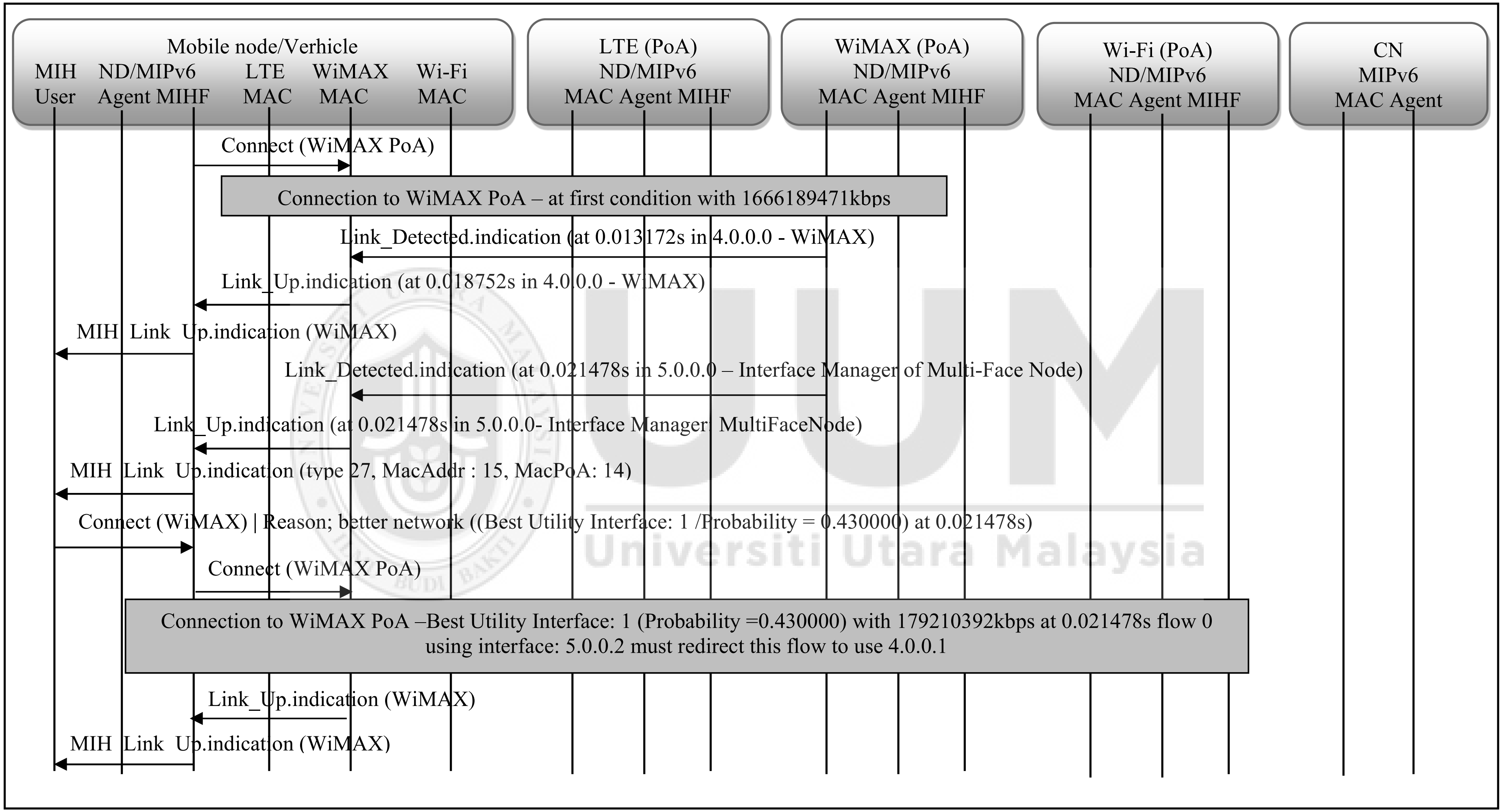


Figure 5.7(b) *The Sequence of Events Triggered by LTE, WiMAX, and Wi-Fi Handover using RSS-Threshold Algorithm*

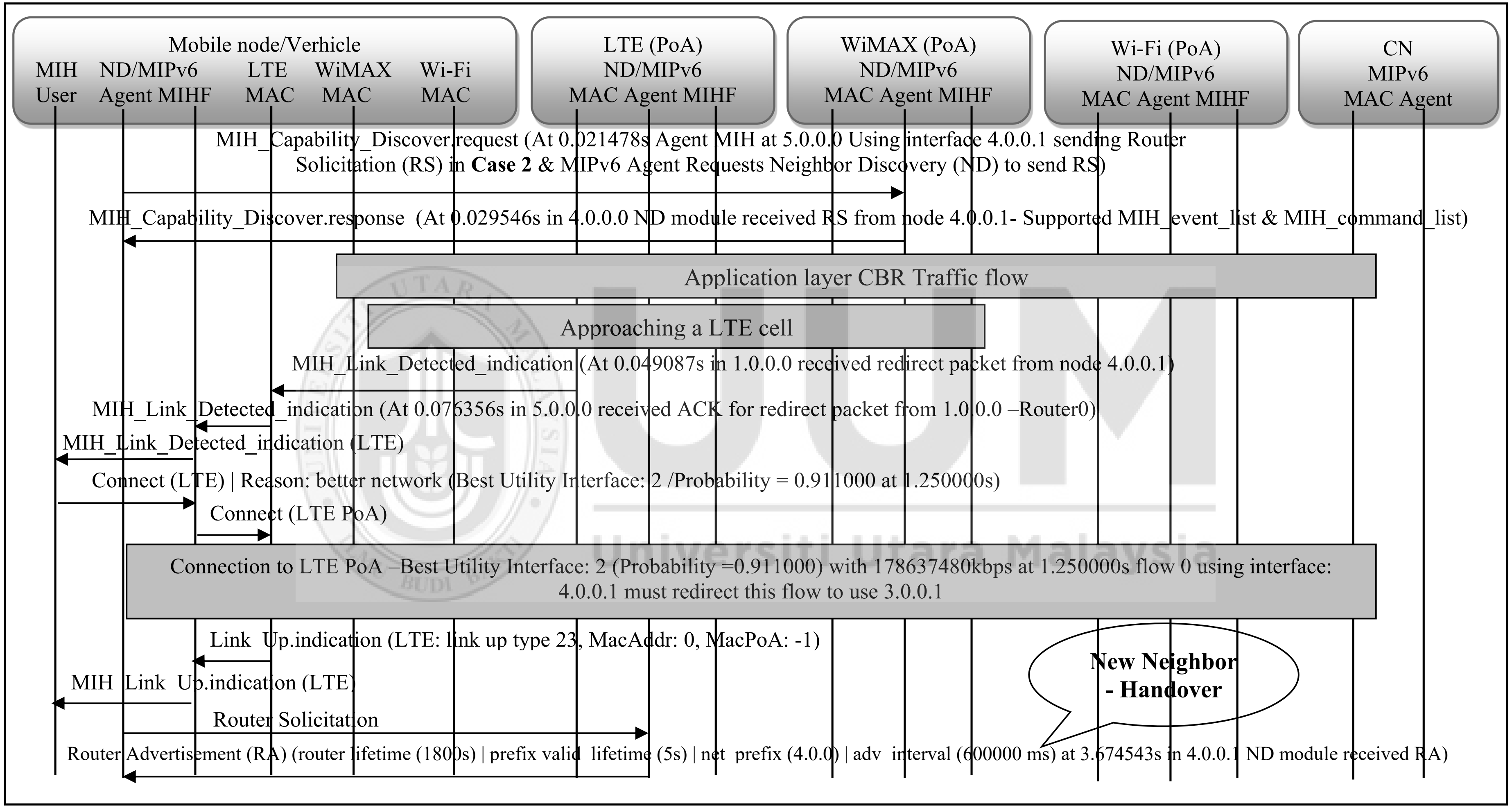


Figure 5.7(c) *The Sequence of Events Triggered by LTE, WiMAX, and Wi-Fi Handover using RSS-Threshold Algorithm*

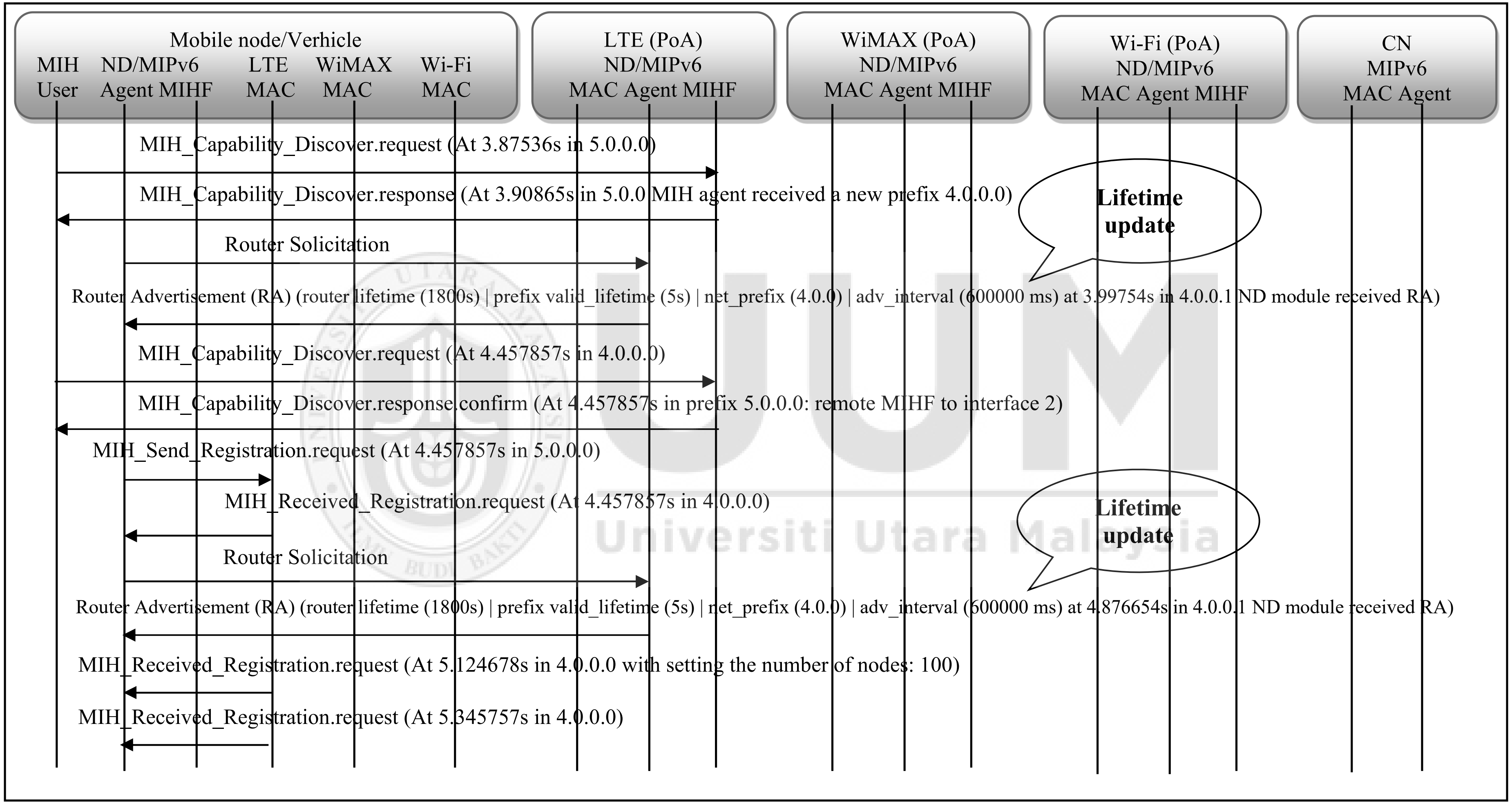


Figure 5.7(d) *The Sequence of Events Triggered by LTE, WiMAX, and Wi-Fi Handover using RSS-Threshold Algorithm*

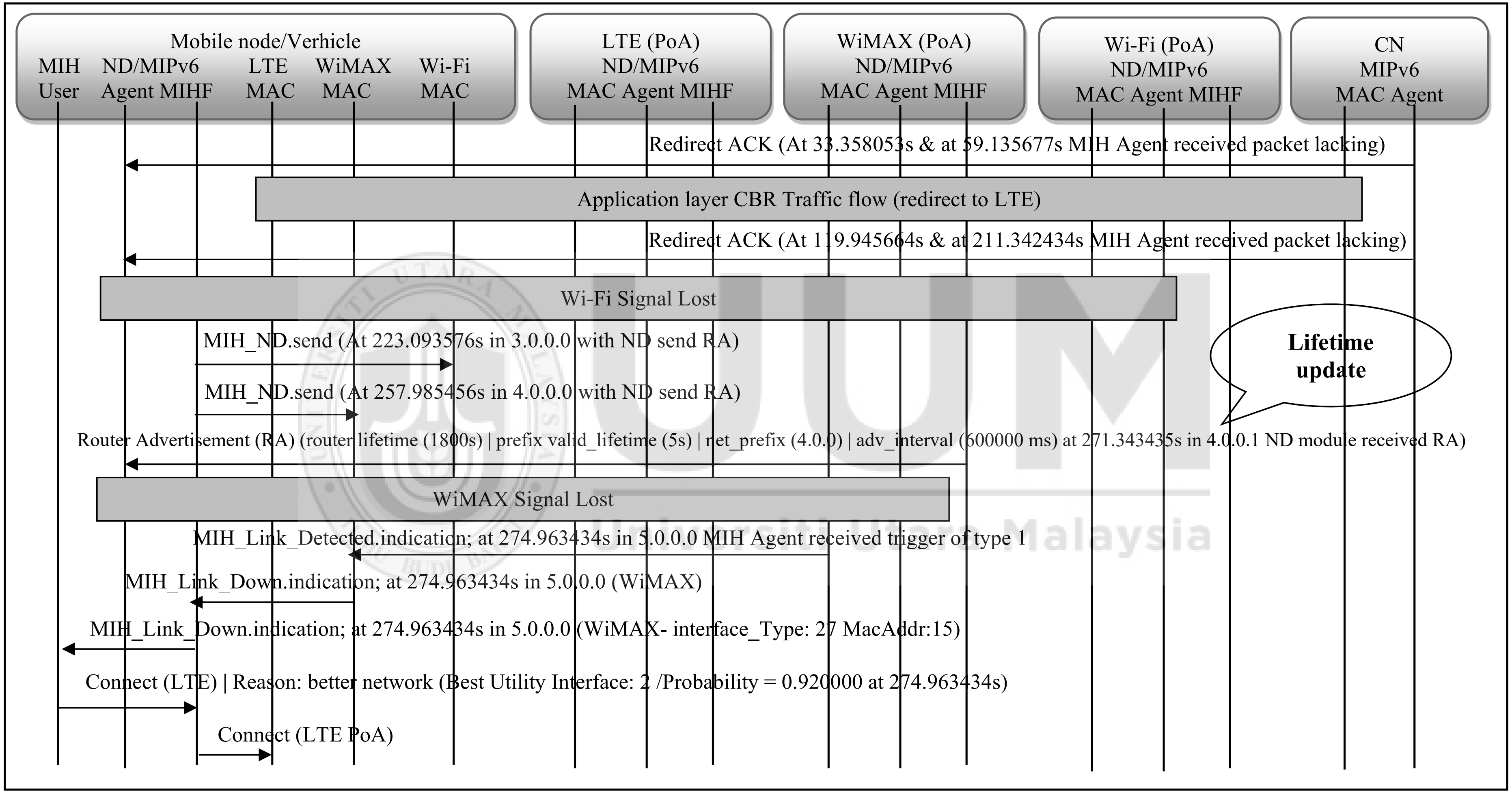
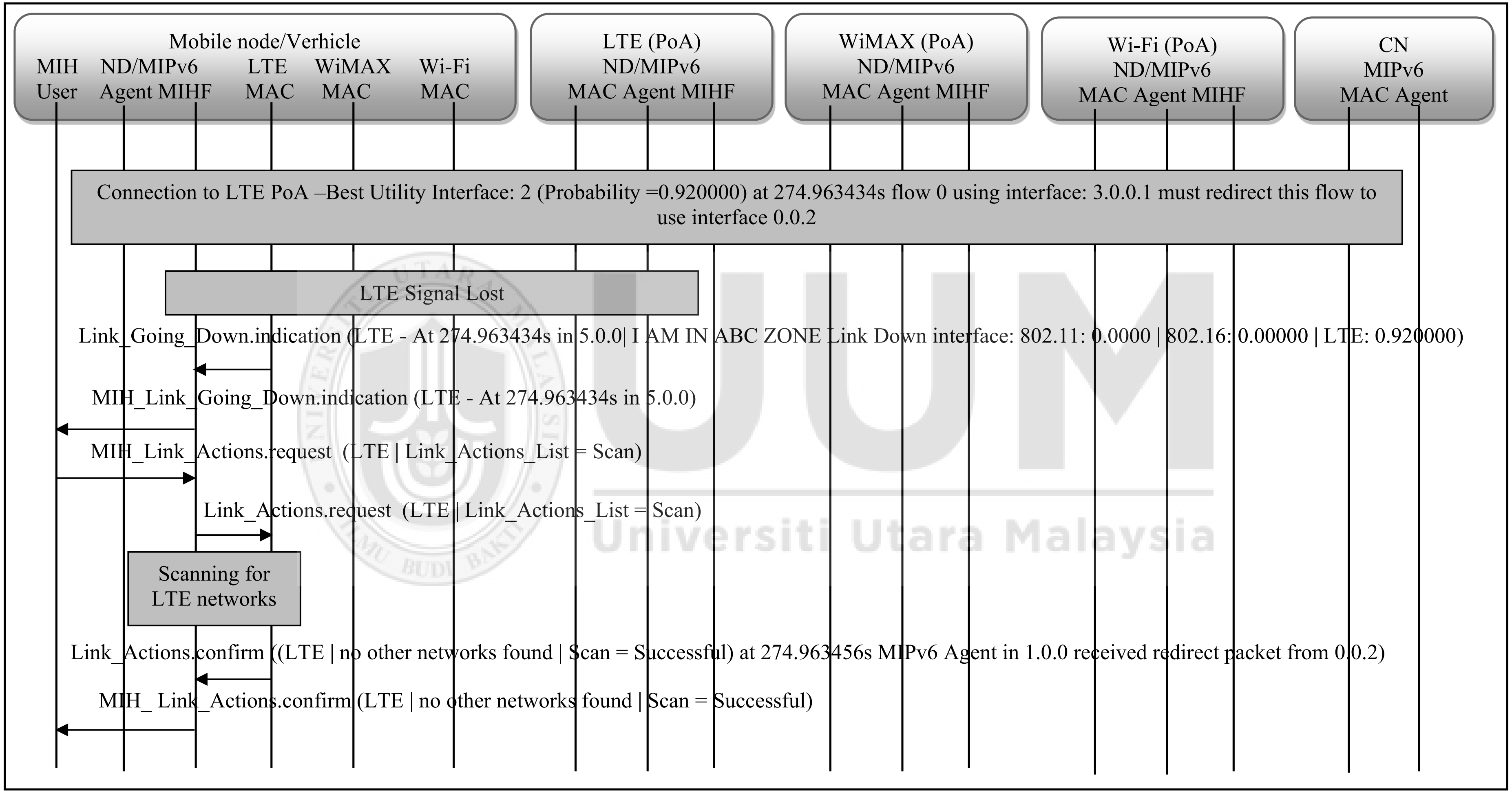


Figure 5.7(e) *The Sequence of Events Triggered by LTE, WiMAX, and Wi-Fi Handover using RSS-Threshold Algorithm*



Connection to LTE PoA –Best Utility Interface: 2 (Probability =0.920000) at 274.963434s flow 0 using interface: 3.0.0.1 must redirect this flow to use interface 0.0.2

Link_Going_Down.indication (LTE - At 274.963434s in 5.0.0| I AM IN ABC ZONE Link Down interface: 802.11: 0.0000 | 802.16: 0.00000 | LTE: 0.920000)

MIH_Link_Going_Down.indication (LTE - At 274.963434s in 5.0.0)

MIH_Link_Actions.request (LTE | Link_Actions_List = Scan)

Link_Actions.request (LTE | Link_Actions_List = Scan)

Link_Actions.confirm ((LTE | no other networks found | Scan = Successful) at 274.963456s MIPv6 Agent in 1.0.0 received redirect packet from 0.0.2)

MIH_ Link_Actions.confirm (LTE | no other networks found | Scan = Successful)

Figure 5.7(f) The Sequence of Events Triggered by LTE, WiMAX, and Wi-Fi Handover using RSS-Threshold Algorithm

5.3 Verification and Validation of Events Generation Process of the Proposed F-SAW Scheme and other Methods

Based on Figures 5.6 and 5.7, the use of the F-SAW algorithm provides better performance compared to RSS-Threshold in terms of times and the weighted probability of maximum score which was executed on the NIST 802.21, as add-on modules. Table 5.2 describes the comparison of the handover sequence events between the F-SAW and RSS-Threshold algorithms in the Vehicular Ad-hoc Networks.

From Table 5.2, the events service is used to assist in the improvement of handover detection. The active status of the trigger includes link detected, link going down (LGD), link down (LD), and link up (UP), provided by the MIES in the MIH mechanism. However, the status depends on the pattern and the current situation of link features such as ABW, RSS, and service type. Referring to Table 5.1, at t=5s at point A, the MNs will start moving and be available to access any potential network. The active status of the trigger of the links shows that the WiMAX is linked up (LU) while both the LTE and Wi-Fi are linked down (LD). However, at t=1s, the MNs change trigger to LTE because the LTE link status is linked up (LU) while the Wi-Fi is still linked down (LD). The movement of the MNs link from the WiMAX to the LTE base station is known as the handover process. At t=50s in point B, the MNs starts moving and entering to the LTE coverage area, which will be detected as Link UP (LU) trigger. The MNs move from the WiMAX base station to the LTE coverage with the status of the link going down (LGD). This active change is known as handover (make and break) because LTE is considered as a better network than WiMAX in terms of RSS and QoS as the Wi-Fi is still Link down (LD). At point B, the event status shows that there are two (2) MIH packets lacking. Therefore, it will affect the

QoS, especially in increasing the packet loss (refer to Subsection 4.3.2.3 in Chapter 4).

After some time, at t=100s the MNs began to move and enter the point C of the LTE, WiMAX, and Wi-Fi ranges. The WiMAX link is going down (LGD), while LTE is still Link UP (LU) and Wi-Fi is still Link Down. The Wi-Fi access will then be disconnected (signal lost connection). When t=100s, in this case, there are twice, the MIH agent will receive packet lacking because the MNs have lost the Wi-Fi connection (refer to Table 5.2). However, when it is detected, the LTE will become link up (LU), while WiMAX is linked down (LD) because of the WiMAX lost connection signal. Finally, at t=249.91s and t=274.96s, the link trigger status for the LTE is a link going down (LGD) in terms of RSS and QoS (ABW and service type).

Table 5.3 and Figure 5.8 show the comparison of the handover trigger sequence events between the F-SAW and RSS algorithms based on time. The results are shown by using the F-SAW algorithm; the connection gradually decreases when the time is between the range of t=0s to t=50s. However, it starts to rapidly decrease when the speed reaches the range between t=50s to t=250s (refer Table 5.2). Thus, the total of average time is reduced to 12.21 seconds when comparing between the F-SAW and RSS-Threshold algorithms. Means that, the proposed F-SAW scheme can avoid unnecessary handover and handover failure at the time of 28s, 52s, 100s, and 196s as known as packet lacking. However, the RSS-Threshold scheme used only RSS was not adequate for a smooth VHO transition but Quality of service (ABW, service type) was vital, as when QoS was taken into account of the proposed F-SAW scheme.

Table 5.2

The Differences between F-SAW and RSS-Threshold Algorithms in the Vehicular Ad-hoc Networks Handover Trigger Sequence of Events

Events	F-SAW	RSS-Threshold	Remarks
Connect to WiMAX PoA (WiMAX Base Station) **WiMAX- Link Up (LU)**	- Best Utility interface:1 - Probability : 0.45 - Times: 0.0186 s	- Best Utility Interface: 1 - Probability: 0.43 - Times: 0.0215 s	- WiMAX connection is the best network and Link-up (LU). - The F-SAW is better than the RSS method in terms of probability and times such as 0.45 and t=0.0186s.
CBR traffic flow Connect to LTE PoA (LTE Base Station) **LTE- Link Up (LU)** (Handover occur)	- Best Utility interface:2 - Probability: 0.95 - Times: 1 s	- Best Utility interface:2 - Probability : 0.91 - Times: 1.25 s	- The LTE connection is the best network and Link-up (LU). - The F-SAW is better than the RSS method in terms of probability and reduces times such as 0.95 and 0.25s of 1.25s. - Handover event triggered from WiMAX to LTE base station.
Neighbor Discovery (ND) received Router Advertisement (RA) **LTE – Link detected**	Router lifetime (1800s), prefix valid_lifetime (5s), net_prefix(4.0.0) and adv_interval (600000ms) at t=3.16s	Router lifetime (1800s), prefix valid_lifetime (5s), net_prefix(4.0.0) and adv_interval (600000ms) at t=3.67s	- The new Neighbor information received by mobile nodes (MNs). - The time taken using the F-SAW method decreases at 0.51s to 3.16s compared to that of the RSS. - MNs make a connection to the LTE base station.
Router Solicitation (RS) to Router Advertisement (RA) **LTE – Link detected**	Router lifetime (1800s), prefix valid_lifetime (5s), net_prefix(4.0.0) and adv_interval (600000ms) at t=3.22s	Router lifetime (1800s), prefix valid_lifetime (5s), net_prefix(4.0.0) and adv_interval (600000ms) at t=3.99s	- ND received RA. - Update Lifetime. - The time of F-SAW is reduced to 0.77s compared to the RSS. - MNs make a connection to the LTE base station.
Router Solicitation (RS) to Router Advertisement (RA) **LTE – Link detected**	Router lifetime (1800s), prefix valid_lifetime (5s), net_prefix(4.0.0) and adv_interval (600000ms) at t=3.48s	Router lifetime (1800s), prefix valid_lifetime (5s), net_prefix(4.0.0) and adv_interval (600000ms) at t=4.87s	- ND received RA. - Update Lifetime. - The time of F-SAW is reduced to 1.39s compared to RSS. - MNs make the connection to LTE base station.
MIH agent received packet lacking	Redirect ACK at t=28.02s and t=52.02s	Redirect ACK at t=33.35s and t=59.13s	- MNs disconnect signals from access networks, especially the LTE base station.
MIH agent received packet lacking	Redirect ACK at t=100.02s and t=196.02s	Redirect ACK at t=119.95s and t=211.34s	- MNs disconnect signals from access networks, especially the LTE base station. - Wi-Fi Signal lost.
Router Solicitation (RS) to Router Advertisement (RA) **LTE – Link detected**	Router lifetime (1800s), prefix valid_lifetime (5s), net_prefix(4.0.0) and adv_interval (600000ms) at t=238.37s	Router lifetime (1800s), prefix valid_lifetime (5s), net_prefix(4.0.0) and adv_interval (600000ms) at t=271.34s	- ND received RA. - Update Lifetime. - The time of F-SAW is reduced 32.97s compared to RSS. - MNs make the connection to the LTE base station. - WiMAX signal lost.

Disconnect WiMAX **Link Down (LD)**	MIH Link Down indication at t=249.91s	MIH Link Down indication at t=274.96s	WiMAX- Signal lost connection
Connect to LTE PoA (LTE Base Station) **LTE- Link Up (LU)**	- Best Utility interface:2 - Probability : 0.95 - Times: 249.91 s	- Best Utility interface:2 - Probability : 0.92 - Times: 274.96s	- The LTE connection is the best network and Link-up (LU). - The F-SAW is better than the RSS method in terms of probability and times.
Link going down (LGD) Disconnect LTE	MIH link going down (LGD) at t=249.91s	MIH link going down (LGD) at t=274.96s	LTE - Signal lost connection

Table 5.3

Comparison of Sequence Generate Events between F-SAW and RSS-Threshold Algorithm

Events	**(A) Proposed F-SAW (s)**	**(B) RSS-Threshold (s)**	**Reduce (s) (A-B)**
WiMAX-Link Up	0.019	0.022	0.003
LTE-Link Up	1.000	1.250	0.250
LTE-link detected (RS-RA)	3.160	3.670	0.510
LTE-link detected(RS-RA)	3.220	3.990	0.770
LTE-link detected(RS-RA)	3.480	4.870	1.390
Packet Lacking -1	28.020	33.350	5.330
Packet Lacking -2	52.020	59.130	7.110
Packet Lacking -3	100.020	119.950	19.930
Packet Lacking -4 (Wi-fi signal Lost)	196.020	211.340	15.320
LTE-link detected(RS-RA)	238.370	271.340	32.970
WiMAX-Link Down (signal Lost)	249.910	274.960	25.050
LTE-Link Up	249.910	274.960	25.050
LTE-Link Going Down	249.910	274.960	25.050
Total Average of Times			**12.21**

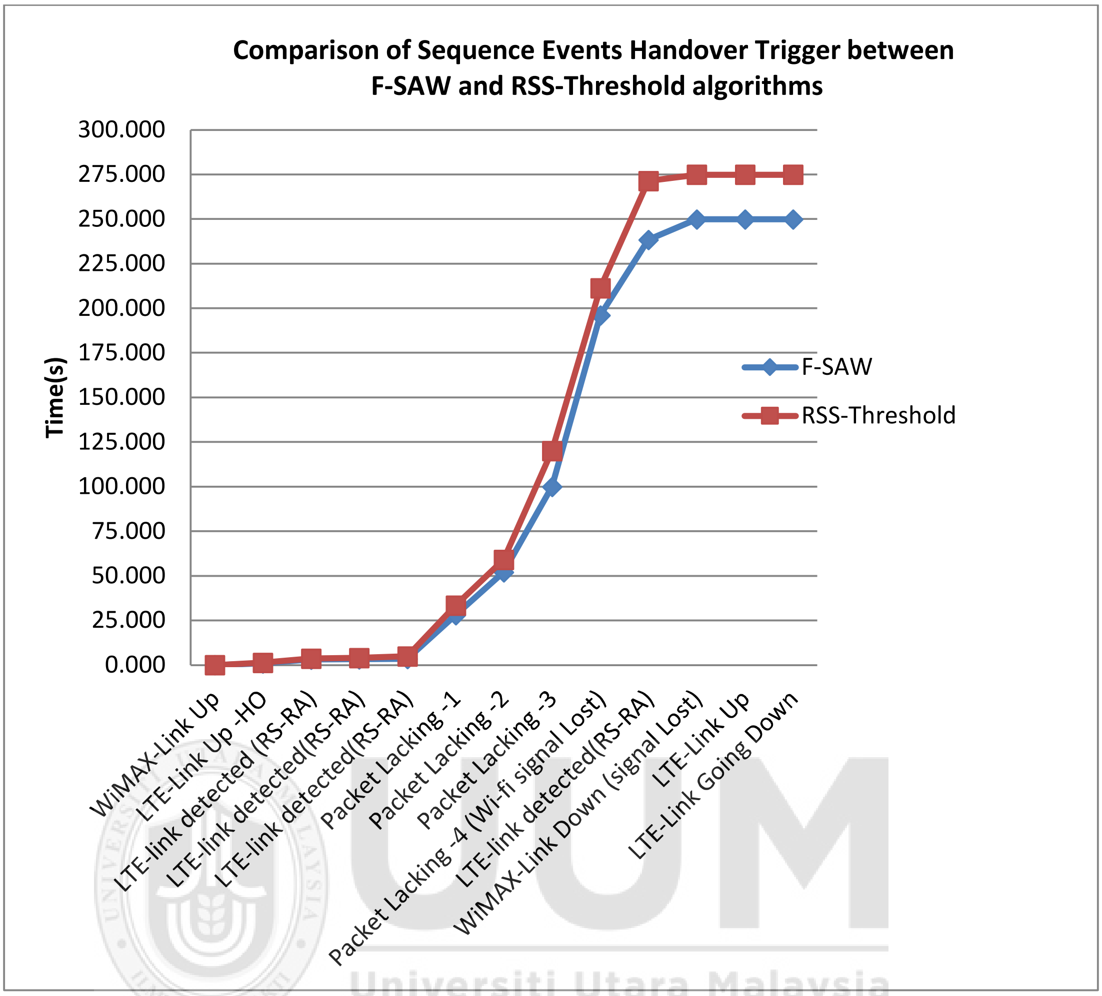


Figure 5.8 *Comparison of the Handover Trigger Sequence Events between F-SAW and RSS-Threshold Algorithms*

Table 5.4 shows a comparison of the vertical handover event generation process in the proposed F-SAW, Proactive Fuzzy-Guided (PFGA) [144], and RSS-Threshold algorithms. The proposed guided link labeling process should be done before the handover decision and execution phases. Based on Table 5.1, At point A, there are differences of trigger links in the three vertical handover event generation processes. When the MNs began to move at point A, the proposed F-SAW and RSS-Threshold triggered link up (LU) at the WiMAX access network, while the UMTS/LTE triggered a link down (LD). However, the PFGA triggered a link-up (LU) at the UMTS/LTE. The trigger link up (LU) then changed from WiMAX to UMTS/LTE access network for the proposed F-SAW and RSS-Threshold while Wi-Fi was still linked down (LD) at point B.

On the other hand, at point B, the PFGA method triggered link up at WiMAX and UMTS/LTE while Wi-Fi is linked coming up (LCU). The final movement of MNs is at point C showing the link-up (LU) status event in the proposed FLB and RSS-Threshold algorithm for UMTS/LTE while PFGA is linked down (LD). However, the event processes of the WiMAX and Wi-Fi in the proposed F-SAW and RSS-Threshold algorithms are indicated as Link going down (LGD) and link down (LD), the PFGA is shown as link-up (LU) at point C. In other words, the handover process events generated by the three vertical handover algorithms depend on the different link statuses such as LU, LCU, and LGD. However, the simulation scenarios in this research, the link down (LD) events do not have to perform the handover process due to the failure of fulfilling the necessary RSS or QoS.

Table 5.4

Comparison Events Generation Process of the Proposed F-SAW and other Methods

Points / Area	**Proposed F-SAW**			**PFGA** [144]			**RSS-Threshold**		
	UMTS/ LTE	**WiMAX**	**Wi-Fi**	**UMTS/ LTE**	**WiMAX**	**Wi-Fi**	**UMTS/ LTE**	**WiMAX**	**Wi-Fi**
A	LD	LU	LD	LU	LD	LD	LD	LU	LD
B	LU	LGD	LD	LU	LU	LCU	LU	LGD	LD
C	LU	LD	LD	LD	LU	LU	LU	LD	LD

Notes:

Link Down – LD

Link UP - LU

Link going down - LGD

Link Coming UP - LCU

5.4 Summary

The vertical handover triggering a process in this study has been conducted by integrating the F-SAW algorithm and MIH mechanism to produce the link status of the vertical events handover trigger. It also has been completed by integrating the RSS-Threshold algorithm and MIH mechanism to show the differences between the handover trigger events of the F-SAW algorithm. As a result, the proposed F-SAW scheme can reduce more time of the handover trigger event compared to that of the RSS-Threshold. Means that, the proposed approach can reduce the number of unnecessary handovers up to 50% means that handover latency and handover failure rates are reduced by 20% while end-to-end delay reduced by 21%.

CHAPTER SIX

THE SELECTION OF THE BEST VERTICAL HANDOVER IN VEHICULAR AD-HOC NETWORKS

This chapter aims to tackle the problems of achieving the best selection among different access networks in heterogeneous vehicular networks. The chapter begins by presenting the overview and implementation of the proposed F-SAW scheme, including the development of the intelligent network selection process for the V2I wireless networks (LTE, WiMAX, and Wi-Fi). The chapter then continues by providing the findings based on the analysis of the proposed scheme as well as elaborating on the verification and validation process. The competent network selection process is accomplished by providing a high-quality service to fulfil users' preferences on the existing applications.

As mentioned in Section 4.1 of Chapter 4, the QoS performance in the heterogeneous vehicular networks can be enhanced by using the FL algorithm. This research used the combination of the vehicular traffic generator and network simulator to generate a complete and realistic simulation of VANETs. The VANETMobiSim simulator comprises of various driver behavior models, was used as the mobility generator. On the other hand, the network simulator used the NS-2 is a discrete network simulator that can be combined with the VanetMobiSim simulator.

6.1 Overview of the F-SAW Scheme

In order to enhance the network selection process in the heterogeneous vehicle networks, the F-SAW scheme was proposed by combining two algorithms to determine the best network during the handover process; fuzzy logic and SAW. The three input parameters provided to the F-SAW scheme include RSS, ABW, and Service types, which were collected from the MIH information service, as mentioned in Subsection 4.1.1 of Chapter 4. The process of determining the highest score was divided into three categories; i) to estimation on the total requested bandwidth, ii) to perform a total of weight for each accessible network (LTE, WiMAX, and Wi-Fi), and iii) select the best AP or BS among candidate access networks.

Figure 6.1 shows the flowchart diagram of the proposed F-SAW scheme for the network selection processes in the vehicular networks. The highlighted block of the proposed F-SAW scheme refers to the contribution in tackling the problems related to the vertical handover decision making of the heterogeneous vehicular networks. Each of the highlight blocks has its condition and the process must be done continuously to achieve accurate results. For example, the maximum total values of parameters should be attained earlier, such as the RSS (ALPHA_i), ABW (A), delay (D), and jitter (J). The cumulative total weighting is then given to measure the total weight of each access network (e.g. LTE, WiMAX, and Wi-Fi) by adding the parameter of cost (C) representing a static value for each of the three different networks (e.g. Wi-Fi, WiMAX, and LTE). Thus, the highest-scoring function implemented in this research, (*Best_AP () procedure)*, was approved by the F-SAW scheme for selecting the best network candidate based on the calculated maximum total weight. The first execution used the FL algorithm to find out the data rate and interface network standard ID of the active network cells that were connected to each vehicle in the simulated scenario. It was accomplished by utilizing the port numbers of each application, as illustrated in Figure 5.5 of Chapter 5. Besides, the velocity of each vehicle was measured persistently by observing its current mobility situation in the simulation.

The essential point to highlight here is the design of the vertical handover decision-making approach employed by the F-SAW scheme, which intelligently started the handover by choosing the network with the highest score. Moreover, the intelligent configured condition statement in the F-SAW scheme permitted the vehicle for the best choice by considering some essential situations. For instance, all vehicles were allowed to access the available AP or BS simultaneously, even though the current vehicle status was idle or busy in the vertical handover direction (LTE to WiMAX or WiMAX to LTE), (LTE to Wi-Fi or Wi-Fi to LTE), and (WiMAX to Wi-Fi or Wi-Fi to WiMAX)) while implementing the real-time application during the busy mode.

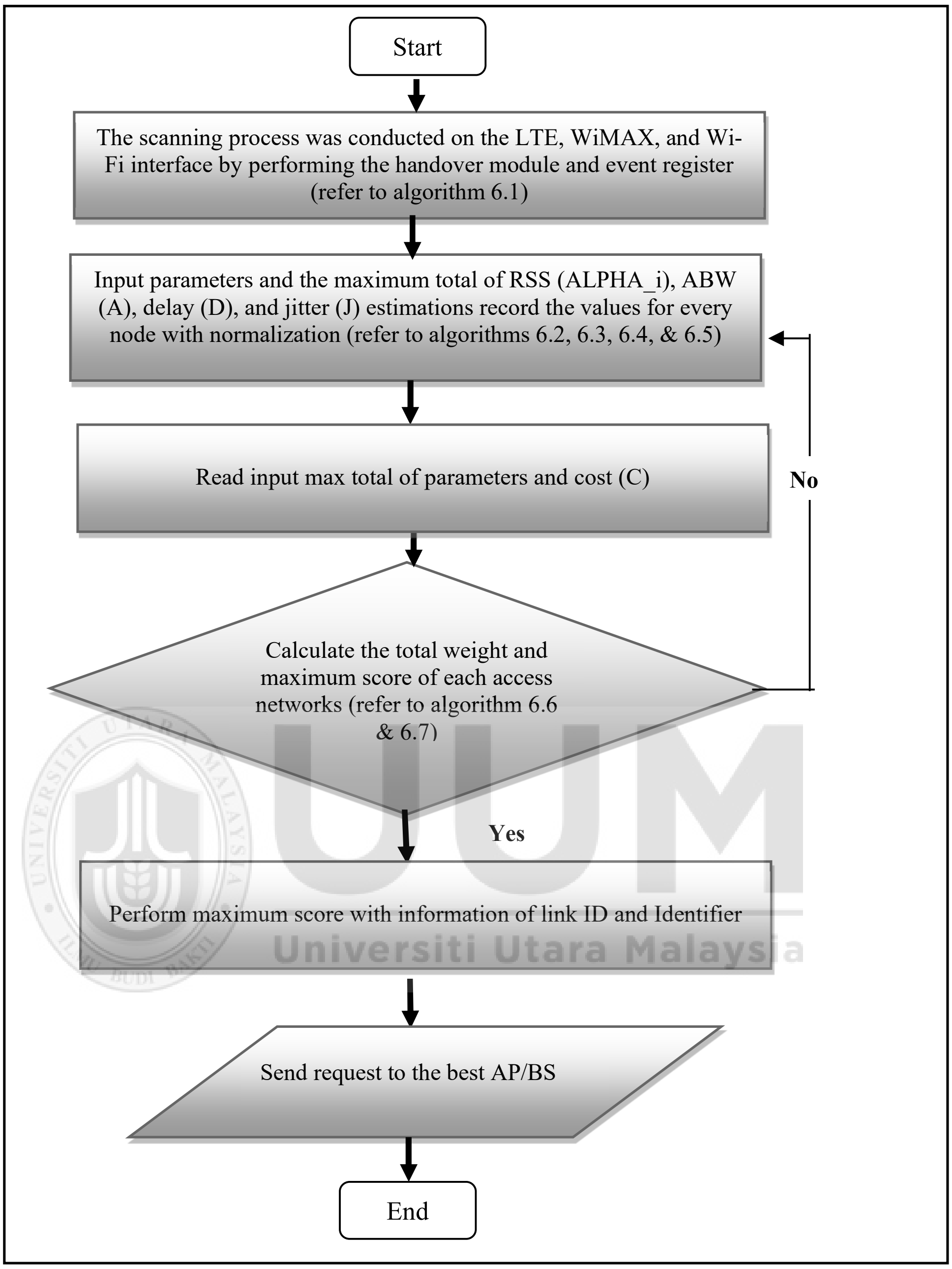


Figure 6.1 *Flowchart of the F-SAW Scheme*

6.2 Detailed Implementation of the Proposed F-SAW Scheme

Based on Figure 4.5 in Chapter 4 provides the explanations on the designing and processing of the AHD scheme. The integration of the proposed F-SAW scheme and MIH mechanism in the NS-2 simulation offers the ability to choose the best candidate among the available access networks. The mobility protocol used in this simulation was the MIPv6, also known as the MIHF agent. The F-SAW scheme was developed using C++ programming, while the interface was designed using the MIH library in the NS-2.29 network simulator. The MIH mechanism and F-SAW scheme were integrated into the MN and divided into two phases, MIH mechanism and F-SAW algorithm. In finalizing the selection of the best network, several processes need to be completed before implementing the algorithm. The initialization and scanning of the handover process must be created in the MIH mechanism phase before the Information Service (IS) collect related information from the candidate of the accessible networks (WI-FI, WiMAX, and LTE) as shown in Algorithm 6.1.

The Algorithm 6.1 was generated to initialize the HO, create the HO module, register, and configure the information communication handover of the MIH mechanism for scanning and obtaining the link status of the accessible networks trigger. Figures 6.1 shows the screenshots of the LTE, Wi-Fi, and WiMAX initialization and get status from LTE, Wi-Fi, and WiMAX networks in the MIH mechanism. Then, the HO process started by performing the scan process on the potential candidate of the access networks to collect information such as RSS, ABW, and service types (static) from the

IS of the MIH. The MIH mechanism process can be integrated with the F-SAW algorithm to select the best candidate among the access networks.

Algorithm 6.1 Handover Algorithm for Initializing and Scanning in the MIH

```
Call handover of the library, simulator, and mobility MIPv6
Declare handover register in MIH
Read value macs.
Initialize variable MIH agent with executing macs address.
    Perform debug of Handover registers with executing MIH and macs.
    for EACH macs (macs.size ())
        Perform link event register (Link Detected, Link Up, Link Going Down,
        and Link Down)
    end for
end
Call Information Handover process link parameter to execute new link status.
Perform the link event sources.
end.
```

Based on Figure 6.1, the scanning process on the accessible networks candidate was implemented in the MIH mechanism, while the collected information was sent to the F-SAW algorithm process.

Algorithm 6.2 F-SAW Algorithm

```
Initialize and call module Handover Algorithm (Algorithm 6.1) with link detected
Declare macs, next entry, ALPHA_i, flow_infosize
    Perform old address, new address, and prefix
    Read value all basic MIH input parameters (refer appendix D)
    Perform the info of link parameter, MIH interface, HO IP and HO frequency
    Response and allocate the packet with HO IP address and HO command
    Perform with time and flow request packet through MIPv6 agent
for EACH macs size ()
  for EACH next entry ()
      Perform event register (Link Detected, Link Up, Link Going Down, and
          Link Down)
      Perform initialize MIH event register and MIH link parameter change.
      Perform link detected with info of event source, mac mobile terminal, and
          new PoA
      Perform HO link layer and HO protocol ARP
```

```
        Initialize HO command (ch)
        Perform link going down
        Initialize the link type, mac mobile terminal, mac PoA, time interval, confidence level
        Perform strength of the signal with ALPHA_i
        Perform process link detected
    end for
end for
for EACH flow_infosize ()
    Perform request bandwidth
end for
    Perform HO configure event source
```

In algorithm 6.2, the F-SAW scheme is used as a part of identification and declaration in the link detection process in terms of event source, *mac* mobile terminal, and new PoA. Furthermore, the strength of the signal that collects the highest signal from the candidate networks was generated and identified. For example, *ALPHA_i is* a variable of the received signal strength that is detected by the MIH mechanism via scanning the interface of candidate access networks, as shown in Algorithm 6.2. Table 6.1 and Figure 6.2 illustrate the initialization scanning status of events sequence in link detection triggered by Wi-Fi, WiMAX, and LTE handover using the F-SAW algorithm.

Table 6.1

The Initialization Scanning Status of Events Sequence

Networks	**Interface address**	**Node ID**	**MAC address**	**Link ID**
Wi-Fi	3.0.1	10	11	Link type 19
WiMAX	4.0.1	14	15	Link type 27
LTE	5.0.1	1	0	Link type 23

```
warning: no class variable Mac/LTE::MIH_UTILITY

        see tcl-object.tcl in tclcl for info about this warning.

warning: no class variable Mac/LTE::NN

warning: no class variable Mac/LTE::bandwidthLTE_

warning: no class variable Mac/LTE::MIH_UTILITY_

        see tcl-object.tcl in tclcl for info about this warning.

warning: no class variable Mac/LTE::NN

warning: no class variable Mac/LTE::bandwidthLTE_

At 0.000000 in 5.0.0 MIH is adding mac 0
At 0.000000 in 5.0.0 MIH is adding mac 11
At 0.000000 in 5.0.0 MIH is adding mac 15
using backward compatible Agent/CBR; use Application/Traffic/CBR instead
 Simulation is running .... please wait ...
Calling MIH_Get_Status
At 0.001000 in 5.0.0, MIH receives get_status for local MIH
MIH_Get_Status results for 3 interface(s):
        Link ID: linkType=23, macMobileTerminal=0, macPoA=-1
        Capabilities are: commands:3, events:3
MIH User subscribing for events 1ff on Mac 0
        Subscription status: requested=1ff, result=3
        Link ID: linkType=19, macMobileTerminal=11, macPoA=-1
        Capabilities are: commands:f, events:1bf
MIH User subscribing for events 1ff on Mac 11
        Subscription status: requested=1ff, result=1bf
        Link ID: linkType=27, macMobileTerminal=15, macPoA=-1
        Capabilities are: commands:f, events:1bf
MIH User subscribing for events 1ff on Mac 15
        Subscription status: requested=1ff, result=1bf
channel.cc:sendUp - Calc highestAntennaZ_ and distCST
highestAntennaZ_ = 1.5,  distCST_ = 513.3
SORTING LISTS ...DONE!
```

Figure 6.2 *Screenshot Initialization and Scanning of MIH Mechanism*

Detail explanations of the MIH status process are provided, as shown in Figure 3.8 in Subsection 3.3.1 of Chapter 3. The MIH has collected the parameters and submitted them to the fuzzy logic process for initiating the handover process. This part is significant because the measurement needs to be done by the F-SAW algorithm before sending accurate information to the MIH event service as exhibited in Figure 3.9 in Subsection 3.3.2 of Chapter 3. The algorithm selection involves three phases. The first is to calculate the value of the bandwidth, delay, and jitter for each network (e.g. LTE, WiMAX, and Wi-Fi). Second is to calculate the bandwidth normalization by dividing the network with the highest to lowest bandwidth. After that, the measurement of the overall delay and jitter dividing the network value with the lowest value others to delay and jitter cases.

Figure 6.1 portrays the estimation of the maximum values of the total RSS (ALPHA_i), ABW (A), delay (D), and jitter (J). The normalization (max method) of these values for every node was recorded and can be measured by following the algorithms 6.3, 6.4, and 6.5, respectively.

Algorithm 6.3 F-SAW algorithm – Calculate the Value of the Bandwidth (ABW) – refer to Appendix D

```
Initialize bandwidth, counter, size (kb) and location
for EACH counter
    Perform maximum bandwidth via each node
    for EACH size
        if (each bandwidth node larger then maximum bandwidth) then
            Perform maximum bandwidth and added location counter
        end if
    end for
end for
Perform a total of bandwidth that divided the value of the network that has the highest
  value by the value Perform of bandwidth using Equation 3.1.
```

Algorithm 6.4 F-SAW algorithm – Calculate the Value of the Delay (D) –refer to Appendix D

```
Initialize counter, size (kc) and location
for EACH counter
    Perform maximum delay via each node
    for EACH size
        if (each delay node larger then maximum delay) then
            Perform amount of delay and added location counter
        end if
    end for
end for
Perform a total of delay that divided the value of the network that has the lowest value
  by the value of delay using Equation 3.2.
```

Algorithm 6.5 F-SAW algorithm – Calculate the Value of the Jitter (J) – refer to Appendix D

```
Initialize counter, size (kj) and location
for EACH counter
    Perform maximum jitter via each node
    for EACH size
        if (each jitter node larger then maximum jitter) then
            Perform amount of jitter and added location counter
        end if
    end for
end for
Perform a total of jitter that divided the value of the network that has the lowest value
  by the value of jitter using Equation 3.2.
```

Algorithms 6.3, 6.4, and 6.5 should be generated with linear scale transformation normalization (max method) before computing the score function for each network in obtaining the maximum score value of the best. The third phase is to calculate the payoff score, which refers to the normalization powered to the weight of each parameter in selecting the one with the maximum score as the best network. Algorithm 6.6 uses the F-SAW algorithm to calculate the payoff weighted of the score function for each network.

Algorithm 6.6 F-SAW algorithm– Calculate the Payoff Weighted – refer to Appendix D

```
Initialize the cost value of LTE, WiMAX, and WI-FI as constant values.
if (index == LTE_BS) then
    Perform a total score by multiplying the normalized rate of each parameter
    (Equation 3.5)
end if
if (index == WIMAX_BS) then
    Perform a total score by multiplying the normalized rate of each parameter
    (Equation 3.5)
end if
if (index == WI-FI_BS) then
    Perform a total score by multiplying the normalized rate of each parameter
    (Equation 3.5)
end if
```

In algorithm 6.6, the total score (utility value) for each alternative (network) was obtained by multiplying each of the normalized parameters (the normalization is divided by its norm). In other words, the total score of each network was acquired by multiplying the normalized performance rating of every parameter by its relative weight (using Equation 3.5). The maximum score will then be figured out to obtain the maximum score value (using Equation 3.6), which will be used to select the best network represented by maximum scores of Wi-Fi, WiMAX, and LTE, as shown in algorithm 6.7.

Algorithm 6.7: F-SAW algorithm – Determine the Maximum Score for Selecting the Best Network – refer to Appendix D

```
if ((TOT_WEIGHT[0]> TOT_WEIGHT[1])&&( TOT_WEIGHT[0]> TOT_WEIGHT[2])) then
    Perform LTE score is high
end if
if((TOT_WEIGHT[1]> TOT_WEIGHT[0])&& (TOT_WEIGHT[1]> TOT_WEIGHT[2])) then
    Perform WiMAX score is high
end if
    Perform Wi-Fi score is high
end if
    Perform MIH request, information LINK ID, and link Identifier
    Perform Output send request the best AP/BS to the MN
```

The continuity of the development of the algorithms from algorithms 6.2 to 6.7 must be followed to get the value of parameters (e.g., RSS, cost, ABW, delay, and jitter) for each network until the value of maximum score for selecting the best AP or BS network can be determined. The network with the highest score is chosen for the best accessible network. The currently accessible network will submit the final result obtained from the F-SAW scheme to the event service of the MIH process for informing the AP or BS. This process is vital to avoid any unnecessary handover issues during the VHO process.

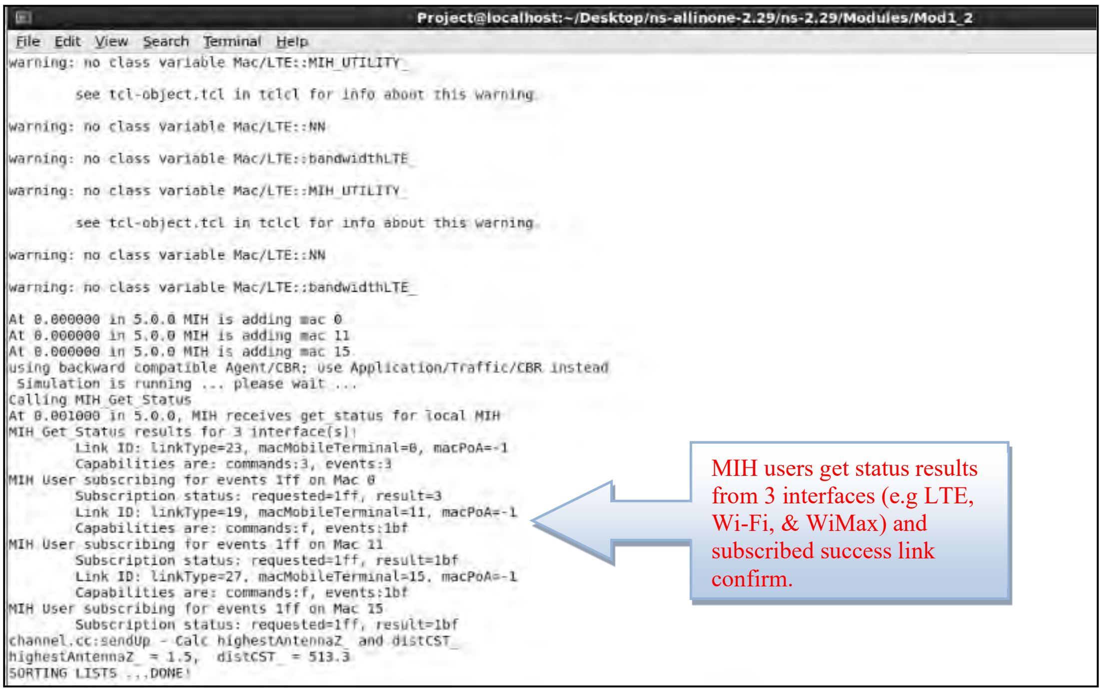
6.3 Findings and Analyses of the proposed F-SAW scheme

Algorithms 6.2, 6.3, 6.4, 6.5, 6.6, and 6.7 provide the findings and results of the simulation analyses. The first refers to algorithm 6.2, which was generated to assign the local MIH interface nodes, as shown in Table 6.2. In Figure 6.3, the MIH will request and get the status result for the local MIH users by identifying the interface address, node ID, MAC address, and link ID for each access network. These entire local MIH users will then connect to the Multiface node (e.g., Multiface node ID is 5.0.0), managed by the MIH mechanism for synchronizing and communicating with other different technologies of the accessible networks (e.g., LTE, WiMAX, and Wi-Fi). As a result, the MIH user-requested event subscription will be confirmed once the three accessible networks have successfully linked the MN node to the LTE (PoA), WiMAX (PoA), and Wi-Fi (PoA).

Table 6.2

The Local Interface Nodes

Networks	**Interface address**	**Node ID**	**MAC address**	**Link ID**	**Local Interface Nodes**
Wi-Fi	3.0.1	10	11	Link type 19	0
WiMAX	4.0.1	14	15	Link type 27	1
LTE	5.0.1	1	0	Link type 23	2



```
warning: no class variable Mac/LTE::MIH_UTILITY_

        see tcl-object.tcl in tclcl for info about this warning.

warning: no class variable Mac/LTE::NN

warning: no class variable Mac/LTE::bandwidthLTE_

warning: no class variable Mac/LTE::MIH_UTILITY_

        see tcl-object.tcl in tclcl for info about this warning.

warning: no class variable Mac/LTE::NN

warning: no class variable Mac/LTE::bandwidthLTE_

At 0.000000 in 5.0.0 MIH is adding mac 0
At 0.000000 in 5.0.0 MIH is adding mac 11
At 0.000000 in 5.0.0 MIH is adding mac 15
using backward compatible Agent/CBR; use Application/Traffic/CBR instead
 Simulation is running ... please wait ...
Calling MIH_Get_Status
At 0.001000 in 5.0.0, MIH receives get_status for local MIH
MIH_Get_Status results for 3 interface(s)!
        Link ID: linkType=23, macMobileTerminal=0, macPoA=-1
        Capabilities are: commands:3, events:3
MIH User subscribing for events 1ff on Mac 0
        Subscription status: requested=1ff, result=3
        Link ID: linkType=19, macMobileTerminal=11, macPoA=-1
        Capabilities are: commands:f, events:1bf
MIH User subscribing for events 1ff on Mac 11
        Subscription status: requested=1ff, result=1bf
        Link ID: linkType=27, macMobileTerminal=15, macPoA=-1
        Capabilities are: commands:f, events:1bf
MIH User subscribing for events 1ff on Mac 15
        Subscription status: requested=1ff, result=1bf
channel.cc:sendUp - Calc highestAntennaZ_ and distCST_
highestAntennaZ_ = 1.5,  distCST_ = 513.3
SORTING LISTS ...DONE!
```

MIH users get status results from 3 interfaces (e.g LTE, Wi-Fi, & WiMax) and subscribed success link confirm.

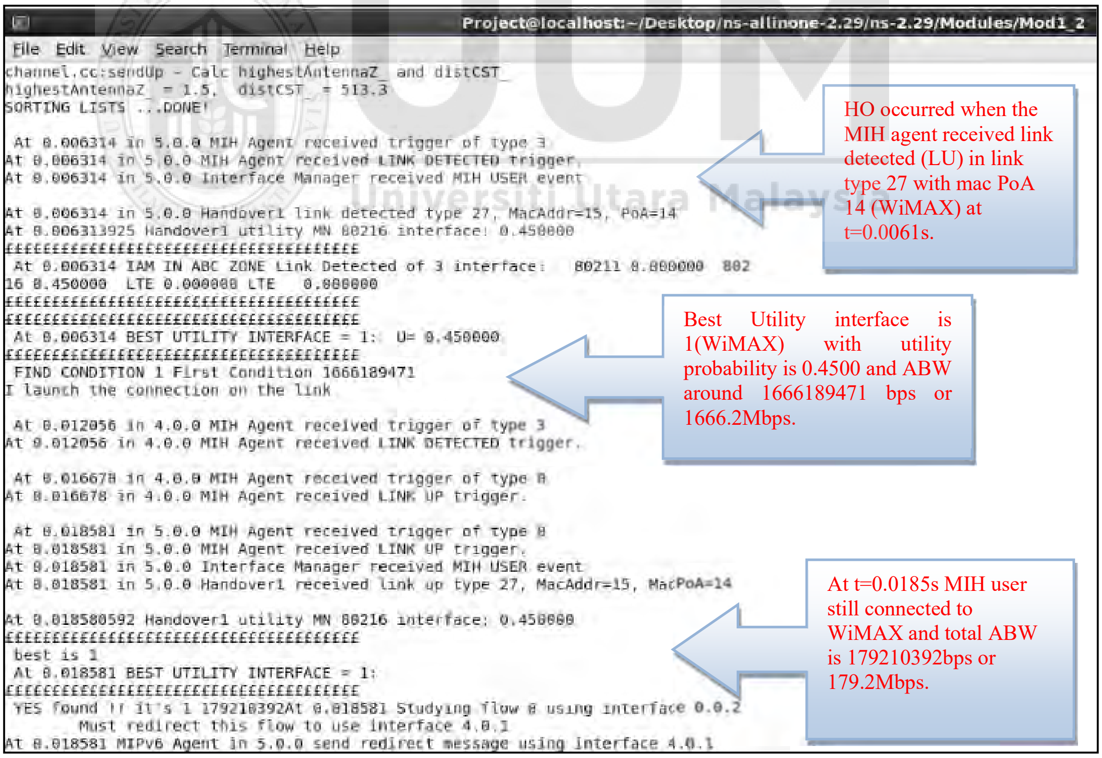
Figure 6.3 *Screenshot of MIH Get Status link from the LTE, WiMAX, and Wi-Fi Networks*

Generally, the three local interfaces of the MIH users were assigned as Wi-Fi (interface 0), WiMAX (interface 1), and LTE (interface 2). Once the MIH agent received trigger of type 3, the link detected process with the link-up (LU) status in link type 27 will be connected to the MAC PoA 14 (WiMAX network), which represents the best utility interface of one (1) at t=0.0063s as depicted in Figure 6.4. As a result, the first handover occurred at t=0.0063s when the MIH users were connected to the MAC PoA WiMAX network because it was selected as the best AP compared to other access networks. Moreover, the HO fulfilled the maximum score of utility requirement with a probability of 0.45000 compared to the other networks, as shown in Table 6.3. The estimated ABW was approximately 1666189471bps or 1666.2Mbps. Furthermore, this connection was still connected to the WiMAX base station until t=0.0185s, and the total amount of ABW is 179210392 bps or 179.2Mbps. The total amount of ABW rapidly decreases at 89.2% from 1666.2Mbps at t=0.0185s due to the movement of vehicles received the lower signal of RSS and faraway from the WiMAX base station.

Table 6.3

The MIH Link Detected Indication to WiMAX Network at t=0.0063s

Networks	Interface address	Interface ID	MAC	Link ID	MAC PoA	Utility Probability
Wi-Fi	3.0.1	0	11	Link type 19	10	0.0
WiMAX	**4.0.1**	**1**	**15**	**Link type 27**	**14**	**0.45**
LTE	5.0.1	2	0	Link type 23	1	0.0



```
channel.cc:sendUp - Calc highestAntennaZ_ and distCST_
highestAntennaZ_ = 1.5,  distCST_ = 513.3
SORTING LISTS ...DONE!

 At 0.006314 in 5.0.0 MIH Agent received trigger of type 3
At 0.006314 in 5.0.0 MIH Agent received LINK DETECTED trigger.
At 0.006314 in 5.0.0 Interface Manager received MIH USER event

At 0.006314 in 5.0.0 Handover1 link detected type 27, MacAddr=15, PoA=14
At 0.006313925 Handover1 utility MN 80216 interface: 0.450000
££££££££££££££££££££££££££££££££££££££££
 At 0.006314 IAM IN ABC ZONE Link Detected of 3 interface:   80211 0.000000  802
16 0.450000  LTE 0.000000 LTE   0.000000
££££££££££££££££££££££££££££££££££££££££
££££££££££££££££££££££££££££££££££££££££
 At 0.006314 BEST UTILITY INTERFACE = 1:  U= 0.450000
££££££££££££££££££££££££££££££££££££££££
 FIND CONDITION 1 First Condition 1666189471
I launch the connection on the link

 At 0.012056 in 4.0.0 MIH Agent received trigger of type 3
At 0.012056 in 4.0.0 MIH Agent received LINK DETECTED trigger.

 At 0.016678 in 4.0.0 MIH Agent received trigger of type 8
At 0.016678 in 4.0.0 MIH Agent received LINK UP trigger.

 At 0.018581 in 5.0.0 MIH Agent received trigger of type 8
At 0.018581 in 5.0.0 MIH Agent received LINK UP trigger.
At 0.018581 in 5.0.0 Interface Manager received MIH USER event
At 0.018581 in 5.0.0 Handover1 received link up type 27, MacAddr=15, MacPoA=14

At 0.018580592 Handover1 utility MN 80216 interface: 0.450000
££££££££££££££££££££££££££££££££££££££££
 best is 1
 At 0.018581 BEST UTILITY INTERFACE = 1:
££££££££££££££££££££££££££££££££££££££££
 YES found !! it's 1 179210392At 0.018581 Studying flow 0 using interface 0.0.2
        Must redirect this flow to use interface 4.0.1
At 0.018581 MIPv6 Agent in 5.0.0 send redirect message using interface 4.0.1
```

HO occurred when the MIH agent received link detected (LU) in link type 27 with mac PoA 14 (WiMAX) at t=0.0061s.

Best Utility interface is 1(WiMAX) with utility probability is 0.4500 and ABW around 1666189471 bps or 1666.2Mbps.

At t=0.0185s MIH user still connected to WiMAX and total ABW is 179210392bps or 179.2Mbps.

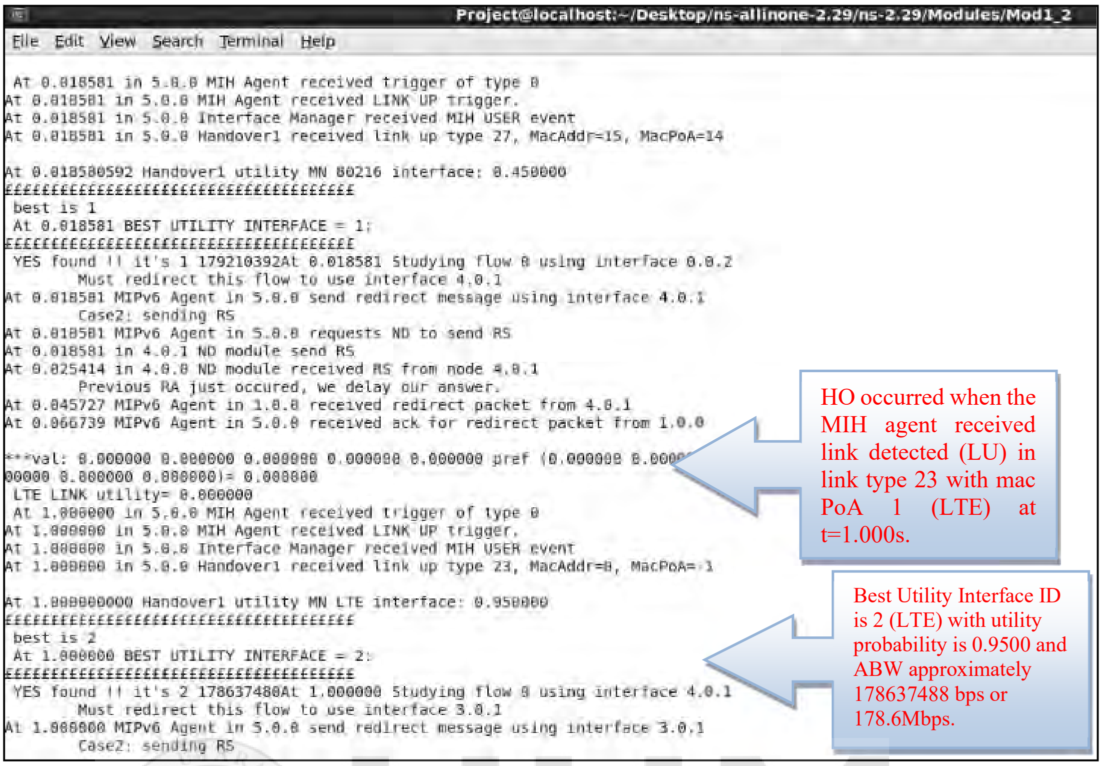
Figure 6.4 *Screenshot of Link Detecting Event in the WiMAX Network*

The MIH users were still connected to the PoA WiMAX at AP until at t=0.0185s, but when it reached t=1.0000s, the MIH user agent will be changed and trigger from the link type 27 to link type 23 with link-up (LU) status. Meaning that the link trigger status link-up had changed from WiMAX to LTE network, which is known as the handover trigger process. As seen in Table 6.4 and Figure 6.5, the handover trigger process occurred between the WiMAX and LTE networks. As a result, the second handover trigger was obtained following the rules whereby if the previous value in the comparator is lower than the current weight score, the link events status of the three interfaces were issued and sent to the MIH (event service) before the handover decision making on. As a result, at t=1.0000s, the MIH link detected indicated to the LTE network such as the utility interface ID 2, MAC PoA 1, and utility probability is 0.95000. The ABW for the handover process from WiMAX to LTE network was also estimated at approximately 178.6Mbps. Hence, the total of ABW had gradually decreased to 0.33% from 179.2Mbps.

Table 6.4

The MIH Link Detected Indication to LTE Network at t=1.0000s

Networks	**Interface address**	**Interface ID**	**MAC**	**Link ID**	**MAC PoA**	**Utility Probability**
Wi-Fi	3.0.1	0	11	Link type 19	10	0.0
WiMAX	4.0.1	1	15	Link type 27	14	0.45
LTE	**5.0.1**	**2**	**0**	**Link type 23**	**1**	**0.95**



```
 At 0.018581 in 5.0.0 MIH Agent received trigger of type 0
At 0.018581 in 5.0.0 MIH Agent received LINK UP trigger.
At 0.018581 in 5.0.0 Interface Manager received MIH USER event
At 0.018581 in 5.0.0 Handover1 received link up type 27, MacAddr=15, MacPoA=14

At 0.018580592 Handover1 utility MN 80216 interface: 0.450000
££££££££££££££££££££££££££££££££££££££££
 best is 1
 At 0.018581 BEST UTILITY INTERFACE = 1;
££££££££££££££££££££££££££££££££££££££££
 YES found !! it's 1 179210392At 0.018581 Studying flow 0 using interface 0.0.2
        Must redirect this flow to use interface 4.0.1
At 0.018581 MIPv6 Agent in 5.0.0 send redirect message using interface 4.0.1
        Case2: sending RS
At 0.018581 MIPv6 Agent in 5.0.0 requests ND to send RS
At 0.018581 in 4.0.1 ND module send RS
At 0.025414 in 4.0.0 ND module received RS from node 4.0.1
        Previous RA just occured, we delay our answer.
At 0.045727 MIPv6 Agent in 1.0.0 received redirect packet from 4.0.1
At 0.066739 MIPv6 Agent in 5.0.0 received ack for redirect packet from 1.0.0

***val: 0.000000 0.000000 0.000000 0.000000 0.000000 pref (0.000000 0.000
00000 0.000000 0.000000)= 0.000000
 LTE LINK utility= 0.000000
 At 1.000000 in 5.0.0 MIH Agent received trigger of type 0
At 1.000000 in 5.0.0 MIH Agent received LINK UP trigger.
At 1.000000 in 5.0.0 Interface Manager received MIH USER event
At 1.000000 in 5.0.0 Handover1 received link up type 23, MacAddr=0, MacPoA=1

At 1.000000000 Handover1 utility MN LTE interface: 0.950000
££££££££££££££££££££££££££££££££££££££££
 best is 2
 At 1.000000 BEST UTILITY INTERFACE = 2;
££££££££££££££££££££££££££££££££££££££££
 YES found !! it's 2 178637488At 1.000000 Studying flow 0 using interface 4.0.1
        Must redirect this flow to use interface 3.0.1
At 1.000000 MIPv6 Agent in 5.0.0 send redirect message using interface 3.0.1
        Case2: sending RS
```

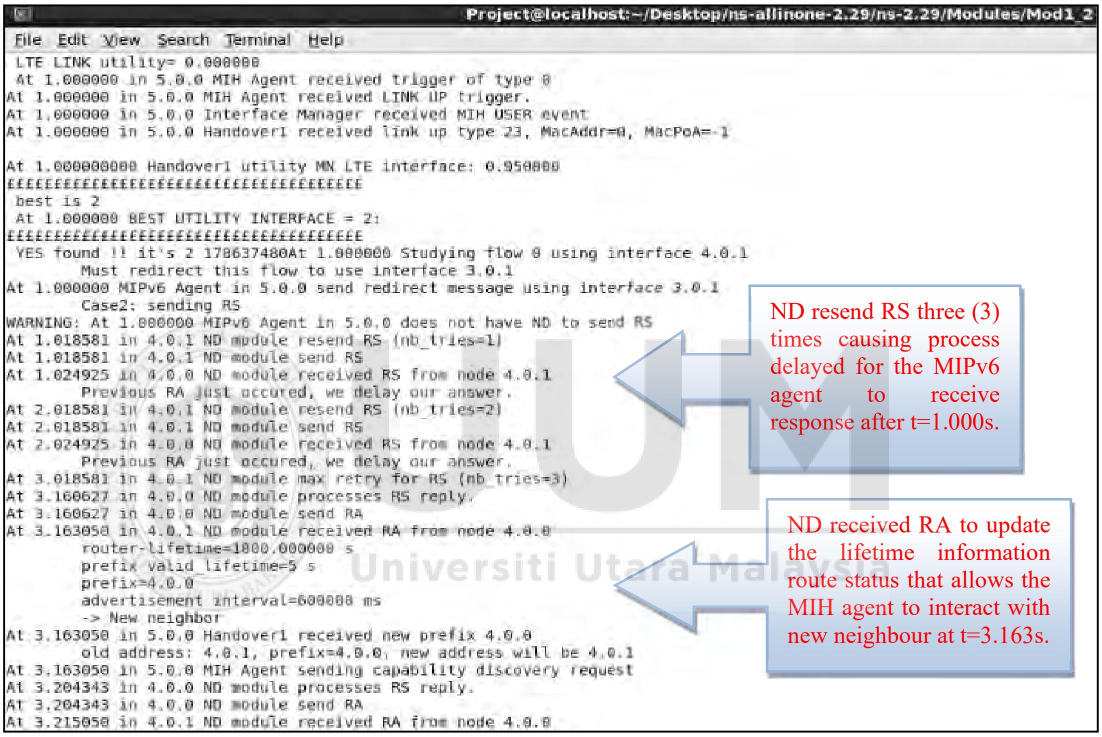
HO occurred when the MIH agent received link detected (LU) in link type 23 with mac PoA 1 (LTE) at t=1.000s.

Best Utility Interface ID is 2 (LTE) with utility probability is 0.9500 and ABW approximately 178637488 bps or 178.6Mbps.

Figure 6.5 *Screenshot of the Handover Triggers Link Detection Event from WiMAX to LTE Network*

At t=1.0000s, the MIH user agent received the link-up (LU) status to connect to the LTE base station and the MIPv6 agent will come up with a warning message stating that it does not have Neighbor Discovery (ND), as shown in Figure 6.6. Therefore, case 2 is used because there is no other connection up or better link. Moreover, this condition produced the ND module that resends will generate the Router Solicitation (RS) via a local interface (4.0.1) to PoA WiMAX (4.0.0) node at t=1.024s. This process occurred three (3) times, causing the delay for the MIPv6 agent to receive the response message. Thus, at t=3.1630s, the ND module received Router Advertisement (RA) for updating table route status to enable interaction with the new neighbor.

Furthermore, the MIH agent will send the capability discovery request, while ND will reply to RS. The lifetime update on the information related to the relationship between the MIH agent and neighbor will be produced from this process. After that, at t=3.2787s, the MIH agent will send a registration request to update the information of the routing table.



```
 LTE LINK utility= 0.000000
 At 1.000000 in 5.0.0 MIH Agent received trigger of type 0
At 1.000000 in 5.0.0 MIH Agent received LINK UP trigger.
At 1.000000 in 5.0.0 Interface Manager received MIH USER event
At 1.000000 in 5.0.0 Handover1 received link up type 23, MacAddr=0, MacPoA=-1

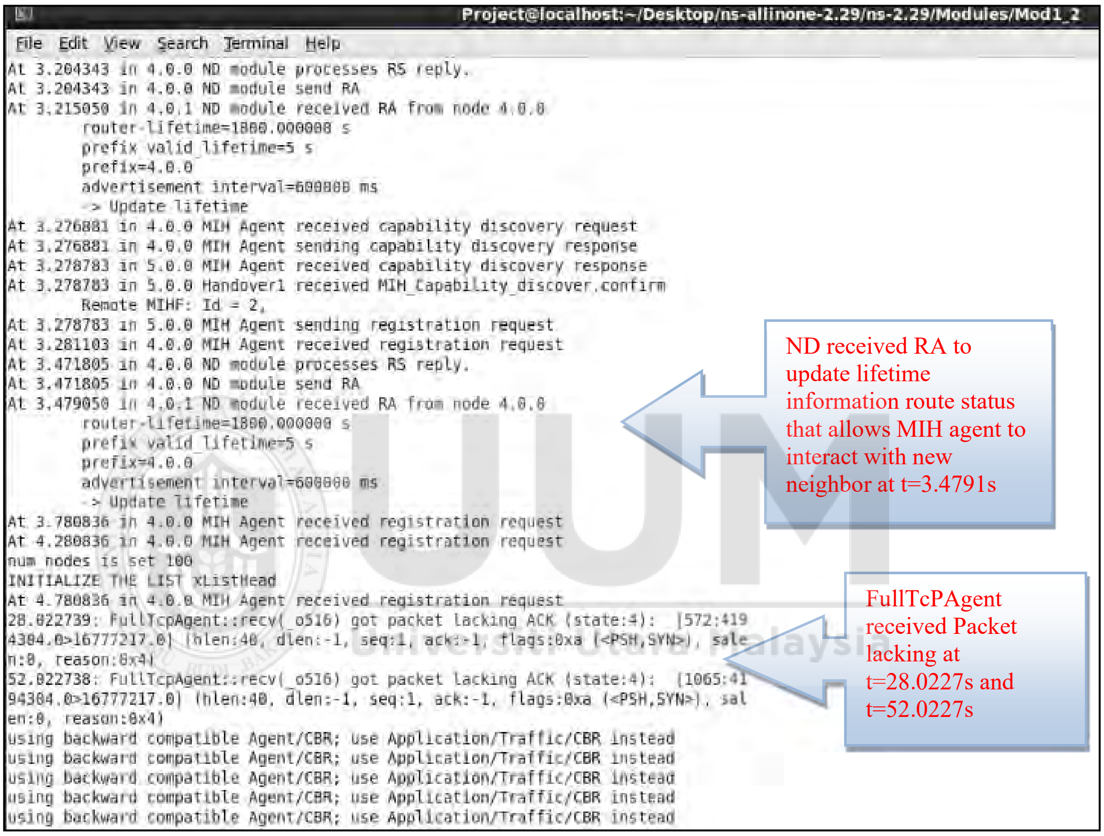
At 1.000000000 Handover1 utility MN LTE interface: 0.950000
££££££££££££££££££££££££££££££££££££££
 best is 2
 At 1.000000 BEST UTILITY INTERFACE = 2:
££££££££££££££££££££££££££££££££££££££
 YES found !! it's 2 178637480At 1.000000 Studying flow 0 using interface 4.0.1
        Must redirect this flow to use interface 3.0.1
At 1.000000 MIPv6 Agent in 5.0.0 send redirect message using interface 3.0.1
        Case2: sending RS
WARNING: At 1.000000 MIPv6 Agent in 5.0.0 does not have ND to send RS
At 1.018581 in 4.0.1 ND module resend RS (nb_tries=1)
At 1.018581 in 4.0.1 ND module send RS
At 1.024925 in 4.0.0 ND module received RS from node 4.0.1
        Previous RA just occured, we delay our answer.
At 2.018581 in 4.0.1 ND module resend RS (nb_tries=2)
At 2.018581 in 4.0.1 ND module send RS
At 2.024925 in 4.0.0 ND module received RS from node 4.0.1
        Previous RA just occured, we delay our answer.
At 3.018581 in 4.0.1 ND module max retry for RS (nb_tries=3)
At 3.160627 in 4.0.0 ND module processes RS reply.
At 3.160627 in 4.0.0 ND module send RA
At 3.163050 in 4.0.1 ND module received RA from node 4.0.0
        router-lifetime=1800.000000 s
        prefix valid_lifetime=5 s
        prefix=4.0.0
        advertisement interval=600000 ms
        -> New neighbor
At 3.163050 in 5.0.0 Handover1 received new prefix 4.0.0
        old address: 4.0.1, prefix=4.0.0, new address will be 4.0.1
At 3.163050 in 5.0.0 MIH Agent sending capability discovery request
At 3.204343 in 4.0.0 ND module processes RS reply.
At 3.204343 in 4.0.0 ND module send RA
At 3.215050 in 4.0.1 ND module received RA from node 4.0.0
```

ND resend RS three (3) times causing process delayed for the MIPv6 agent to receive response after t=1.000s.

ND received RA to update the lifetime information route status that allows the MIH agent to interact with new neighbour at t=3.163s.

Figure 6.6 *Screenshot of the Handover Triggers Link Detection Event of the LTE network with ND Module and Delay*

Figure 6.7 illustrates the link detection status event of the LTE access network. At t=3.4791s, another lifetime information update process occurred for allowing the MIH agent to interact with a neighbor. After that, at t=4.7808s, the MIH agent will receive the registration request. However, four (4) times packet loss had occurred whereby the *FullTcpAgent* had received packet lacking ACK at t=28.022s, t=52.022s, t=100.022s, and t=196.022s as shown in Figures 6.7 and 6.8. Therefore, the real payload (user data) was not transferred even though the receiver realized the size of the payload when it received the TCP packet. This occurrence had prevented many application-layer protocols from being executed.



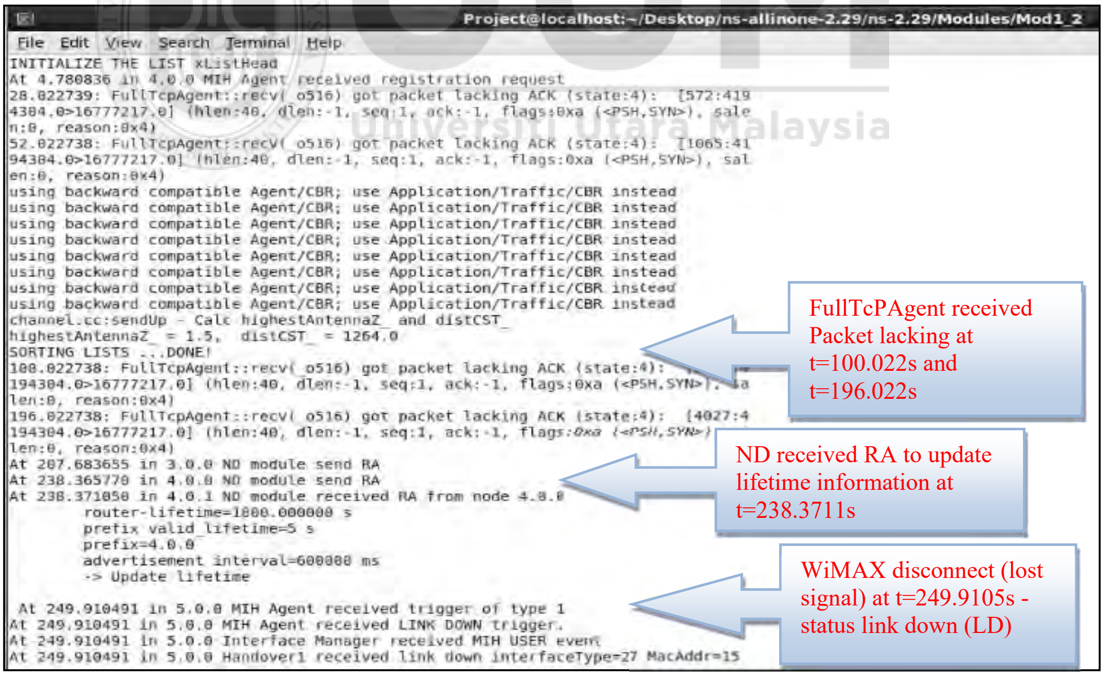
```
At 3.204343 in 4.0.0 ND module processes RS reply.
At 3.204343 in 4.0.0 ND module send RA
At 3.215050 in 4.0.1 ND module received RA from node 4.0.0
        router-lifetime=1800.000000 s
        prefix valid lifetime=5 s
        prefix=4.0.0
        advertisement interval=600000 ms
        -> Update lifetime
At 3.276881 in 4.0.0 MIH Agent received capability discovery request
At 3.276881 in 4.0.0 MIH Agent sending capability discovery response
At 3.278783 in 5.0.0 MIH Agent received capability discovery response
At 3.278783 in 5.0.0 Handover1 received MIH_Capability_discover.confirm
        Remote MIHF: Id = 2,
At 3.278783 in 5.0.0 MIH Agent sending registration request
At 3.281103 in 4.0.0 MIH Agent received registration request
At 3.471805 in 4.0.0 ND module processes RS reply.
At 3.471805 in 4.0.0 ND module send RA
At 3.479050 in 4.0.1 ND module received RA from node 4.0.0
        router-lifetime=1800.000000 s
        prefix valid lifetime=5 s
        prefix=4.0.0
        advertisement interval=600000 ms
        -> Update lifetime
At 3.780836 in 4.0.0 MIH Agent received registration request
At 4.280836 in 4.0.0 MIH Agent received registration request
num nodes is set 100
INITIALIZE THE LIST xListHead
At 4.780836 in 4.0.0 MIH Agent received registration request
28.022739: FullTcpAgent::recv(_o516) got packet lacking ACK (state:4):  [572:419
4304.0>16777217.0] (hlen:40, dlen:-1, seq:1, ack:-1, flags:0xa (<PSH,SYN>), sale
n:0, reason:0x4)
52.022738: FullTcpAgent::recv(_o516) got packet lacking ACK (state:4):  [1065:41
94304.0>16777217.0] (hlen:40, dlen:-1, seq:1, ack:-1, flags:0xa (<PSH,SYN>), sal
en:0, reason:0x4)
using backward compatible Agent/CBR; use Application/Traffic/CBR instead
using backward compatible Agent/CBR; use Application/Traffic/CBR instead
using backward compatible Agent/CBR; use Application/Traffic/CBR instead
using backward compatible Agent/CBR; use Application/Traffic/CBR instead
using backward compatible Agent/CBR; use Application/Traffic/CBR instead
```

ND received RA to update lifetime information route status that allows MIH agent to interact with new neighbor at t=3.4791s

FullTcPAgent received Packet lacking at t=28.0227s and t=52.0227s

Figure 6.7 *Screenshot of the Handover Triggers Link Detecting Event with Packet Lacking*

However, at t=207.6836, even though ND consistently tries to send the RA through the PoA Wi-Fi (3.0.0), the link still indicates link down (LD). The ND will also resend the RA via the PoA WiMAX (4.0.0) and when the RA reply was received via the local interface (4.0.1), the lifetime information from a neighbor will be updated at t=238.3711s, as shown in Figure 6.8. Moreover, the MIH agent received the link trigger at type 1, link down, link type 27, and the MAC address is 15 at t= 249.9105s. For that reason, the MIH Agent notified that the MN's WiMAX interface had been disconnected (WiMAX signal lost) from the WiMAX cell, as illustrated in Figure 6.10. When the MN's MIH Agent received the *Link Down (LD)* event, it also controls the LTE interface to perform a link scan using the *Link Action Request* to search for other nearby LTE networks. Then no other networks were found at t=249.96046s the *Link Action Confirm* command will be received. The LTE base station was still connected to the MN's MIH agent for supplying the user with the required services because it was chosen as the best network. The simulation experiment ended at approximately t=250s.



```
INITIALIZE THE LIST xListHead
At 4.780836 in 4.0.0 MIH Agent received registration request
28.022739: FullTcpAgent::recv( o516) got packet lacking ACK (state:4):  [572:419
4304.0>16777217.0] (hlen:40, dlen:-1, seq:1, ack:-1, flags:0xa (<PSH,SYN>), sale
n:0, reason:0x4)
52.022738: FullTcpAgent::recv( o516) got packet lacking ACK (state:4):  [1065:41
94304.0>16777217.0] (hlen:40, dlen:-1, seq:1, ack:-1, flags:0xa (<PSH,SYN>), sal
en:0, reason:0x4)
using backward compatible Agent/CBR; use Application/Traffic/CBR instead
using backward compatible Agent/CBR; use Application/Traffic/CBR instead
using backward compatible Agent/CBR; use Application/Traffic/CBR instead
using backward compatible Agent/CBR; use Application/Traffic/CBR instead
using backward compatible Agent/CBR; use Application/Traffic/CBR instead
using backward compatible Agent/CBR; use Application/Traffic/CBR instead
using backward compatible Agent/CBR; use Application/Traffic/CBR instead
using backward compatible Agent/CBR; use Application/Traffic/CBR instead
channel.cc:sendUp - Calc highestAntennaZ_ and distCST_
highestAntennaZ_ = 1.5,  distCST_ = 1264.0
SORTING LISTS ...DONE!
100.022738: FullTcpAgent::recv( o516) got packet lacking ACK (state:4):
194304.0>16777217.0] (hlen:40, dlen:-1, seq:1, ack:-1, flags:0xa (<PSH,SYN>), sa
len:0, reason:0x4)
196.022738: FullTcpAgent::recv( o516) got packet lacking ACK (state:4):  [4027:4
194304.0>16777217.0] (hlen:40, dlen:-1, seq:1, ack:-1, flags:0xa (<PSH,SYN>)
len:0, reason:0x4)
At 207.683655 in 3.0.0 ND module send RA
At 238.365770 in 4.0.0 ND module send RA
At 238.371050 in 4.0.1 ND module received RA from node 4.0.0
        router-lifetime=1800.000000 s
        prefix valid_lifetime=5 s
        prefix=4.0.0
        advertisement interval=600000 ms
        -> Update lifetime

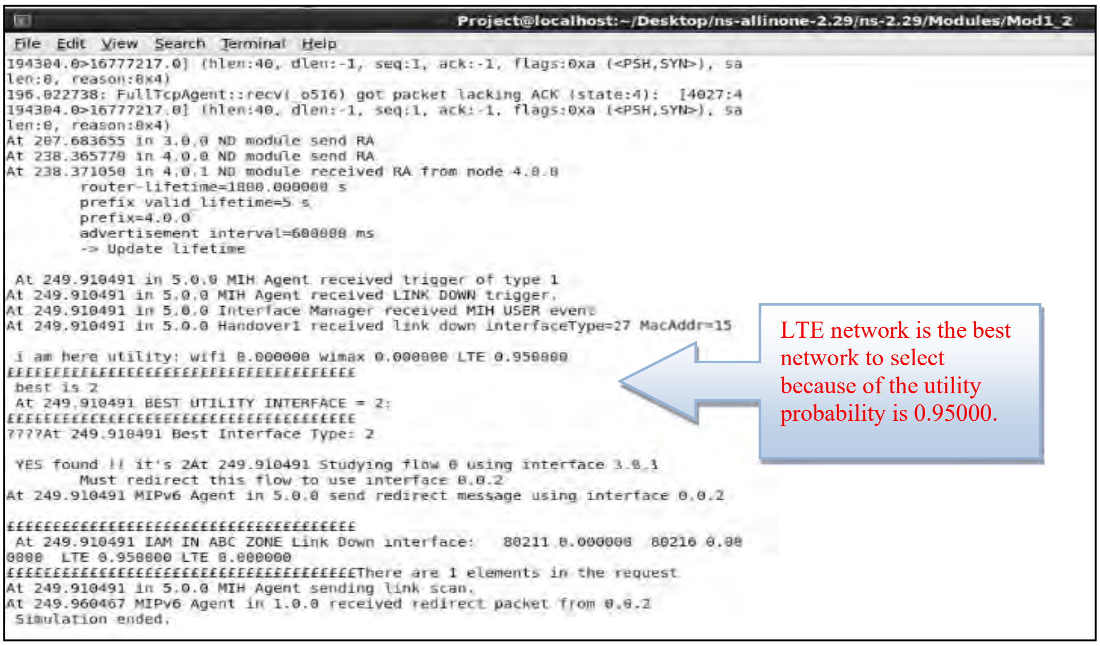
 At 249.910491 in 5.0.0 MIH Agent received trigger of type 1
At 249.910491 in 5.0.0 MIH Agent received LINK DOWN trigger.
At 249.910491 in 5.0.0 Interface Manager received MIH USER event
At 249.910491 in 5.0.0 Handover1 received link down interfaceType=27 MacAddr=15
```

FullTcPAgent received Packet lacking at t=100.022s and t=196.022s

ND received RA to update lifetime information at t=238.3711s

WiMAX disconnect (lost signal) at t=249.9105s - status link down (LD)

Figure 6.8 *Screenshot of the Handover Triggers Link Detection Event with WiMAX Disconnect*



```
194304.0>16777217.0] (hlen:40, dlen:-1, seq:1, ack:-1, flags:0xa (<PSH,SYN>), sa
len:0, reason:0x4)
196.022738: FullTcpAgent::recv( o516) got packet lacking ACK (state:4):  [4027:4
194304.0>16777217.0] (hlen:40, dlen:-1, seq:1, ack:-1, flags:0xa (<PSH,SYN>), sa
len:0, reason:0x4)
At 207.683655 in 3.0.0 ND module send RA
At 238.365770 in 4.0.0 ND module send RA
At 238.371050 in 4.0.1 ND module received RA from node 4.0.0
        router-lifetime=1800.000000 s
        prefix valid lifetime=5 s
        prefix=4.0.0
        advertisement interval=600000 ms
        -> Update lifetime

 At 249.910491 in 5.0.0 MIH Agent received trigger of type 1
At 249.910491 in 5.0.0 MIH Agent received LINK DOWN trigger.
At 249.910491 in 5.0.0 Interface Manager received MIH USER event
At 249.910491 in 5.0.0 Handover1 received link down interfaceType=27 MacAddr=15

 i am here utility: wifi 0.000000 wimax 0.000000 LTE 0.950000
££££££££££££££££££££££££££££££££££££££
 best is 2
 At 249.910491 BEST UTILITY INTERFACE = 2:
££££££££££££££££££££££££££££££££££££££
????At 249.910491 Best Interface Type: 2

 YES found !! it's 2At 249.910491 Studying flow 0 using interface 3.0.1
        Must redirect this flow to use interface 0.0.2
At 249.910491 MIPv6 Agent in 5.0.0 send redirect message using interface 0.0.2

££££££££££££££££££££££££££££££££££££££
 At 249.910491 IAM IN ABC ZONE Link Down interface:   80211 0.000000  80216 0.00
0000  LTE 0.950000 LTE 0.000000
££££££££££££££££££££££££££££££££££££££There are 1 elements in the request
At 249.910491 in 5.0.0 MIH Agent sending link scan.
At 249.960467 MIPv6 Agent in 1.0.0 received redirect packet from 0.0.2
 Simulation ended.
```

LTE network is the best network to select because of the utility probability is 0.95000.

Figure 6.9 *Screenshot of the Handover Triggers Link Detection Event with Link up to LTE Network*

The target of the F-SAW scheme is to select the best network from various network technology candidates. Table 6.5 shows the results of the competition among the three accessible technology networks for the traffic light scenario. From the analysis, the utility probability (score function) of the LTE access network is highest than Wi-Fi and WiMAX of 0.95 scores. The score function (reward) is also shown in Figure 6.9 and Figure 10, as well as the score value of Wi-Fi, which is 0 (zero) as compared to WiMAX and LTE. The value zero score of Wi-Fi was obtained due to the disconnected signal (Wi-Fi signal lost) and the achieved link trigger status was link down (LD). It indicates that the link of the Wi-Fi network did not fulfill the requirement of RSS and QoS. Due to avoid any unnecessary handover and service disruption, a message of transforming the link status was smoothly sent. The purpose of this F-SAW method is to choose the best candidate among the access networks, and at the same time, it is noticeable that the link quality of the RSS and QoS (e.g., ABW and service type) can enhance the performance of VHO prediction.

Table 6.5

The Payoffs of the Three Technology Networks at t=250s

Networks	**Interface ID**	**MAC PoA**	**Utility Probability (Score Function)**
Wi-Fi	0	10	0.0
WiMAX	1	14	0.45
LTE	**2**	**1**	**0.95**

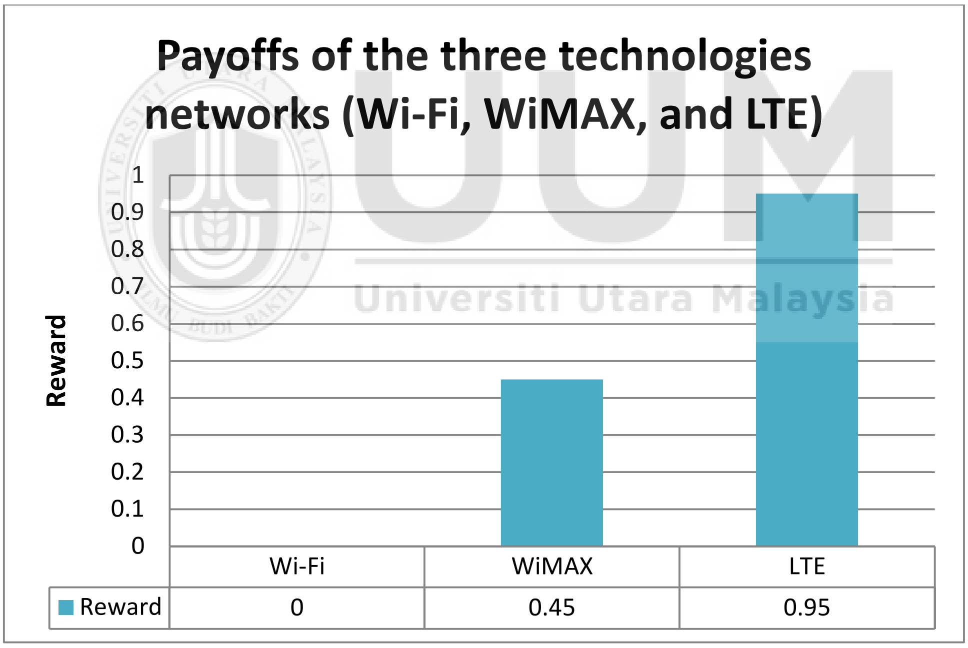


Figure 6.10 *Payoffs of the Three Technology Networks using the F-SAW scheme*

The integration of the FL and SAW algorithms allows the analysis of the variance positions in selecting the best VHO. The FL algorithm helps in solving uncertainty about complex systems, particularly in avoiding any unnecessary handover. The SAW is a typical method usually applied to a selection process. The utility function (score function) method is engaged in measuring the payoff based on the user's satisfaction and preferences. It is represented by the importance weight of each parameter, namely the number of competing networks (e.g., Wi-Fi, WiMAX, and LTE) and QoS demands such as delay, monetary cost, available bandwidth, and jitter.

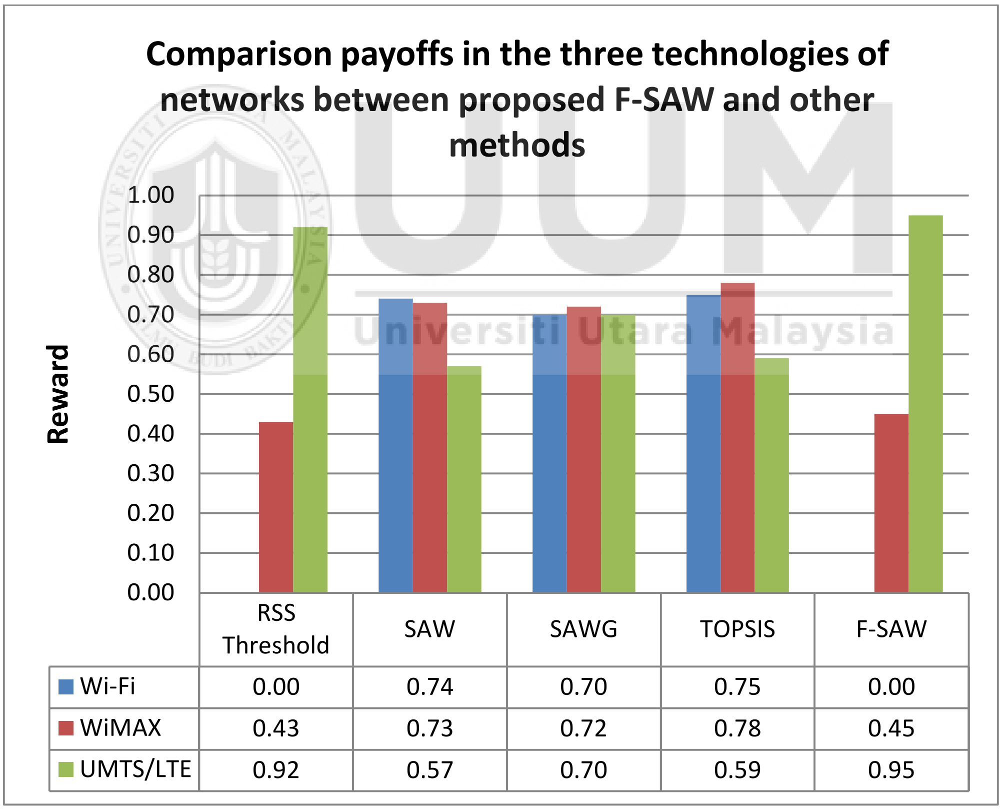
6.4 Verification and Validation of the Proposed F-SAW Scheme with other Methods

The verification and validation of the proposed algorithm were conducted by comparing the results of F-SAW with the other four existing methods. The first is the RSS-Threshold method that only uses the input RSS parameter as an indicator of link quality for handover prediction. The second, third, and fourth methods are the Simple Additive Weighting (SAW), Simple Additive Weighting Game (SAWG), and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) as presented by Yass et al. in [87]. Table 6.6 shows the payoff for the three network technologies using the RSS-Threshold, SAW, SAWG, TOPSIS, and F-SAW schemes of the QoS handover process.

Table 6.6

The Payoff Comparison between F-SAW and other Schemes in the Three Network Technologies

Method	**Wi-Fi (Score Value)**	**WiMAX (Score Value)**	**UMTS/LTE (Score Value)**
RSS Thershold	0.0	0.43	0.92
SAW	0.74	0.73	0.57
SWAG	0.70	0.72	0.70
TOPSIS	0.75	0.78	0.59
F-SAW	0.0	0.45	0.95



	RSS Threshold	SAW	SAWG	TOPSIS	F-SAW
🟦 Wi-Fi	0.00	0.74	0.70	0.75	0.00
🟥 WiMAX	0.43	0.73	0.72	0.78	0.45
🟩 UMTS/LTE	0.92	0.57	0.70	0.59	0.95

Figure 6.11 *Payoffs Comparison between F-SAW and other Methods in the Three Network Technologies*

Figure 6.11 shows the comparison payoffs between the proposed F-SAW and other methods in the three network technologies. The results indicate that the F-SAW method obtained the highest score of 0.95 in the UMTS/LTE network compared to the other methods. Specifically, the utility score for the SAW method is 0.57, while SAWG is 0.70, TOPSIS is 0.59, and RSS-Threshold is 0.92. The utility score of the gap in coverage between the F-SAW and other methods in the LTE network, which are: 40% for the SAW, 26.32% for SAWG, 37.89% for TOPSIS, and 3.26% for RSS-Threshold. Therefore, the proposed F-SAW scheme chosen LTE as the best access network much better than other methods.

However, in WiMAX, the utility score of the proposed scheme is 0.45, much lower compared to the other three methods, SAW, SAWG, and TOPSIS of are 0.73 (62.22%), 0.72 (60%), and 0.78 (73.33%), respectively. The lowest score is 0.43% of the RSS-Threshold method. However, in the Wi-Fi network, the utility score of the proposed F-SAW method is zero because it does not fulfill the RSS and QoS requirements. The movement of the MNs or vehicles from the start to the end (point A to point C) of the simulation time indicates that the results of the proposed F-SAW scheme are much better in terms of the QoS handover network performance compared to the other methods. Hence, the LTE network has been chosen as the best accessible network base station. Based on the result, it can be concluded that the research objectives have been achieved.

6.5 Summary

This chapter presents the evaluation of the performance of the proposed F-SAW scheme. The simulation experiments using the NS-2.29 simulator software demonstrate that F-SAW is the most suitable to be chosen as the best scheme. It also can be used in different access network technologies comprising of multicriteria parameters such as RSS, cost, available bandwidth, delay, jitter, and speed velocity.

CHAPTER SEVEN

DISCUSSION, FUTURE OF WORKS AND CONCLUSION

The target of this thesis is to develop the AHD and F-SAW schemes in the vehicular wireless networks (VANET) by integrating the Fuzzy logic and Simple Additive Weighting (SAW) algorithms for three primary purposes; i) measuring the QoS handover process performance, ii) triggering link status of the handover process in VANET, and iii) choosing the best wireless candidates network in a heterogeneous vehicular ad-hoc network. By incorporating the Fuzzy logic algorithm into the AHD scheme, the QoS of VHO performance in VANET is enhanced. This chapter concludes the work presented in this thesis and presents significant research contributions. The achievements obtained by addressing the research objectives are also highlighted, followed by the limitations, as well as future research directions and opportunities.

7.1 Discussion on the Research Achievements

This section elaborates on the main key points that address the research objectives. Throughout this research, the essential gaps relating to the incompetence of the AP prediction methods in the WLANs coverage and unsuccessful link detection status in the handover triggering process are identified. The gap also includes the uncertainty issue on the network selection and prediction techniques in the field of wireless heterogeneous vehicular networks. The following subsections discuss the achievement of the main research objectives.

7.1.1 The First Contribution Achieved by the AHD Scheme

The first accomplishment in this research is attained by answering the first research objective, listed in Chapter 1. The following are brief explanations of the procedures conducted in achieving the first research objective.

Research Objective 1: To design a new candidate selection mechanism in the VHO decision algorithm to select the best qualified AP and BS candidates without degrading the performance of ongoing applications due to handover delay, handover latency, and packet loss.

This research objective was measured by using the FL algorithm for proposing the AHD scheme to obtain the final handover decision making when AP or BS gained the highest quality of services (QoS) link which helps to reduce delay, handover latency, and packet loss without degrading the performance of the continuing applications. The simulation results show that the proposed AHD scheme achieved the best in terms of handover delay, handover latency, packet loss, throughput, and packet delivery averages as compared to the other methods, specifically the RSS-Threshold and MIH-based (refer to Chapter 4). Most significantly, the proposed AHD scheme specifically contributes to the QoS of the heterogeneous vehicular ad-hoc network based on a simulation scenario. The simulation was performed by allocating the multi-criteria of parameters to the wireless network candidates by employing an adaptive fuzzy inference system before triggering the handover process. The AHD scheme that supports the FL algorithm proved to be better in terms of preserving the MAC-layer delay and QoS by gaining the lowest average score as compared to the other existing

AP prediction approaches. To be more precise, the AHD scheme increases the overall QoS in terms of reducing the average handover latency, handover delay, and packet loss of 20%, 21%, and 13%, respectively, compared to the RSS-Threshold algorithm. Similarly, the simulation experiment using the MIH-based algorithm suggests that the average points of those QoS parameters were also reduced up to 11%, 12.2%, and 7%, as shown in Tables 4.1, 4.2, and 4.3 of Subsection 4.3.3 in Chapter 4.

7.1.2 The Second Contribution Achieved by the F-SAW Algorithm

The second achievement of this research refers to the proposed F-SAW algorithm, highlighted in Chapter 5. This achievement contributes to answering the second objective of this research. The following are short descriptions of the related activities performed in achieving the second research objective.

Research Objective 2: To develop a handover triggering mechanism that integrates multiple attribute parameters using context information of vertical handover decision in vehicle-to-infrastructure (V2I) heterogeneous wireless network.

The proposed F-SAW scheme makes a decision using the context information based performance of the handover process. The handover performance presents the triggering status link event, QoS, and utility function or maximum score for achieving the highest performance (handover latency, throughput, delay, and packet loss) at the cost of complexity. Statistical analysis has verified that by using the proposed F-SAW scheme, delay, and time that are usually related to the handover process have been solved when compared to other existing studies. On the other hand, the simulation results described in Chapter 5 show that the proposed scheme is better in terms of reducing the delivery delay with a constants bit rate (CBR) application. The comparison between the F-SAW and RSS-Threshold algorithms in the trigger sequence events of the handover process was presented in Table 5.3 of Section 5.3 in Chapter 5 by highlighting the reduction of the average total of 12.21 seconds.

7.1.3 The Third Contribution Achieved by the F-SAW Scheme

One of the key objectives of this research relates to the selection of candidates in different network technologies using the F-SAW approaches proposed in Chapter Six. This issue relates to the third research objective of this research, and the following are the descriptions of the achievement.

Research Objective 3: To develop the performance evaluation of the intelligent network selection mechanism to select the best available access network in the vehicle-to-infrastructure (V2I) heterogeneous wireless networks.

The third research objective was achieved through the proposed F-SAW scheme by developing a traffic light scenario in the NS-2 simulator that allows any vehicle to access the available internet in various network technologies. However, the network selection depends on several parameters and conditions related to the fuzzy logic and SAW algorithms to enable a more realistic simulation that is comprised of actual conditions involving moving vehicles and traffic rules. The proposed F-SAW scheme employed the neighbor network information acquired from the IS MIH to convey predictive guided labeling of link status as a mechanism of avoiding unnecessary handover. Besides overcoming the problem of service interruption, the proposed scheme helps to select the best network technology according to user preference by continuously sending the changing message to the link status without reducing the network QoS. The simulation results indicate that the F-SAW can achieve the best in terms of unnecessary handovers possibilities as well as the average total of handover latency, handover delay, and packet loss, as compared to the other vertical handover decision making schemes such as the Multi-Criteria Utility Function and Integrated. Also, by integrating the two algorithms (Fuzzy logic and SAW) for selecting the different access networks can be done more systematically and efficiently. When compared to the RSS-Threshold algorithm, the proposed F-SAW scheme managed to reduce the total average of the handover latency, delay, and packet loss in the three accessible network technologies (WI-FI-WiMAX-LTE) up to 20%, 21%, and 13%, respectively as shown in Tables 4.1, 4.2, and 4.3 of Subsection 4.3.3 in Chapter 4. On the other hand, the utility function (score value) results show the proposed F-SAW scheme decided to select the LTE network due to the highest probability values up to 0.95 scores as compared with other schemes as shown in Table 6.5 and Figure 6.11 of Section 6.4 in Chapter 6.

7.2 Limitations of the Study

One of the major challenges in this research relates to the limitation of the simulation model in terms of availability and reliability. This limitation can be solved by acquiring various simulation models that allow smoother implementation in different scenarios. However, it is a challenge to design and implement a 4G network in the NS-2 simulation, which does not provide complete modules and samples to assist in the development of more complicated scenarios. Thus, more efforts are required in this regard to achieve more realistic scenarios, especially on the movement of vehicles within a traffic light environment. The various levels of technology in the network are also difficult to synchronize due to the different abilities in terms of signal, data rate, transmission range, network load, and others. For example, the highest technology network in this research is the LTE configuration that must be conducted first to make sure it works. Furthermore, the node creation in *$LTE_conf* must be followed by the Radio Network Controller (RNC), base station, and User Equipment (UE). Then, the node will continue by following the access point (Wi-Fi) and base station (WiMAX) configuration (refer to Appendix B – Algorithm Main Module index 4.2).

The hardship of developing the proposed handover management schemes using test-bed is one of the limitations of this research. The measurements conducted in this research were only based on the simulation tool because of cost and resource limitations. Thus, such constraints hindered the proposed work to be appraised in a more realistic form. Finally, the proposed scheme does not consider any security issues.

7.3 Future Directions and Research Opportunities

The objectives of this research have been achieved by implementing the AHD and F-SAW schemes for designing a wireless network. The previous chapters have pointed out that the handover QoS performance, handover prediction process, and network selection schemes are better compared to the other existing approaches. These existing schemes need to be improved by considering a way to discover a set of key intelligence that can enhance the ability of the mobile node to obtain complicated results. Moreover, the improved scheme is capable of developing seamless wireless connectivity of vehicles that moves at high transmission speed, particularly in heterogeneous wireless networks such as 5G technology. For example, the use of several mobility models such as the Integrated Mobility Model (IMM) to perform the real-world scenarios for the vehicular ad-hoc network is crucial in evaluating the performance of routing protocols (e.g., AODV, DSR, and OLSR). This new IMM can be integrated with the Manhattan mobility, stop sign, freeway mobility, traffic sign, and other similar models. Furthermore, based on the simulation results, it is discovered that the IMM provides more featured scenarios by representing both the rural and urban areas. Various routing protocols (e.g., AODV, DSR, and OLSR) were simulated then the results were compared.

The study on the traffic scenario can be added combined with other access network technologies such as Dedicated Short Range Communication (DSRC), which is also known as Wireless Access for Vehicular Environment (WAVE) communication system and protocols. The WAVE involves the V2V and V2I communication based on the IEEE 802.11p protocol and IEEE 1609.1-4 standards. However, since the Internet service providers (ISPs) are still facing challenges in providing internet services, guaranteed quality of service level, or specific preferences, best-effort services will be given to their consumers. The ISPs will try to provide the best service by inputting all information from users and network systems for attaining the following intentions: high radio transmission signal, network range, bandwidth, and reliability, as well as low service charge, power consumption, and network latency, strong refuge, and suitable vehicle speed. Most importantly, any further improvement in the proposed scheme must be able to establish seamless wireless communication and enhance the QoS for vehicular ad-hoc networks.

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Appendix A

Create and Configure Data Spatial Model provided by the University of Stuttgart Informatik – CanuMobiSim

This algorithm will be generated by using VANETMobiSim simulation and integrated with NS-2 simulation.

```
Call <?xml version="1.0" ?>
# Cars in a City Center using the SpaceGraph and MOBIL.
# Initialisation of parameter input
Initialise <universe>
Initialise <dimx>1000.0</dimx>
 Initialise <dimy>1000.0</dimy>
Initialise <seed>18</seed>

# Create and generate of output
execute <extension
class="de.uni_stuttgart.informatik.canu.mobisim.extensions.NSOutput"
output="VANET.txt" />
# Set up timeline of simulation
execute <extension
class="de.uni_stuttgart.informatik.canu.mobisim.simulations.TimeSimulation"
param="3600.0" />
# Execution the spatial Model and setting up the traffic light
execute <extension name="SpatialModel"
class="de.uni_stuttgart.informatik.canu.spatialmodel.core.SpatialModel" min_x="0"
max_x="1000" min_y="0" max_y="1000">
 <max_traffic_lights>1</max_traffic_lights>
<reflect_directions>true</reflect_directions>
 <number_lane full="false" max="4" dir="true">4</number_lane>
</extension>
execute <extension name="TrafficLight"
execute class="eurecom.spatialmodel.extensions.TrafficLight" step="10000" />
```

```
execute <extension class="eurecom.spacegraph.SpaceGraph" cluster="true">
execute <clusters density="0.000001">
execute <cluster ID="suburban">
 execute <density>0.000005</density>
 execute <ratio>1.0</ratio>
execute <speed>20</speed>
execute </cluster>
 execute </clusters>
execute </extension>
 execute <extension name="PosGen"
class="de.uni_stuttgart.informatik.canu.tripmodel.generators.RandomInitialPositionG
enerator" />
execute <extension name="TripGen"
class="de.uni_stuttgart.informatik.canu.tripmodel.generators.RandomTripGenerator"
>
execute <reflect_directions>true</reflect_directions>
execute <minstay>5.0</minstay>
 execute <maxstay>30.0</maxstay>
execute </extension>
# Create input 100 nodes
Initialise <nodegroup n="100">
# Generate the Mobility Model with Intelligent Driver Model with Lane Changes
(IDM-LC)
execute <extension class="polito.uomm.IDM_LC" initposgenerator="PosGen"
tripgenerator="TripGen">
 execute <minspeed>3.33</minspeed>
execute <maxspeed>13.89</maxspeed>
 execute <step>0.1</step>
 execute <b>0.5</b>
 execute </extension>
execute </nodegroup>
# Generate the Graphic User Interface
execute <extension
class="de.uni_stuttgart.informatik.canu.mobisimadd.extensions.GUI">
```

```
 execute <wIDth>640</wIDth>
 execute <height>480</height>
 execute <step>1</step>
 execute </extension>
execute <extension
 class="de.uni_stuttgart.informatik.canu.spatialmodel.extensions.DumpSpatialModel"
 output="dumped_graph_double_mult_all.fig"/>

 execute </universe>
```

Appendix B

Create and Configure the Main Module of VANET in NS-2 Simulation

The algorithm of the main program for heterogeneous wireless networks in VANET

```
# A.  Scenario:
#    1. Create a multi-interface node using different technologies (LTE, WiMAX, and Wi-Fi.
#    2. There is a TCP connection between the router0 and MultiFaceNod.
#    3. Traffic starts on LTE/WLAN interface.
#
#B.  Topology scenario:
#       Traffic light scenario that integrated VANETMobiSim and NS-2 simulations.

# Algorithm Main Module Index 4.1- Create input of  LTE, WLAN, and WiMAX
#_____________________________________________________________________________

# Initialisation and checking input parameters
Initialise set NS /home/Project/Desktop/ns-allinone-2.29/ns-2.29/
if {$argc != 0} {
          puts ""
          puts "Wrong Number of Arguments! No arguments in this topology"
          puts ""
          exit (1)
}

# Create X and Y dimensions of the topology
Initialise set opt(x)  2000                    ;# X dimension of the topography
initialise set opt(y)  2000                    ;# Y dimension of the topography

#Packet Size input – Packet Size, RSS, and Velocity
Initialise set Packet 1024;#INPUT PACKET SIZE

execute source $NS.ns
execute global ns

initialise set RSS 30;#dB
initialise set MaxSpeed 100;#kmph
initialise set MinSpeed 0;#kmph
initialise set velocity 20;

#Set debug attributes
call Agent/ND set debug_ 1
call Agent/MIH set debug_ 1
call Agent/MIHUser/IFMNGMT/MIPV6 set debug_ 1
call Agent/MIHUser/IFMNGMT/MIPV6/Handover/Handover1 set debug_ 1

#Mac/802_16 set debug_ 1
initialise set NS /home/Project/Desktop/ns-allinone-2.29/ns-2.29/

#defines function for flushing and closing files
```

```
execute exec echo "$velocity $Packet" >.arguements
proc finish {} {
  execute global ns f NS
  execute $ns flush-trace
  execute close $f
  execute  puts " Simulation ended."
          #exec rm -rf out.nam &
          #exec cp .nam out.nam & mih wont support NAM
          #exec nam $NS.nam & ;#defaulted to manual
   exit 0
}

# set global variables
Initialise set output_dir.

#create the simulator
Initialise set ns [new Simulator]
execute $ns use-newtrace

#open file for trace
Initialise set f [open out.res w]
execute $ns trace-all $f

# set up for hierarchical routing(needed for routing over a base station)
execute $ns node-config -addressType hierarchical
initialise AddrParams set domain_num_  6          ;# domain number
initialise AddrParams set cluster_num_{1 1 1 1 1 1};# cluster number for #each domain
initialise AddrParams set nodes_num_ {3 1 3 2 2 1};# number of nodes for each cluster


# Algorithm Main Module Index 4.2- Configure LTE, WLAN and WiMAX networks
#______________________________________________________________________________

# configure $LTE_conf.
# Note: The $LTE_conf configuration MUST be done first; otherwise it does not work
#      Furthermore, the node creation in $LTE_conf MUST be as follow
#      RNC, base station, and UE (User Equipment)

initialise $ns set hsdschEnabled_ 1addr
initialise $ns set hsdsch_rlc_set_ 0
initialise $ns set hsdsch_rlc_nif_ 0

# configure RNC node
execute $ns node-config -$LTE rnc
initialise set rnc [$ns create-Umtsnode 0.0.0] ;# node ID is 0.
execute puts "rnc: tcl=$rnc; ID=[$rnc ID]; addr=[$rnc node-addr]"
execute $ns at 0.0 "$rnc label RNC"

initialise $rnc set X_ 100.0
initialise $rnc set Y_ 500.0
```

```
initialise $rnc set Z_ 0.0
# configure $LTE_conf base station
execute $ns node-config -$LTE bs \
                    -downlinkBW 384kbs \
                    -downlinkTTI 10ms \
                    -uplinkBW 384kbs \
                    -uplinkTTI 10ms \
                    -hs_downlinkTTI 2ms \
          -hs_downlinkBW 384kbs

initialise set LTEnode [$ns create-Umtsnode 0.0.1] ;# node ID is 1
execute puts "LTEnode: tcl=$LTEnode; ID=[$LTEnode ID]; addr=[$LTEnode node-addr]"

initialise $LTEnode set X_ 200.0
initialise $LTEnode set Y_ 500.0
initialise $LTEnode set Z_ 0.0

# connection RNC and LTE base station
execute $ns setup-Iub $LTEnode $rnc 622Mbit 622Mbit 15ms 15ms DummyDropTail 2000

execute $ns node-config -$LTE ue \
                    -baseStation $LTEnode \
                    -radioNetworkController $rnc

initialise set iface0 [$ns create-Umtsnode 0.0.2] ;# node ID is 2
initialise set iface01 [$ns create-Umtsnode 0.0.3] ;# node ID is 2
initialise set iface02 [$ns create-Umtsnode 0.0.4] ;# node ID is 2
initialise set iface03 [$ns create-Umtsnode 0.0.5] ;# node ID is 2

execute puts "iface0($LTE_conf): tcl=$iface0; ID=[$iface0 ID]; addr=[$iface0 node-addr]"
execute puts "iface01($LTE_conf): tcl=$iface0; ID=[$iface01 ID]; addr=[$iface01 node-
addr]"
execute puts "iface02($LTE_conf): tcl=$iface0; ID=[$iface02 ID]; addr=[$iface02 node-
addr]"
execute puts "iface03($LTE_conf): tcl=$iface0; ID=[$iface03 ID]; addr=[$iface03 node-
addr]"

execute $ns at 0.0 "$iface0 label User"

# Node address for router0 and router1 are 4 and 5, respectively.
initialise set router0 [$ns node 1.0.0]
execute puts "router0: tcl=$router0; ID=[$router0 ID]; addr=[$router0 node-addr]"

execute $ns at 0.0 "$router0 label router0"

initialise $router0 set X_ 300.0
initialise $router0 set Y_ 500.0
initialise $router0 set Z_ 0.0

initialise set router1 [$ns node 2.0.0]
```

```
execute puts "router1: tcl=$router1; ID=[$router1 ID]; addr=[$router1 node-addr]"
execute $ns at 0.0 "$router1 label router1"

initialise $router1 set X_ 400.0
initialise $router1 set Y_ 500.0
initialise $router1 set Z_ 0.0

# Connection the links Router0 and Router1
execute $ns duplex-link $rnc $router1 622Mbit 0.4ms DropTail 1000
execute $ns duplex-link $router1 $router0 100MBit 5ms DropTail 1000
execute $rnc add-gateway $router1

# Create MutiFaceNodes. It MUST be done before the 802.11
execute $ns node-config -multif ON                    ;#to create MultiFaceNode
initialise set multiFaceNode [$ns node 5.0.0]          ;# node ID is 6
execute $ns node-config  -multiIf OFF                 ;#reset attribute
execute puts "multiFaceNode: tcl=$multiFaceNode; ID=[$multiFaceNode ID];
addr=[$multiFaceNode node-addr]"

# Create and Configure Wi-Fi 802.11 nodes
# Parameter for wireless nodes
initialise set opt(chan)          Channel/WirelessChannel       ;# channel type for 802.11
initialise set opt(prop)          Propagation/TwoRayGround   ;# radio-propagation model
802.11
initialise set opt(netif)         Phy/WirelessPhy                ;# network interface type
802.11
initialise set opt(mac)           Mac/802_11                     ;# MAC type 802.11
initialise set opt(ifq)           Queue/DropTail/PriQueue        ;# interface queue type 802.11
initialise set opt(ll)            LL                             ;# link layer type 802.11
initialise set opt(ant)           Antenna/OmniAntenna            ;# antenna model 802.11
initialise set opt(ifqlen)        50                             ;# max packet in ifq 802.11
initialise set opt(adhocRouting)   DSDV                          ;# routing protocol 802.11
initialise set opt(umtsRouting)    ""                            ;# routing for $LTE_conf (reset
node config)

# Configure rate for 802.11
initialise Mac/802_11 set basicRate_ 1Mb
initialise Mac/802_11 set dataRate_ 11Mb
initialise Mac/802_11 set bandwidth_ 11Mb

#Create the topography
initialise set topo [new Topography]
execute $topo load_flatgrID $opt(x) $opt(y)
#puts "Topology created"
initialise set chan [new $opt(chan)]

# Create God
execute create-god 11                                    ;# give the number of nodes

# Configure 802.11 for 20m radius 2.4Ghz
```

```
execute Phy/WirelessPhy set Pt_ 0.025
execute Phy/WirelessPhy set freq_ 2412e+6
execute Phy/WirelessPhy set RXThresh_ 6.12277e-09
execute Phy/WirelessPhy set CSThresh_ [expr 0.9*[Phy/WirelessPhy set RXThresh_]]

# Configure 802.11 as Access Points (AP)
execute $ns node-config  -adhocRouting $opt(adhocRouting) \
            -llType $opt(ll) \
            -macType $opt(mac) \
            -channel $chan \
            -ifqType $opt(ifq) \
            -ifqLen $opt(ifqlen) \
            -antType $opt(ant) \
            -propType $opt(prop)    \
            -phyType $opt(netif) \
            -topoInstance $topo \
            -wiredRouting ON \
            -agentTrace ON \
            -routerTrace OFF \
            -macTrace ON  \
            -movementTrace OFF \
            -energyModel EnergyModel \
            -rxPower 0.3 \
             -txPower 0.6 \
            -initialEnergy 10

# Configure Base station 802.11
initialise set bstation802 [$ns node 3.0.0] ;
initialise $bstation802 set X_ 500.0
initialise $bstation802 set Y_ 500.0
initialise $bstation802 set Z_ 0.0

execute $ns at 0.0 "$bstation802 label BS11"
execute puts "bstation802: tcl=$bstation802; ID=[$bstation802 ID]; addr=[$bstation802
node-addr]"

# Configure the BSS for the base station
initialise set bstationMac [$bstation802 getMac 0]
initialise set AP_ADDR_0 [$bstationMac ID]
execute puts "bss_ID for bstation 1=$AP_ADDR_0"
execute $bstationMac bss_ID $AP_ADDR_0
execute $bstationMac enable-beacon
execute $bstationMac set-channel 1

# Create of the wireless interface 802.11 –iface1 and iface2
execute $ns node-config -wiredRouting OFF \
           -macTrace ON
initialise set iface1 [$ns node 3.0.1]
initialise set iface2 [$ns node 3.0.2]                          ;# node ID is 8.
initialise set iface2 [$ns node 3.0.3]
```

```
execute $iface1 random-motion 0                              ;# disable random motion
execute $iface2 random-motion 0
execute $iface1 base-station [AddrParams addr2ID [$bstation802 node-addr]] ;#attach mn to basestation
execute $iface2 base-station [AddrParams addr2ID [$bstation802 node-addr]] ;#attach mn to basestation
initialise $iface1 set X_ 687
initialise $iface1 set Y_ 7
initialise $iface1 set Z_ 0.0


initialise $iface2 set X_ 726
initialise $iface2 set Y_ 138
initialise $iface2 set Z_ 0.0

execute $ns at 0.0 "$iface1 label User"
execute $ns at 0.0 "$iface2 label User"

execute [$iface1 set mac_(0)] set-channel 1
execute [$iface2 set mac_(0)] set-channel 1

# Define node movement. We start from outside the coverage, cross it and leave.
execute $ns at 0 "$iface1 setdest 1600.0 1000.0 3.0"
execute puts "iface1: tcl=$iface1; ID=[$iface1 ID]; addr=[$iface1 node-addr]"
execute puts "iface2: tcl=$iface2; ID=[$iface2 ID]; addr=[$iface2 node-addr]"
execute source $NS.ns

# Add link to backbone
execute $ns duplex-link $bstation802 $router1 100MBit 15ms DropTail 1000

# Create Wimax 802.16  nodes
initialise set opt(netif)         Phy/WirelessPhy/OFDM        ;# network interface type 802.16
initialise set opt(mac)            Mac/802_16                  ;# MAC type 802.16
execute Phy/WirelessPhy set Pt_ 0.025
execute Phy/WirelessPhy set RXThresh_ 2.025e-12
execute Phy/WirelessPhy set CSThresh_ [expr 0.9*[Phy/WirelessPhy set RXThresh_]]

# Configure WiMAX 802.16
execute $ns node-config  -adhocRouting $opt(adhocRouting) \
             -llType $opt(ll) \
             -macType $opt(mac) \
             -channel $chan \
             -ifqType $opt(ifq) \
             -ifqLen $opt(ifqlen) \
             -antType $opt(ant) \
             -propType $opt(prop)    \
             -phyType $opt(netif) \
             -topoInstance $topo \
             -wiredRouting ON \
             -agentTrace ON \
```

```
               -routerTrace OFF \
               -macTrace ON  \
               -movementTrace OFF

# Configure Base station 802.16
initialise set bstation802_16 [$ns node 4.0.0] ;
initialise $bstation802_16 set X_ 700
initialise $bstation802_16 set Y_ 500
initialise $bstation802_16 set Z_ 0.0
execute $ns at 0.0 "$bstation802_16 label BS802_16"
execute puts "bstation802_16: tcl=$bstation802_16; ID=[$bstation802_16 ID];
addr=[$bstation802_16 node-addr]"
initialise set clas [new SDUClassifier/Dest]
[$bstation802_16 set mac_(0)] add-classifier $clas

#Set the scheduler for the node. Must be changed to -shed [new $opt(sched)]
initialise set bs_sched [new WimaxScheduler/BS]
[$bstation802_16 set mac_(0)] set-scheduler $bs_sched
[$bstation802_16 set mac_(0)] set-channel 1

# Create the WiMAX interface 802.16 – iface3 and iface4
execute $ns node-config -wiredRouting OFF \
               -macTrace ON
initialise set iface3 [$ns node 4.0.1]                          ;# node ID is 8.
initialise set iface4 [$ns node 4.0.2]                          ;# node ID is 8.

execute $iface3 random-motion 0                                 ;# disable random motion
execute $iface3 base-station [AddrParams addr2ID [$bstation802_16 node-addr]] ;#attach
mn to basestation
execute $iface4 random-motion 0                                 ;# disable random motion
execute $iface4 base-station [AddrParams addr2ID [$bstation802_16 node-addr]] ;#attach
mn to basestation

initialise $iface3 set X_ 472.0
initialise $iface3 set Y_ 107.0
initialise $iface3 set Z_ 0.0

initialise $iface4 set X_ 497.0
initialise $iface4 set Y_ 1.1
initialise $iface4 set Z_ 0.0

execute $ns at 0.0 "$iface3 label User"
execute $ns at 0.0 "$iface4 label User"

initialise set clas [new SDUClassifier/Dest]
[$iface3 set mac_(0)] add-classifier $clas

initialise set clas1 [new SDUClassifier/Dest]
[$iface4 set mac_(0)] add-classifier $clas1
```

```
#Set the scheduler for the node. Must be changed to -shed [new $opt(sched)]
initialise set ss_sched [new WimaxScheduler/SS]
[$iface3 set mac_(0)] set-scheduler $ss_sched
[$iface3 set mac_(0)] set-channel 1

initialise set ss_sched1 [new WimaxScheduler/SS]
[$iface4 set mac_(0)] set-scheduler $ss_sched1
[$iface4 set mac_(0)] set-channel 1

# Define node movement. We start from outside the coverage, cross it and leave.
execute $ns at 0 "$iface3 setdest 1600.0 1000.0 3.0"
execute $ns at 60.12 "$iface1 setdest 395.0 1.0 3.0"
execute $ns at 124.12 "$iface1 setdest 681 67 3.0"

execute puts "iface3: tcl=$iface3; ID=[$iface3 ID]; addr=[$iface3 node-addr]"
execute puts "iface4: tcl=$iface4; ID=[$iface4 ID]; addr=[$iface4 node-addr]"

# Add link to backbone invisible duplex
execute $ns duplex-link $bstation802_16 $router1 100MBit 15ms DropTail 1000


# Create interfaces to MultiFaceNode
execute $multiFaceNode add-interface-node $iface1
execute $multiFaceNode add-interface-node $iface0
execute $multiFaceNode add-interface-node $iface3
execute $multiFaceNode add-interface-node $iface4
execute $multiFaceNode add-interface-node $iface2

# installation N D modules
# take care of $LTE_conf
# Note: The ND module is on the rnc node NOT in the base station
initialise set nd_rncUMTS [$rnc install-nd]
execute $nd_rncUMTS set-router TRUE
execute $nd_rncUMTS router-lifetime 1800
execute $nd_rncUMTS enable-broadcast FALSE
execute $nd_rncUMTS add-ra-target 0.0.2 ;#in $LTE_conf there is no notion of broadcast.
                        #We fake it by sending unicast to a list of nodes
initialise set nd_ue [$iface0 install-nd]

# Installation the ND to Wi-Fi
initialise set nd_bs [$bstation802 install-nd]
execute $nd_bs set-router TRUE
execute $nd_bs router-lifetime 1800
initialise set nd_mn [$iface1 install-nd]

# Installation the ND to WIMAX
initialise set nd_bs2 [$bstation802_16 install-nd]
execute $nd_bs2 set-router TRUE
execute $nd_bs2 router-lifetime 1800
initialise set nd_mn2 [$iface3 install-nd]
```

```
# Installation the ND to Ethernet
initialise set nd_router [$router1 install-nd]
execute $nd_router set-router TRUE
execute $nd_router router-lifetime 1800

# Installation the  interface manager into multi-interface node and CN
call Agent/MIHUser/IFMNGMT/MIPV6/Handover/Handover1 set case_ 2
initialise set handover [new Agent/MIHUser/IFMNGMT/MIPV6/Handover/Handover1]
execute $multiFaceNode install-ifmanager $handover
execute $nd_mn set-ifmanager $handover
execute $handover nd_mac $nd_mn [$iface1 set mac_(0)] ;#to know how to send RS
execute $nd_mn2 set-ifmanager $handover
execute $handover nd_mac $nd_mn2 [$iface3 set mac_(0)] ;#to know how to send RS
execute $nd_ue set-ifmanager $handover
initialise set ifmgmt_cn [$router0 install-default-ifmanager]

# Installation the MIH in multi-interface node
initialise set mih [$multiFaceNode install-mih]
execute $handover connect-mih $mih ;#create connection between MIH and iface management

# Installation the MIH on Wi-Fi and WiMAX (AP/BS)
initialise set mih_bs [$bstation802 install-mih]
initialise set tmp_bs [$bstation802 set mac_(0)]
execute $tmp_bs mih $mih_bs
execute $mih_bs add-mac $tmp_bs

initialise set mih_bs [$bstation802_16 install-mih]
initialise set tmp_bs [$bstation802_16 set mac_(0)]
execute $tmp_bs mih $mih_bs
execute $mih_bs add-mac $tmp_bs

# Create traffic: TCP application between router0 and Multi interface node
# Create a TCP agent and attach it to multi-interface node
initialise set tcp_(0) [new Agent/TCP/FullTcp]
execute $multiFaceNode attach-agent $tcp_(0) $iface0  ;# new command- the interface used for sending
initialise set app_(0) [new Agent/Null] ;#we can use this or the next line

# Ceate a TPC agent and attach it to router0
initialise set tcp_(1) [new Agent/TCP/FullTcp]
execute $ns attach-agent $router0 $tcp_(1)

# Create a CBR traffic source and attach it to tcp_(1)
initialise set cbr_(0) [new Application/Traffic/CBR]
execute $cbr_(0) set packetSize_ $Packet
execute $cbr_(0) set interval_ 0.5
execute $cbr_(0) attach-agent $tcp_(1)
```

```
# Connect both TCP agent
execute $handover add-flow $tcp_(0) $tcp_(1) $iface0 1
execute $tcp_(0) listen
execute puts "tcp stream made from [$router0 node-addr] and [$iface0 node-addr]"

# Registration in $LTE_conf. This will create the MACs in UE and base stations
execute $ns node-config -llType $LTE_conf/RLC/AM \
                        -downlinkBW 384kbs \
                        -uplinkBW 384kbs \
                        -downlinkTTI 20ms \
                        -uplinkTTI 20ms \
                        -hs_downlinkTTI 2ms \
                        -hs_downlinkBW 384kbs


# The first HS-DCH, we must create. If any other, then use attach-dch
initialise set dch0 [$ns create-dch $iface0 $tcp_(0)]
execute $ns attach-dch $iface0 $handover $dch0
execute $ns attach-dch $iface0 $nd_ue $dch0


# Register the MIH module with all the MACs
initialise set tmp2 [$iface0 set mac_(2)] ;#in $LTE_conf and using DCH the MAC to use is
2 (0 and 1 are for RACH and FACH)
execute $tmp2 mih $mih
execute $mih add-mac $tmp2            ;#inform the MIH about the local MAC
initialise set tmp2 [$iface1 set mac_(0)] ;#in 802.11 one interface is created
execute $tmp2 mih $mih
execute $mih add-mac $tmp2            ;#inform the MIH about the local MAC
initialise set tmp2 [$iface3 set mac_(0)] ;#in 802.16 one interface is created
execute $tmp2 mih $mih
execute $mih add-mac $tmp2            ;#inform the MIH about the local MAC
execute proc attach-CBR-traffic { node sink size interval } {

#Get an instance of the simulator
initialise   set ns [Simulator instance]

#Create a CBR  agent and attach it to the node
 initialise set cbr [new Agent/CBR]
 execute $ns attach-agent $node $cbr
 execute $cbr set packetSize_ $size
 execute  $cbr set interval_ $interval

#Attach CBR source to sink;
  execute $ns connect $cbr $sink
 execute return $cbr
 }

# Enable trace file
#$LTEnode trace-outlink $f 2
```

```
initialise set tcp(0) [new Agent/TCP]
execute $ns attach-agent $router0 $tcp(0)
initialise set sink(0) [new Agent/LossMonitor]
execute $ns attach-agent $iface1  $sink(0)
execute exec tracemonitor
execute $ns at 10 "$cbr_(0) start" ;#we should make sure we have $LTE_conf link up before starting to send.
initialise set nav [attach-CBR-traffic $router0 $sink(0) $Packet .05]
execute $ns at 1.1 "$nav start"

# Set the original status of the interface. By default, they are up and a link-up,
# Need to put them down first.
execute $ns at 0 "[eval $iface0 set mac_(2)] disconnect-link" ;#$LTE_conf UE

# Set the starting time for Router Advertisements
execute $ns at 3 "$nd_bs start-ra"
execute $ns at 3 "$nd_bs2 start-ra"
execute $ns at 1.0 "[eval $iface0 set mac_(2)] connect-link"     ;
execute $ns at 250 "finish"
execute puts " Simulation is running ... please wait ..."
execute exec ns topology &
execute $ns run
```

Appendix C

Algorithm Output QoS of Vertical Handover Decision in VANET

```
#  Algorithm Output Module Index 4.3- Results for Handover latency, Delay, Packet loss,
#                                              Throughput and Success ratio
#___________________________________________________________________________

#Initialisation C++ library
initialise BEGIN {highest_packet_ID = 0; count =0; sent =0;drops=0;}
{
initialise action = $1;
initialise time = $2;
initialise node =$3;
initialise type = $5;
initialise pkt_size = $6;
initialise packet_ID =$11;
initialise received =0;
initialise sendLine = 0;
initialise recvLine = 0;
initialise dropLine = 0;

 initialise $0 ~/^s.* AGT/ {
       execute sendLine ++ ;
}

initialise $0 ~/^r.* AGT/ {
      execute recvLine ++ ;
}

initialise $0 ~/^f.* RTR/ {
       execute fowardLine ++ ;
}
initialise $0 ~/^D.* cbr/ {

if ($8 > 712) {
      execute dropLine ++ ;
}
}
# Calculate handover latency (hdelay)
if (packet_ID > highest_packet_ID)
  initialise highest_packet_ID = packet_ID;
 if (action == "+"){
 if (type == "tcp" || type == "cbr" ){
   execute send_time[packet_ID] = time;}
#else {send_time[packet_ID] = 0;}
}
else if (action == "r"){
 if (type == "tcp" || type == "cbr" ){
```

```
      execute rcv_time[packet_ID] = time;
   }
else{rcv_time[packet_ID] = 0;}

  execute hdelay = time-start;
 }

# Rip off the header
 if ((type == "tcp" || type == "cbr") && ($1 =="r" || $1 == "+")){
         execute recvdSize += pkt_size
}
if($1 =="r"  && ($5 == "tcp" || $5 == "cbr" ))
{
#printf("Packet");
execute count ++;
}

if ($1 =="d") {

execute drops++;
}

}
 END
#Calculate the Packet loss, Total delay, Throughput, and Success ratio
 {packet_no = 0; total_delay = 0;
      for (packet_ID = 0; packet_ID <=highest_packet_ID; packet_ID++){
           if ((send_time[packet_ID]!=0) && (rcv_time[packet_ID]!=0) && end < 230){
               execute start = send_time[packet_ID];
               execute end = rcv_time[packet_ID];
               execute packet_duration = end-start;}
else
    initialise packet_duration = -1;

if (packet_duration > 0)
{
execute packet_no++;
  execute total_delay = total_delay + packet_duration;

}

}
execute printf("Throughput            : %.4f\n",(recvdSize)*(8/1000));
execute printf("Delay                 : %.6f\n",total_delay);
execute printf("Success ratio        : %.4f\n", sendLine,recvLine, (recvLine/sendLine));
execute printf("Handoff Latency   : %.2f\n",hdelay);
execute printf("Total Packet loss   : %d  \n",dropLine);


}
```

Appendix D

Developing the proposed F-SAW scheme using C++ programming in NS-2 Simulation

```
/*
 * Implementation of Handover module with Fuzzy logic and SAW (F-SAW)
 */

// Initialisation and generate the three modules
call #include "handover-infocom.h"
call #include "simulator.h"
call #include "mip6.h"


call static class InfocomHandoverClass : public TclClass {
public:
InfocomHandoverClass() : TclClass("Handover/Infocom") {}
TclObject* create(int, const char*const*) {
return (new InfocomHandover());
}
} class_simplehandover;


// Create a handover module

call InfocomHandover::InfocomHandover() : Handover(), connectingMac_(0)
{
execute prefix_timer_ = new PrefixHandleTimer (this);
}

call void InfocomHandover::register_mih ()
{
initialise MIHAgent *mih;
execute vector <Mac *> macs;

 execute assert (ifMngmt_);
 execute debug ("At %f in %s InfocomHandover registers the MACs\n", NOW, \
            Address::instance().print_nodeaddr(ifMngmt_->addr()));

execute mih = ifMngmt_->get_mih();
execute macs = mih->get_local_mac ();

 for (int i=0; i < (int) macs.size() ; i++) {
//register event
initialise mih->event_register (ifMngmt_, macs.at (i), MIH_LINK_DETECTED);
 initialise mih->event_register (ifMngmt_, macs.at (i), MIH_LINK_UP);
initialise mih->event_register (ifMngmt_, macs.at (i), MIH_LINK_GOING_DOWN);
```

```
initialise mih->event_register (ifMngmt_, macs.at (i), MIH_LINK_DOWN);
}
}

// Information communication of handover module
call void InfocomHandover::process_link_parameter_change (link_parameter_change_t
*e)
{
 initialise MIHAgent *mih;
execute link_parameter_config_t *config;
execute debug("At %f in %s InfocomHandover processes Link Parameter Change\n", \
          NOW, Address::instance().print_nodeaddr(ifMngmt_->addr()));

execute assert (ifMngmt_);
execute mih = ifMngmt_->get_mih();
execute config = Handover::get_mac_info (e->eventSource);

//Add test to see which parameter has changed, for now it can only be assoc status
//  if()
//  config->assoc = e->new_value.assoc;
//printf("New Status for the link : %d", config->assoc);
}

// Develop and implement the FUZZY based Selection Algorithm

call void InfocomHandover::Selection_Algorithm (link_detected_t *e)
{

initialise MIHAgent *mih;
execute char *os = Address::instance().print_nodeaddr(old_address);
execute char *ns = Address::instance().print_nodeaddr(new_address);
execute char *ps = Address::instance().print_nodeaddr(prefix);

// All basic MIH input parameters
initialise bind("delay", &delay_);
initialise bind("useAdvInterval_", &useAdvInterval_);
initialise bind("router_lifetime_", &rtrlftm_);
initialise bind("prefix_lifetime_", &prefix_lifetime_);
initialise bind("minRtrAdvInterval_", &minRtrAdvInterval_);
initialise bind("maxRtrAdvInterval_", &maxRtrAdvInterval_);
initialise bind("minDelayBetweenRA_", &minDelayBetweenRA_);
initialise bind("maxRADelay_", &maxRADelay_);
initialise bind("broadcast_", &broadcast_);
initialise bind("default_port_", &default_port_);
initialise bind("rs_timeout_", &rs_timeout_);
initialise bind("max_rtr_solicitation_", &max_rtr_solicitation_);

execute link_parameter_config_t *config;
execute assert (ifMngmt_);
execute mih = ifMngmt_->get_mih();
execute mih_interface_info **info = mih->get_interfaces ();
```

```
initialise int nb_info = mih->get_nb_interfaces ();
execute hdr_ip *iph = HDR_IP(p);
execute hdr_freq *rh = HDR_FREQ(p);

// Response the packet
execute Packet *p_res = allocpkt();
execute hdr_ip *iph_res = HDR_IP(p_res);
execute hdr_fres *rh_res = HDR_FRES(p_res);
execute hdr_cmn *hdrc_res = HDR_CMN(p_res);

execute assert (HDR_CMN(p)->ptype() == PT_FREQ);

execute debug ("At %f MIPv6 Agent in %s received flow request packet\n", NOW,
MYNUM);

//We check if we can accept the client
 //check how many links detected

for (int i=0; i < (int) macs.size() ; i++) {
        for ( ; n ; n=n->next_entry()) {

 // Create a link detected to process
initialise mih->event_register (ifMngmt_, macs.at (i), MIH_LINK_DETECTED);
initialise mih->event_register (ifMngmt_, macs.at (i), MIH_LINK_UP);
initialise mih->event_register (ifMngmt_, macs.at (i), MIH_LINK_DOWN);
initialise mih->event_register (ifMngmt_, macs.at (i), MIH_LINK_GOING_DOWN);
initialise mih->event_register (ifMngmt_, macs.at (i),
MIH_LINK_PARAMETERS_CHANGE);
execute link_detected_t *e2 = (link_detected_t*) malloc (sizeof (link_detected_t));
initialise e2->eventSource = e->eventSource;
initialise e2->macMobileTerminal = e->eventSource->addr();
initialise e2->macNewPoA = n->bss_ID();
initialise e2->mihCapability = 1;
execute hdr_cmn *ch = HDR_CMN(p);
initialise char    *mh = (char*) HDR_MAC(p);
execute hdr_ll   *lh = HDR_LL(p);
execute hdr_arp*ah = HDR_ARP(p);

initialise ch->uid()
execute link_going_down_t *e = (link_going_down_t*) malloc (sizeof
(link_going_down_t));
initialise e->linkIdentifier.type = linkType_;
initialise e->linkIdentifier.macMobileTerminal = macTerminal;
initialise e->linkIdentifier.macPoA = macPoA;
initialise e->timeInterval = (unsigned int)(interval*1000);
initialise e->confidenceLevel = confIDence;
execute e->strength = wifp->getDist(wifp->getCSThresh(), wifp->getPt(), 1.0, 1.0,
                    highestZ , highestZ, wifp->getL(),
                    wifp->getLambda()); ;
        execute e->reasonCode = reason;
        execute e->uniqueEventIdentifier = id;
```

```
            execute mih_->recv_event (MIH_LINK_GOING_DOWN, e);
                        execute ALPHA_i =e->strength;//~
                        execute process_link_detected (e2);
 }
}
for (int i= 0 ; i < (int) (rh->flow_info.size()) ; i++){
            execute requested_bw += rh->flow_info.at(i)->minBw();
 }
execute config = Handover::get_mac_info (e->eventSource);

// Compute the total requested bandwidth and record bandwidth values for every
node
initialise X_BW[kb] =config->bandwidth;
initialise kb ++;
initialise int size =kb;
initialise int location =1;
for(ij=0;ij<kb;ij++){
            execute maximum = X_BW[0];

             for (c = 1; c < size; c++)
 {
             if (X_BW[c] > maximum)
{
execute maximum  = X_BW[c];
execute location = c+1;
 }
}

}
execute R_Ban =X_BW[kb-1]/maximum; //same for all the networks

// Measure the delay handover
initialise int size =kc;
initialise int location =1;
for(ij=0;ij<kc;ij++){
            execute maximum = delay[0];

            for (c = 1; c < size; c++)
 {
            if (delay[c] > maximum)
 {
execute maximum  = delay[c];//measure delay
execute location = c+1;
 }
 }

}
execute R_Cost =delay[kb-1]/maximum;  //same for all the networks

// Measure the jitter handover
initialise int size =kj;
```

```
initialise int location =1;
for(ij=0;ij<kj;ij++){
            execute maximum = jitter[0];

            for (c = 1; c < size; c++)
 {
            if (jitter[c] > maximum)
{
           execute maximum  = jitter[c];
execute location = c+1;
}
 }
}
execute R_Jitter =jitter[kb-1]/maximum;//same for all the networks

//zi = ?a z ?a (Equation 1)
//ALPHA_i ~ Firing strength
// Compute the total weight score among of the candidate access networks
initialise int LTE_Cost=0.7;
initialise int WiMAX_Cost=0.5;
initialise int WI-FI_Cost=0.2;

if (index == LTE_BS) {
execute TOT_WEIGHT[0] = (ALPHA_i * LTE_Cost * (R_Jitter * R_Cost  * R_Ban));
}

if (index == WIMAX_BS) {
execute TOT_WEIGHT[1] = (ALPHA_i * WiMAX_Cost * (R_Jitter * R_Cost  *
R_Ban ));
}

if (index == WI-FI_BS) {
execute TOT_WEIGHT[2] = ALPHA_i * WI-FI_Cost * (R_Jitter * R_Cost  * R_Ban
));
 }

//Execution to select the best networks among LTE, WIMAX, and WI-FI

if((TOT_WEIGHT[0] >TOT_WEIGHT[1]) && (TOT_WEIGHT[0]
>TOT_WEIGHT[2]) ){
execute BEST_AP  = LTE_BS;  //LTE score is high

}

if((TOT_WEIGHT[1] >TOT_WEIGHT[0]) && (TOT_WEIGHT[1]
>TOT_WEIGHT[2]) ){
execute BEST_AP  = WIMAX_BS;  //wimax n/w score is high

}
```

```
if((TOT_WEIGHT[2] >TOT_WEIGHT[0]) && (TOT_WEIGHT[2]
>TOT_WEIGHT[1]) ){
execute BEST_AP  = WI-FI_BS;   // Wi-Fi n/w score is high

}
execute mih_configure_req_s * req = (mih_configure_req_s *) malloc (sizeof
            (mih_configure_req_s));
execute req->information = 1 << CONFIG_LINK_ID;
execute req->linkIdentifier = e->linkIdentifier;
execute mih_->mih_configure_link (this, BEST_AP, req);  //send request to best base
station

}

// follow process link
call void InfocomHandover::process_link_detected (link_detected_t *e)
{
initialise MIHAgent *mih;
execute link_parameter_config_t *config;
execute assert (ifMngmt_);
execute mih = ifMngmt_->get_mih();
execute mih_interface_info **info = mih->get_interfaces ();
initialise int nb_info = mih->get_nb_interfaces ();
execute hdr_ip *iph = HDR_IP(p);
execute hdr_freq *rh = HDR_FREQ(p);

// Repsonse packet
execute Packet *p_res = allocpkt();
execute hdr_ip *iph_res = HDR_IP(p_res);
execute hdr_fres *rh_res = HDR_FRES(p_res);
execute hdr_cmn *hdrc_res = HDR_CMN(p_res);

execute assert (HDR_CMN(p)->ptype() == PT_FREQ);
execute debug ("At %f MIPv6 Agent in %s received flow request packet\n", NOW,
MYNUM);

 // Check if can accept the client and compute the total requested bandwidth

for (int i= 0 ; i < (int) (rh->flow_info.size()) ; i++){
  execute requested_bw += rh->flow_info.at(i)->minBw();
 }
 execute config = Handover::get_mac_info (e->eventSource);

// Record bandwidth values for every node
 execute debug ("At %f in %s InfocomHandover link detected \n\ttype %d, bandwidth =
%f,        MacAddr=%d, PoA=%d\n", \
 NOW, Address::instance().print_nodeaddr(ifMngmt_->addr()), \
 config->type, config->bandwidth, e->eventSource->addr(),e->macNewPoA);

 //CASE 1: we don't have any connection up, we want to use this one
 for(int i=0;i < nb_info; i++) {
```

```
 if (info[i]->status_==LINK_STATUS_UP || connectingMac_ == info[i]->mac_) {
//case 1: we already have a connection up. Is this one better?
execute link_parameter_config_t *config2 =  Handover::get_mac_info (info[i]->mac_);
//compare to the new one
if (config2->type == LINK_ETHERNET
          || (config2->type == LINK_802_11 && config->type != LINK_ETHERNET)) {
//we have a better interface already. don't connected
  execute debug ("\twe have a better interface already. don't connect\n");
          execute free (config2);
          execute goto done;
 }
execute free (config2);
}
 }
 if (nb_info>0 )
          execute debug ("\tThe new interface is better...connect\n");
else
          execute debug ("\tThis is the first interface...connect\n");

//case 2: there is no other connection up or better, we want to use this one
 //INFOCOM - no better, but check if the better was already refused (added the
condition)
if (config->type == LINK_802_11 /*&& config->assoc == true*/) {
  execute debug ("\tI launch the connection on the link\n");
 execute connectingMac_ = e->eventSource;
 execute mih->link_connect (e->eventSource, e->macNewPoA);
 }

execute done:
execute free (e);
execute free (info);
execute free (config);
}

/*
 * Process the link-up event
* @param e The event information
*/
call void InfocomHandover::process_link_up (link_up_t *e)
{
//We can use interface and let's switch the flows to the new interface
//Here we suppose that we only connect to the best interface
initialise MIHAgent *mih;
execute link_parameter_config_t *config;
execute vector <FlowEntry*> flows;
execute vector <FlowEntry*> flows_to_redirect;
execute assert (ifMngmt_);
execute mih = ifMngmt_->get_mih();

// First clear the connectingMac_ if necessary
 if (e->eventSource == connectingMac_) {
```

```
 execute connectingMac_ = NULL; //we are not waiting for it anymore
}

execute config = Handover::get_mac_info (e->eventSource);
execute debug ("At %f in %s InfocomHandover received link up \n\ttype %d,
bandwidth = %f,            MacAddr=%d\n", \
 NOW, Address::instance().print_nodeaddr(ifMngmt_->addr()),\
 config->type, config->bandwidth, e->eventSource->addr());
execute free (e);
//free (mac_infos);
execute free (config);
}
```

```
/*
* Process the link down event
* @param e The event information
*/
call void InfocomHandover::process_link_down (link_down_t *e)
{
//We look if there is any flow that uses this interface.
//if yes, then we need to switch to another interface
initialise MIHAgent *mih;
execute link_parameter_config_t *config;
execute link_parameter_config_t *config2;
execute vector <FlowEntry*> flows;
execute mih_interface_info **mac_infos;
initialise int nb_mac_infos;
initialise int best_index, best_type, found=0;
execute assert (ifMngmt_);

execute debug ("At %f in %s InfocomHandover received link down \n\t type %d, bandwidth =
%f, MacAddr=%d\n", \
 NOW, Address::instance().print_nodeaddr(ifMngmt_->addr()),\
 config->type, config->bandwidth, e->eventSource->addr());

execute mih = ifMngmt_->get_mih();


if (connectingMac_) {
  //another link went down but we know we are connecting to another one
//it may also be the one from the handover
execute debug ("\tWe are connecting to another interface, we don't look for another one\n");
execute return;
}

execute config = Handover::get_mac_info (e->eventSource);

//get the flows
execute flows = ifMngmt_->get_flows ();
 //get list of interfaces
execute mac_infos = ifMngmt_->get_mih ()-> get_interfaces ();
execute nb_mac_infos = ifMngmt_->get_mih ()->get_nb_interfaces ();

//printf ("\t++We have %d interfaces and %d flows\n", nb_mac_infos, flows.size());

//get the first one
execute best_index = 0 ;
 if (nb_mac_infos > 0) {
while (best_index < nb_mac_infos && (mac_infos[best_index]->mac_ == e->eventSource
          || mac_infos[best_index]->status_ != LINK_STATUS_UP))
 execute best_index++ ;

if (best_index < nb_mac_infos){
initialise found = 1;
```

```
execute config2 = Handover::get_mac_info (mac_infos[best_index]->mac_);
execute best_type = config2->type;
execute free (config2);
 }
 }
for (int mac_index = best_index+1 ; mac_index < nb_mac_infos ; mac_index++) {
         if (mac_infos[mac_index]->mac_ != e->eventSource
        && mac_infos[mac_index]->status_ == LINK_STATUS_UP) {
 //maybe we can use this one..
execute config2 = Handover::get_mac_info (mac_infos[mac_index]->mac_);
         if ( (best_type == LINK_802_11 && config2->type == LINK_ETHERNET)
         || (best_type == LINK_LTE && (config2->type == LINK_802_11
                                       || config2->type == LINK_ETHERNET))){
        execute best_type = config2->type;
        execute best_index = mac_index;
        }
        execute free (config2);
 }
}

//check if we found another better one
if (found) {
execute Tcl& tcl = Tcl::instance();
execute Node *node;
execute tcl.evalf ("%s get-node", e->eventSource->name());
execute node = (Node*) TclObject::lookup(tcl.result());
//we transfer the flows
for (int i=0 ; i < (int)flows.size() ; i++) {
//printf ("Studying flow %d using interface %s\n", i,
Address::instance().print_nodeaddr(flows.at(i)->interface()->address()));
//find the interface the flow is using
if ( flows.at(i)->interface() == node){
//we redirect this flow to the new interface
initialise Node *new_node;
execute tcl.evalf ("%s get-node", mac_infos[best_index]->mac_->name());
execute new_node = (Node*) TclObject::lookup(tcl.result());
execute debug ("\tMust redirect this flow to use interface
%s\n",Address::instance().print_nodeaddr(new_node->address()));
execute tcl.evalf ("%s target [%s entry]", flows.at(i)->local()->name(), new_node->name());
((MIPV6Agent*) ifMngmt_)->send_update_msg (flows.at(i)->remote(),new_node);
execute flows.at(i)->update_interface(new_node);
 }
 }
}
else {
        execute printf ("\tNo better interface found :-(\n");
}
execute free (config);
 execute free (mac_infos);
execute free (e);
}
```

```
/*
* Process the link going down event
 * @param data the event information
*/
call void InfocomHandover::process_link_going_down (link_going_down_t *e)
{
//If we want to anticipate, look for any other link connect.
// We could also start redirecting the flows to another interface.

execute debug ("At %f in %s InfocomHandover received Link going down \n\t probability =
          %d%%\n", \ NOW, Address::instance().print_nodeaddr(ifMngmt_->addr()),\
           e->confIDenceLevel);

 execute free (e);
}

call void InfocomHandover::process_new_prefix (new_prefix* data)
{
execute debug ("At %f in %s InfocomHandover received new prefix %s\n", \
          NOW, Address::instance().print_nodeaddr(ifMngmt_->addr()),\
          Address::instance().print_nodeaddr(data->prefix));

  //prefix_timer_ = new PrefixHandleTimer (this, data);
//prefix_timer_->new_data (data);
//prefix_timer_->sched (5);
execute compute_new_address (data->prefix, data->interface);
//cout << "creating timer\n" ;
execute process_new_prefix2 (data);
}


/*
 * Process a new prefix entry
 * @param data the new prefix information
*/
call void InfocomHandover::process_new_prefix2 (new_prefix* data)
{
  initialise MIHAgent *mih;
  execute link_parameter_config_t *config;
  execute link_parameter_config_t *config2;
  execute vector <FlowEntry*> flows;
  execute vector <FlowEntry*> flows_to_redirect;
  execute mih_interface_info **mac_infos;
  initialise int nb_mac_infos;
  execute Mac *mac;
  execute Tcl& tcl = Tcl::instance();
```

```
//Now we got the address of new PoA
 //get the MAC for which we received a new prefix.
 execute tcl.evalf ("%s set mac_(0)",data->interface->name());
 execute mac = (Mac*) TclObject::lookup(tcl.result());

 //check if that is a better interface and redirect flows.
 //We can use interface, let's switch the flows to the new interface
 //Here we suppose that we only connect to the best interface

 execute assert (ifMngmt_);
 execute mih = ifMngmt_->get_mih();
 execute config = Handover::get_mac_info (mac);
 execute debug ("At %f in %s InfocomHandover processes new prefix %s\n", \
           NOW, Address::instance().print_nodeaddr(ifMngmt_->addr()),\
           Address::instance().print_nodeaddr(data->prefix));
 //compute_new_address (data->prefix, data->interface);

 //Get the node of the new interface
 execute Node *new_node = data->interface;
 //tcl.evalf ("%s get-node", e->eventSource->name());
 //new_node = (Node*) TclObject::lookup(tcl.result());

 //we check if there are flows that are using an interface with less priority
 execute flows = ifMngmt_->get_flows ();
 execute mac_infos = ifMngmt_->get_mih ()-> get_interfaces ();
 execute nb_mac_infos = ifMngmt_->get_mih ()->get_nb_interfaces ();
 //for each interface
 for (int mac_index = 0 ; mac_index < nb_mac_infos ; mac_index++) {
   if (mac_infos[mac_index]->mac_ != mac) {
     //this is not the new interface
     //get mac information
     execute config2 =  Handover::get_mac_info (mac_infos[mac_index]->mac_);
     //compare to the new one
     if (config2->type == LINK_LTE && (config->type == LINK_802_11 ||config->type ==
          LINK_ETHERNET)  || (config2->type == LINK_802_11 && config->type ==
          LINK_ETHERNET)) {
          execute debug ("\tThe new up interface is better...checking for flows to redirect\n");
          //this is not the best interface type
          //get the flows that are using this interface
          initialise Node *node;
          execute tcl.evalf ("%s get-node", mac_infos[mac_index]->mac_->name());
          execute node = (Node*) TclObject::lookup(tcl.result());
          //if (!node)
            //  printf ("Node not found\n");
          //printf ("Found not so good interface on node %s\n",
          Address::instance().print_nodeaddr(node-           >address()));
          for (int i=0 ; i < (int)flows.size() ; i++) {
            //printf ("Studying flow %d using interface %s\n", i,
          Address::instance().print_nodeaddr(flows.at(i)->interface()->address()));
            //find the interface the flow is using
            if ( flows.at(i)->interface() == node){
              //we redirect this flow to the new interface
              execute debug ("\tMust redirect flow from interface %s to %s\n",\
```

```
                        Address::instance().print_nodeaddr(flows.at(i)->interface()->address()), \
                        Address::instance().print_nodeaddr(new_node->address()));
                  execute flows.at(i)->tmp_iface = new_node;
                  execute flows_to_redirect.push_back (flows.at(i));
                 }
               }
           }
          execute free (config2);
        }
      }

      if ((int) flows_to_redirect.size()>0) {
        initialise Node *bstation;
        //tcl.evalf ("%s get-node-by-mac %d", Simulator::instance().name(), e->macNewPoA);
        execute tcl.evalf ("%s  get-node-by-addr %s", Simulator::instance().name(),
              Address::instance().print_nodeaddr(data->prefix));

        execute bstation = (Node*) TclObject::lookup(tcl.result());
        ((MIPV6Agent*) ifMngmt_)->send_flow_request (flows_to_redirect, new_node, bstation-
    >address());
      }
      execute free (mac_infos);
      execute free (config);
      execute free (data);
    }

    call int InfocomHandover::compute_new_address (int prefix, Node *interface)
    {
      initialise int new_address;
      initialise int old_address = interface->address();
      execute Tcl& tcl = Tcl::instance();
      execute new_address = (old_address & 0x7FF)|(prefix & 0xFFFFF800);

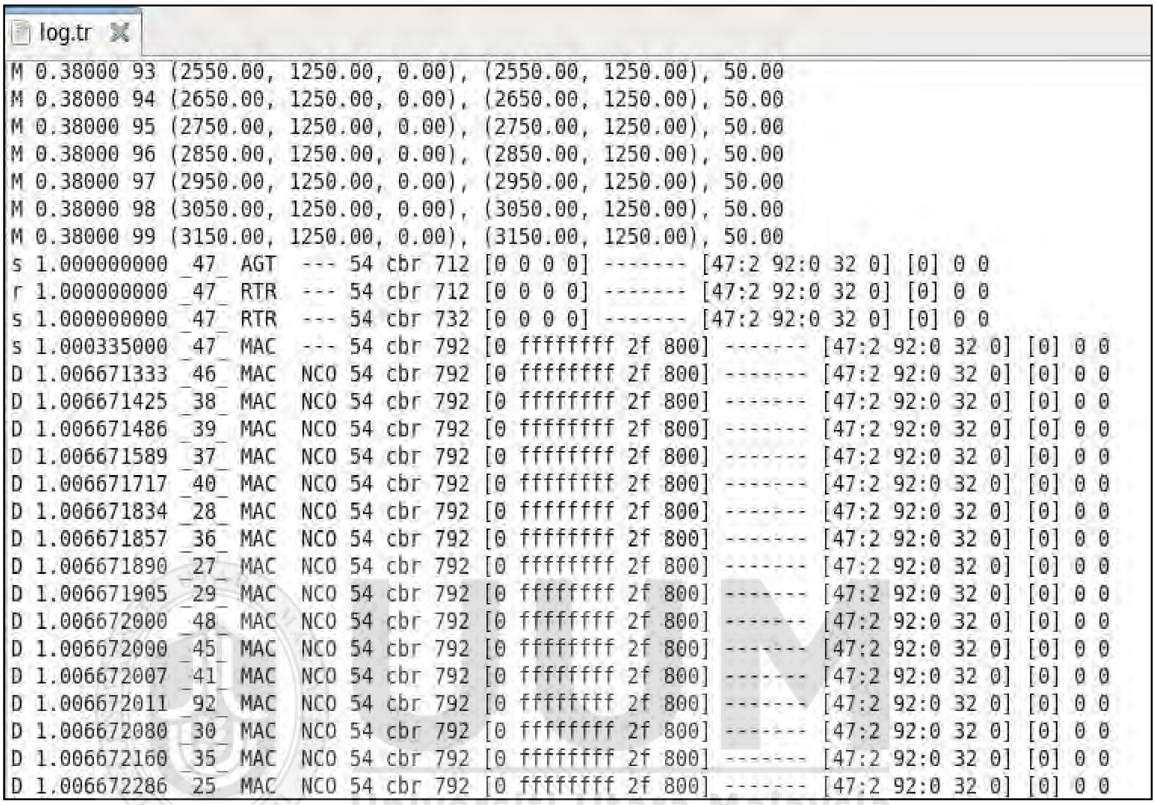
      initialise char *os = Address::instance().print_nodeaddr(old_address);
      initialise char *ns = Address::instance().print_nodeaddr(new_address);
      initialise char *ps = Address::instance().print_nodeaddr(prefix);
      execute debug ("\told address: %s, prefix=%s, new address will be %s\n", os, ps, ns);

      //update the new address in the node
      execute tcl.evalf ("%s addr %s", interface->name(), ns);
      execute tcl.evalf ("[%s set ragent_] addr %s", interface->name(), ns);
      execute tcl.evalf ("%s base-station [AddrParams addr2ID %s]",interface->name(),ps);
      // If we update the address, then we also need to update the local route.
       execute delete []os;
      execute delete []ns;
      execute delete []ps;

      execute return new_address;
    }
```

Appendix E

Apart from result log trace file in NS-2 Simulation



```
M 0.38000 93 (2550.00, 1250.00, 0.00), (2550.00, 1250.00), 50.00
M 0.38000 94 (2650.00, 1250.00, 0.00), (2650.00, 1250.00), 50.00
M 0.38000 95 (2750.00, 1250.00, 0.00), (2750.00, 1250.00), 50.00
M 0.38000 96 (2850.00, 1250.00, 0.00), (2850.00, 1250.00), 50.00
M 0.38000 97 (2950.00, 1250.00, 0.00), (2950.00, 1250.00), 50.00
M 0.38000 98 (3050.00, 1250.00, 0.00), (3050.00, 1250.00), 50.00
M 0.38000 99 (3150.00, 1250.00, 0.00), (3150.00, 1250.00), 50.00
s 1.000000000 _47_ AGT  --- 54 cbr 712 [0 0 0 0] ------- [47:2 92:0 32 0] [0] 0 0
r 1.000000000 _47_ RTR  --- 54 cbr 712 [0 0 0 0] ------- [47:2 92:0 32 0] [0] 0 0
s 1.000000000 _47_ RTR  --- 54 cbr 732 [0 0 0 0] ------- [47:2 92:0 32 0] [0] 0 0
s 1.000335000 _47_ MAC  --- 54 cbr 792 [0 ffffffff 2f 800] ------- [47:2 92:0 32 0] [0] 0 0
D 1.006671333 _46_ MAC  NCO 54 cbr 792 [0 ffffffff 2f 800] ------- [47:2 92:0 32 0] [0] 0 0
D 1.006671425 _38_ MAC  NCO 54 cbr 792 [0 ffffffff 2f 800] ------- [47:2 92:0 32 0] [0] 0 0
D 1.006671486 _39_ MAC  NCO 54 cbr 792 [0 ffffffff 2f 800] ------- [47:2 92:0 32 0] [0] 0 0
D 1.006671589 _37_ MAC  NCO 54 cbr 792 [0 ffffffff 2f 800] ------- [47:2 92:0 32 0] [0] 0 0
D 1.006671717 _40_ MAC  NCO 54 cbr 792 [0 ffffffff 2f 800] ------- [47:2 92:0 32 0] [0] 0 0
D 1.006671834 _28_ MAC  NCO 54 cbr 792 [0 ffffffff 2f 800] ------- [47:2 92:0 32 0] [0] 0 0
D 1.006671857 _36_ MAC  NCO 54 cbr 792 [0 ffffffff 2f 800] ------- [47:2 92:0 32 0] [0] 0 0
D 1.006671890 _27_ MAC  NCO 54 cbr 792 [0 ffffffff 2f 800] ------- [47:2 92:0 32 0] [0] 0 0
D 1.006671905 _29_ MAC  NCO 54 cbr 792 [0 ffffffff 2f 800] ------- [47:2 92:0 32 0] [0] 0 0
D 1.006672000 _48_ MAC  NCO 54 cbr 792 [0 ffffffff 2f 800] ------- [47:2 92:0 32 0] [0] 0 0
D 1.006672000 _45_ MAC  NCO 54 cbr 792 [0 ffffffff 2f 800] ------- [47:2 92:0 32 0] [0] 0 0
D 1.006672007 _41_ MAC  NCO 54 cbr 792 [0 ffffffff 2f 800] ------- [47:2 92:0 32 0] [0] 0 0
D 1.006672011 _92_ MAC  NCO 54 cbr 792 [0 ffffffff 2f 800] ------- [47:2 92:0 32 0] [0] 0 0
D 1.006672080 _30_ MAC  NCO 54 cbr 792 [0 ffffffff 2f 800] ------- [47:2 92:0 32 0] [0] 0 0
D 1.006672160 _35_ MAC  NCO 54 cbr 792 [0 ffffffff 2f 800] ------- [47:2 92:0 32 0] [0] 0 0
D 1.006672286 _25_ MAC  NCO 54 cbr 792 [0 ffffffff 2f 800] ------- [47:2 92:0 32 0] [0] 0 0
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