IMPROVING INITIATION, DECISION AND EXECUTION PHASES FOR VERTICAL HANDOVER IN HETEROGENEOUS WIRELESS MOBILE NETWORKS

Omar Abd Alraheem Omar Khattab

School of Computing, Science and Engineering
College of Science and Technology
the University of Salford, Salford, UK

Submitted in Partial Fulfilment of the Requirements of the Degree of Doctor of Philosophy, August 2014

ACKNOWLEDGMENTS

First and foremost, I am eternally grateful to the Almighty Allah for all the blessings He gave me and for enabling me to complete this thesis. I would like to seize this opportunity to thank a number of people whose role has been reason in this success.

I would like to express my deepest sense of gratitude to my great supervisor Dr. Omar Alani for his guidance, encouragement and trust throughout my PhD research studies. After three years of patience and hard work, my dream has really come true with his support. Therefore, I would love the congratulation compliments which I may receive to be extended to him.

I would like also to thank the members of my assessment committee, Dr. Martin Hope, Dr. Steven Hill, Prof. Nigel Linge and Dr. Bernardi Pranggono for their constructive remarks and recommendations.

I owe a big thank to all my true friends and to the university‘s staff who stood by my side during my journey of PhD.

I am so grateful to my fabulous family, especially my parents, brothers, sisters, nephews and nieces who have pushed themselves to the extreme ends to ensure that I continue my education to the highest level. Truly, without their love, sacrifices and support, I would not have reached this point in my life and this PhD research work would not have been possible.

Last but not least, I must not forget myself from some appreciation. I would like to compliment myself for the full time study, tremendous efforts and unlimited patience given towards the completion of this study in a record time of exactly three years and getting many achievements during this period.

ABSTRACT

One of the challenging issues in Next Generation Wireless Systems (NGWS) is seamless Vertical Handover (VHO) during the mobility between different types of technologies (3GPP and non-3GPP) such as Global System for Mobile Communication (GSM), Wireless Fidelity (Wi-Fi), Worldwide Interoperability for Microwave Access (WiMAX), Universal Mobile Telecommunications System (UMTS) and Long Term Evolution (LTE). Therefore, the telecommunication operators are required to develop an interoperability strategy for these different types of existing networks to get the best connection anywhere, anytime without interruption of the ongoing sessions. In order to identify this problem accurately, the research study presented in this thesis provides four surveys about VHO approaches found in the literature. In these surveys, we classify the existing VHO approaches into categories based on the available VHO techniques for which we present their objectives and performances issues. After that, we propose an optimised VHO approach based on the VHO approaches that have been studied in the literature and take into consideration the research problems and conclusions which are arisen in our surveys. The proposed approach demonstrates better performance (packet loss, latency and signaling cost), less VHO connection failure (probability of minimising VHO reject sessions), less complexity and an enhanced VHO compared with that found in the literature. It consists of a procedure which is implemented by an algorithm.

The proposed procedure of loose coupling and Mobile Internet Protocol version 4 (MIPv4) provides early buffering for new data packets to minimise VHO packet loss and latency. Analysis and simulation of the proposed procedure show that the VHO packet loss and latency are significantly reduced compared with previous MIPv6 procedures found in the literature.

The proposed algorithm is composed of two main parts: Handover Initiation and Optimum Radio Access Technologies (RATs) list of priority. The first part includes two main types of VHO and gives priority to imperative sessions over alternative sessions.

This part is also responsible for deciding when and where to perform the handover by choosing the best RATs from the multiple ones available. Then, it passes them to the decision phase. This results in reducing the signaling cost and the inevitable degradation in Quality of Service (QoS) as a result of avoiding unnecessary handover processes. The second part defines RATs list of priority to minimise VHO connection failure. Analysis and simulation based performance evaluations then demonstrate that the proposed algorithm outperforms the traditional algorithms in terms of: **(a)** the probability of VHO connection failure as a result of using the optimum RATs list of priority and **(b)** the signaling cost and the inevitable degradation in QoS as a result of avoiding unnecessary handover processes.

KEYWORDS

Vertical Handover (VHO); Heterogeneous Wireless Networks; Media Independent Handover (MIH); Internet Protocol Multimedia Subsystem (IMS); Next Generation Wireless Systems (NGWS); Fourth Generation (4G); Global System for Mobile Communication (GSM); Wireless Fidelity (Wi-Fi); Worldwide Interoperability for Microwave Access (WiMAX); Universal Mobile Telecommunications System (UMTS); Long Term Evolution (LTE); Admission Control (AC); Access Network Discovery and Selection Function (ANDSF); Access Network Selection (ANS); Fuzzy Logic Inference System (FIS); Mobile Internet Protocol version 4 (MIPv4); Mobile Internet Protocol version 6 (MIPv6); Mobile User (MU); User Equipment (UE); Mobile Station (MS); Mobile Node (MN); Mobile Equipment (ME); Subscriber Station (SS); Radio Access Technologies (RATs); Wireless Network Selection Function (WNSF); Packet Loss; Latency; Connection Failure; Signaling Cost; Interworking Architectures; Loose Coupling (LC); Tight Coupling (TC).

TABLE of CONTENTS

Chapter 3: Available Techniques of Vertical Handover (VHO) in Heterogeneous Wireless Networks

Chapter 4: Connection Failure and Signaling Cost Drawbacks in Heterogeneous Wireless Networks

Chapter 5: New Procedure for Enhancing the VHO in Heterogeneous Wireless Networks

Chapter 6: New Algorithm for Enhancing the VHO in Heterogeneous Wireless Networks

Chapter 7: Conclusions and Future Work

LIST of FIGURES

LIST of TABLES

LIST of ABBREVIATIONS

2G	Second Generation.
3G	Third Generation.
3GPP	3rd Generation Partnership Project.
4G	Fourth Generation.
AAA	Authentication, Authorisation and Accounting.
AAVHO	Automatically Alternative Vertical Handover.
ABC	Always Best Connected.
AC	Admission Control.
AGW	Access Gateway.
AHP	Analytic Hierarchy Process.
AIVHO	Automatically Imperative Vertical Handover.
ANDSF	Access Network Discovery and Selection Function.
ANS	Access Network Selection.
AP	Access Point.
AS	Application Server.
ASNGW	Access Service Network Gateway.
ATIS	Alliance for Telecommunications Industry Solutions.
AUC	Authentication Unit Centre.
BBERF	Bearer Binding and Event Reporting Function.
BCE	Binding Cache Entry.
BE	Best Effort.
BER	Bit Error Rate.
BGCF	Breakout Gateway Control Function.
BS	Base Station.
BSC	Basic System Controller.
BSS (GSM)	Basic Service Set.
BSS (Wi-Fi)	Basic Station Subsystem.

BTS	Basic Transceiver System.
BU	Binding Update.
CBR	Constant Bit Rate.
CDMA	Code Division Multiple Access.
CE	Consumer Electronic.
CMR	Call to Mobility Ratio.
CN	Correspondent Node.
CoA	Care of Address.
CS	Circuit Switched.
CSCF	Call Session Control Function.
CSN	Connectivity Services Network.
DFF	Data Forwarding Function.
DHCP	Dynamic Host Configuration Protocol.
DL	Down Link.
DRX	Discontinued Reception.
DSL	Digital Subscriber Line.
DTX	Discontinued Transmission.
EDGE	Enhanced Data Rates for Global System for Mobile Communication Evolution.
EIR	Equipment Identity Register.
ENUM	Electronic Numbering.
EPC	Evolved Packet Core.
ertPS	extended non-real-time Polling Service.
ESS	Extended Service Set.
ETSI	European Telecommunication Standards Institute.
E-UTRAN	Evolved Universal Mobile Telecommunications System Terrestrial Radio Access Network.
EVDO	Evolution Data Optimised.
FA	Foreign Agent.
FAF	Forward Authentication Function.
FDD	Frequency Division Duplex.

FIS	Fuzzy logic Inference System.
FL	Fuzzy Logic.
FTP	File Transfer Protocol.
GGSN	Gateway General Packet Radio Service Support Node.
GMSC	Gateway Mobile Station Switching Centre.
GPRS	General Packet Radio Service.
GRA	Grey Relational Analysis.
GSM	Global System for Mobile Communication.
HA	Home Agent.
HAWAII	Handover Aware Wireless Access Internet Infrastructure.
HC	Hybrid Coupling.
HEL	Handover Execution Latency.
HF	Handover Factor.
HHO	Horizontal Handover.
HIP	Host Identity Protocol.
HL	Handover Latency.
HLR	Home Location Register.
HPL	Handover Preparation Latency.
HSDPA	High Speed Downlink Packet Access.
HSPA	High Speed Packet Access.
HSS	Home Subscriber Service.
HTTP	Hypertext Transfer Protocol.
IBSS	Independent Basic Service Set.
ICSCF	Interrogating Call Session Control Function.
IEEE	Institute of Electrical and Electronics Engineers.
IETF	Internet Engineering Task Force.
IMS	Internet Protocol Multimedia Subsystem.
IMT-Advanced	International Mobile Telecommunication-Advanced.
IPTV	Internet Protocol Television.
ISDN	Integrated Services Digital Network.
ISP	Internet Service Provider.

ITU-R	International Telecommunication Radio Communication Sector.
IWU	Interworking Unit.
LAN	Local Area Network.
LC	Loose Coupling.
LCWC	Loosely Coupled WiMAX Cellular.
LMA	Local Mobility Anchor.
LTE	Long Term Evolution.
MAC	Medium Access Control.
MADM	Multiple Attribute Decision Making.
MAG	Mobile Access Gateway.
MAN	Metropolitan Area Network.
MAVHO	Manually Alternative Vertical Handover.
MCC	Mobile Country Code.
MCHO	Mobile Controlled Handover.
MCNA	Mobile Controlled Network Assisted.
ME	Mobile Equipment.
MF	Membership Function.
MGC	Media Gateway Controller.
MGCF	Media Gateway Control Function.
MGW	Media Gateway.
MICS	Media Independent Command Service.
MIES	Media Independent Event Service.
MIH	Media Independent Handover.
MIHF	Media Independent Handover Function.
MIIS	Media Independent Information Service.
MIMO	Multiple Input Multiple Output.
MIPv4	Mobile Internet Protocol version 4.
MIPv6	Mobile Internet Protocol version 6.
MME	Mobility Management Entity.
MN	Mobile Node.
MN_MM	Mobile Node Mobility Manger.

MNC	Mobile Network Code.
MPEG	Moving Pictures Expert Group.
MPLS	Multiprotocol Label Switching.
MRFC	Media Resource Function Controller.
MRFP	Multimedia Resource Function Processor.
MS	Mobile Station.
MSC	Mobile Station Switching Centre.
MU	Mobile User.
MUAR	Mobile User and Advertisement Router.
MUHA	Mobile User and Home Agent.
NAI	Network Access Identifier.
NAP	Network Access Provider.
NCHO	Network Controlled Handover.
NCMA	Network Controlled Mobile Assisted.
NE	Network Element.
NET_MM	Network Mobility Manager.
NGWS	Next Generation Wireless Systems.
NN	Neural Network.
nrtPS	non-real-time Polling Service.
NSP	Network Service Provider.
NSS	Network and Switching Subsystem.
OFDMA	Orthogonal Frequency Division Multiple Access.
OMC	Operation Maintenance Centre.
OSS	Operation Support Subsystem.
PBA	Proxy Binding Acknowledge.
PBU	Proxy Binding Update.
PCEF	Policy and Charging Enforcement Function.
PCRF	Policy and Charging Rules Function.
PCSCF	Proxy Call Session Control Function.
PDP	Packet Data Protocol.
PFMIPv6	Proxy First Mobile Internet Protocol version 6.

PGW	Packet Data Network Gateway.
PKM	Privacy Key Management.
PLMN	Public Land Mobile Network.
PMIPv6	Proxy Mobile Internet Protocol version 6.
PoA	Point of Attachment.
PoC	Push to-talk-over Cellular.
PoS	Point of Service.
PS	Packet Switched.
PSNR	Peak Signal to Noise Ratio.
PSTN	Public Switched Telephone Network.
QoS	Quality of Service.
RAN	Radio Access Network.
RAS	Radio Access Station.
RAT	Radio Access Technology.
RLC	Radio Link Control.
RNC	Radio Network Control.
RNS	Radio Network Subsystem.
RRM	Radio Resource Management.
RSS	Received Signal Strength.
rtPS	real-time Polling Service.
SAE	System Architecture Evolution.
SAW	Simple Additive Weighting.
SC	Single Carrier.
SCFDMA	Single Carrier Frequency Division Multiple Access.
SDU	Service Data Unit.
SGSN	Serving General Packet Radio Service Support Node
SGW	Serving Gateway.
SIM	Subscriber Identity Module.
SIP	Session Initiation Protocol.
S-MAG	Source-Mobile Access Gateway.
SMS	Short Message Service.

SN	Source Node.
SNR	Signal to Noise Ratio.
SoRs	Sufficient of Resources.
SS	Subscriber Station.
SS7	Signaling System Number 7 Protocol.
TC	Tight Coupling.
TCWC	Tightly Coupled WiMAX Cellular.
TDD	Time Division Duplex.
TDM	Time Division Multiplexing.
TDMA	Time Division Multiple Access.
THIG	Topology Hiding Interworking Gateway.
TMAG	Target Mobile Access Gateway.
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution.
UE	User Equipment.
UGS	Unsolicited Grant Service.
UL	Up Link.
UMTS	Universal Mobile Telecommunications System.
USIM	Universal Mobile Telecommunications System Subscriber Identity Module.
VGSN	Virtual General Packet Radio Service Support Node.
VHL	Vertical Handover Latency.
VHO	Vertical Handover.
VIP	Virtual Internet Protocol.
VLR	Visitor Location Register.
VoD	Video on Demand.
VoIP	Voice over Internet Protocol.
VPN	Virtual Private Network.
WAG	Wireless Local Area Network Access Gateway.
WAN	Wide Area Network.
WCDMA	Wideband Code Division Multiple Access.
WEP	Wireless Equivalent Privacy.
Wi-Fi	Wireless Fidelity.

WiMAX	Worldwide Interoperability for Microwave Access.
WLAN	Wireless Local Area Network.
WNSF	Wireless Network Selection Function.

LIST of SYMBOLS

$1/C_i$	Low Service Cost.
$1/L_i$	Low Network Latency.
$1/P_i$	Low Battery Power Requirement.
A	Set of Alternatives.
B	Matrix.
B_{wl}	Bandwidth of the Wireless Link.
C	Set of Handover Decision Criteria (Attributes) that can be Expressed as Fuzzy Sets in the Space of Alternatives.
CA_i	High Network Coverage Area.
D_i	High Data Rate.
E_i	Good Security.
$f_i(u)$	Objective Function Evaluated for a Network.
K	Number of Available Radio Access Technologies (RATs).
LAUTRD	Latency of Authentication Respond.
LAUTRT	Latency of Authentication Request.
LRATMU	Latency of Target Radio Access Technology (RAT) Passed to Mobile User (MU).
LTB	Latency of Binding Update.
LTBA	Latency of Binding Acknowledgment with Home Agent.
L_{wl}	Latency of the Wireless Link.
$N_f(X)$	Normalized Function of a Parameter.
Pkt_loss	Percentage of Packet Loss.
PP_x	Router or Agent Route Lookup Latency and Packet Processing Latency.
p_1	Probability of Successful Checking Resources on Available Radio Access Technologies (RATs).
p_2	Probability of Minimising Vertical Handover (VHO) Connection Failure.

R	Number of Available Successful Radio Access Technologies (RATs).
R_i	High Reliability.
S_{ctrl}	Average Size of a Control Message.
S_i	Good Signal Strength.
T_{AA}	Time Latency for Automatically Alternative Vertical Handover (VHO) Trigger.
T_{agt_adv}	Period at Which Access Point (AP)/Base Station (BS) Sends Agent Advertisement over the Wireless Link.
T_{AI}	Time Latency for Automatically Imperative Vertical Handover (VHO) Trigger.
T_{AN-MAG}	Latency between Access Point (AP)/Base Station (BS) and Mobile Access Gateway (MAG).
TBS	Time of the Buffering Signaling.
t_{cell}	Value of Cell Residence Time.
$T_{DOMAIN-AAA}$	Latency between Entities in Proxy Mobile Internet Protocol version 6 (PMIPv6)-Domain and Authentication, Authorisation and Accounting (AAA)/Media Independent Information Service (MIIS) Server.
T_{MA}	Time Latency for Manually Alternative Vertical Handover (VHO) Trigger.
$T_{MAG-LMA}$	Latency between Mobile Access Gateway (MAG) and Local Mobility Anchor (LMA).
T_{MU-AN}	Latency between Mobile User (MU) and Access Point (AP)/Base Station (BS).
U	Vector of Input Parameters.
V	Unit Eigenvector.
VHL	Vertical Handover (VHO) Latency
$VHL_{Combination}$	Vertical Handover (VHO) Latency of Combination Procedure between Media Independent Handover (MIH) and Access Network Discovery and Selection Function (ANDSF).

$\boldsymbol{VHL_{I\,AM\,4\,VHO}}$	Vertical Handover (VHO) Latency for Imperative Alternative Media Independent Handover (MIH) for Vertical Handover Procedure.
$\boldsymbol{VHL_{802.21}}$	Vertical Handover (VHO) Latency for IEEE 802.21-Enabled PMIPv6 Procedure.
$\boldsymbol{VHL_{PFMIPv6}}$	Vertical Handover (VHO) Latency for Proxy First Mobile Internet Protocol version 6.
$\boldsymbol{VHL_{PMIPv6}}$	Vertical Handover (VHO) Latency for Proxy Mobile Internet Protocol version 6.
$\boldsymbol{VL_i}$	Good Mobile Terminal Velocity.
$\boldsymbol{W}$	Weighting Matrix.
$\boldsymbol{w_X}$	Weight Which Indicates the Importance of a Parameter.
$\boldsymbol{Y}$	Base Station (BS) in a Cellular Coverage Area.
$\boldsymbol{y_t}$	Only One Target Base Station (BS) Selected.
$\boldsymbol{Z}$	Access Point (AP) in a Cellular Coverage Area.
$\boldsymbol{z_t}$	Only One Target Access Point (AP) Selected.
$\boldsymbol{\lambda_{max}}$	Maximum Eigenvalue.
$\boldsymbol{\mu_{Ci}(A_j)}$	Degree of Membership of Alternative A_j in the Criterion C_i.
$\boldsymbol{p}$	Probability of Successful Checking Resources on any Individual Radio Access Technology (RAT).
$\boldsymbol{q}$	Probability of Failure Checking Resources on any Individual Radio Access Technology (RAT).

Chapter 1

Thesis Introduction and Methodology

1.1 Introduction

With the advancement of RATs, mobile communications has been more widespread than ever before. Therefore, the number of users of mobile communication networks has increased rapidly. For example, it has been reported that “today, there are billions of mobile phone subscribers, close to five billion people with access to television and tens of millions of new internet users every year” [1] and there is a growing demand for services over broadband wireless networks due to the diversity of services which can’t be provided with a single wireless network anywhere, anytime [2, 3, 4, 5 and 6]. This fact means that heterogeneous environment of wireless systems such as Global System for Mobile Communication (GSM), Wireless Fidelity (Wi-Fi), Worldwide Interoperability for Microwave Access (WiMAX), Universal Mobile Telecommunications System (UMTS) and Long Term Evolution (LTE) will coexist providing Mobile Users (MUs) with roaming capability across different networks. These heterogeneous wireless access networks vary widely in terms of multiple attributes such as coverage area, supported data rate for services and cost [3]. This in turn means that each wireless access network has its different characteristics. For example, Third Generation (3G) wireless networks like UMTS can provide a high coverage area, but it supports low data rate which is insufficient to satisfy data intensive applications (e.g., video streaming requires high data rate for better performance) as well as having a very high service cost. In contrast the Wi-Fi wireless network provides a high data rate, low cost but low coverage area. The limitations of these wireless access networks can be overcome by joining these technologies through Vertical Handover (VHO) interworking architectures which is essential to provide ubiquitous wireless access ability with high coverage area, high data rate and low cost to MUs. Therefore, multiple networks (3rd Generation Partnership Project (3GPP) e.g., UMTS and non-3GPP e.g., WiMAX), multiple services (e.g., web browsing, file downloading and streaming application) and multiple radio interfaces (multimode mobile terminal) are three main things which should be taken into account when considering heterogeneous wireless networks.

The main focus of this thesis is to develop a VHO approach to optimise the performance of VHO in heterogeneous wireless network environment. This chapter begins with section 1.1.1 introducing the problem statement and motivation of the research in this thesis, followed by 1.1.2 which presents thesis contributions. Then, section 1.1.3 presents the research methodology. In section 1.2.1, a summary of publications and awards is presented. In section 1.2.2, a summary of training sessions is presented and finally, the thesis organisation is presented in section 1.3.

1.1.1 Problem Statement and Motivation

In the literature, a variety of VHO approaches have been proposed to provide seamless VHO. A detailed survey of these proposed approaches can be found in (chapter 3, [88, 109 and 115]) and (chapter 4, [137]) of this thesis. These VHO approaches lack an exhaustive consideration of details on network operation in case of VHO decision criteria either imperatively due to the network conditions such as Radio Signal Strength (RSS) or alternatively due to the user's preferences such as high security. Another problem is that the studies reporting these approaches lack adequate detail for implementation. Besides, there are two more problems with the existing VHO approaches. The first one is that these approaches tend to provide seamless VHO by improving packet loss and latency performance. However, new logical entities are necessary to achieve this goal, this inevitably leads to an increased complexity and additional implementation cost. The second problem is that these approaches mainly concentrate on the packet loss and latency while the connection failure and the signaling cost, two of vital factors in providing seamless VHO, have not been considered thoroughly.

The research project presented in this thesis provides an optimised VHO approach. It demonstrates better performance (packet loss, latency and signaling cost), less VHO connection failure (probability of minimising VHO reject sessions), less complexity and an enhanced VHO compared with that found in the literature.

1.1.2 Thesis Contributions

We present a new approach based on the VHO approaches that have been studied in the literature for enhancing the VHO heterogeneous wireless network environment. It can be implemented with the Media Independent Handover (MIH) framework which is more flexible and has better performance compared with the available VHO techniques found in the literature. The proposed approach considers and tackles four main VHO mobility elements which are responsible to provide seamless VHO in heterogeneous wireless network environment and which have yet to be addressed thoroughly in the literature. These four elements are: packet loss, latency, signaling cost and probability of VHO connection failure (probability of minimising VHO reject sessions). The proposed approach consists of a procedure with three phases which is implemented by an algorithm to provide significant improvements on the VHO phases compared with that found in the literature. These three phases, as described below, are: Handover Initiation, Handover Decision and Handover Execution. These three phases are described below.

1. **Handover Initiation**

A handover initiation phase is presented which provides details on network operation in case of VHO initiated imperatively due to RSS or alternatively due to the user's preferences (e.g., low cost, high data rate and low latency) and taking into account higher priority to execute imperative session (i.e. more exhaustive). This phase is also responsible for deciding when and where to perform the handover by choosing the best RATs from the multiple ones available and then pass them to the decision phase. This results in reducing the signaling cost and the inevitable degradation in QoS as a result of avoiding unnecessary handover processes.

2. **Handover Decision**

A handover decision phase is presented using a VHO algorithm based on our approach which achieves less VHO connection failure (probability of minimising VHO reject sessions) as a result of using the optimum RATs list of priority.

3. **Handover Execution**

A handover execution phase is presented which helps to provide better VHO performance with minimal packet loss (softer) and minimal latency (faster) due to buffering new data packets earlier.

1.1.3 Research Methodology

The research methodology that has been used is an iterative process where new ideas have been added to existing solutions found in the literature and published previously. Feedback from supervisor, examiners, senior scientists and reviewers at meetings, assessments, conferences and journals, has been taken into account. The following research methodology has been developed and adopted for this research program. The main phases of the methodology are shown in Figure.1.1.

1. **Reviewing previous literature**

First of all, we have reviewed the evolution of wireless access networks and the handover management within heterogeneous wireless networks. Then, we have surveyed previous relevant works about a variety of VHO approaches which have been proposed to provide seamless VHO. We have acquired good knowledge for developing a VHO approach to optimise the performance of VHO in heterogeneous wireless network environment by performing a comprehensive study from previous literature.

2. **Identification, studying and analysing the research problems**

In order to identify the research problems accurately, we have presented and published four surveys about VHO approaches found in the literature (chapter 3, [88, 109 and 115]) and (chapter 4, [137]). In these surveys, we have classified the existing VHO approaches into categories based on the available VHO techniques for which we have presented their objectives and performances issues.

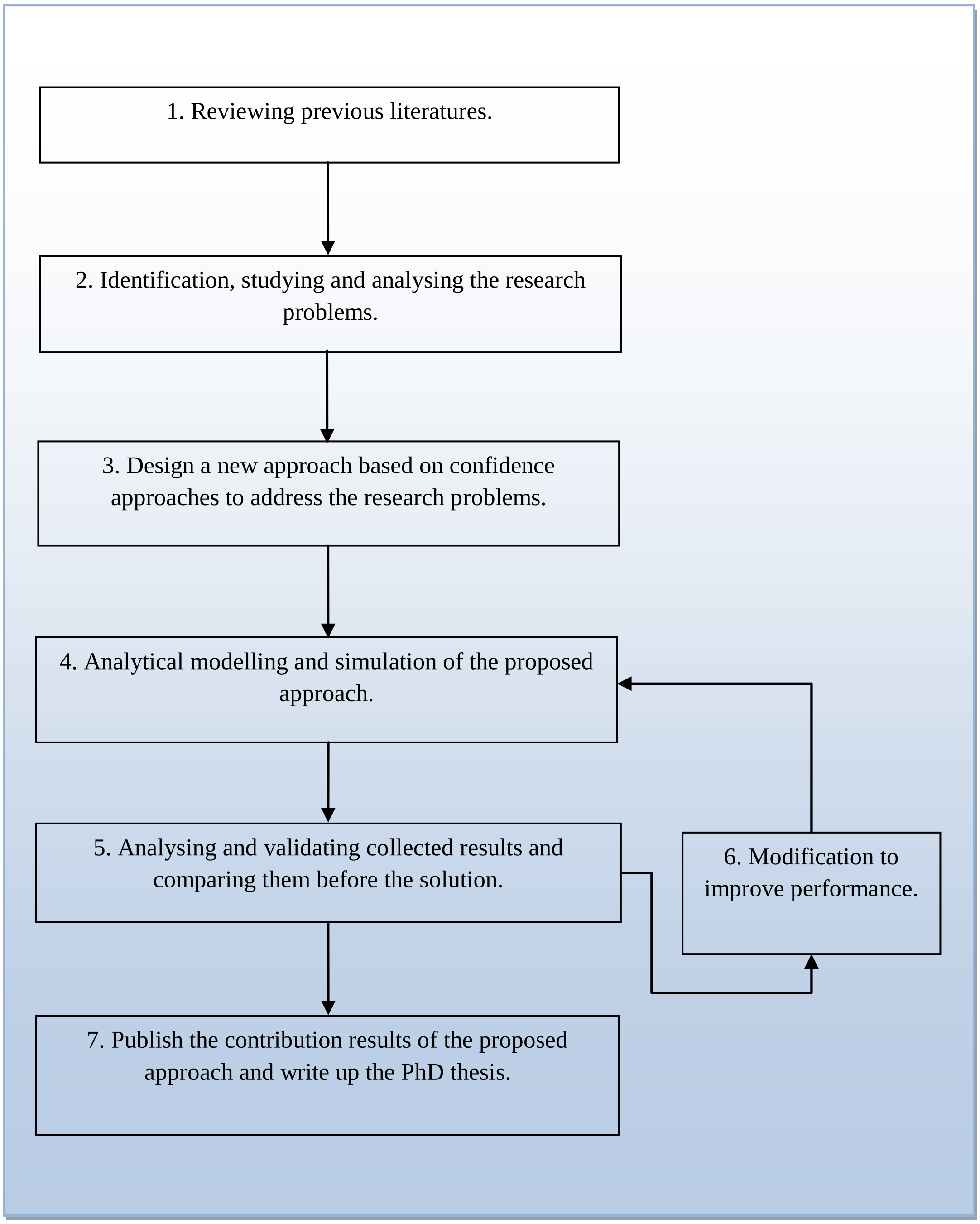

Figure 1.1: Research Methodology

3. **Design a new approach based on confidence approaches to address the research problems**

It should take into consideration the research problems which have arisen in previous phase (chapter 3, [88, 109 and 115]) and (chapter 4, [137]). Therefore, we have presented and published our approach in (chapter 5 (5.2, 5.2.1) and chapter 6 (6.2), [92]) based on the VHO approaches that have been studied in the literature for enhancing the VHO heterogeneous wireless network environment. The proposed approach consists of a procedure which is implemented by an algorithm.

4. **Analytical modelling and simulation of the proposed approach**

In this phase, we have provided analytical and simulation results of our approach.

5. **Analysing and validating collected results and comparing them before the solution**

In this phase, we have focused on the validation of the proposed approach in order to test and analyse its performance and reliability. The effectiveness of the new approach has been tested and validated.

6. **Modification to improve performance**

In this phase, we have used our validation of the test results to modify and improve the performance of the proposed approach; the thing which allowed us to produce an improved version.

7. **Publish the contribution results and write up the PhD thesis**

In this phase, the results of the proposed approach of procedure and algorithm have been presented and published in (chapter 5 (5.2.1.1, 5.2.1.1.1 and 5.2.1.2), [141, 142]) and (chapter 6 (6.2.1, 6.2.1.1 and 6.2.2), [145, 146]), respectively and the writing of the complete PhD thesis has been finished.

1.2 Summary of Publications, Awards and Training Sessions

1.2.1 Summary of Included Publications and Awards

Refereed Journal Articles

1. Khattab, O.; Alani, O.;, "Simulation of Performance Execution Procedure to Improve Seamless Vertical Handover in Heterogeneous Networks," *International Journal of Advanced Computer Science and Applications (IJACSA)*, vol. 5, no. 6, Jun 2014, pp. 109-113.

2. Khattab, O.; Alani, O.;, "A Survey on MIH vs. ANDSF: Who Will Lead the Seamless Vertical Handover Through Heterogeneous Networks?," *International Journal of Future Generation Communication and Networking (IJFGCN)*, vol. 6, no. 4, Aug 2013, pp. 1-11.

3. Khattab, O.; Alani, O.;, "A Survey on Media Independent Handover (MIH) and IP Multimedia Subsystem (IMS) in Heterogeneous Wireless Networks," *International Journal of Wireless Information Networks (IJWIN)*, Springer, vol. 20, no. 2, Jun 2013, pp. 215-228.

4. Khattab, O.; Alani, O.;, "I AM 4 VHO: New Approach to Improve Seamless Vertical Handover in Heterogeneous Wireless Networks," *International Journal of Computer Networks & Communications (IJCNC)*, vol. 5, no. 3, May 2013, pp. 53-63.

5. Khattab, O.; Alani, O.;, "Mobile IPv4 Based Procedure for Loose Coupling Architecture to Optimise Performance in Heterogeneous Wireless Networks," *International Journal of Computer Networks and Wireless Communications (IJCNWC)*, vol. 3, no. 1, Feb 2013, pp. 56-61.

<u>Papers in Refereed External Published Conferences Proceedings</u>

1. Khattab, O.; Alani, O.;, “Algorithm for Seamless Vertical Handover in Heterogeneous Mobile Networks,” *IEEE Technically Co-Sponsored Science and Information Conference,* 27-29 Aug 2014, pp. 1-8.

2. Khattab, O.; Alani, O.;, “The Design and Calculation of Algorithm for Optimising Vertical Handover Performance,” *9th IEEE/IET International Symposium on Communication Systems, Networks and Digital Signal Processing 2014 (CSNDSP 2014)*, 23-25 Jul 2014, pp. 421-426.

3. Khattab, O.; Alani, O.;, “An Overview of Interworking Architectures in Heterogeneous Wireless Networks: Objectives, Features and Challenges,” *10th International Network Conference 2014 (INC 2014)*, 8-10 Jul 2014, pp. 71-79.

4. Khattab, O.; Alani, O.;, “Survey on Media Independent Handover (MIH) Approaches in Heterogeneous Wireless Networks,” *IEEE 19th European Wireless 2013 (EW 2013)*, 16-18 Apr 2013, pp. 1-5.

5. Khattab, O.; Alani, O.;, “Improvements to Seamless Vertical Handover between Mobile WiMAX, Wi-Fi and 3GPP through MIH,” *13th Annual Post Graduate Symposium on the Convergence of Telecommunications, Networking and Broadcasting 2012 (PGNET 2012)*, 25-26 Jun 2012, pp. 31-35.

Abstracts in Internal Published Conferences Proceedings

1. Khattab, O.; Alani, O.;, "New Algorithm for Minimising Connection Failure in Heterogeneous Mobile Networks," *4th Computing Science and Engineering Post Graduate Conference*, 13 Nov 2013, Salford University, Salford, UK.

2. Khattab, O.; Alani, O.;, "New Procedure for Improving Vertical Handover Performance in Heterogeneous Mobile Networks," *Salford Postgraduate Annual Research Conference 2013 (SPARC 2013)*, 5-6 Jun 2013, Salford University, Salford, UK.

3. Khattab, O.; Alani, O.;, "Improving Vertical Handover (VHO) Performance in Heterogeneous Mobile Networks," *3rd Computing Science and Engineering Post Graduate Conference*, 14 Nov 2012, Salford University, Salford, UK.

Posters in External Published Conferences and Events Proceedings

1. I have been selected among hundreds of applicants to present the poster, entitled "New Procedure for Improving Vertical Handover Performance in Heterogeneous Mobile Networks," *SET for Britain Exhibition in the Engineering Section, House of Commons*, 18 Mar 2013, London, UK.

2. I have been selected as one of the ten sponsored students' poster contestants, entitled "MIH vs. ANDSF: Who Will Lead the Radio Access Technologies through the Vertical Handover?," *Terena Networking Conference 2012 (TNC 2012)*, 21-24 May, Reykjavík University, Reykjavík, Iceland.

Posters in Internal Published Conferences and Events Proceedings

1. Prize winner for best poster, entitled "New Algorithm for Minimising Connection Failure in Heterogeneous Mobile Networks," *Dean's Annual Research Showcase, Digital, Media and Information Technology Section,* 19 Jun 2013, Salford University, Salford, UK.

2. A poster entitled "MIH vs. ANDSF: Who Will Lead the Radio Access Technologies through the Vertical Handover?," *Dean's Annual Research Showcase*, *Digital, Media and Information Technology Section* , 20 Jun 2012, Salford University, Salford, UK.

3. A poster entitled "Technical Challenges with Ubiquitous Networks," *Salford Postgraduate Annual Research Conference 2012 (SPARC 2012)*, 30-31 May 2012, Salford University, Salford, UK.

The Dean's Prize for Postgraduate Research Student

1. I have been awarded the Dean's Prize for postgraduate student in recognition of my outstanding research work and achievements as a postgraduate research student, *Dean's Annual Research Showcase,* 18 Jun 2014, Salford University, Salford, UK.

1.2.2 Summary of Included Training Sessions

Internal Training Sessions (Salford University, Salford, UK)

1. 7-May-2014 Locating and Using Archives for Research.
2. 31-Jan-2013 Structuring Your Research Finding.

3. 21-Jan-2013 Abstract Writing.
4. 4-Dec-2012 PhD Progression Points.
5. 29-Nov-2012 Applying a Project Management Approach to Progress your Work.
6. 1-Nov-2012 Critical Thinking at Postgraduate Level.
7. 31-Oct-2012 Supporting and Motivating your Research.
8. 28-Mar-2012 Publishing Papers in Refereed Journal.
9. 28-Mar-2012 Maximizing Impact at Conferences.
10. 22-Mar-2012 Online Copyright.
11. 14-Mar-2012 Information Management for the Web.

External Summer School

1. *Communications, Networking and Photonics*, 18-22 Jun 2012, Edinburgh University, Edinburgh, UK.

Internal Workshops (Salford University, Salford, UK)

1. 12 Jun 2012 Approaching Publishers: Guidance for Academic Authors.

Internal Seminars (Salford University, Salford, UK)

1. How Can ICT Support Collaborative Work? Drivers and Challenges, 21 Mar 2012.

2. Data Centre Challenges, CISCO, 14 Mar 2012.

1.3 Thesis Organisation

The structure of the thesis comprises of six chapters, set out as follows:

Chapter 1: in this chapter, we have given a brief introduction to the subject matter provided, introducing the reader to the problem statement and motivation. We also have listed contributions and research methodology. Finally, summary of publications, awards and training sessions have been presented.

Chapter 2: in this chapter, we give a critical overview of the evolution of wireless access networks and the handover management within heterogeneous wireless networks. Five basic questions define this chapter to clearly understand the purpose of this research study: how have wireless access networks evolved? What are heterogeneous wireless networks? Who needs heterogeneous wireless networks? Why are heterogeneous wireless networks necessary? and finally, what is the handover management within heterogeneous wireless networks?.

Chapter 3: in this chapter, we present three surveys of VHO approaches for which we present their objectives and performances issues. In the first one, we survey two main VHO interworking architectures: loose coupling and tight coupling and highlight their objectives, features and challenges. In the second one, we present a comprehensive survey of VHO approaches designed to provide seamless VHO based on MIH and IP Multimedia Subsystem (IMS) frameworks. To offer a systematic and exhaustive comparison in this survey, we present two types of comparison: a comparison between the frameworks (MIH and IMS) and a comparison between the four categories based on these frameworks (MIH based category, IMS based category, Mobility Internet Protocol (MIP) under IMS based category and MIH and IMS combination based category). In the third one, we survey the VHO approaches proposed in the literature that applied in conjunction with MIPv4 and MIPv6 under MIH. In this survey, we classify the VHO approaches into two categories based on MIPv4 and MIPv6 under MIH.

Chapter 4: in this chapter, we present a comprehensive survey of VHO approaches designed to provide seamless VHO based on MIH and Access Network Discovery and Selection Function (ANDSF) mechanism for which we present their objectives and performances issues. To offer a systematic comparison in this survey, the VHO approaches are categorised into three groups based on MIH and ANDSF: ANDSF based VHO approaches, MIH based VHO approaches and MIH and ANDSF combination based VHO approaches.

Chapter 5: in this chapter, we present our Imperative Alternative Media Independent Handover for Vertical Handover (I AM 4 VHO) approach which based on the VHO approaches that have been studied in the literature. It consists of a procedure which is implemented by an algorithm. We present the proposed I AM 4 VHO procedure as the first part of our approach for providing seamless VHO with minimal packet loss and latency.

Chapter 6: in this chapter, we present the proposed I AM 4 VHO algorithm as the second part of our approach for providing seamless VHO with a lower probability of VHO connection failure, signaling cost and inevitable degradation in QoS.

Chapter 7: in this chapter, we summarise the overall contents of the thesis and outline the future work.

Chapter 2

Background and Overview

2.1 Introduction

The rapid evolutions in broadband wireless networks and the growing MU's demand for communication services anywhere, anytime are driving an evolution toward the seamless integration between different RATs in heterogeneous wireless networks to provide the best connected services to the MU constantly [3]. The benefits of heterogeneous wireless networks are many and varied. These include: flexibility, reducing cost, simplifying the operation and maintenance, rapid deployment of services and applications, new services, high data transmission, customisation, support multimedia services at lower cost of transmission, the mobility of the sessions and the possibility to transfer the context [3].

In order to make this chapter more clear and understandable for general readership, we divide its sections into questions as follows: in sections 2.2, 2.3, 2.4, 2.5 and 2.6, background information on heterogeneous wireless networks are presented to answer the following questions respectively: how have wireless access networks evolved? What are heterogeneous wireless networks? Who needs heterogeneous wireless networks? Why are heterogeneous wireless networks necessary? and finally, what is the handover management within heterogeneous wireless networks. In the last section 2.7, some conclusions are presented.

2.2. How Have Wireless Access Networks Evolved?

Nowadays, wireless communication technologies have become an integral part of people's daily life and businesses all over the world. Due to the rapid increase in the number of the MUs who demand the service of communicating via wireless networks, the wireless access networks have evolved from the first generation to the fourth generation.

This section presents a background of those main access networks technologies; namely, GSM, UMTS, Wi-Fi, WiMAX and LTE.

2.2.1 Global System for Mobile Communication (GSM)

Global System for Mobile Communication (GSM) is a Second Generation (2G) wireless access technology. The GSM is the first cellular system to specify digital modulation and network level architectures and services, the first important set of Radio Frequency (RF) for GSM standard started at 1900 MHz [7]. The GSM was first introduced in Europe in 1991 and today is one of the most popular digital cellular telecommunications systems widely used over the world [7]. Due to the increase of the number and the requirement of GSM subscriber the GSM wireless access technology is still an attractive area for research in the field of mobile telecommunication [7, 8 and 9].

A variety of services are offered by GSM wireless access technology. The GSM services are a subset of Integrated Services Digital Network (ISDN) services and the most basic and important service offered by the system is telephony [10, 11 and 12]. In addition, GSM can send and receive several types of data services at bit rates up to 9600 bps [10, 11 and 12].

GSM uses two bands of 25 MHz: 890-915 MHz and 935-960 MHz for transmitting and receiving, respectively and it also uses Frequency Division Duplex (FDD), Frequency Division Multiple Access (FDMA) and Time Division Multiple Access (TDMA) [7, 9]. The receive band is divided into 128 channels each with 200 KHz bandwidth, each channel is shared between as many as eight users [7]. The GSM system is mainly built up of three parts: Network and Switching Subsystem (NSS), Basic Station Subsystem (BSS) and Operation Support Subsystem (OSS) [7]. The NSS includes the equipment and functions related to end-to-end calls, management of subscribers, switching and communicating with other networks such as ISDN and Public Switched Telephone Network (PSTN) [7]. The NSS includes the following units: Mobile-Station Switching Centre (MSC), Home Location Register (HLR), Visitor Location Register (VLR), Authentication Unit Centre (AUC) and Equipment Identity Register (EIR) [7], this is shown in Figure.2.1. The HLR is a centralised database that contains subscriber information and location information of all the users residing in the area of MSC [7]. The VLR is a database of all roaming mobiles in the area of MSC but not residing there [7]. The AUC is a database that provides HLR and VLR with authentication parameters and encryption keys required for security purposes [7]. The EIR is a database that includes numbers of all registered mobile units [7]. The BSS is built up of Basic System Controller (BSC), Basic Transceiver System (BTS) and Mobile Station (MS), also the BSS consists of many of BSCs each of which controls many BTSs and it is associated with the channel management, transmission functions and radio link control [7]. The BSS provides and manages radio transmission paths between MSs and MSC which is the heart of NSS and it provides call setup, routing, switching, handover and other functions [7]. The BSS also manages the radio interface between MSs and all other subsystems of GSM while OOS is built up of Operation Maintenance Centre (OMC) and system software which manages and monitors whole GSM system [7].

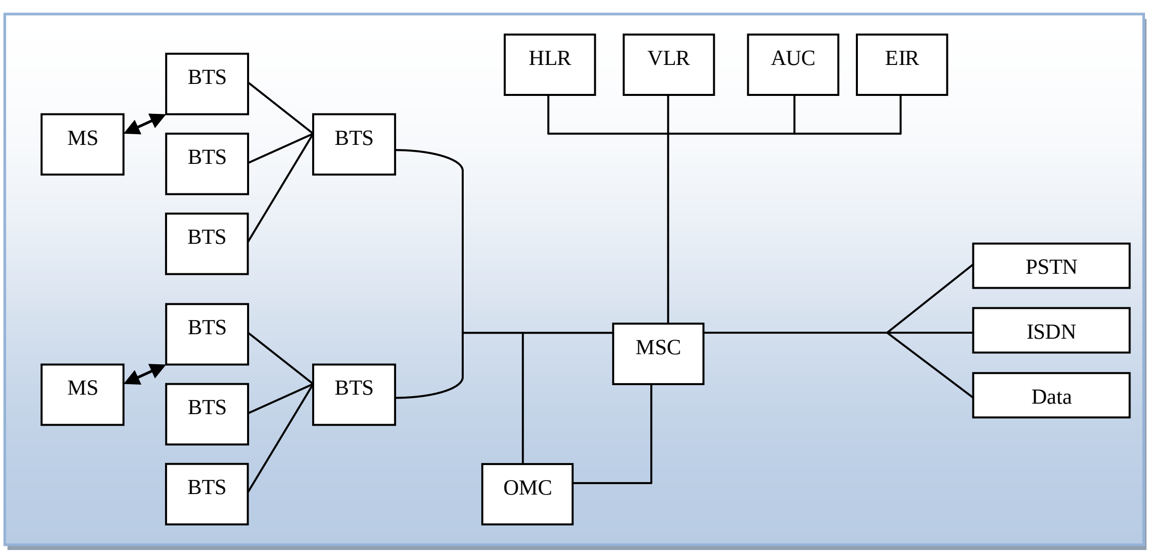

Figure 2.1: Global System for Mobile (GSM) Structure [7]

The disadvantage in the GSM technology occurs when a radiation noise is generated from an antenna propagation signal of a Smartphone [9]. This leads the voice quality of the Smartphone to be degraded [9].

2.2.2 Universal Mobile Telecommunications System (UMTS)

2G systems like GSM were originally designed for efficient delivery of voice services. 3G systems like UMTS were designed from the beginning for mobile voice and data users [5]. Therefore, UMTS is the evolution of GSM system and General Radio Packet Service (GPRS) developed by Third Generation Partnership Project (3GPP) to increase the support for some features such as data rate in radio interface and the compatibility for the two services domains: Packet Switched (PS) and Circuit Switched (CS) data transmission [13]. Some of the most common keys drive of this type of UMTS access technology [14]:

- Growth in the market for fixed networked multimedia services.
- Increasing demand for rapid and remote access to information.
- E-Commerce and transaction based applications.

The key enablers of UMTS [14]:

- Appropriate regulatory framework.
- Advances in spectrum efficient radio technologies and data compression techniques.
- Development of open UMTS standards.
- Improvements in user interface design and display technologies.
- Reduced size, power and cost of mobile devices.
- Early exploitation of GPRS and GSM2 and services.

The UMTS provides different types of services [14, 15 and 16]:

- Mobile services such as voice, email, fax and Short Message Service (SMS).

- Mobile multimedia services
  - Medium: asymmetric, bursty typically less than 1 Mbyte (e.g., Local Area Network (LAN)/internet access and on-line shopping).
  - High: asymmetric, bursty, high data rate (e.g., fast LAN/internet access for large reports with graphics and video clips).
  - High interactive: asymmetric and continuous, real time applications requiring minimum delay (e.g., videoconferencing and collaborative working).
- Physical layer: the radio access using Wideband Code Division Multiple Access (WCDMA) as underlying air radio interface. The WCDMA supports both FDD and Time Division Duplex (TDD) modes of operation.
- Data rate: the UMTS supports different data rates depending on propagation channel condition and the moving speed of mobile. For example, user moving over than 120 Km/h with maximum 500 Km/h in rural areas can expect speeds of 144 Kbps, user moving less than 120 Km/h and urban outdoor environment can expect rates of 384 Kbps, users indoor or moving at less 10 Km/h can reaches speed 2Mbs [3].
- Radio Link Control (RLC): the RLC part of the data link layer takes care of issues such as acknowledged and unacknowledged data transfer, transparency, QoS settings, error notification and the establishment of RLC connections.
- Low delays with packet round trip times below 200 ms.
- Seamless mobility also for packet data applications.
- QoS differentiation for high efficiency of service delivery.
- Simultaneous voice and data capability.
- Interworking with existing GSM/GPRS networks.
- Security: the UMTS improved security features come from five security keys:
  - Network access security is designed to provide secure access to users for 3G services and to protect any potential attacks on the radio access link.
  - Network domain provides security in the core network and protects a network against attacked from the wired interface.

- User domain security features provide secure access to MUs.
- Application domain security features support the secure exchange of messages between the user and provider domains.
- Visibility and configurability security allow for the configuration of security features by the user on the device.

In the Figure.2.2, the architecture of UMTS network consists of three different blocks. the first one, User Equipment (UE) which is composed of Mobile Equipment (ME) and UMTS Subscriber Identity Module (USIM) card [16]. The ME is the radio terminal used for radio communication over Uu interface while USIM is a smartcard that includes the subscriber identity, performs authentication algorithms and stores authentication and encryption keys and some subscription information that are needed at the terminal [16]. The second one, UMTS Terrestrial Radio Access Network (UTRAN) comprises sets of NodeB and Radio Network Controller (RNC) [16]. The NodeB converts the data flow between Iub and Uu interfaces, it also participates in radio resource management [16]. The RNC owns and controls the radio resources in its domain as it is the service access point for all services UTRAN which provides the core network; for example, management of connections to UE [16]. The third one, GSM/UMTS core network. A brief description of the elements of GSM/UMTS core network is provided as follows [16]:

- HLR: the HLR is a centralised database located in the user's home system that stores the master copy of the user's service profile. The service profile consists of important things such as information on allowed services, forbidden roaming areas and supplementary service information (e.g., status of call forwarding and call forwarding number). It is created when any new user subscribes to the system and it remains stored as long as the subscription is active. In order to routing incoming transactions to UE (e.g., calls or short messages) the HLR also stores the UE's location on the level of MSC/VLR and/or SGSN.

- MSC/VLR: the MSC/VLR is the switch (MSC) and database (VLR) that serves the UE in its current location for CS services. The MSC function is used to switch the CS transactions while VLR function includes a copy of the visiting user's service profile and more precise information on UE's location within the serving system. The part of the network that is accessed via MSC/VLR is often referred to as CS domain. The MSC also has a role in the early UE handling.
- Gateway Mobile-Station Switching Centre (GMSC): the GMSC is the switch at the point where UMTS Public Land Mobile Network (PLMN) is connected to the external CS networks. All incoming and outgoing CS connections go through GMSC.
- Serving General Packet Radio Service Support Node (SGSN) functionality: the SGSN is similar to that of MSC/VLR but it is usually used for PS services. The support is also required for early UE handling operation like SGSN and MSC.
- Gateway General Packet Radio Service Support Node (GGSN) functionality: the GGSN is close to that of GMSC but is in relation to PS services.

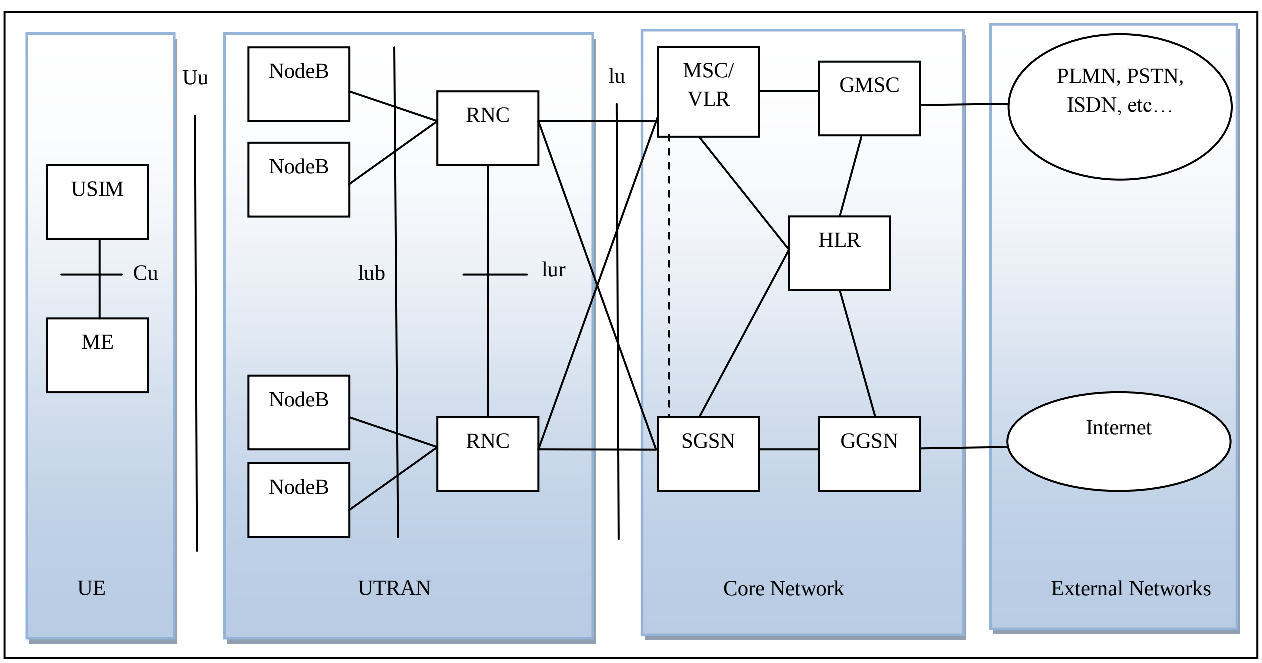

Figure 2.2: Universal Mobile Telecommunications System (UMTS) Architecture [16]

The external networks consist of CS and PS networks. The CS support connections like the existing telephony service (e.g., ISDN and PSTN). The PS supports connections for packet data services (e.g., internet) [16].

In UMTS system there are number of interfaces between the logical networks elements which have been defined as follows [16]:

- Cu interface: this is the communication interface between USIM smartcard and ME. It matches a standard format for smartcards.
- Uu interface: this is the WCDMA radio interface. The Uu is the interface through which UE accesses the fixed part of the system and is therefore probably the most important open interface in UMTS.
- Iu interface: this is the communication interface between UTRAN and the core network. Similarly to the corresponding interfaces in GSM. It supports different protocol stacks for interfacing with CS or PS. The open Iu interface gives UMTS operators the possibility of acquiring UTRAN and core network from different manufacturers.
- Iur interface: the open Iur interface allows the communication interface between adjacent RNCs from different manufacturers and therefore complements the open Iu interface.
- Iub interface: the Iub is the physical communication interface between NodeB and RNC.

From a UMTS network perspective, 3GPP defines different QoS classes: conversational class, streaming class, interactive and background class [17, 18, 19, 20, 21 and 22]. Table.2.1 shows the different traffic type and their QoS constraints [23, 24]. These QoS constraints can be used as a basis for decision making (e.g., priorities video streaming over web browsing traffic) [25]. The QoS classes are discussed in [17, 18, 19, 20, 21, 22 and 26]:

- Conversational class: the conversational class services are mainly for conversational real time applications such as voice, video telephony and video gaming. This class services can be supported by fixed resource allocation in the network. This class is the most sensitive to delay.
- Streaming class: the streaming class services are meant for streaming media applications such as multimedia, Video on Demand (VoD) and webcast. In this class a certain amount of delay variation is tolerable due to application level buffering. Besides, this class service is a variant of the constant bit rate and real time variable bit rate services.
- Interactive class: the interactive class is applicable for services requiring assured throughput. To ensure better response times for this class a higher scheduling priority compared with the background class may be required such as web browsing, network gaming and database access. Traffic flow prioritization is taken into account within the service class.
- Background class: the background class services are for traditional best effort services such as e-mail, SMS and downloading. This is traffic has the lowest priority among all the classes. This class is class insensitive to delay.

Traffic Type	Application	Service Data Unit (SDU) Loss Rate	End to End Delay
Conversation	Voice.	$< 10^{-2}$	< 150 ms.
Streaming	Streaming.	$< 10^{-1}$	< 250 ms.
Interactive	Web.	$< 10^{-3}$	< 4 s.
Background	FTP.	$< 10^{-3}$	-

Table 2.1: UMTS Traffic Type and QoS Requirements for Different Traffic Type [25]

However, UMTS provides low data rate and high cost additional capacity in spectrum [4, 5].

2.2.3 Wireless Fidelity (Wi-Fi)

The Wi-Fi (IEEE 802.11) is wireless telecommunication system designed to provide broadband for Wireless Local Area Network (WLAN) where the users use the mobile devices (e.g., mobiles and laptops) to access the internet in small geographic area such as university's buildings, airports and railway stations. Over 97% of laptops today come with Wi-Fi as a standard feature and an increasing number of handhelds and Consumer Electronics (CEs) devices are adding Wi-Fi capabilities [27] as Wi-Fi technology in conformance with IEEE 802.11 are growing every year [28]. The initial standard IEEE 802.11, which came in 1997, had a data rate of 1 Mbps [29]. By year 1999 this was changed; 802.11a (54 Mbps at wider frequency band), 802.11b (11 Mbps, same frequency band but a different modulation technique) and 802.11g (using modulation technique of 802.11a but frequency band of 802.1lb) [29]. During the period between 1990-2000, the IEEE committee, which had already created wired LAN standards (802.3 Ethernet), started processing wireless LAN standard [29]. As Ethernet was dominant at that time, the committee decided to make wireless standard 802.11 compatible with Ethernet above data link layer; however, it was different from Ethernet in link layer and physical layer due to various issues faced the wireless communication [29]. 3GPP standard differentiates two types of Wi-Fi access technology [30]:

- Untrusted: introduced in the early stages of Wi-Fi specification in 3GPP Release 6 (2005). Untrusted access includes any type of Wi-Fi access that either is not under control of the operator (e.g., public open hotspot, subscriber's home (WLAN) or that does not provide sufficient security (e.g., authentication and encryption).
- Trusted: trusted access generally refers to operator-built Wi-Fi access with over the air encryption and a secure authentication method.

The Wi-Fi provides different types of services [30, 31 and 32]:

- Low cost: the industrial wiring is highly expensive; therefore, the wire replacement will save cost.
- Mobility: moving around (e.g., university's buildings, airports and railway stations) without losing connectivity.
- Availability of user devices that support the technology.
- Dynamic chain configuration: tighter coupling between fabric and office enables to draw an improved production environment and dynamically re-configured.
- Widespread existing deployments.
- Network administrators can set up or increase networks without installing new wires.
- Capability to address new users and devices without mobile subscription (i.e. Subscriber Identity Module (SIM)).
- Integration of services: the Wi-Fi solution can also transport office traffic, stepping forward the evolution set by industrial Ethernet, optimising network maintenance and enabling the connection to the office.
- Globally available spectrum capacity.
- Standards availability for integration into mobile networks.

However, the radio range of Access Points (APs) in Wi-Fi technology is limited; therefore, the MUs need to change the APs frequently during their movements [33]. The Wi-Fi architecture is composed of three modes: Independent Basic Service Set (IBSS), Basic Service Set (BSS) and Extended Service Set (ESS) [34]. Typical examples of IBSSs are networks formed by personal digital assistants, laptops and cell phones where these types of networks are short lived [34]. The BSS is a special station called AP which allows a network to connect with another network typically a wired network such as Ethernet but it can also be wireless [34]. Sets of BSSs can then be combined to form ESS where a roaming station in ESS needs a handover protocol to define how the APs handover connections for stations [34], this is shown in Figure.2.3.

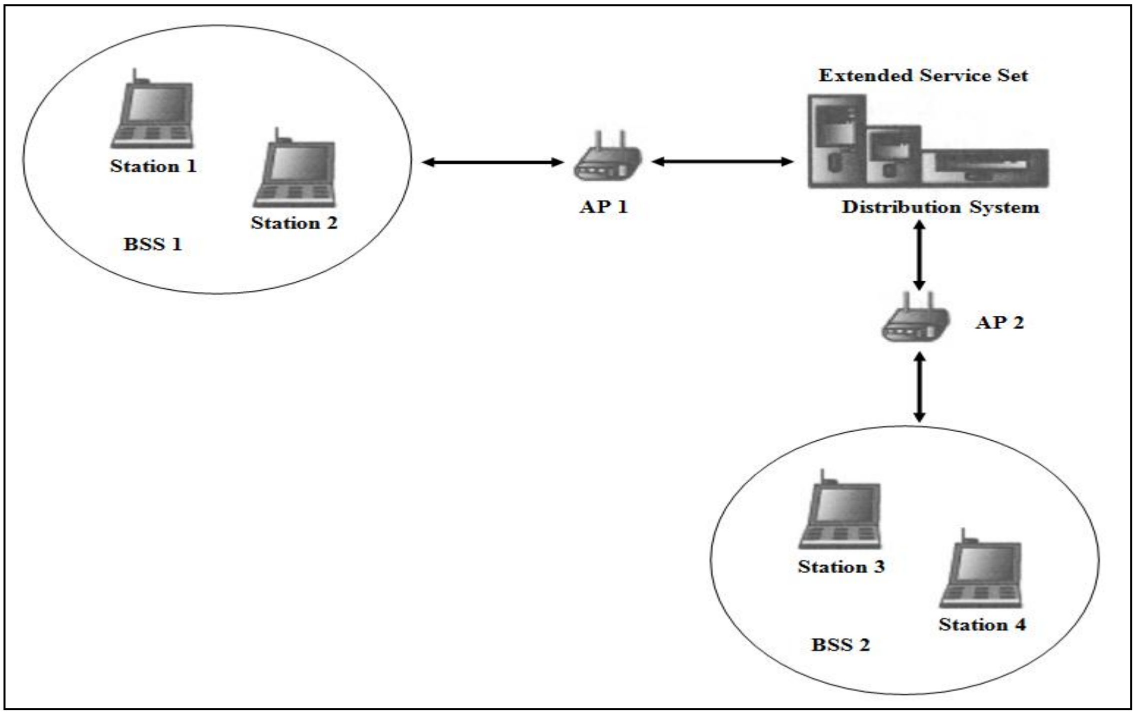

Figure 2.3: Extended Service Set (ESS) and Distribution System [34]

2.2.4 Fourth Generation Communication Systems (4G)

During the last few years, telecommunication authorities were busy while working out how to emerge to the next generation of wireless technology environment which was motivated by the growing demand for advanced telecommunication services which require wider spectrum and higher QoS [35]. Besides, the telecommunication industry experts are required to develop an interoperability strategy for new mobile wireless systems which can satisfy users' demands of telecommunication systems [35]. Growing demand for new applications required to be supported by new mobile systems such as Voice over Internet Protocol (VoIP), video conference, Push to-talk-over Cellular (PoC), multimedia messaging, multiplayer games, Virtual Private Networks (VPNs), web browsing, email access, audio and video Streaming, content download of ring tones, video clips and File Transfer Protocol (FTP) [36]. These applications require higher throughput, wider bandwidth, smaller delay and innovative transmission methods which will give higher spectral efficiency and good quality [35]. Therefore, WiMAX and LTE technologies are considered as candidates to achieve the 4G requirements announced by International Telecommunication Radio Communication Sector (ITU-R) which is known as International Mobile Telecommunication-Advanced (IMT-Advanced) [35]. Figure.2.4 shows the evolution of WiMAX and LTE standards. It also shows the Enhanced Data Rates for GSM Evolution (EDGE) which is the evolution of GSM to provide third generation services with bit rates up to 500 kbps within a GSM [16]. The 4G wireless networks must support the following criteria: **(a)** high data rate (1 Gbps peak rate for low mobility and 100 Mbps peak rate for high mobility) **(b)** high capacity **(c)** low cost per bit **(d)** low latency **(e)** good QoS **(f)** good coverage and **(g)** mobility support at high speeds [38].

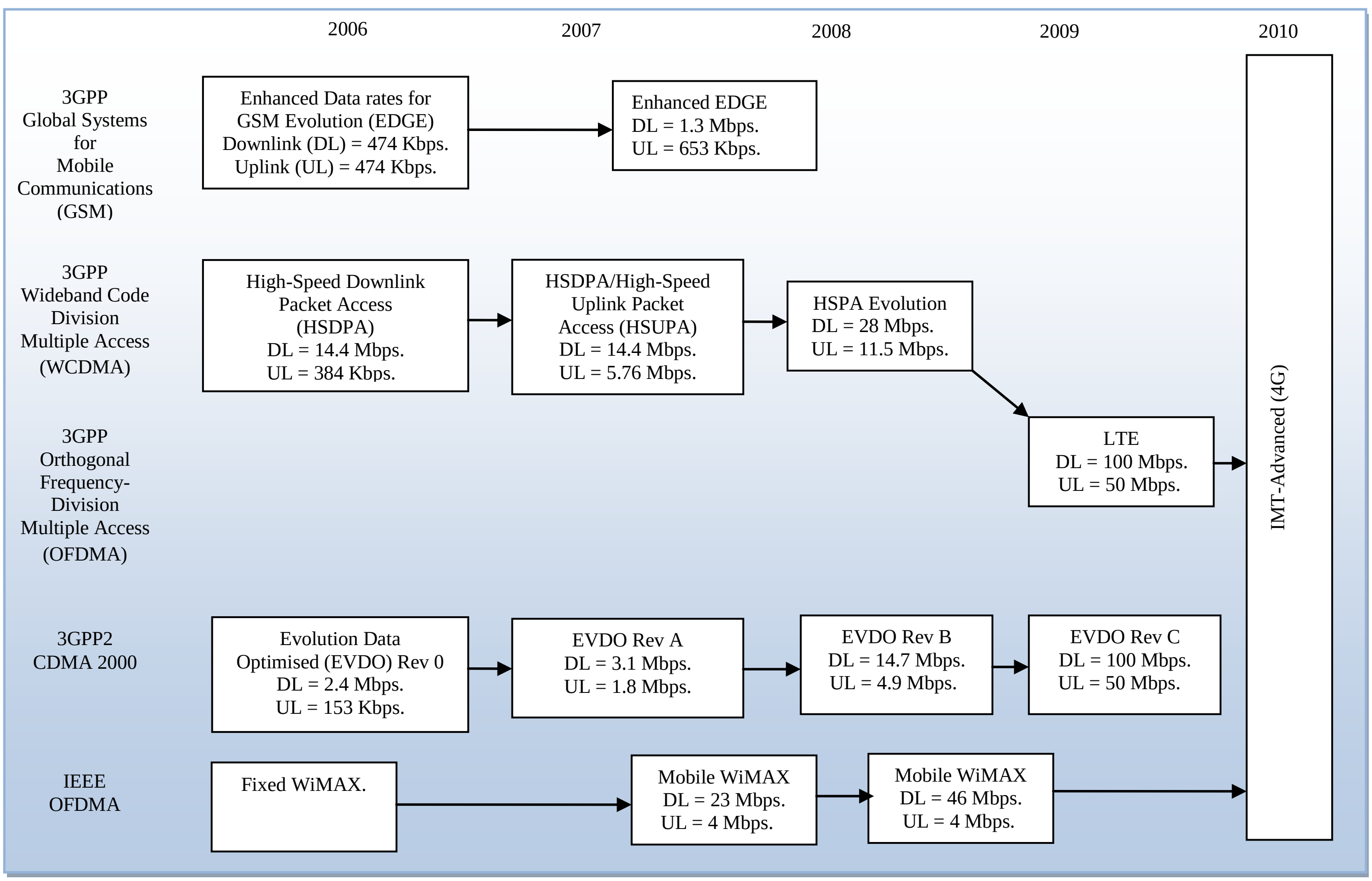

Figure 2.4: The WiMAX and LTE Standards' Development [37]

2.2.4.1 Worldwide Interoperability for Microwave Access (WiMAX)

The WiMAX (IEEE 802.16) is a telecommunication system designed to provide high speed broadband wireless access which is a probable replacement candidate for cellular wireless networks (e.g., GSM) or can be used as an overlay to enhance capacity [39]. There are many versions of WiMAX (IEEE 802.16) standards. The IEEE 802.16d (802.16-2004) provides fixed WiMAX network while IEEE 802.16e (802.16-2005) is an amendment to 802.16-2004 and it is directed to support for mobility; therefore, also known as "Mobile WiMAX" [39]. The WiMAX revision IEEE 802.16m expected to offer peak rates of at least 1 Gbps fixed speed and 100 Mbps to MUs [40]. A list of the main features and requirements for IEEE 802.16m compared with IEEE 802.16e are given in Table.2.2. In addition to offering high speed broadband internet access, WiMAX provides VoIP and Internet Protocol Television (IPTV) services to customers with comparative ease which enables the WiMAX to be a replacement for Digital Subscriber Line (DSL) cable and telephony services [39]. The WiMAX Forum which includes more than 300 companies from the computer and telecommunications industries, certifies interoperability of WiMAX products from various vendors and has been working to secure spectrum across the world for deploying WiMAX [37]. Hundreds of WiMAX networks have been commercially deployed across the world; for example, in the US, Clearwire has a large operation with service offerings in cities such as Chicago, Philadelphia and Las Vegas [37]. The IEEE 802.16d defines four main classes of QoS [42, 43]: Unsolicited Grant Service (UGS), real-time Polling Service (rtPS), non-real-time Polling Service (nrtPS) and Best Effort (BE), this is shown in Table.2.3. The conversational and streaming services of UMTS correspond to UGS and rtPS services in WiMAX. The interactive service can be mapped to nrtPS and BE services in WiMAX in different application scenarios, this is shown in Figure.2.5. In IEEE 802.16e and IEEE 802.16m the extended non-real-time Polling Service (ertPS) class has been introduced which combines the advantages of both UGS and rtPS [41].

Requirement	IEEE 802.16e	IEEE802.16m
Aggregate Data Rate	63 Mbps.	100 Mbps for mobile stations, 1 Gbps for fixed.
Operating Radio Frequency	2.3 GHz, 2.5-2.7 GHz, 3.5 GHz.	< 6 GHz.
Duplexing Schemes	TDD and FDD.	TDD and FDD.
Multiple Input Multiple Output (MIMO) Support	Up to 4 streams, no limit on antennas.	4 or 8 streams, no limit on antennas.
Coverage	10 Km.	3 Km, 5-30 Km and 30-100 Km, depending on scenario.
Handover Inter-Frequency Interruption Time	35-50 ms.	30 ms.
Handover Intra-Frequency Interruption Time	Not specified.	100 ms.
Handover between 802.16 Standards (for Corresponding Mobile Station)	From 802.16e serving BS to 802.16e target BS.	From legacy serving BS to legacy target BS. From 802.16m serving BS to legacy target BS. From legacy serving BS to 802.16m target BS. From 802.16m serving BS to 802.16m target BS.
Handover with other Technologies	Not specified.	IEEE 802.11, 3GPP2, GSM/EDGE, (E-) UTRA (LTE TDD) using IEEE 802.21 Media Independent Handover (MIH).
Mobility Speed	Vehicular: 120 Km/h.	Indoor: 10 Km/h. Basic coverage urban: 120 Km/h. High speed: 350 Km/h.
Position Accuracy	Not specified.	Location determination latency: 30 s. Handset based: 50 m (67-percentile), 150 m (95-percentile). Network based: 100 m (67-percentile), 300 m (95-percentile).
IDLE to ACTIVE State Transition	390 ms.	50 ms.
QoS Classes	UGS, nrtPS, ertPS, rtPS, BE.	UGS, nrtPS, ertPS, rtPs, BE.

Table 2.2: Most Important Features and System Requirements of Mobile WiMAX Standards [41]

Service Flow	Definition	Applications
Unsolicited Grant Services (UGS)	Support Constant Bit Rate (CBR), real time data streams with fixed size data packets issued at periodic intervals.	T1/E1, VoIP without silence suppression.
real-time Polling Services (rtPS)	Support real time data streams with variable size data packets issued at periodic intervals.	Moving Picture Expert Group (MPEG) video, VoIP with silence suppression.
non-real-time Polling Services (nrtPS)	Support delay tolerant data streams with variable size data packets issued at periodic intervals.	FTP, Telnet.
Best Efforts (BE)	Support delay tolerant data streams background traffic or any either application that do not require any guarantee in QoS.	HTTP, Email.

Table 2.3: Service Flow for WiMAX [44]

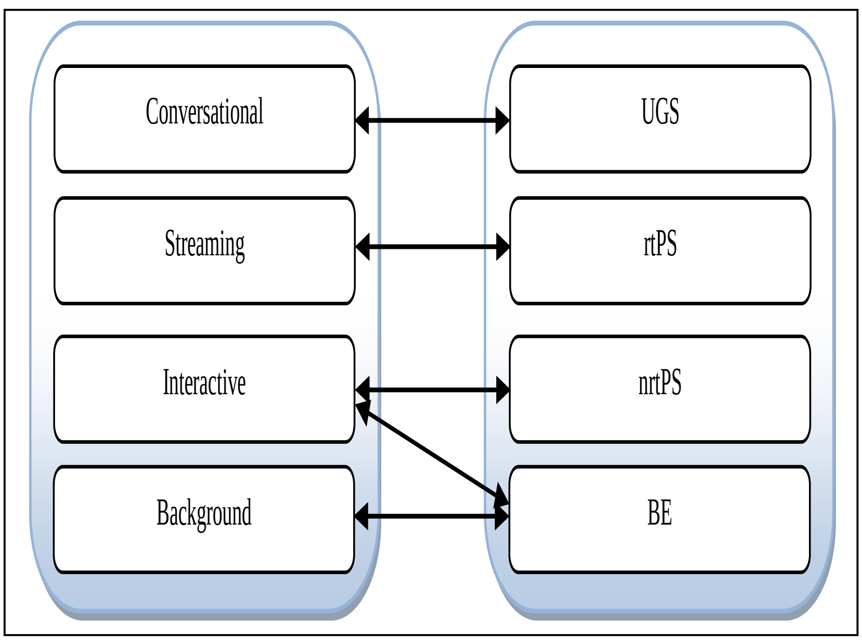

Figure 2.5: Mapping between UMTS and 802.16 QoS Classes [45]

In the Figure.2.6, the architecture of WiMAX network consists of two main blocks. The first one is the Access Services Network (ASN) and the second is the Connectivity Services Network (CSN) [38]. The ASN comprises of Base Station (BS) and ASN Gateway (ASNGW) which are connected over an IP infrastructure [38]. The ASNGW helps in service security anchoring, traffic accounting and mobility support for MS where MIP Home Agent (HA) in CSN enables global mobility [38]. The Authentication, Authorisation and Accounting (AAA) is one of main elements in the operation of WiMAX network architecture [38]. It is a server located in CSN network for processing control signals from the ASNGW to authenticate the MS against the MS's profile stored in AAA server's database; once authenticated, the AAA server sends the MS's profile including QoS parameters to ASNGW [38]. The HA processes control signals from ASNGW and assigns the MIP address to MS and anchors the IP payload where HA server provides connectivity to the internet for data traffic [38]. When MS makes the VoIP call, control is passed to CSN IP Multimedia System (IMS) servers which then process the call [38]. When the call is to a telephone number that is outside WiMAX network, the IMS servers selects either Media Gateway Controller (MGC) or Media Gateway (MGW) as appropriate gateway to interface to PSTN [38]. Finally, when the call is to an end unit in another 3GPP networks, it is routed through the interworking gateway unit within the CSN [38]. The MS communicates with the BS by using the 802.16 air interface and via an all-IP bearer and control as well [38]. The MS traffic is tunneled as payload between the BS and the ASNGW where WiMAX does not have a Time Division (TDM) bearer [38]. In most service provider configurations, the CSN network elements are redundant and geographically separate, besides, the ASNGW network elements within ASN are configured in a redundant manner; typically within the same premises [38]. The Network Access Provider (NAP) can include multiple ASNs where mobility within these ASNs does not have to be anchored at the CSN [38]. The MS can roam out of its home Network Service Provider (NSP) to a visited NSP where

AAA server in the visited NSP uses control signaling to get information from the home NSP for this purpose (e.g., credentials and profiles) [38].

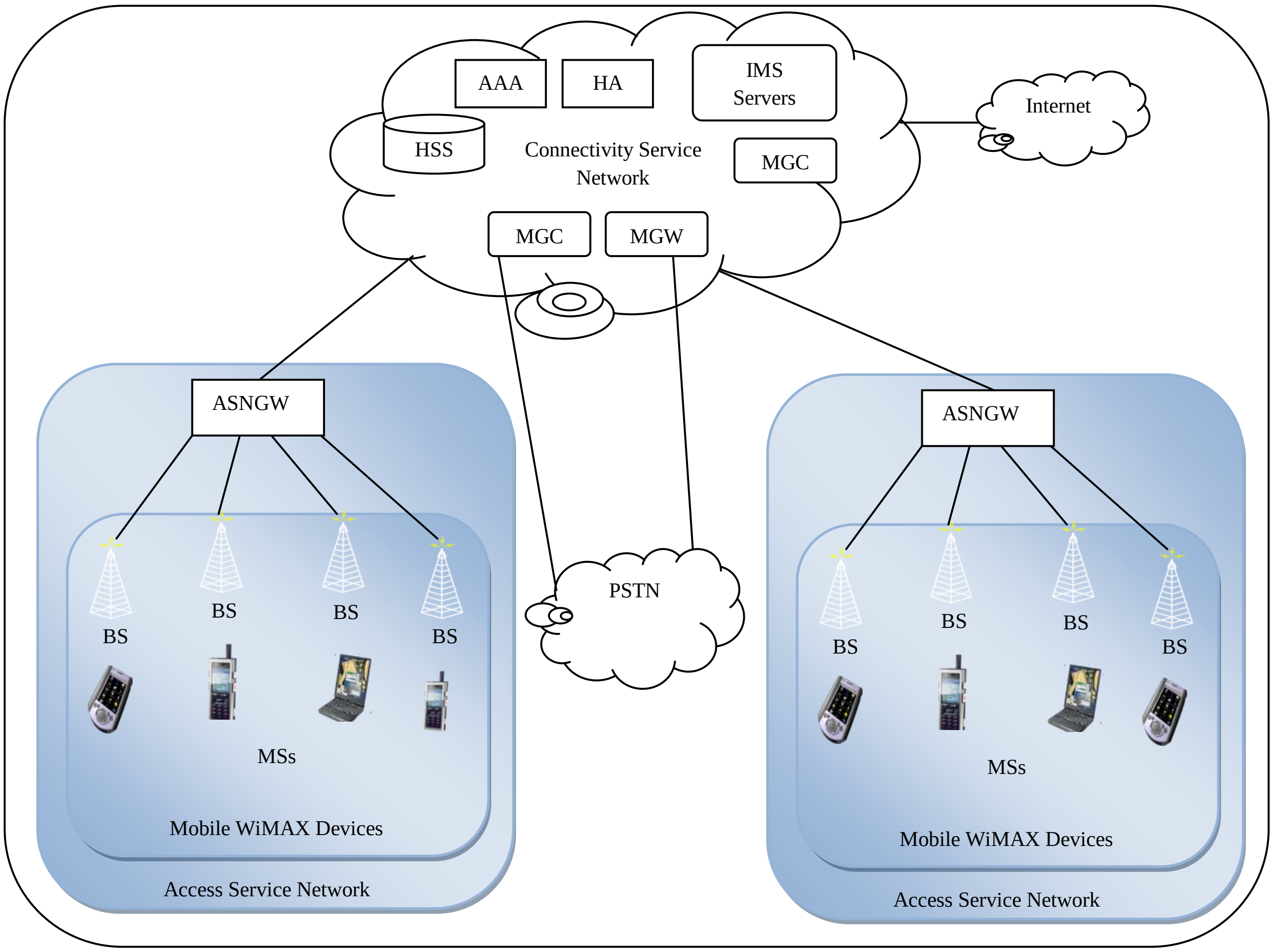

Figure 2.6: Mobile WiMAX Network [38]

2.2.4.2 Long Term Evolution (LTE)

3GPP's LTE standard evolved from the high speed packet access cellular standards. 3GPP includes some international standardisations bodies from the US, Europe, Japan, South Korea and China [37]. The 3GPP partner from the US is the Alliance for Telecommunications Industry Solutions (ATIS) and the ATIS members include leading telecommunications companies such as AT&T, Cisco and Verizon [37]. The LTE network is officially known as "document 3GPP Release 8" and sometimes it is called 3.9G because it almost achieves full compliance with IMT-Advanced requirements [37]. In September 2009, 3GPP submitted its LTE-Advanced proposal for IMT-Advanced, officially called "document 3GPP Release 10" [37]. In December 2009, Swedish telecom operator (TeliaSonera) launched the first commercial deployments of LTE in Stockholm, Sweden, Oslo and Norway [37]. The Stockholm's network was supplied by Ericsson, the Oslo's network was supplied by Huawei while the modems were supplied by Samsung [37].

LTE is a telecommunication system designed to provide higher data rate, higher throughput and lower air-interface latency compared with 2G and 3G systems [46]. This higher performance will make it possible to enhance the broadband data on demanding applications beyond web browsing and voice which require higher data rate and stricter QoS constraints such as video service [46]. In the Figure.2.7, the architecture of LTE network consists of two main blocks. The first one is the Evolved Universal Mobile Telecommunications System Terrestrial Radio Access Network (E-UTRAN) and the second is the Evolved Packet Core (EPC) [38]. The UE (e.g., smart phones and laptops) connects to the wireless network through eNodeB within E-UTRAN where E-UTRAN connects to EPC which is IP-based while EPC connects to the provider wire line IP network [38].

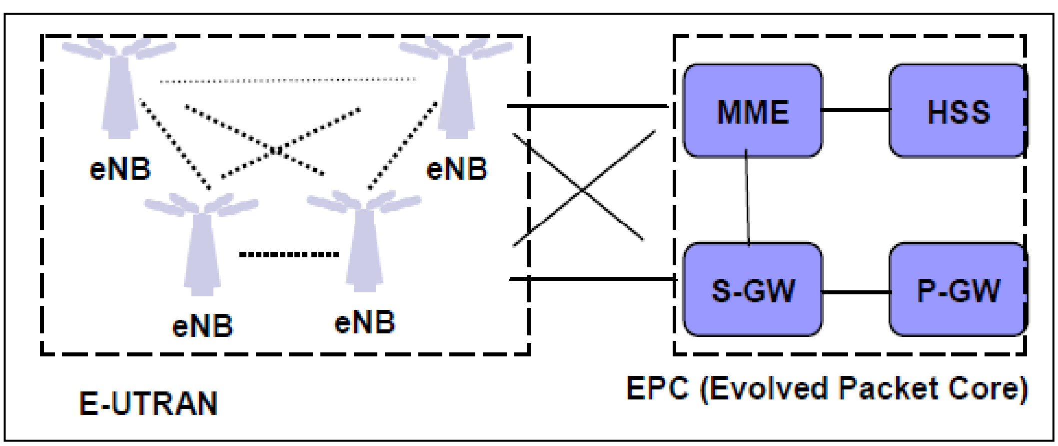

Figure 2.7: LTE – System Architecture Evolution (SAE) [38]

Unlike the 3G wireless, the LTE network architecture has three main differences [38]. The first one, it has fewer types of Network Elements (NEs) and the LTE network consists of two types of NEs: eNodeB which is an enhanced base station and Access Gateway (AGW) which incorporates all the functions required for EPC [38]. The second one, LTE supports a meshed architecture which allows greater efficiency and performance gains; for example, a single eNodeB can communicate with multiple UEs and AGWs in EPC [38]. The third one, a flat all IP-based architecture is utilised and traffic originating at UE is generated in native IP format [38]. These packets are then processed by the eNodeB and the AGW using many of the standard functions that are present in IP-based devices (e.g., routers) [38]. As well as signaling, control protocols for the network are also IP-based [38]. The UE data packets are backhauled from eNodeB to the AGW over the provider's transport network using IP and Multiprotocol Label Switching (MPLS) networks as the primary vehicle for backhaul in 4G [38]. The communication with AGW occurs over the transport network where some of the other high level functions carried out by eNodeB include: **(a)** inter-cell Radio Resource Management (RRM) **(b)** radio admission control **(c)** scheduling via dynamic resource allocation **(d)** enforcement of negotiated QoS on uplink and **(e)** compression and decompression of packets destined to/from UE [38]. The AGW consists of multiple modules including: **(a)** Home Subscriber Service (HSS) **(b)** Packet Data Network Gateway (P-GW) **(c)** Serving Gateway (S-GW) and **(d)** Mobility Management Entity (MME) [38]. The LTE standard has sufficient flexibility to allow vendors to combine these different modules into a single device or into multiple devices (e.g., separating the MME and S-GW into different devices) [38].

The MME is the main control node for LTE which is responsible to [38]:

- Manage UE identity as well as handling mobility and security authentication.
- Track the UE while it is in idle mode.
- Choose the SGW for UE during its initial attach to the network as well as during intra-LTE handover.

- Authenticate the user via interaction with HSS.
- Enforce UE roaming restrictions.
- Handle the security key management function in LTE.

The S-GW plays vital role to [38]:

- Terminate the interface towards the E-UTRAN.
- Route and forward data packets.
- Act as the mobility anchor during inter eNodeB handovers.
- Replicate packets to satisfy lawful intercept requirements and functions.

The P-GW carries out main functions [38]:

- Terminate the interface towards the packet data network (i.e. the service provider wire line network).
- Allow the UE to communicate with devices beyond the service provider main IP network; for example, the UEs may simultaneously connect to multiple P-GWs in order to connect to multiple provider IP networks.
- Policy enforcement.
- Per-user packet filtering.
- Billing and charging support.
- Anchor for mobility between 3GPP and non-3GPP technologies such as WiMAX and CDMA based 3G.
- Allocate the IP address for UE.

The HSS is responsible for [38]:

- Maintaining per-user information.
- Managing subscriber’s activities as well as for security.
- Containing the subscription related information to support network entities handling the calls.
- Generating authentication data and provides it to MME where there is a challenge response authentication and key agreement procedure between MME and UE.

- Connecting to the packet core based on IP-based diameter protocol and not the Signaling System number 7 protocol (SS7) used in traditional telecommunication networks.

2.2.4.3 A Comparison between WiMAX and LTE as the Next Generation Mobile Networks

In this section, we present comparison between WiMAX and LTE as the next generation mobile networks in terms of the main technical specifications: physical layer, latency, QoS oriented, resource allocation, power conservation and security, this is shown in Table.2.4.

2.2.4.3.1 WiMAX and LTE Technical Specifications

- Physical layer: it can be seen in Table.2.4 that both WiMAX and LTE use Orthogonal Frequency Division Multiple Access (OFDMA) in the downlink which is power inefficient but it is tolerable in the downlink because the power amplifier is placed at BS or at eNodeB in 3GPP [37]. On the other hand, these technologies differ in the uplink where WiMAX continues to use OFDMA while LTE’s approach is more advanced by using Single Carrier Frequency Division Multiple Access (SCFDMA) which helps the mobile terminal to maintain a highly efficient signal transmission using its power amplifier; therefore, the LTE uplink signal saves power without degrading system flexibility or performance [37].
- Latency: both WiMAX and LTE specifications provide high data rate and small enough latency to satisfy bandwidth intensive and real time applications such as voice applications which could tolerate a delay of between 50 and 200 ms without the user perceiving any degradation in quality [37]. These standards also support user’s mobility during their moving at speeds of up to 350 Km/h [37].

	LTE (3GPP R8)	LTE-Advanced (3GPP R10)	WiMAX 802.16e (R1.0)	WiMAX 802.16m (R2.0)
Physical Layer	DL:* OFDMA†. UL:* SC-FDMA‡.	DL: OFDMA. UL: SC-FDMA.	DL: OFDMA. UL: OFDMA.	DL: OFDMA. UL: OFDMA.
Duplex Mode	FDD and TDD§.	FDD and TDD.	TDD.	FDD and TDD.
User Mobility	217 mph (350 Km/h).	217 mph (350 Km/h).	37 to 74 mph (60 to 120 Km/h).	217 mph (350 Km/h).
Channel Bandwidth	1.4, 3, 5, 10, 15, 20 MHz.	Aggregate components of Release 8.	3.5, 5, 7, 8.75, 10 MHz.	5, 10, 20, 40 MHz.
Peak Data Rates	DL: 302 Mbps (4x4 antennae) UL : 75 Mbps (2x4) at 20 MHz FDD.	DL: 1 Gbps. UL : 300 Mbps.	DL: 46 Mbps (2x2) UL : 4 Mbps (1x2) at 10 MHz TDD 3:1 (downlink/uplink ratio).	DL > 350 Mbps (4x4) UL > 200 Mbps (2x4) at 20 MHz FDD.
Spectral Efficiency	DL: 1.91 bps/Hz (2x2). UL: 0.72 bps/Hz (1x2).	DL: 30 bps/Hz. UL: 15 bps/Hz.	DL: 1.91 bps/Hz (2x2). UL: 0.84 bps/Hz (1x2).	DL > 2.6 bps/Hz (4x2). UL > 1.3 bps/Hz (2x4).
Latency	Link layer < 5 ms. Handover < 50 ms.	Link layer < 5 ms. Handover < 50 ms.	Link layer ~ 20 ms. Handover ~ 35 to 50 ms.	Link layer < 10 ms. Handover < 30 ms.
VoIP Capacity	80 users per sector/ MHz (FDD).	>80 users per sector/ MHz (FDD).	20 users per sector/ MHz (TDD).	>30 users per sector/ MHz (TDD).
*Downlink/Uplink, †Orthogonal Frequency Division Multiple Access, ‡Single Carrier Frequency Division Multiple Access, §Frequency Division Duplexing and Time Division Duplexing.				

Table 2.4: WiMAX and LTE Technical Specifications [37]

- QoS oriented, resource allocation: both WiMAX and LTE support QoS and allocating bandwidth to users to satisfy their demands (e.g., streaming audio and video) by using frames to reserve resources for a connection, this is shown in Figure.2.8 where each of WiMAX and LTE divides the time into two frames, to specify the resource allocation during a frame in WiMAX, the duration of WiMAX frame ranges from 2 to 20 ms, each frame consists of downlink and uplink portions, the downlink traffic goes from the BS to Subscriber Station (SS) or MS, the uplink traffic goes from MS or SS to BS, at a frame's start, the BS transmits the downlink map and uplink map [37], this is shown in Figure.2.8a. In LTE, each frame lasts 10 ms and consists of 10 subframes of 1 ms each where subframes 0 and 5 are always reserved for downlink which result in BS transmits any special information to manage the subsequent transmissions [37]. LTE provides a switchpoint method which offers a more dynamic way of allocating traffic by allowing the transmission to switch between the downlink and uplink several times in a frame; for example, in Figure.2.8.b, there is a switchpoint at subframe 1[37]. This means that subframe 0 is a downlink and that subframe 1 starts with a downlink, continues with a guard period and finishes with an uplink [37]. Subframes 2, 3 and 4 continue the uplink until we reach subframe 5, which is a downlink in the second half of the frame, subframes 5 and 6 are downlink and subframes 8 and 9 are uplink [37].

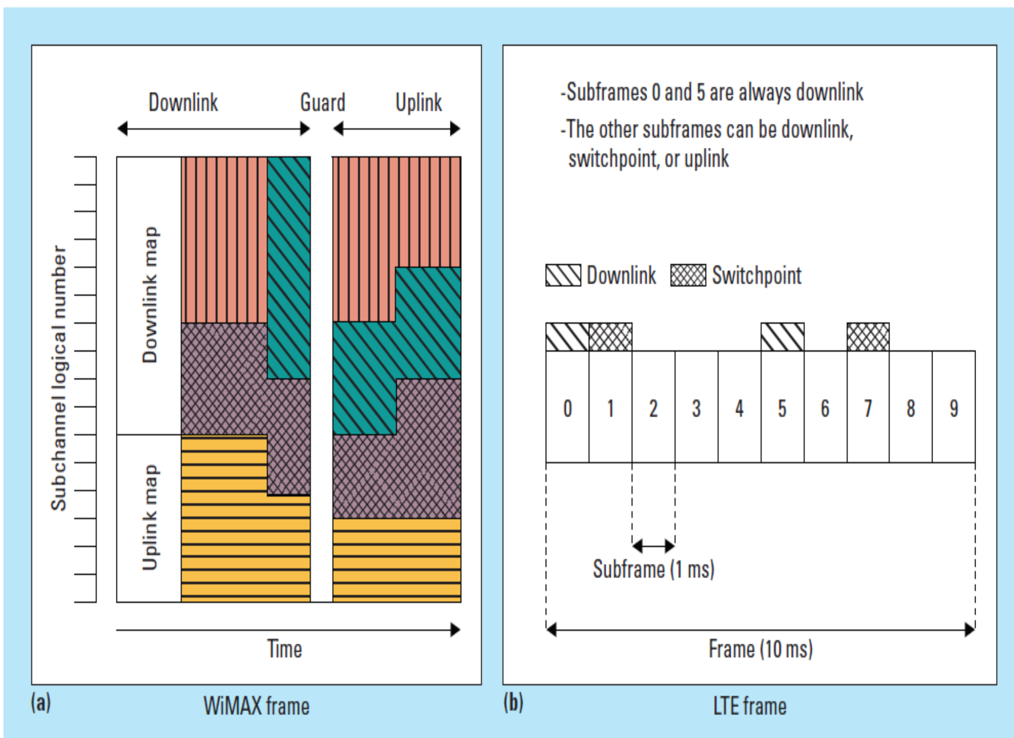

Figure 2.8: Both WiMAX and LTE Employ Reservation Based Access Using the Concept of Frames. Frames in (a) WiMAX (the Different Colors Represent Different Users) and (b) LTE Standards [37]

- Power conservation: the power consumption is a critical issue in any standard like WiMAX and LTE which support devices running on batteries, especially when the mobile devices have limited power capabilities [37]. Therefore, these standards require power conservation both in the hardware circuit and protocols to turn off the transceiver when there is no data to transmit or receive [37]. In order to power conservation in LTE, two modes are provided: Discontinued Reception (DRX) and Discontinued Transmission (DTX) [37]. The DRX mode has an on/off cycle for the user's radio [37]. In the "on" mode, the radio can transmit and receive data [37]. In the "off" mode, it does not communicate with other equipment and thus save power; even in the middle of a voice conversation the radio can be turned off when no packets are arriving or awaiting transmission [37]. Alternatively in WiMAX a sleep mode lets a device negotiate with a BS concerning when the device will turn off its radio, and this standard specifies three power saving classes [37]. These classes have varying on/off cycles and other parameters related to the type of data being transmitted; for example, a file downloading can have an elongated off period, the download will resume once the radio is on again, but the radio must be on when new traffic arrives for a real time conversation [37].

- Security: both WiMAX and LTE provide significant attention to security mechanisms. WiMAX provides privacy to the data transmitted over the network (i.e. encrypts the transmitted data) and it also provides an authentication procedure which allows the authorised users access to the network services [37]. The IEEE 802.16 standard defines a security sublayer at the bottom of the Medium Access Control (MAC) layer, this sublayer has two protocols [37]: A Privacy Key Management (PKM) protocol and an encapsulation protocol. The PKM protocol distributes security keys between BS and the subscriber or the MS, while the encapsulation protocol encrypts the transmitted data [37]. WiMAX also features a multicast and broadcast rekeying algorithm to refresh traffic keying material to ensure secured multicast and broadcast services [37]. LTE provides similar security mechanisms between the MS and the BS to encrypt a communication using security keys [37]. It also presents a key derivation protocol such as resetting the connection if a corrupt key is detected [37]. However, there are main issues of 4G wireless security that should be considered by designers

[38]: **(a)** security issues for 4G mobile wireless devices and the supporting network architectures will need to take into account all the security issues of accessing the internet either from a fixed location or during mobility **(b)** any new additional encryption methods and security mechanisms that are applied to IP networks affect the performance and traffic handling capacity of the service provider's network; therefore, standards bodies and vendors will require to care of the security issues in terms of the performance and costs of a particular security solution and **(c)** the next decade will have a new generation of 4G devices and applications.

2.2.4.3.2 Coupling of WiMAX and LTE

The interworking relationship includes connecting two or more different RATs (3GPP and non-3GPP) such as WiMAX and LTE to allow MUs to access to these interworked networks and to maintain their ongoing sessions [47]. For this purpose, there are main requirements for interworking that need to be taken into consideration as follows [47]:

- Mobility support between WiMAX and LTE where the user should be notified of service degradation during the traversal between these technologies.
- Partnership or roaming agreements between mobile WiMAX and the LTE network operator (i.e. the operator should give the user the same benefits as if the interworking is handled within one network operator).
- Subscriber billing and accounting between roaming partners must be handled.
- Subscriber identification should be such that it can be used both in WiMAX or in pure LTE environment.
- The subscriber database could either be shared or it could be separate for the two networks but sharing subscribers' security association. The subscriber database could be HLR/HSS or AAA server which provide by 3GPP and Internet Engineering Task Force (IETF), respectively.

Based on the above considerations, different types of integration approaches can be classified between WiMAX and LTE [47]:

- Open Coupling: in this type of integration, there is no effective integration between WiMAX and LTE technologies in terms of authentication procedures and control procedures related to QoS and mobility management [47]. In this case, the interaction is only between the billing management systems of each network technology [47], this is shown in Figure.2.9.

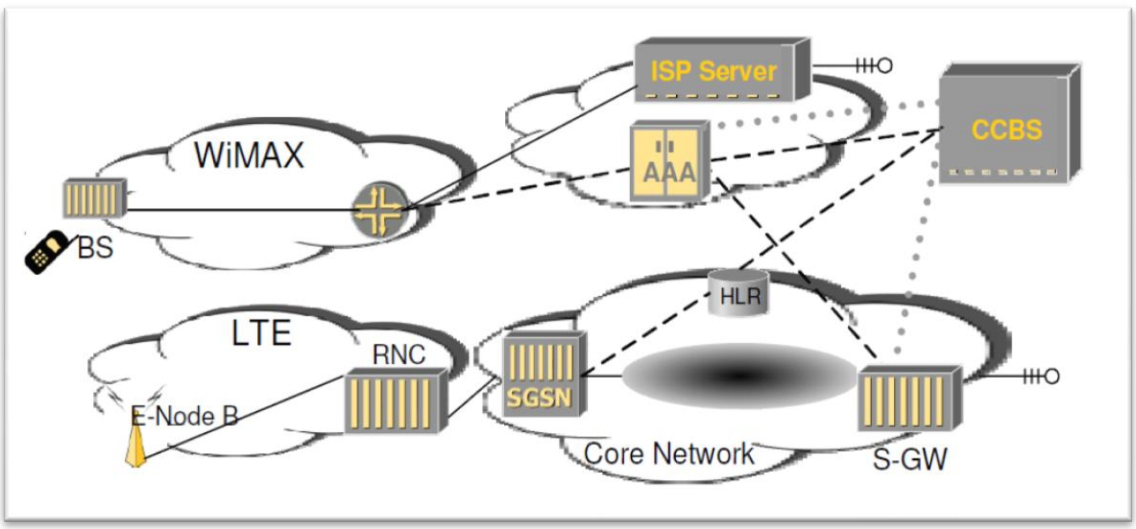

Figure 2.9: Open Coupling Integration between 4G Networks [47]

- Loose Coupling: in this type of integration, the interaction is limited only between the billing management systems and the control planes of each network technology regarding the authentication procedure; therefore, one customer database and procedure is used and a new link between Internet Service Provider (ISP) and the 3G core network is provided [47], this is shown in Figure.2.10. The main consequence of this type of integration is that the traversal between these technologies is not seamless because the service in progress is dropped [47].

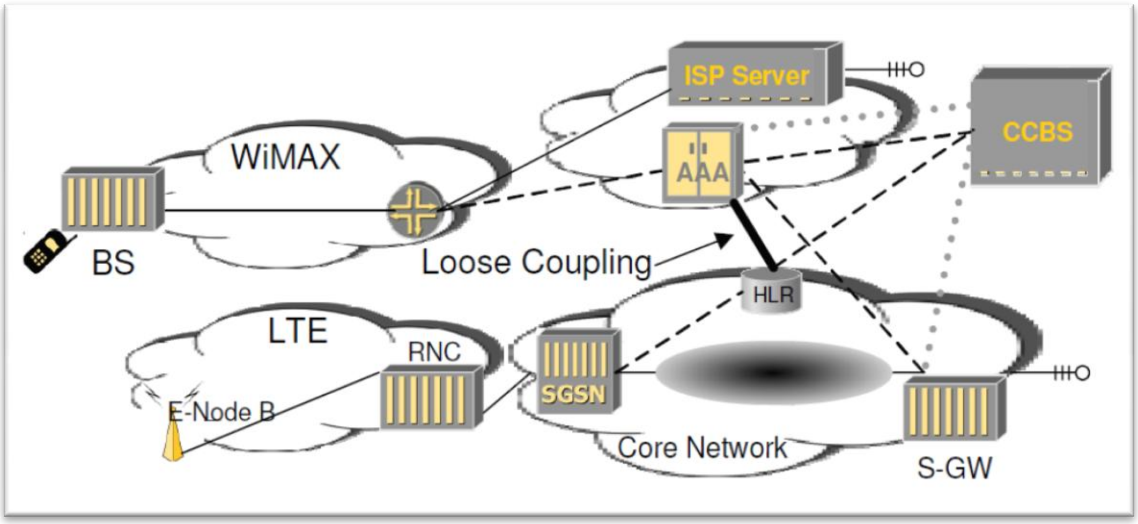

Figure 2.10: Loose Coupling Integration between 4G Networks [47]

- Tight Coupling: in this type of integration as it is shown in Figure.2.11, the SGSN is the interface between WiMAX and LTE technologies which located at the core network and it allows the traverse between these technologies to be controlled and triggered which result in more seamless traverse between WiMAX and LTE compared with the loose coupling [47]. However, in this integration it is still difficult to support a seamless traverse between different technologies [47].

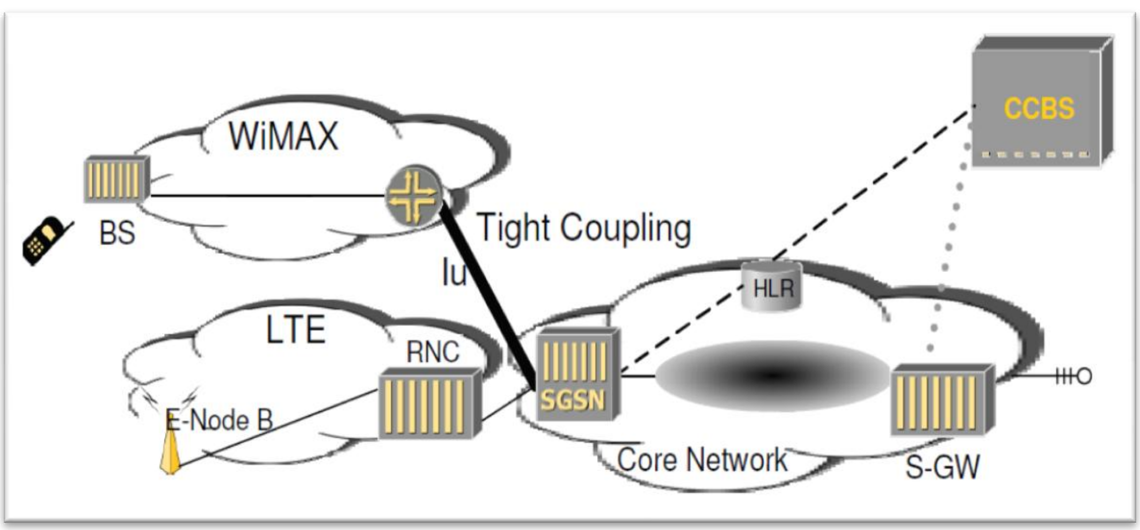

Figure 2.11: Tight Coupling Integration between 4G Networks [47]

- Very Tight Coupling: in this type of integration, there is a new interface between RNC and WiMAX to perform a seamless traverse between different technologies (e.g., GSM/LTE and WiMAX) where BS of WiMAX connected to RNC which is able to control the radio resources of the area covered by BS [47], this is shown in Figure.2.12.

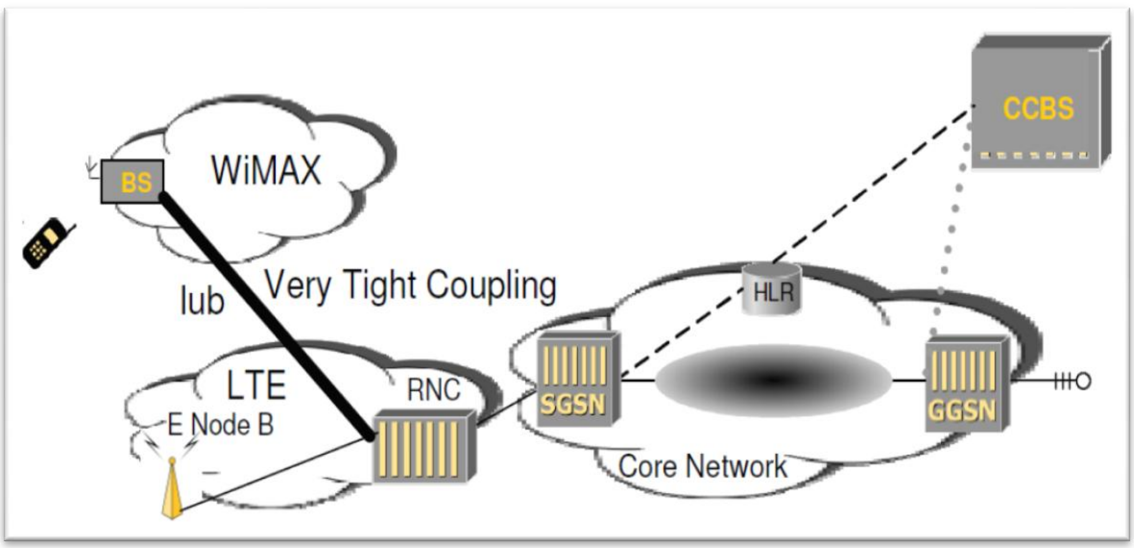

Figure 2.12: Very Tight Coupling Integration between 4G Networks [47]

2.3 What are Heterogeneous Wireless Networks?

The growing demand for services (e.g., web browsing, file downloading and e-mail) from MUs anywhere, anytime is on the increase regardless of the technological constraints which are associated with different types of RATs such as UMTS, WiMAX and LTE, besides, there is no single RAT is able to satisfy the requirements for all different wireless communications scenarios. Therefore, the telecommunication operators are required to develop an interoperability strategy for these different types of existing networks to get the best connection anywhere, anytime between heterogeneous wireless networks [2].

2.4 Who Needs Heterogeneous Wireless Networks?

There are two main parties that need heterogeneous wireless networks; the first one is the operator and the second is the MUs. The operators always seek to improve the final user experience and optimum use of the network by making a transition from the source network to target network as transparent as possible. The thing which will be reflected positively on operators to get more subscribers (users' loyalty) and more profit eventually; this is shown in Figure.2.13. On the other side, the MUs need to maintain network capability anywhere, anytime without interruption on their ongoing sessions.

Figure 2.13: Operators' Vision of Using Heterogeneous Wireless Networks

2.5 Why are Heterogeneous Wireless Networks Necessary?

4G will include multiple integrated mobile and wireless networks and all of them will coexist in a heterogeneous wireless access environment. At the same time each RAT has its advantages and disadvantages as shown in Table.2.5. Therefore, the complementarity between RATs is still required due to their characteristics. For example, the integration between WiMAX and LTE would satisfy users' demands to ongoing their sessions without noticeable degradation. Consequently, it would allow the service provider to get more profit.

Access Technology	Advantages	Disadvantages
3GPP (UMTS, 3G, Wide Area Network (WAN))	Wide coverage area. High security.	Not suitable small, indoor and densely populated area. High service cost. High deployment cost. Low medium data rate from 144 Kbps to 2 Mbps depending on characteristics of the environment and the moving speed of mobile; for example, user moving over than 120 Km/h with maximum 500 Km/h in rural areas can expect speeds of 144 Kbps, user moving less than 120 Km/h and urban outdoor environment can expect rates of 384 Kbps, users indoor or moving at less 10 Km/h can reaches speed 2Mbs.
Wi-Fi (Wireless Local Area Network (WLAN), IEEE 802.11, Local Area Network (LAN))	Cheap service cost. Low deployment cost. Support rates from 1 Mbps to 54 Mbps depending on environment. For example, for 1 Mbps maximum the rate indoor is 100 m and outdoor is 450 m. For 54 Mbps the rate is 30 m indoor and 100 m outdoor.	Limited in large space mobility. Weak security.
WiMAX (Metropolitan Area Network (MAN), IEEE 802.16, 4G)	Medium coverage area. Medium service cost. Medium deployment cost. Medium security. Scalability. The current WiMAX revision IEEE 802.16m expected to offer peak rates of at least 1 Gbps fixed speed and 100 Mbps to MUs.	Limited in large space mobility.
LTE (E-UTRAN, 4G)	Wide coverage area. High security. High throughput. Low air interference latency compared with 2G/3G systems. As set by ITU for IMT-Advanced: increased peak data rate, DL 3 Gbps and UL 1.5 Gbps (LTE-Advanced).	High service cost. High deployment cost.

Table 2.5: Advantages and Disadvantages for UMTS, Wi-Fi, WiMAX and LTE [3, 4, 37, 38, 39, 46, 51, 52, 53, 54, 55 and 56]

From a MUs point of view, there are many features of heterogeneous wireless networks such as the following [48, 49 and 50]:

- High usability: anywhere, anytime and with any system.
- Multiple services from various providers such as web browsing, file downloading, VoIP and streaming application.
- Support for telecommunications services and multimedia services with high data rate at low transmission cost.
- Personal customisation services.
- Multiple communication capabilities to support two or more types of RATs.
- Exploitation of interworking devices between heterogeneous wireless access networks in order to mitigate the hardware and the software complexity in the MU.

2.6 What is the Handover Management within Heterogeneous Wireless Networks?

Handover management is a process which allows the MUs to continue their ongoing sessions when moving within the same RAT coverage areas or traversing different RATs. In heterogeneous wireless networks, the handover management is crucial because RATs typically differ in terms of multiple parameters such as RSS, data rate, reliability, service cost, security, power consumption requirements, coverage area and latency. Therefore, complementarity to these RATs through VHO interworking architectures is essential to provide ubiquitous wireless access ability with the best available access network which suits the MU’s requirements (e.g., high coverage area, high data rate and low cost). There are two main VHO interworking architectures [57, 58, 59, 60 and 61]: loose coupling and tight coupling. A detailed survey of these VHO interworking architectures can be found in the next chapter of this thesis.

2.6.1 Handover Classifications

Handover has been classified in accordance with the following five categories [62], this is shown in Figure.2.14.

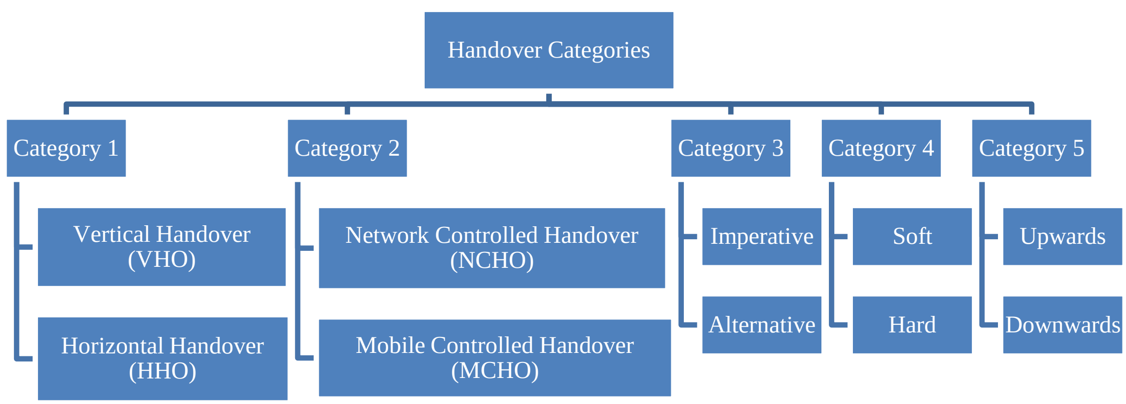

Figure 2.14: Vertical Handover Classifications

1. **Mobility Scenarios (Category 1)**

Mobility scenarios can be classified into Horizontal Handover (HHO) which is known homogeneous, intra-system or micro mobility (between different cells of the same RAT) and VHO which is also known heterogeneous, inter-system or macro mobility (between different types of RATs). The homogeneous RAT is typically required when the serving access router becomes unavailable due to the MU's movement (i.e. when RSS of the serving access router (e.g., BS or AP) deteriorates below a certain threshold value). In heterogeneous RATs, there are more criteria rather than only RSS (i.e. the MUs will benefit from different RATs characteristics (e.g., RSS, data rate, security and cost)).

In the literature, the VHO procedure is divided into three phases: Initiation, Decision and Execution [63, 64, 65, 66 and 67] as described below.

A. Handover Initiation

The handover initiation is a process where the MU, that is equipped with multiple interfaces, searches for an available wireless access networks. In this phase, all required information for the handover decision is gathered, some of this information is related to the user's preferences (e.g., cost and security), network (e.g., latency and coverage) and terminal (e.g., battery and velocity).

B. Handover Decision

The handover decision (Access Network Selection (ANS)) is responsible for deciding when and where to perform the handover (HHO or VHO) by choosing the best handover access network from the multiple ones available. It then passes the information to handover execution. For example, suppose that the MU, who is operating on UMTS, has discovered its available neighbours cells such as WiMAX and Wi-Fi. The handover decision process needs to answer the following questions: *when* and *where* to handover on WiMAX/Wi-Fi. The first question which should be answered whether or not the MU requires initiating handover process to the discovered cells. In homogeneous wireless networks, the RSS measurements are used to determine whether the handover is required or not. While in heterogeneous wireless networks the RSS measurements are insufficient for the challenges of the next heterogeneous wireless networks' generation. Therefore, the VHO decision needs more criteria (e.g., data rate, service cost and security) compared with HHO (RSS). Secondly, the MU evaluates different criteria of each available network before choosing the best one. A target network must be typically agreed between the user's preferences and the network policy.

C. Handover Execution

In this phase, once a target network is selected and a handover decision is made, the active session for the MU will be maintained and continued on the new wireless access network. The handover execution involves the MU's authentication and the actual transfer of data packets to a new target network in order to reroute the MU's connection path to new Point of Attachment (PoA). It can be implemented by mobility management protocols such as MIPv4 and MIPv6. After that, the resources of the old RAT are eventually released.

Packet loss and latency are the major drawbacks in the execution phase. They are incurred especially when the MU moves between different RATs due to mobility management protocols mechanisms. Many approaches based on MIPv4 and MIPv6 have been proposed for implementing handover when roaming across heterogeneous wireless networks. In order to address the above drawbacks, we survey these approaches in chapter 3 and present a new procedure in chapter 5 to provide significant improvements and better performance (packet loss and latency) compared with that found in the literature.

2. Handover Control (Category 2)

The handover control (handover decision) can be taken by either the network entity or the MU, these cases are called Network Controlled Handover (NCHO) and Mobile Controlled Handover (MCHO) respectively [62]. In NCHO, the network operators' goals are mainly associated with how to manage network resources and fulfiling the current users' requirements while maximizing their revenue [62]. In MCHO, the MU's goal is to get the best connection anywhere, anytime by focusing on satisfying user's requirements and preferences regardless of network operation's complexities and efficient network operation associated with this, things which do matter from operator's perspective [62].

The handover control usually includes some measurements and information which are obtained from one entity or both and which are about when and where to perform the handover. Therefore, the handover control can be categorised as: **(a)** Network Controlled Handover/Mobile Assisted Handover (NCHO/MAHO), when a network has the primary control over the handover conducting, exploiting information and measurements gathered from the MU. **(b)** Mobile Controlled Handover/Network Assisted Handover (MCHO/NAHO), when the MU has the primary control over the handover exploiting information provided by the network [62]. There are some main characteristics of NCHO and MCHO, this is shown in Table.2.6.

The main characteristics of the NCHO are provided as follows [68]:

- The network can redirect the MU to another radio site or frequency that has enough capacity to handle its ongoing communications.
- The network can also coordinate the mobility of all MUs in a way that overall traffic is evenly distributed across all radio resources, congestions are reduced and total throughput is reduced.
- The radio network may lack some parameters that impact the handover decision such as user's preferences, the exact type of active services on the MU and some operator policies pertaining to mobility between mobile WiMAX and 3GPP accesses.

On the other side, the MCHO's characteristics are provided as follows [68]:

- The MU can make the handover decision based on its up-to date radio measurements, preconfigured user's preferences and all downloaded operator mobility policies.
- The MU does not need to send any inter-technology radio measurement to the network.

- The impact on 2G/3G and mobile WiMAX access networks is reduced. For example, the 3G radio access does not require to receive measurement reports or make decisions on handing over for WiMAX cells.
- The 3G radio access does not need to keep track of the available radio resources on WiMAX side and vice versa.

In [62, 64], the most conducted experiments and publications in the VHO approaches [64, 66, 69, 70, 71, 72, 73, 74, 75 and 76] adopted the MCHO which has shown the following features:

- Reduces overall complexity in a network.
- Reduces signaling overhead.
- Reduces handover latency.
- More flexible.

Handover Control	Advantages	Disadvantages
Network Controlled Handover (NCHO)	Handle the MU ongoing communications. Coordinate the mobility of all MUs.	Lack some parameters that impact the handover decision.
Mobile Controlled Handover (MCHO)	The Handover decision based on its up-to date radio measurements, preconfigured user's preferences and all downloaded operator mobility policies. No need to send any inter-technology radio measurement to a network from the MU. The impact on the 2G/3G and mobile WiMAX access networks is minimised. No need for 3G radio access to keep track of the available radio resources on the WiMAX side and vice versa. Less complexity in a network. Less signaling overhead. Less handover latency. More flexible.	Focusing on satisfying user's requirements and preferences regardless of network operation complexities and efficient network operation.

Table 2.6: Comparison of Handover Control

3. Imperative and Alternative Initiation (Category 3)

There are two main initiation reasons for a VHO decision: imperative handover and alternative handover [74, 77]. Imperative handover is triggered by physical events regarding the RAT interfaces availability (e.g., RSS is going down) to keep on going session. Alternative handover is triggered by user's preferences (e.g., data rate and cost).

4. Soft and Hard Handover (Category 4)

The handover type is considered soft when the MUs create a connection to a target network prior to the release of previous source network; it is also referred to make before break handover for achieving seamless mobility [62]. On the other hand, when a new connection is established after the release of the previous one, the handover is known as hard or break before make handover [62].

5. Upwards and Downwards (Category 5)

Finally, the handover is categorised upwards and downwards. In upwards handover, the VHO is the handover to the RAT located with a larger cell size and lower bandwidth (i.e. the MU moves between the network supporting a high data rate but smaller coverage (e.g., Wi-Fi) and the network achieving higher coverage but lower data rate (e.g., UMTS)) [62]. Contrary to this, with downwards handover, the VHO is the handover to the RAT located with a smaller cell size and larger bandwidth (i.e. the MU moves from a large coverage cell with a low data rate to a small coverage cell which supports high data rate) [62].

2.6.2 Handover Multimode Mobile Terminal

The NGWS will consist of heterogeneous wireless access networks such as UMTS, Wi-Fi, WiMAX and LTE where MUs can access these technologies and services using a single device. This device is equipped with multiple radio interfaces include devices capable of supporting multiple RATs by incorporating several interface cards and appropriate software for switching between multiple access systems. The decision regarding the transferring between different RATs is based on network conditions, mobile conditions, user's preferences, QoS requirements (application) and service cost. In order to design multimode mobile terminals, there are three main requirements [50]:

- From the user's point of view, the inputs to the terminal should be minimal. It is preferable to carry out these decisions in an automated way rather than checking the user whenever a new RAT becomes available or an old RAT disappears.
- Target networks should be selected based on multiple criteria such as network conditions, user's preferences and QoS requirements.
- Traffic should be balanced while transferring between RATs to get seamless VHO.

The multimode mobile terminal must be capable of [78]:

- Detecting available RATs and their capabilities.
- Selecting, activating and configuring the connections to appropriate attachment points.
- Accessing, modifying and storing the user's profile.
- Supporting the applications in seamlessly handing over the existing connections from old access network to new access network.

2.6.3 Handover Techniques

As mentioned previously, heterogeneous wireless networks consist of multiple RATs; not one RAT only. Besides, there is no RAT that can provide simultaneously high data rate, high coverage area, low service cost and low latency to a large number of MUs. It is beneficial for MUs to switch their connections between different RATs in order to maintain their connectivity without interruption according to their preferences. To fulfil these requirements for seamless handover, many techniques were proposed for integration between different RATs: interworking architectures, mobility management protocols, Access Network Discovery and Selection Function (ANDSF) mechanism and interworking frameworks. A detailed survey of these techniques can be found in chapter 3 and chapter 4 of this thesis.

1. **Interworking Architectures**

The interworking relationship includes connecting two or more different RATs (3GPP and non-3GPP) such as UMTS, Wi-Fi, WiMAX and LTE to allow MUs to access these interworked networks and to maintain their ongoing sessions. The interworking architectures can be classified into two main approaches: loose coupling and tight coupling.

2. **Mobility Management Protocols**

The mobility management protocols such as MIPv4 and MIPv6 allow the MU to roam between different physical points of attachment especially the roaming between different RATs. Mobility management can be categorised into two types where each of them requires a mobility management protocol to complement its work: micro mobility and macro mobility. In the micro mobility, the MU roams within the same RAT (e.g., moves between APs) while the movement of the MU between different RATs is referred to as the macro (e.g., moves between AP and BS).

3. **Access Network Discovery and Selection Function (ANDSF) Mechanism**

The 3GPP Group had proposed the ANDSF mechanism to provide a seamless VHO between different RATs and to mitigate the impacts of radio signals impairment between 3GPP and non-3GPP. ANDSF also works as a store of RATs information that is queried by the MU to make handover decision.

4. **Interworking Frameworks**

Two main interworking frameworks were proposed by IEEE Group and 3GPP for integration between different RATs; namely, Media Independent Handover (MIH) and IP Multimedia Subsystem (IMS) where each of them requires a mobility management protocol to complement its work such as MIP and Session Initiation Protocol (SIP), respectively.

2.6.4 Handover Criteria

As mentioned previously, homogeneous RATs are mainly consider RSS as the only decision criteria when a serving access router becomes unavailable due to the MU's movement (i.e. when RSS of a serving access router (e.g., BS or AP) deteriorates below a certain threshold value) [79]. While in heterogeneous RATs, the criteria which are taken into account to maximize the user's satisfaction are more than merely RSS (e.g., RSS, data rate, security and cost), the thing which can help the MUs to choose the best RAT among all available candidates networks [79]. In this respect, we focus on the research's efforts and recent developments for improving performance of a VHO process where several parameters have been proposed for use in the VHO decision: RSS, network connection time, available bandwidth, power consumption, monetary cost, security and user's preferences [80, 81 and 82], this is shown in Figure.2.15.

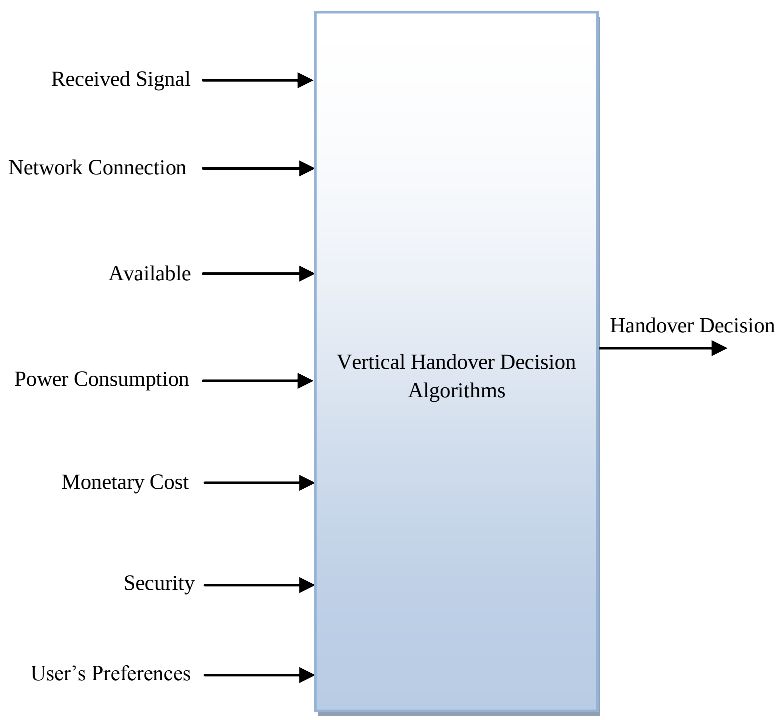

Figure 2.15: Parameters Used for Making Vertical Handover Decisions [80]

1. **Received Signal Strength (RSS)**

RSS is the most widely used parameter in HHO as a decision criteria because it is easy to measure and is directly related to QoS. There is a relationship between RSS readings and the distance between the MU and its PoA [80].

2. **Network Connection Time**

The network connection time is the period during which the MU remains connected to its PoA as it is related to the MU's location and velocity [80]. Both, the distance between the MU and its PoA and the velocity of the MU, affect the RSS at the MU. The network connection plays two vital roles [80]. The first one is choosing the right moment to trigger the handover so that QoS can be maintained at a satisfactory level; for example, if the handover carried out too early between different RATs, the network resources would be wasted, and if it is carried out too late, it would cause a handover failure [80]. The second role which the network connection plays is reducing the number of unnecessary handovers; as handing over to a target RAT with potentially a short connection time should be discouraged [80]. The network connection time is especially significant for VHO because, usually, heterogeneous wireless networks have different sizes of network coverage areas [80].

3. **Available Bandwidth**

The available data rate is a measure of available data communication resources expressed in bps [80]. It is used as an indicator of traffic conditions in RAT and is especially important for delay-sensitive applications; for example, applications such as video streaming will perform better when higher bandwidth is available [80].

4. **Power Consumption**

Power consumption is a critical issue especially if the MUs have limited power capabilities; therefore, it would be preferable in such situations to handover to a network with lower power requirements which would help extending valuable battery life [80].

5. **Monetary Cost**

The cost of services offered by different networks with different charging policies might be a major thing to be considered by users and may affect their choices of RAT and consequently the handover decision; for example, the user may prefer to connect with the cheapest available RAT in order to incur a minimum service cost [80].

6. **Security**

Appropriate security for some applications enhances information integrity and confidentiality of the transmitted data; therefore, sometimes a network with high security is preferred over one which provides lower levels of data security [80].

7. **User's Preferences**

User's preferences towards an access network could lead to perform the handover by choosing the best RATs from the multiple ones available [80]. For example, if a target network to which the MU performs the handover does not offer high security, the user may decide to stay at the current RAT while another user may keen to choose a cheaper network to access web information regardless of the security level.

2.6.5 Handover Access Network Selection Methods

A key parameter of the VHO management procedure is the Access Network Selection (ANS) in the decision phase. There are many proposals introduced by researchers about ANS, (e.g., [63, 64]); however, the proposed ANS schemes lack unity while a number of issues still need to be resolved such as the discrepancy between user centric and network centric schemes [62]. In the user centric scheme, the goal is how to get the best connection anywhere, anytime regardless of network operation complexities which matters from the operator's perspective [62]. This in turn means that there are several conditions based on networks' perspective and users' perspective should be taken into account to get the Always Best Connected (ABC) between heterogeneous wireless networks: network conditions, mobile conditions, user's preferences, QoS requirements and service cost. Therefore, the MUs can exploit all available RATs to automatically select the best access network which meets their requirements such as service costs and QoS through changing weight factors and constraints in a single objective optimisation function [71]. There are three main ANS methods used in heterogeneous networks: Multiple Attribute Decision Making (MADM), Fuzzy Logic (FL) and Neural Networks (NNs) [83].

A. Multiple Attribute Decision Making (MADM)

The MADM deals with the problem of choosing an alternative from a set of alternatives which are characterized in terms of their attributes where the most popular classical MADM methods are: Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Simple Additive Weighting (SAW), Analytic Hierarchy Process (AHP) and Grey Relational Analysis (GRA) [63, 64, 83 and 84]:

- Technique for Order Preference by Similarity to Ideal Solution (TOPSIS): the chosen candidate network is the one which is the closest to the ideal solution and which is obtained by considering the best value for each metric.
- Simple Additive Weighting (SAW): the overall score candidates' network is determined by the weighted sum of all the attribute values.
- Analytic Hierarchy Process (AHP): divides a network selection problem into several sub-problems and assigns a weight value for each sub-problem.
- Grey Relational Analysis (GRA): is used to rank the candidate networks and select the one with the highest ranking.

In [64], a comparison between these methods in terms of bandwidth, delay, jitter and Bit Error Rate (BER) was presented. It was shown in [64] that the SAW and the TOPSIS provided similar performance to all four traffic classes used while the GRA provided a slightly higher bandwidth and lower delay for interactive and background traffic classes. The results also showed that these methods depended on the importance of the weights assigned to the parameters. However, the classical MADM methods cannot efficiently deal with a decision problem which contains imprecise data [64].

B. Fuzzy Logic (FL)

FL is applied to select when and over which network to handover among different available access networks and it is combined and evaluated with the multiple criteria simultaneously in order to develop advanced decision algorithms for both non-real-time and real-time applications [64]. FL has features as following [64, 5]:

- Dealing with imprecise data and multiple inputs parameters for making a VHO decision, high efficiency, flexible, supported non-real time and real time service and robust mathematical framework.
- Reducing unnecessary VHO (elimination of the ping pong effect), reducing signaling cost due to VHO processes and improving QoS due to VHO.

C. Neural Networks (NNs)

The NN method was proposed to satisfy user bandwidth requirements by selecting only an appropriate time to handover based on RSS, whereas the FL method makes a handover decision based on choosing an appropriate time and a most suitable access network according to user's preferences [64].

2.7 Chapter Summary

In this chapter, we have given a critical overview of the evolution of wireless access networks and the handover management within heterogeneous wireless networks. Five basic questions have defined this chapter to clearly understand the purpose of this research study: how have wireless access networks evolved? What are heterogeneous wireless networks? Who needs heterogeneous wireless networks? Why are heterogeneous wireless networks necessary? and finally, what is the handover management within heterogeneous wireless networks?.

Chapter 3
Available Techniques of Vertical Handover (VHO) in Heterogeneous Wireless Networks

3.1 Introduction

This chapter and the subsequent chapter introduce the reader to four concepts of available VHO techniques to facilitate understanding the design and functioning of our new approach proposed in chapter 5 and chapter 6: interworking architectures, frameworks, mobility management protocols and mechanism. In this chapter, we focus on the first three VHO techniques while the mechanism will be considered in chapter 4. Therefore, in this chapter, we provide three surveys of VHO interworking architectures and VHO approaches for which we present their objectives and performances issues. In the first one, we survey two main VHO interworking architectures: loose coupling and tight coupling as published in [88]. We make a fair comparison based on their performance in terms of latency, probability of packet loss, mobility management, congestion, complexity, overload, additional modification requirement and additional cost requirement. In the second one, a comprehensive survey of VHO approaches designed to provide seamless VHO based on MIH and IMS frameworks is presented as published in [109]. To offer a systematic and exhaustive comparison in this survey, we present two types of comparison: a comparison between the frameworks (MIH and IMS) and a comparison between the four categories based on these frameworks (MIH based category, IMS based category, MIP under IMS based category and MIH and IMS combination based category).

In the third one, we survey the VHO approaches proposed in the literature and classify them into two categories based on MIPv4 and MIPv6 under MIH as published in [115].

The chapter begins with section 3.2 which is a full discussion on background of available VHO techniques in heterogeneous wireless networks. In the last section 3.3, some conclusions are presented.

3.2 Background of VHO Techniques

The NGWS will consist of heterogeneous wireless access networks such as UMTS, Wi-Fi, WiMAX and LTE. These different RATs have significant different capabilities in terms of coverage area, supported data rate for services, cost, etc [3]. For example, the UMTS provides high coverage area, high cost and data rate from 144 Kbps to 2 Mbps at 10 Km/h to maximum 500 Km/h depending on propagation channel condition while Wi-Fi provides low coverage area, low cost and high data rate (e.g., for 1 Mbps maximum the rate indoor is 100 m and outdoor is 450 m, for 54 Mbps the rate is 30 m indoor and 100 m outdoor) [3]. Therefore, complementarity to these technologies through VHO interworking architectures is essential to provide ubiquitous wireless access ability with high coverage area, high data rate and low cost to MUs. Consequently, the challenge would be the ability to move MUs seamlessly between these different types of wireless networks. To fulfil these requirements for seamless VHO many techniques were proposed for integration between the aforementioned technologies: interworking architectures, frameworks, mobility management protocols and mechanism; these are discussed next.

3.2.1 Interworking Architectures

Loose coupling and tight coupling are two main VHO interworking architectures proposed by European Telecommunication Standards Institute (ETSI) in 2001[85] for integrating between different types of technologies [86]. In this section, we survey loose and tight coupling VHO interworking architectures and highlight their objectives, features and challenges.

3.2.1.1 Loose Coupling

In loose coupling architecture, each of the existing access wireless networks such as UMTS, Wi-Fi and WiMAX is independently deployed [58]. Both of WiMAX and Wi-Fi data do not pass through 3GPP core network [87]. This in turn means there is no need to modify current architecture, no additional cost and the interworking point occurs after 3GPP core network in particular, follow GGSN with internet [87]. The networks interconnection in this architecture also based on MIP while for roaming service the AAA server connects between different RATs which allow the Wi-Fi and WiMAX data go directly to the internet without requiring for direct link between their components and 3GPP core network [87]. Figure.3.1 shows an example of loose coupling between UMTS and WiMAX.

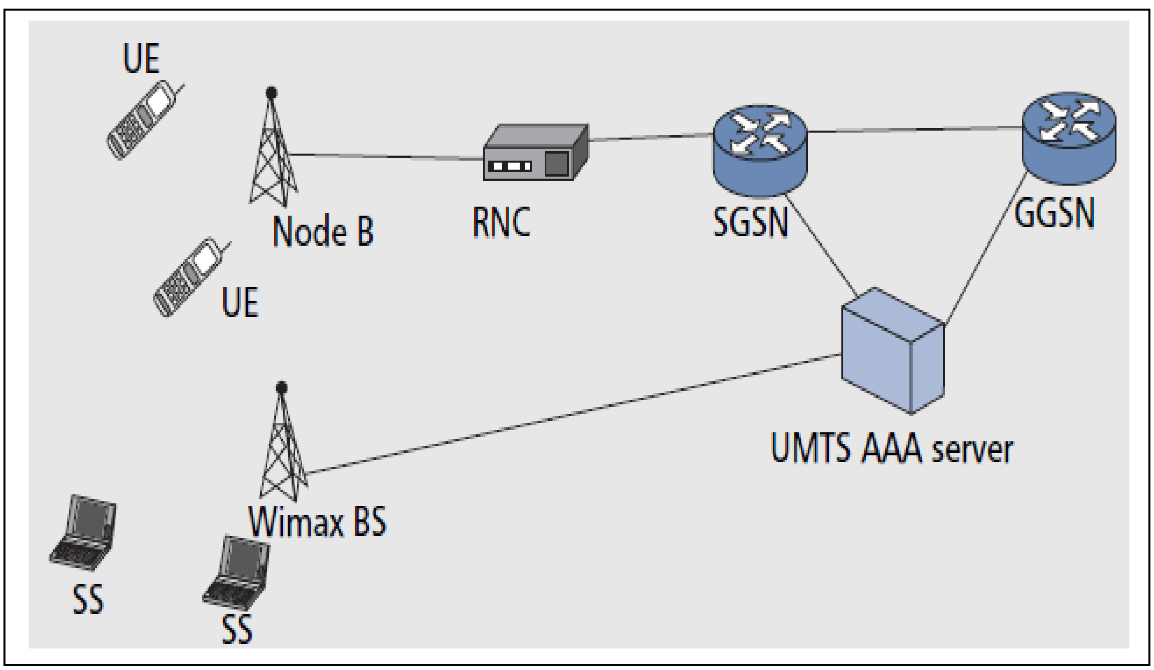

Figure 3.1: Loose Coupling Integration [56]

3.2.1.2 Tight Coupling

In tight coupling architecture, the Wi-Fi and WiMAX data pass through 3GPP core network before going to the internet and significant modifications of existing access wireless networks are necessary for providing seamless service to the MU to move from one network to another [87]. This in turn impacts 3GPP core network performance in terms of complexity, congestion and packet loss due to overload [6]. The networks interconnection in this architecture is based on existing 3GPP core network functionalities (e.g., core network resources, subscriber databases and billing systems) that ensure MUs to continue their ongoing sessions when moving within different RATs [6]. There are two types of tight coupling [6, 87]:

A. Tight Coupling Integration at GGSN Level

In this architecture, all of RATs are connected together by Virtual GPRS Support Node (VGSN) which is responsible to exchange subscriber information and route packets between the wireless access networks, the handover duration (latency) is equivalent with loose coupling where MIP is used (no need of MIP functionalities) and it requires less complexity modification in 3GPP core network [65], this is shown in Figure.3.2.

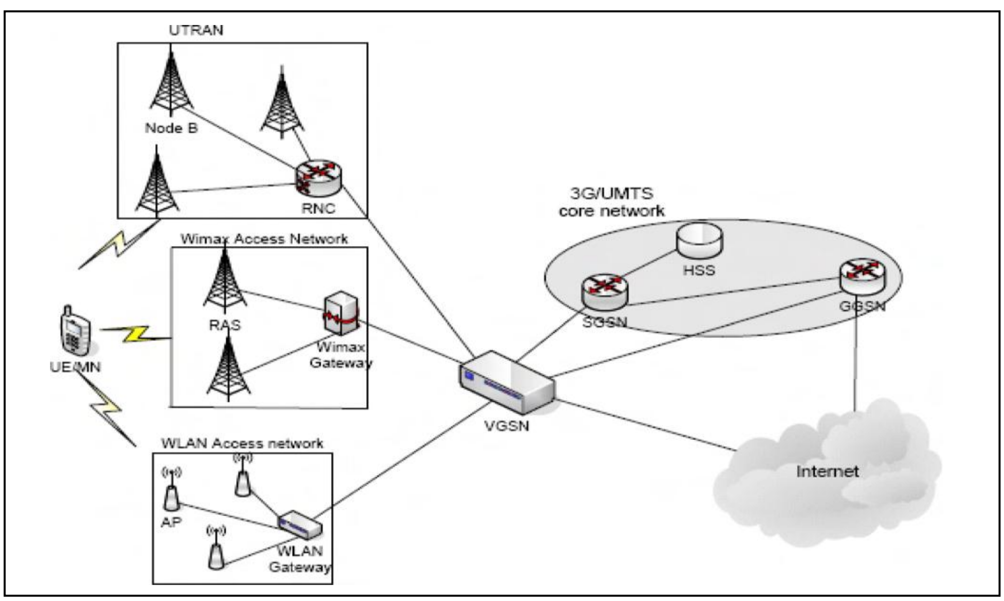

Figure 3.2: Tight Coupling Integration at GGSN Level [6]

B. Tight Coupling Integration at RNC Level

In this architecture, the AP and BS in Wi-Fi and WiMAX, respectively are connected with RNC by Interworking Unit (IWU). The IWU main functionality is to translate protocol and signaling exchange between RNC and another RATs interface such as AP and BS [6], this is shown in Figure.3.3.

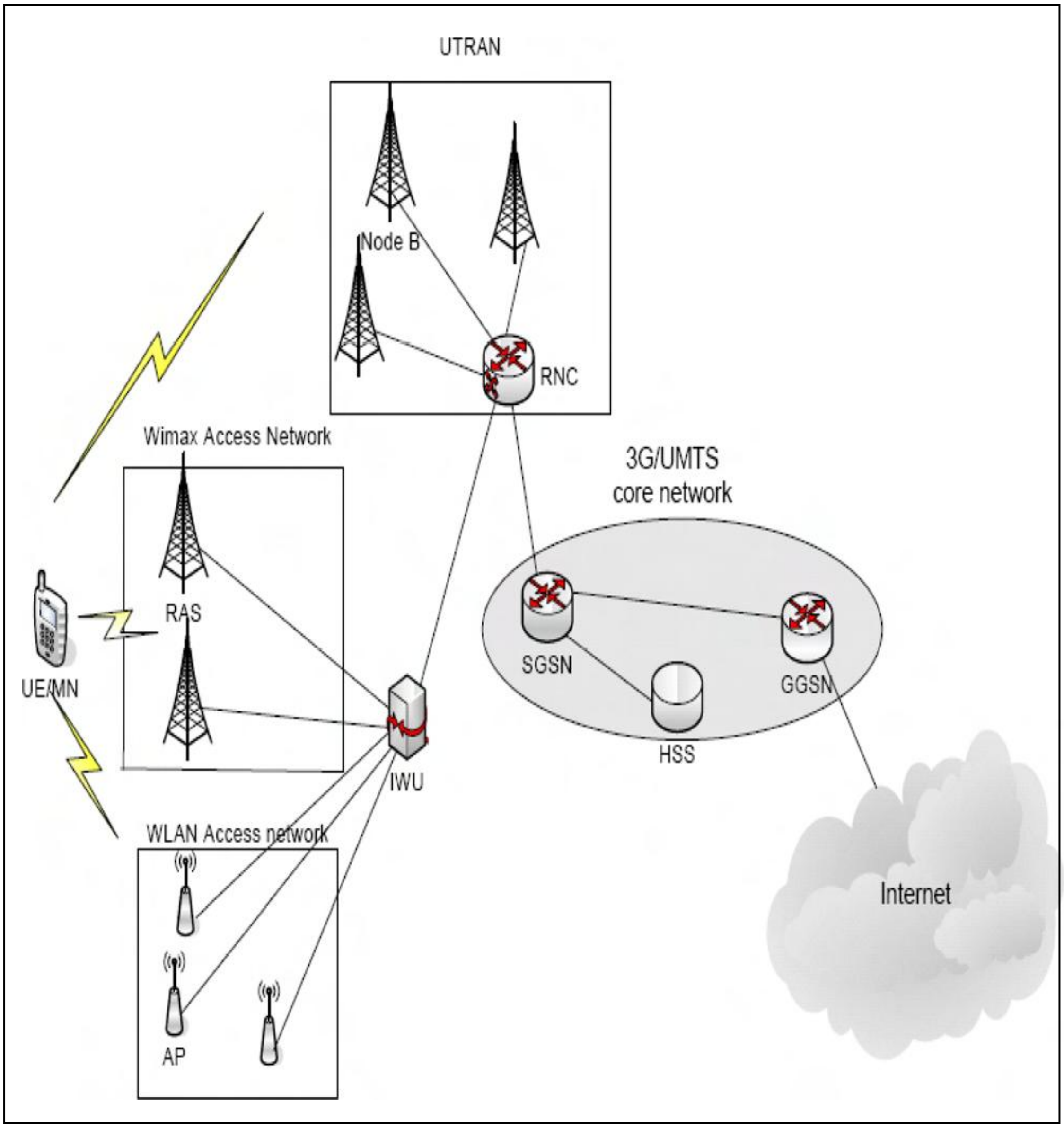

Figure 3.3: Tight Coupling Integration at RNC Level [6]

3.2.1.3 Loose vs. Tight Coupling Comparison

In sections 3.2.1.1 and 3.2.1.2, we have surveyed two main VHO interworking architectures: loose coupling and tight coupling. Their purposes, features and challenges have been discussed and published in [88]. To provide comparison of the two VHO interworking architectures, we summarise their specifications on: efficiency of handover duration, probability of packet loss, mobility management, congestion, complexity, overload, additional modification and additional cost, this is shown in Table.3.1. According to our comparison between the VHO interworking architectures in Table.3.1, loose coupling seems to supersede tight coupling for the majority of the compared characteristics [88]. It provides the same efficiency for handover duration when MIP is used and lower probability of packet loss than tight coupling which is incurred due to overload in 3GPP core network [88].

Characteristics	Tight Coupling	Loose Coupling
Efficiency of Handover Duration	Low.	Similar with MIP.
Probability of Packet Loss	High.	Low.
Mobility Management	3GPP Core Network Functionalities.	MIP.
Congestion	High.	Low.
Complexity	High.	Low.
Overload	High.	Low.
Additional Modification	High.	No.
Additional Cost	High.	No.

Table 3.1: Comparing Loose vs. Tight Coupling [88]

3.2.2 Access Network Discovery and Selection Function (ANDSF) Mechanism

3GPP Group proposed ANDSF in 2008 (Release 8) [91] to provide a seamless VHO between different RATs and to mitigate the impacts of radio signals impairment between 3GPP and non-3GPP. In this mechanism, there is no need to the measurements reports between different RATs, and hence, no need to the modification on legacy radio systems (no additional cost). The ANDSF also works as a store of RATs information that is queried by the MU to make handover decision. As shown in Figure.3.4, this information about neighbour cells, operator's policies and preferences, QoS, capabilities, etc. [93]. A detailed survey of this technique can be found in chapter 4 of this thesis.

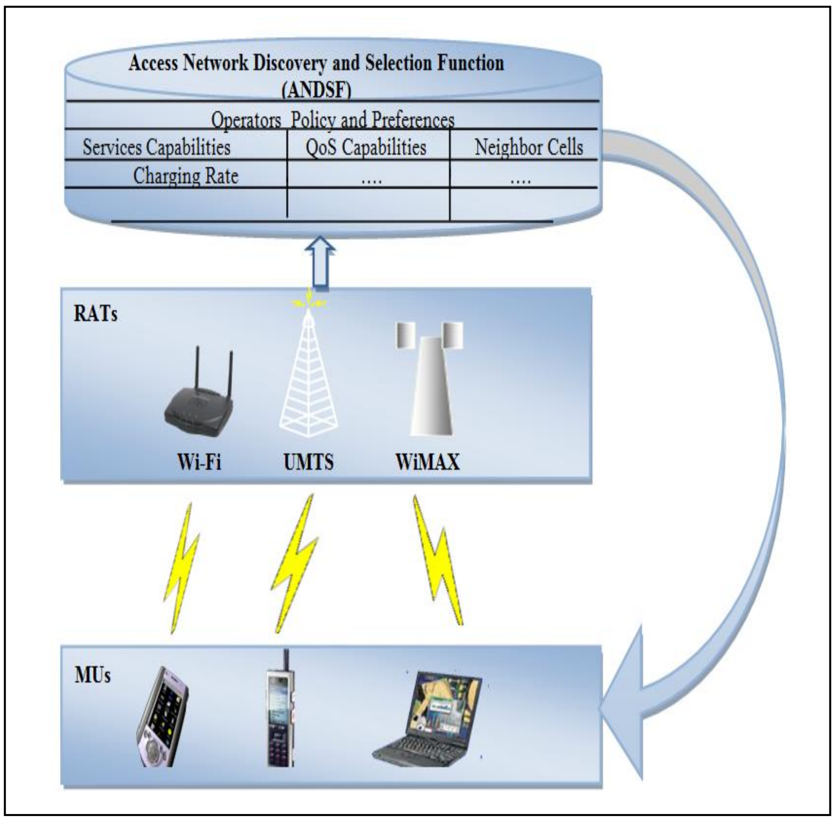

Figure 3.4: Access Network Discovery and Selection Function (ANDSF) Passing Information about Radio Access Technologies (RATs) to Mobile Users (MUs) [92]

3.2.3 Interworking Frameworks

One challenge of wireless networks integration is to provide ubiquitous wireless access ability and seamless handover for mobile communication devices between different types of technologies such as Wi-Fi, WiMAX, UMTS and LTE. This challenge is critical as MUs are becoming increasingly demanding for services regardless of the technological complexities associated with them. To fulfil these requirements for seamless VHO two main interworking frameworks were proposed by IEEE Group and 3GPP for integration between the aforementioned technologies; namely, MIH and IMS where each of them requires mobility management protocol to complement its work such as MIP and SIP, respectively.

3.2.3.1 Media Independent Handover (MIH) Framework

The IEEE Group released IEEE 802.21 standard Media Independent Handover (MIH) in 2009 to provide seamless VHO between heterogeneous wireless networks that include both wireless (3GPP and non-3GPP) and wired media [89, 90, 94, 95, 96, 97, 98, 99, 100 and 101]. The IEEE 802.21 defines two entities; the first one, Point of Service (PoS) which is responsible for establishing communication between a network and the MU under MIH and the second one, PoA which is RAT access point. The MIH also provides three main services: Media Independent Event Service (MIES), Media Independent Command Service (MICS) and Media Independent Information Service (MIIS) [102] such that the MIH relies on the presence of mobility management protocols (e.g., MIP and SIP), this is shown in Figure.3.5.

A. Media Independent Event Service (MIES)

It is responsible for detecting events and reporting them between the MU and the network (e.g., link up on the connection (established), link down (broken) and link going down (breakdown imminent)), this is shown in Table.3.2.

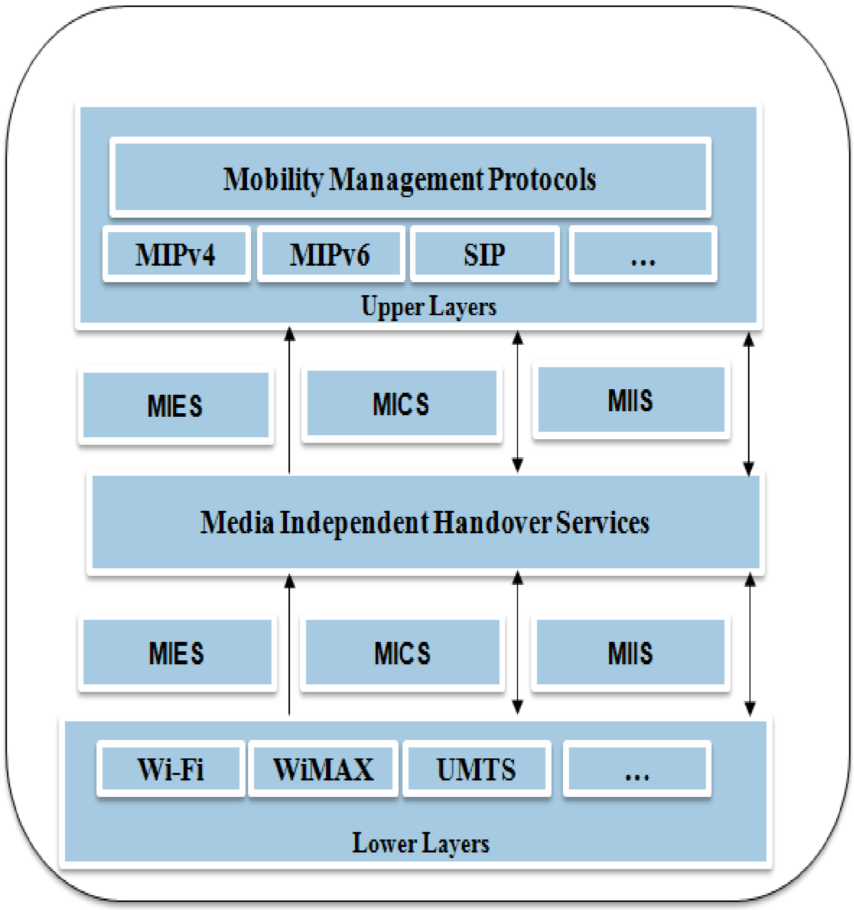

Figure 3.5: Media Independent Handover (MIH) [103]

B. Media Independent Information Service (MIIS)

It is responsible for collecting all information required to identify if the handover is needed or not and pass the information to MUs (e.g., available networks, locations, capabilities and cost), this is shown in Table.3.3 and Figure.3.6.

C. Media Independent Command Service (MICS)

It is responsible for issuing the commands based on information which is gathered by MIIS and MIES (e.g., MIH handover initiate, MIH handover prepare, MIH handover commit and MIH handover complete), this is shown in Table.3.4.

No	Event Type	Event Name	Description
1	State Change.	Link Up.	L2 connection established.
2	State Change.	Link Down.	L2 connection is broken.
3	Predictive.	Link Going Down.	L2 connection breakdown imminent.
4	State Change.	Link Detected.	New L2 link has been found.
5	State Change.	Link Parameters Change.	Change in specific link parameters has crossed pre-specified thresholds (link speed, quality metrics).
6	Administrative.	Link Event Rollback.	Event rollback.
7	Link Transmission.	Link SDU Transmit Status.	Improve handover performance through local feedback as opposed to waiting for end-to-end notifications.
8	Link Synchronous.	Link Handover Imminent.	L2 intra-technology handover imminent (subnet change). Notify handover information without change in link state.
9	Link Synchronous.	Link Handover Complete.	Notify handover state.

Table 3.2: Link Layer Events [103]

Information Element	Description	Comments
List of Networks Available	List all network types that are available given client location.	E.g., 802.11, 802.16, GSM, GPRS/EDGE, UMTS networks.
Location of PoA	Geographical location, civic address and PoA ID.	E.g., GML format for LBS or network management purpose.
Operator ID	Name of a network provider.	E.g., Could be equivalent to network ID.
Roaming Partners	List of direct roaming agreements.	E.g., in form of Network Access Identifier (NAIs) or Mobile Country Code (MCC) + Mobile Network Code (MNC).
Cost	Indication of costs for service/network usage.	E.g., Free/not free or (flat rate, hourly, day or weekly rate).
Security	Link layer security supported.	Cipher suites and authentication methods, technology specific, e.g., Wireless Equivalent Privacy (WEP) in 802.11, 802.11i, Privacy Key Management (PKM) in 802.16, etc.
QoS	Link QoS parameters.	802 wide representation, application friendly.
PoA Capabilities	Emergency services, IMS services, etc.	Higher layer services.
Vendor Specific IEs	Vendor/operator specific information.	Custom information.

Table 3.3: Handover Information Elements [103]

No	Command Name	MIHF <> MIHF	Description
1	MIH Handover Initiate.	Client <> Network.	Initiates handovers and sends a list of suggested networks and suggested PoA (AP/BS).
2	MIH Handover Prepare.	Network <> Network.	This command is sent by Media Independent Handover Function (MIHF) on old network to MIHF on suggested new network. This allows the client to query for resources on new network and also allows to prepare the new network for handover.
3	MIH Handover Commit.	Client <> Network.	In this case the client commits to do the handover based on selected choices for network and PoA.
4	MIH Handover Complete.	Client <> Network. Network <> Network.	This is a notification from new network PoA to old network PoA that handover has been completed, new PoA has been established and any pending packets may now be forwarded to new PoA.

Table 3.4: Handover Commands for Network Initiated Handovers [103]

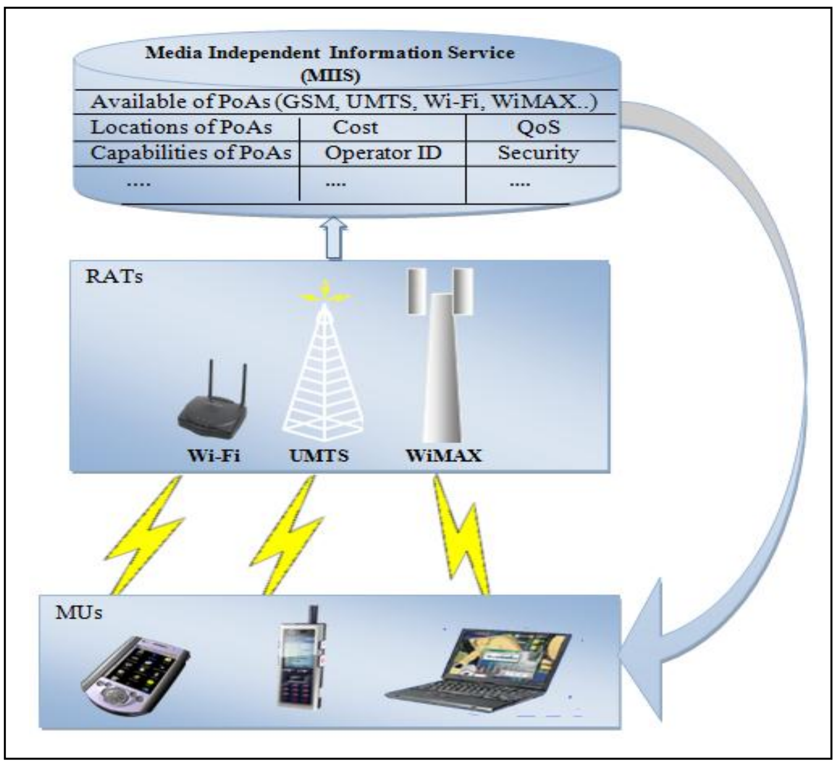

Figure 3.6: Media Independent Information Service (MIIS) Passing Information about Radio Access Technologies (RATs) to Mobile Users (MUs) [92]

However, no handover decision is made within MIH [104], "the actual algorithms to be implemented are left to the designers" [80] and the security for re-authentication at a target network and implementation of the decision algorithm are out of the scope of MIH [95].

3.2.3.2 IP Multimedia Subsystem (IMS) Framework

The IP Multimedia Subsystem (IMS) was introduced in 2002 by 3GPP (Released 5) to support multimedia services in UMTS [39, 56, 57 and 105] and provides access security to IMS. However, it started supporting multimedia service for both wireless (3GPP and non-3GPP) and wired networks in Release 7 [106]. The IMS is defined as a 3-layer architecture consisting of transport layer, control layer and application layer, this is shown in Figure.3.7.

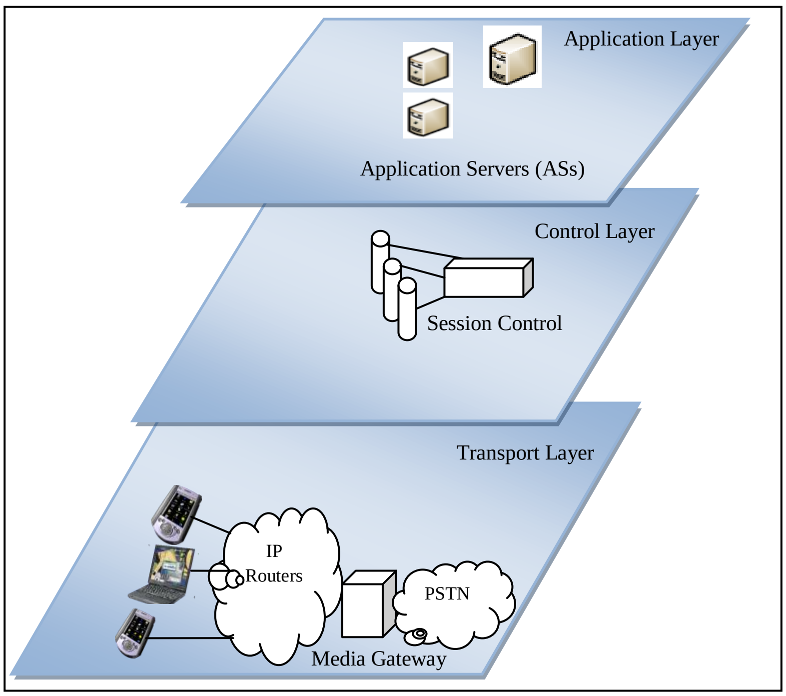

Figure 3.7: Application, Control and Transport Layers of an IP Multimedia Subsystem (IMS) [107]

A. Transport Layer

It includes all the entities for the supported access networks which allow IMS devices and MUs connect the IMS through many types of access networks (e.g., Wideband Code

Division Multiple Access (WCDMA), UMTS, Wi-Fi, WiMAX, Ethernet and DSL). It also allows the IMS device to receive/send call either through PSTN or the Media Gateway (MGW) [107].

B. Control Layer

This layer includes three SIP signaling servers that are known as Call Session Control Functions (CSCFs) which are responsible for establishing, managing and terminating media sessions. It also includes other entities (i.e. HSS, Breakout Gateway Control Function (BGCF), Media Gateway Control Function (MGCF), Media Resource Function Controller (MRFC) and Multimedia Resource Function Processor (MRFP)) [107], this is shown in Table.3.5.

Components	Roles
Breakout Gateway Control Function (BGCF)	Select the network in which the connection to the PSTN will be made.
Home Subscriber Service (HSS)	Database stores user authorisation and profile information which is queried by SCSCF server for providing the service to the user.
Interrogating-Call Session Control Functions (I-SCSF)	• Assigning a S-CSCF to the user. • SIP registration. • Generating charging data records. • Acting as a Topology Hiding Interworking Gateway (THIG).
Media Gateway Control Function (MGCF)	Sends or receives calls to/from the PSTN/Circuit-Switched Network.
Media Resource Function Controller (MRFC)	Controls the MRFP to provide media processing required by the Application Servers (ASs).
Multimedia Resource Function Processor (MRFP)	Performs all of the media processing required such as conferencing, voice mail, etc.
Proxy-Call Session Control Functions (P-CSCF)	• Authorising the bearer resources for the appropriate QoS level. • Monitoring. • Emergency calls. • Header compression. • Interrogating- CSCF (I-CSCF) identification.
Serving-Call Session Control Functions (S-CSCF)	• It provides routing services typically using Electronic Numbering (ENUM) lookups. • It inspects every message as it sits on the path of all signaling messages. • It enforces the policy of the network operator.

Table 3.5: Control Layer of an IP Multimedia Subsystem (IMS) [109]

C. Application Layer

In this layer, the Application Server (AS) is responsible for hosting and executing all the services offered by IMS.

However, in this framework, handover decision is out of its scope and unlike the MIH framework the MU obliges to discover neighbour cells with no assistance by periodically conducting a radio scanning in the background which result in [109]:

- Limited information is discovered.
- The MU needs two receivers work concurrently one for scanning and another for ongoing session while one receiver may be incurred probability of missing data from serving cell.
- High MU power consumption.
- Upgrades legacy cells (2G/3G) due to broadcast information about 4G neighbours cells such as WiMAX and LTE.

3.2.3.3 VHO Approaches Classifications Based on Frameworks

Although researches about VHO under MIH and IMS frameworks have been surveyed recently in [108], highlights on their objectives and performances issues have not been considered yet [109]. Therefore, in this section, we classify VHO approaches proposed in the literature into four categories based on MIH and IMS frameworks in order to present their objectives and performances issues. We identify the four categories: MIH based category, IMS based category, MIP under IMS based category and finally, MIH and IMS combination based category.

3.2.3.3.1 MIH Category

Many VHO approaches have been proposed in the literature applied in conjunction with MIPv4 and MIPv6 under MIH [2, 94 and 110] and [104, 111, 112, 113 and 114], respectively [115].

In [2], the authors proposed an algorithm to guarantee the continuity of service during a communication session in heterogeneous wireless networks between Wi-Fi, WiMAX and 3G scenarios such that a set of components organised in three layers which offered the MU the possibility to monitor its resources and its network performance. The RSS, link layer throughput, link quality, loss rate and contention rate parameters were considered to make VHO decision. This algorithm allowed the user a possibility to select the mode which corresponds to his/her context: manual mode or an automatic mode. The manual mode gave the user the control to select a target RAT in which he/she wanted to continue his/her communication. This mode did not take into account the signaling cost and the inevitable degradation in QoS as result of unnecessary VHO processes. In automatic mode, the user gave to the system the control of VHO. The implementation of their algorithm which was in real environment by Meditel Telecommunication operator in Morocco showed throughput (KBite/s) and latency (ms) considering streaming traffic for WiMAX, Wi-Fi and 3G were (62.24, 60.48, 55.99) and (20.1, 22.4, 46.2), respectively [2]. However, this work is content only with selecting one target RAT for the checking resources.

In [94], the authors presented the integration process of MIH with Wi-Fi, WiMAX and UMTS scenarios in order to provide seamless VHO with low latency and zero packet loss. The RSS parameter was considered to make VHO decision before source PoA link was disconnected due to RSS going down. The latency was divided into two phases: Handover Preparation Latency (HPL) and Handover Execution Latency (HEL). The HPL was the time interval in which the MU queried the MIIS about available RATs for handover, the HEL was the time since the MU sent/received authentication messages to its target network (new PoA) until the reception of the first packet on a target network. The Ns-2 Simulator was used considering two types of traffic IPTV and VoIP. The results for handover between Wi-Fi and WiMAX showed that HPL was approximately

125 ms, HEL was 45 ms and jitter was 1.5 ms, and for handover between WiMAX and UMTS results showed that latency due to HPL was approximately 36 ms, HEL was 110 ms and jitter was 4.3 ms [94]. Finally, the handover between UMTS and Wi-Fi results showed that HPL was approximately 31 ms, HEL was 48 ms and jitter was 6.3 ms [94] while no performance evaluation provided regarding packet loss.

In [104], a new approach that combined MIH and ANDSF was proposed for improving the VHO behaviour such that ANDSF is an entity produced by 3GPP to provide seamless VHO between different RATs. The aim of the proposed approach was to eliminate packet loss and improve the resource release mechanism in a source access network between WiMAX and LTE scenario. However, no evaluations or validation about the work has been provided.

In [110], the authors presented MIH vertical handover approach in order to provide seamless VHO with low latency, they also presented MIH Layer 2 (MIH L2) trigger handover decision algorithm based on RSS taking into account Wi-Fi and WiMAX scenario. Analytical modelling and Ns-2 simulator were used considering FTP traffic. The result showed that latency was considerably reduced compared with MIPv4 through the pre-registration process using the L2 trigger [110].

In [111], the authors presented fast handover approach for heterogeneous wireless networks that utilised MIH with Proxy Mobile IPv6 (PMIPv6) to support heterogeneous wireless networks performance between Wi-Fi and WiMAX scenario taking into account RSS to make VHO decision. The analytical modelling results showed that the proposed approach reduced latency time by 26% and packet losses by 90% [111].

In [112], the authors presented a performance evaluation of VHO decision algorithm using MIH and considering Wi-Fi, WiMAX and UMTS scenarios to select a target RAT.

Constant Bit Rate (CBR) traffic was used in order to evaluate VHO latency, throughput and packet loss in an Ns-2 simulator. The RSS and network capacity parameters were considered to make VHO decision. The results showed the Wi-Fi offered the highest throughput, reaching up to 28.2 Mbps [112]. Then WiMAX offered up to 11 Mbps while UMTS offered a 2.04 Mbps data rate. Concerning latency, the UMTS took an average of 29.96 ms to deliver one packet whereas WiMAX and Wi-Fi offered lower latencies: 0.81 and 0.23 ms [112], respectively. Finally, the packet loss between seven VHO scenarios was considered: Wi-Fi(1)-WiMAX(1), Wi-Fi(2)-WiMAX(2), WiMAX(1)-Wi-Fi(1), WiMAX(1)-UMTS, WiMAX(2)-UMTS, UMTS-Wi-Fi(2) and UMTS-WiMAX(1) (81, 0, 0, 679, 664, 0 and 0), respectively [112]. However, this work is content only with selecting one target RAT for the checking resources.

In [113], a new approach that enabled seamless VHO in wireless heterogeneous environments was presented. The proposed approach combined the MIPv6 mobility management protocol, the MIH, and a mobility control entity to perform VHO with minimal packet loss and latency between Wi-Fi and 3G (High Speed Packet Access (HSPA)) scenario taking into account the RSS parameter to make VHO decision. The Network Mobility Manager (NET_MM) and Mobile Node Mobility Manger (MN_MM) were two logical entities developed in the proposed approach. The NET_MM was the network entity that controls, with the help of MN_MM which placed on the MU device. The authors divided the latency into two periods: Handover Latency (HL) and Handover Execution Latency (HEL). The HL was the time interval in which the MU did not receive any packets as a result of handover until the first packet received by target network (new PoA), the HEL was the time since the MU sent a Binding Update (BU) to its HA until the reception of the first packet on the new target network. Testbed experiment was developed considering two types of traffic video and VoIP. The results showed that latency was zero when using video or VoIP traffic at HL while at HEL was approximately 0.5 sec whereas packet loss was approximately 0.18% [113].

In [114], the authors presented analytical modelling of VHO latency for Proxy MIPv6 (PMIPv6), Proxy First MIPv6 (PFMIPv6) and IEEE 802.21-enabled PMIPv6 (MIH-enabled PMIPv6) between Wi-Fi and WiMAX scenario in [116, 117] taking into account RSS to make VHO decision. The Analytical results for MIH-enabled PMIPv6 showed that L2 latency was approximately 50 ms while between the MU and a source network/target network was 50-150 ms [114].

3.2.3.3.2 IMS Category

In the literature there are many approaches which have been proposed about VHO based on SIP under IMS [58, 118, 119 and 120].

In [58], analytical modelling was presented in order to evaluate the signaling cost of mobility management during VHO between WiMAX and UMTS scenario. The results showed that transmission signaling cost, the transmission processing cost and the queuing signaling cost increased linearly with the increasing value of IMS arrival rate [58].

In [118], the authors presented an internetworking approach to provide the continuity of service during and after VHO session while moving between Wi-Fi and UMTS scenario. The OPNET simulator was used considering VoIP traffic and result showed that latency was approximately 150 ms [118].

In [119], the authors presented two WiMAX-3G interworking approaches: Loosely Coupled WiMAX-Cellular (LCWC) and Tightly Coupled WiMAX-Cellular (TCWC) based on loosely and tightly coupling VHO interworking architectures, respectively to investigate the effects of these VHO interworking architectures on SIP-based IMS registration and session setup procedures such that tight coupling required significant modifications of existing access networks for providing seamless service to the MU to move from one network to another which resulted in additional cost. They also analysed the effects of their WiMAX-3G interworking approach on the IMS signaling latency.

Analytical modelling and Ns-2 simulator were used considering VoIP, MPEG, FTP and Hypertext Transfer Protocol (HTTP) traffics. The results showed that IMS registration latency for WiMAX in TCWC architecture was lower than in LCWC architecture whereas the IMS registration latency for 3G was the same for both TCWC and LCWC, also the IMS session setup latency in TCWC architecture was lower than latency in LCWC architecture when a Source Node (SN) was in a 128 Kbps 3G network and the Correspondent Node (CN) was in a 24 Mbps WiMAX [119].

In [120], the authors presented Wi-Fi and WiMAX scenario and three coupling architectures such as Tight Coupling (TC), Loose Coupling (LC) and Hybrid Coupling (HC) to investigate VHO latency, mobile scanning interval activity and neighbour advertisement received. The OPNET simulator showed that HC obtained less latency than LC and TC such that the latency at the 50th minute was approximately 0.022 sec [120].

3.2.3.3.3 MIP under IMS Category

In the literature there are many approaches which have been proposed about VHO based on MIP under IMS [52, 121, 122 and 123].

In [52], the authors presented an approach in order to provide seamless VHO between WiMAX and UMTS scenario with no packet loss and minimum latency taking into account the RSS parameter to make VHO decision. The OPNET simulator was used considering FTP and VoIP traffics and results showed that the average latency using FTP was approximately 45.7 ms in UMTS and 28.8 ms in WiMAX while the latency was approximately 31.6 ms in UMTS and 19.8 ms in WiMAX using VoIP [52]. However, no performance evolution provided regarding packet loss.

In [121], the authors presented a new cross-layer mobility management approach to provide smaller VHO latency and lower signaling overhead. Analytical modelling showed latency between the MU and HA, the MU and CN was approximately 52-76 ms and 47-87 ms, respectively while signaling cost between the MU and HA, the MU and CN was approximately 2000-8750 and 2500-7500, respectively [121].

In [122], the authors presented new approach to investigate various performances such as VHO packet loss, latency, jitter and signaling cost. Analytical modelling and OPNET simulator were used considering VoIP traffic. The simulator showed the average session setup and VHO latency between UMTS to WiMAX scenario was 190 ms and 210 ms, respectively while packet loss was approximately 0.34 when number of VHO was reached to 6, it also showed that the signaling cost exponentially reduced with increasing Call-to-Mobility Ratio (CMR) when the session arrival rate and service rate were constant while jitter was exponentially increasing [122].

In [123], the authors presented an approach in order to provide seamless VHO with QoS support between WiMAX and UMTS scenario taking into account the RSS and QoS for video conference to make VHO decision while no performance evolution provided regarding VHO.

3.2.3.3.4 MIH and IMS Combination Category

In the literature there are two approaches which have been proposed about VHO based on combination between MIH and IMS [124, 125].

In [124], the authors presented an approach between Wi-Fi, WiMAX and UMTS scenarios in order to perform intelligent and accurate VHO with better packet loss and latency taking into account the RSS to make VHO decision. The authors divided the latency into two periods: handover latency between the MU and Advertisement Router (MU-AR) and handover latency between the MU and HA (MU-HA). The analytical modelling results taking into account video streaming showed that latency was approximately 50 ms-100 ms at the MU-AR and 50 ms at the MU-HA time while packet loss was zero [124].

In [125], the author presented new approach to minimise handover latency and improving perceived video quality in terms of Peak Signal-to-Noise Ratio (PSNR). The PSNR or Signal-to-Noise Ratio (SNR) parameters was considered to make VHO decision. Analytical modelling and testbed experiment between 3G and Wi-Fi indicated that the VHO latency was reduced by 12 sec compared with non-integrated MIH/IMS frameworks [125].

3.2.3.4 Comparison of VHO Approaches

In section 3.2.3.3, we have discussed eighteen VHO recent approaches found in the literature [2, 52, 58, 94, 104, 110, 111, 112, 113, 114, 118, 119, 120, 121, 122, 123, 124 and 125] and classified them into four categories based on MIH and IMS frameworks in order to present their objectives and performances issues. To offer a systematic and exhaustive comparison in this survey, we present two types of comparison: a comparison between the frameworks (MIH and IMS) and a comparison between the four categories based on these frameworks (MIH based category, IMS based category, MIP under IMS based category and MIH and IMS combination based category).

3.2.3.4.1 Comparison between the Frameworks

In order to provide a comparison of the two frameworks, we summarise their specifications with regard to fourteen aspects: producer, released, mobility management protocol, legacy RATs, security, implementation of the decision algorithm, wired and wireless multimedia service, available RATs provider, available RATs provider capability, upgrade, additional cost, components, battery consumptions (MU) and receivers (MU), this is shown in Table.3.6.

As shown in section 3.2.3.2, the IMS framework includes large number of components, it is based on SIP for mobility management and the MU obliges to discover neighbour cells with no assistance by periodically conducting a radio scanning in the background which result in: **(a)** limited information is discovered **(b)** the MU needs two receivers work concurrently one for scanning and another for ongoing session while one receiver may be incurred probability of missing data from serving cell **(c)** high MU power consumption and **(d)** upgrades legacy cells (2G/3G) due to broadcast information about 4G neighbours cells (e.g., WiMAX and LTE) which results in additional cost.

As shown in section 3.2.3.1, MIH presents less number of components compared with IMS, it is based on various mobility management protocols such as MIPv4 and MIPv6 which are best standard for VHO and presents MIIS which is responsible for collecting all information required to identify if the handover is needed or not and pass the information to MUs (e.g., available networks, locations, capabilities and cost) which results in: **(a)** large amount of information is provided **(b)** one receiver for ongoing session **(c)** low MU power consumption and **(d)** no need to upgrade legacy cells (no additional cost); hence, the majority of approaches found in the literature are based on MIH framework. However, security check is out of its scope.

Whereas the common area between them includes support wired and wireless multimedia service and legacy RATs while implementation of the decision algorithm is out of their scope.

The Specification	MIH	IMS
Producer	IEEE Group.	3GPP.
Released	2009.	2002.
Mobility Management Protocol	MIPv4,MIPv6,HIP,SIP, etc.	SIP.
Legacy RATs	Support.	Support.
Security	Out of scope.	Support.
Implementation of the Decision Algorithm	Out of scope.	Out of scope.
Wired & Wireless Multimedia Service	Support.	Support.
Available RATs Provider	MIIS.	Cell broadcasting.
Available RATs Provider Capability	Large.	Limited.
Upgrade	No need.	Legacy cells (2G/3G).
Additional Cost	No.	Yes.
Components	Five.	Eleven.
Battery Consumptions (MU)	Low.	High.
Receivers (MU)	One.	Two.

Table 3.6: Comparative Summary of the Two Frameworks (MIH and IMS) [109]

3.2.3.4.2 Comparison between the Categories

In order to provide a comparison of the four categories, we summarise their features with regard to eight aspects: objective, VHO decision criteria, applicable area, additional entity, cost, complexity, evaluation method and traffic, this is shown in Table.3.7. We observe that the MIH is the only category which presents solutions include all existing networks: 3G (e.g., UMTS and HSPA) and 4G (e.g., WiMAX and LTE), also the VHO approaches [2, 94 and 112] present comprehensive solutions to ensure the VHO between three types of different RATs: Wi-Fi, WiMAX and 3G, followed by MIH and IMS combination category which deals with three types of different RATs in approach [124] while the rest of categories are content with two types of RATs, this is shown in Figure.3.8.

As for the main objective, the MIH category's performance focuses on two vital parameters that make VHO seamless: packet loss and latency, followed by MIP under IMS category which also focuses on signaling cost, followed by MIH and IMS combination category and finally, the majority approaches of IMS category focus on latency while packet loss is out of its scope, this is shown in Figure.3.9.

For VHO decision criteria, the MIH category presents approaches to make VHO decision based on various network parameters as in [2, 112], followed by MIH and IMS combination category and MIP under IMS category due to (PSNR, SNR, RSS), (QoS, RSS), respectively while in IMS category the VHO decision criteria is not mentioned.

In terms of complexity, the MIH and IMS combination category is very complex due to the combination between the frameworks (MIH and IMS) which results in additional entities and cost, followed by MIP under IMS category due to MIP components (HA and FA), followed by IMS with less complexity due to the large number of its components that require for VHO session, lastly, MIH category is simple compared with above categories due to less number of components which are able to play vital role for providing seamless VHO by selecting target RAT.

Finally, the evolution methods in this survey are various between real environment, testbed, simulation tools and analytical modelling. We observe that the MIH is the dominant category compared with the other categories because it is mostly in the practical and it is sole providing one empirical work of real environment [2]. See Figure.3.10.

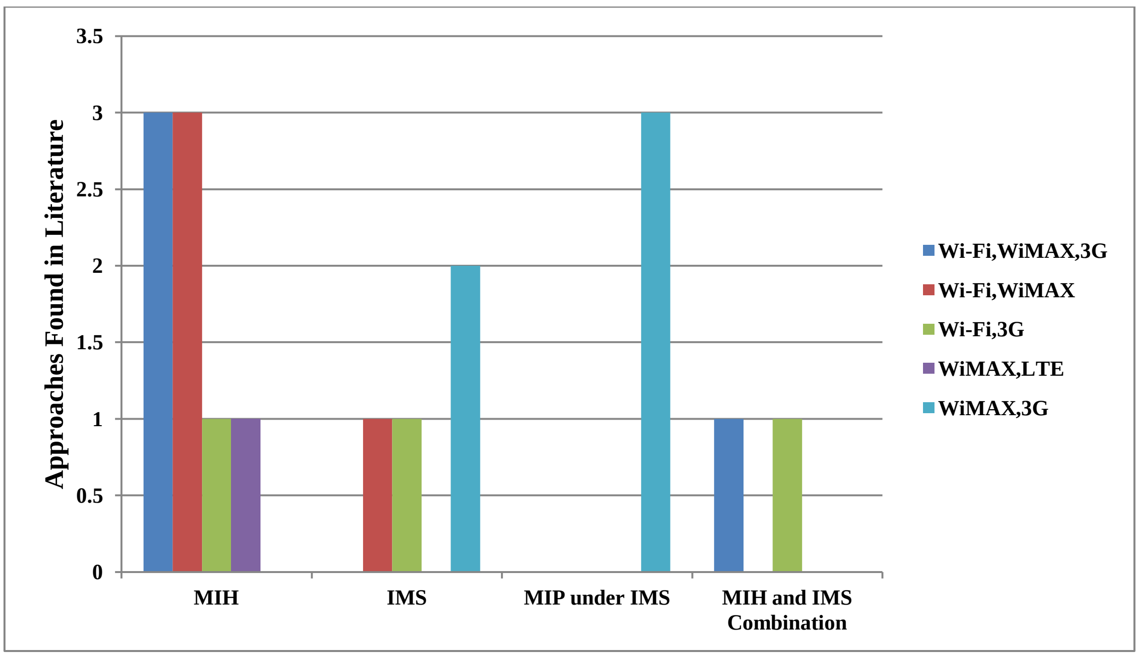

Figure 3.8: Comparison between the Categories (RATs) [109]

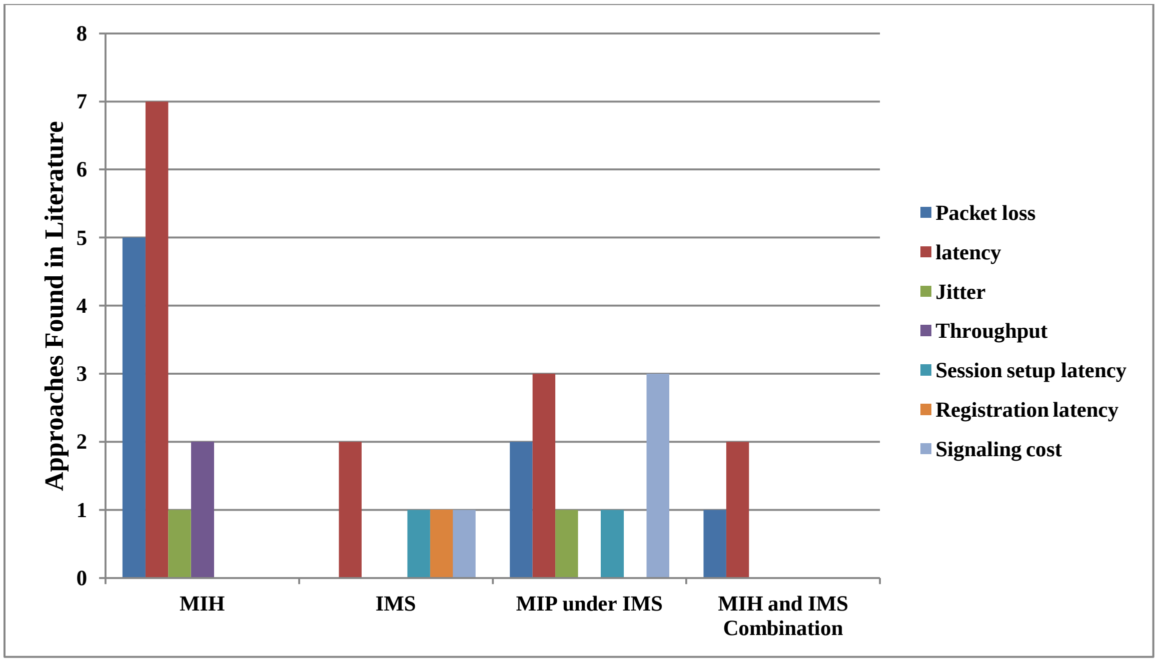

Figure 3.9: Comparison between the Categories (Performances) [109]

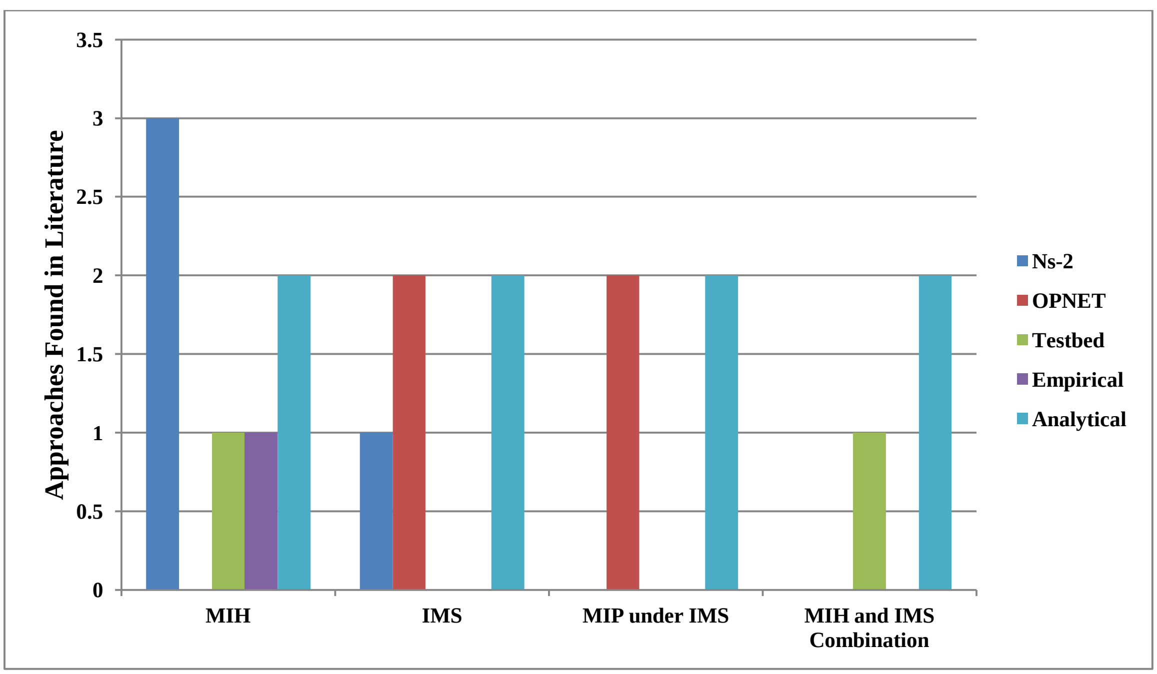

Figure 3.10: Comparison between the Categories (Evaluation Methods) [109]

Category	Approach Found in Literature	Main Objective	VHO Decision Criteria	Applicable Area	Additional Entity	Additional Cost	Evaluation Method	Traffic	Complexity
MIH	[2]	Latency. Throughput.	RSS. Network performance. Link throughput. Link quality. Loss rate. Connection rate.	Wi-Fi WiMAX 3G.	Yes.	Yes.	Empirical.	Streaming.	Simple.
	[94]	Latency. Packet loss. Jitter.	RSS.	Wi-Fi WiMAX UMTS.	No.	No.	Simulation (Ns-2).	VoIP. IPTV.	
	[104]	Packet loss.	Not mentioned.	WiMAX LTE.	Yes.	Yes.	Not evaluation.	Not mentioned.	
	[110]	Latency.	RSS.	Wi-Fi WiMAX.	No.	No.	Simulation (Ns-2).	FTP.	
	[111]	Latency. Packet loss.	RSS.	Wi-Fi WiMAX.	No.	No.	Analytical.	Not mentioned.	
	[112]	Latency. Packet loss. Throughput.	RSS. Network capacity.	Wi-Fi WiMAX UMTS.	No.	No.	Simulation (Ns-2).	CBR.	
	[113]	Latency. Packet loss.	RSS.	Wi-Fi 3G(HSPA).	Yes.	Yes.	Testbed.	VoIP. Video.	
	[114]	Latency.	RSS.	Wi-Fi WiMAX.	No.	No.	Analytical.	Not mentioned.	
IMS	[118]	Latency.	Not mentioned.	Wi-Fi UMTS.	No.	No.	Simulation (OPNET).	VoIP.	Less complexity.
	[119]	Registration latency. Session setup latency.	Not mentioned.	WiMAX 3G.	TCWC (Yes). LCWC (No).	Yes. No.	Analytical & Simulation (Ns-2).	VoIP, MPEG, FTP, HTTP.	
	[58]	Signaling cost.	Not mentioned.	WiMAX UMTS.	No.	No.	Analytical.	Not mentioned.	
	[120]	Latency.	Not mentioned.	Wi-Fi WiMAX.	HC (Yes). TC (Yes). LC (No).	Yes. Yes. No.	Simulation (OPNET).	Not mentioned.	
MIP under IMS	[121]	Latency. Signaling cost.	Not mentioned.	Not mentioned.	Yes.	Yes.	Analytical.	Real time service.	Complexity.
	[122]	Latency. Session setup latency Packet loss. Jitter. Signaling cost.	Not mentioned.	UMTS WiMAX.	Yes.	Yes.	Analytical & Simulation (OPNET).	VoIP.	
	[52]	Latency. Packet loss.	RSS.	WiMAX UMTS.	Yes.	Yes.	Simulation (OPNET).	VoIP. FTP.	
	[123]	Signaling cost.	RSS. QoS.	WiMAX UMTS.	Yes.	Yes.	Not evaluation.	Video conference.	
MIH and IMS Combination	[124]	Latency. Packet loss.	RSS.	Wi-Fi, WiMAX UMTS.	Yes.	Yes.	Analytical.	Video streaming.	High complexity.
	[125]	Latency.	SNR. PSNR.	3G Wi-Fi.	Yes.	Yes.	Analytical & Testbed.	Video.	

Table 3.7: Comparative Summary of the Eighteen VHO Approaches Based on MIH and IMS Frameworks [109]

3.2.4 Mobility Management Protocols

The mobility management has gained importance due to the rapidly increasing number of MUs requesting services over broadband wireless networks. The mobility management has enabled MUs to maintain their ongoing sessions especially when traversing between different RATs. In order to fulfil these requirements for seamless mobility the IETF produced mobility management protocols; these can be classified into five types [89]:

A. Mobile IP (Mobile IPv4, Mobile IPv6)

The MIPv4 and MIPv6 are the best standard for handling wide mobility in IP based networks (macro-mobility) such that MUs traversing different RATs and keeping two IP addresses, one for identification and the other for routing [89].

B. Cellular IP and Handover Aware Wireless Access Internet Infrastructure (HAWAII)

Unlike MIP protocols, this type of protocols is suitable for local movements (micro-mobility) such that MUs roaming within same RATs coverage areas [89].

C. Host Identity Protocol (HIP)

A new name space used between the IP layer and the transport protocols. The namespace separates IP addresses and the host identifier [89]

D. Virtual Internet Protocol (VIP)

It is a virtual IP layer that uses the principle of a virtual network address and a physical network address to internet naming [89].

E. Session Initiation Protocol (SIP)

It is defined to support real-time multimedia services in mobile networks at application layer such that handles both pre-session mobility and mid-session mobility management [89].

However, MIPv4 and MIPv6 are the best standard for VHO in heterogeneous wireless networks [89]; therefore, we consider both of them in the next section.

3.2.4.1 Comparison of VHO Approaches Classifications Based on MIPv4 and MIPv6

Many VHO approaches have been proposed in the literature applied in conjunction with MIPv4 and MIPv6 under MIH [2, 94 and 110] and [104, 111, 112, 113 and 114], respectively [115]. A detailed survey of these approaches can be found in section 3.2.3.3.1. In this section, we classify these approaches into two categories based on MIPv4 and MIPv6 under MIH in order to present their performances issues and characteristics. To provide comparison of the two categories, we summarise their features with regard to eight aspects: objective, VHO decision criteria, applicable area, additional entity, additional cost, complexity, evaluation method and traffic, this is shown in Table.3.8.

In MIPv6 category, the approach [104] is high complex than others due to the combination between MIH and ANDSF, followed by less complexity in [112] and [113] due to VHO decision parameters (network capacity, RSS) and new additional entities result in additional cost (NET_MM, MN_MM), respectively. Finally, simple approach in [111] and [114] due to no additional entities required and the VHO decision criteria based on one parameter (RSS).

In MIPv4 category, we observe that the approach in [2] is complex than others due to collect and normalize various VHO decision parameters (RSS, link layer throughput, link quality, loss rate and contention rate) as it requires set of components organised in three layers which offer the MU the possibility to monitor its resources and its network performance which result in additional cost, followed by simple approach in [94] and [110].

In summary, through a fair comparison between mobility management protocols categories, we show in the Table.3.8 that the MIPv4 category under MIH could continue in the future due its characteristics and performances which are: **(a)** mostly in practical such that one of them is empirical work of real environment **(b)** less complex **(c)** implement three types of RATs and **(d)** multiple parameters for VHO decision making are considered.

Category	Approach Found in Literature	Main Objective	VHO Decision Criteria	Applicable Area	Additional Entity	Additional Cost	Complexity	Evaluation Method	Traffic
MIPv4	[2]	Latency. Throughput.	RSS. Network performance. Link throughput. Link Quality. Loss rate. Connection rate.	Wi-Fi WiMAX 3G.	Yes.	Yes.	Complex.	Empirical.	Streaming.
	[94]	Latency. Packet loss. Jitter.	RSS.	Wi-Fi WiMAX UMTS.	No.	No.	Simple.	Simulation (Ns-2).	VoIP. IPTV.
	[110]	Latency.	RSS.	Wi-Fi WiMAX.	No.	No.	Simple.	Analytical & Simulation.	FTP.
MIPv6	[104]	Packet loss.	Not mentioned.	WiMAX LTE.	Yes.	Yes.	High complex.	Not evaluation.	Not mentioned.
	[111]	Latency. Packet loss.	RSS.	Wi-Fi WiMAX.	No.	No.	Simple.	Analytical.	Not mentioned.
	[112]	Latency. Packet loss. Throughput.	RSS. Network capacity.	Wi-Fi WiMAX UMTS.	No.	No.	Less complex.	Simulation.	CBR.
	[113]	Latency. Packet loss.	RSS.	Wi-Fi 3G(HSPA).	Yes.	Yes.	Less complex.	Testbed.	VoIP. Video.
	[114]	Latency.	RSS.	Wi-Fi WiMAX.	No.	No.	Simple.	Analytical.	Not mentioned.

Table 3.8: Comparative Summary of the Two Categories Based on MIPv4 and MIPv6 [115]

3.3 Chapter Summary

This chapter has presented three surveys of the VHO interworking architectures and the VHO approaches in order to identify the research problems accurately. In the first one, we have surveyed two main VHO interworking architectures: loose coupling and tight coupling. Their objectives, features and challenges have been discussed and published in [88]. We have made a fair comparison based on their performance in terms of latency, probability of packet loss, mobility management, congestion, complexity, overload, additional modification requirement and additional cost requirement. A better performance is provided by loose coupling compared with tight coupling; therefore, it has been concluded in this survey [88] that the loose couple VHO interworking architecture is more suitable to work with MIH and enhance its vital role in heterogeneous wireless network environment while the tight coupling with MIH requires future work improvements in terms of probability of packet loss, congestion, complexity, overload, additional modification and additional cost.

In the second one, a comprehensive survey of VHO approaches designed to provide seamless VHO based on MIH and IMS frameworks has been discussed and published in [109] in order to present their performances issues and characteristics. To offer a systematic and exhaustive comparison in this survey, we have presented two types of comparison: a comparison between the frameworks (MIH and IMS) and a comparison between the four categories based on these frameworks (MIH based category, IMS based category, MIP under IMS based category and MIH and IMS combination based category). The comparison between the frameworks has shown that the MIH framework plays critical role in providing seamless VHO with less number of vital components which results in: **(a)** large amount of information is provided **(b)** one receiver for ongoing session **(c)** low MU power consumption and **(d)** no need to upgrade legacy cells (no additional cost). However, the security for re-authentication at a target network and implementation of the decision algorithm are still required improving by designers. The comparison between the four categories has shown that the MIH is the only category which presents solutions include all existing networks 3G (e.g., UMTS and HSPA) and 4G (e.g., WiMAX and LTE), it presents comprehensive solutions to ensure VHO between three types of different RATs: Wi-Fi, WiMAX and 3G, it deals with multiple parameters to make VHO decision, it has been practically tested, it is simple compared with the other categories and finally, there is one approach uses empirical work of real environment. From this survey [109], we have concluded that the MIH is the dominant category due to its characteristics for providing seamless VHO (i.e. MIH is more flexible and has better performance) while the other categories require further improvements in terms of two vital parameters (packet loss and latency) which make the VHO more seamless, VHO decision criteria, additional entities, complexity, diversity of RATs and evaluation using empirical work of real environment.

In the third one, we have surveyed the VHO approaches proposed in the literature that applied in conjunction with MIPv4 and MIPv6 under MIH. We have classified the VHO approaches into two categories based on mobility management protocols (MIPv4 and MIPv6) under MIH for which we have presented their performances issues and characteristics as published in [115]. We have concluded in this survey [115] that the MIPv6 category is usually based on RSS to make VHO decision and the majority of its evaluation reside in the theoretical analysis stage which need testing or still too complex for implementation. This category also has been mostly used between two RATs and implemented one approach through testbed to get optimal results [115]. While MIPv4 category is usually based on multiple parameters, it has been practically tested and mostly used between three RATs [115]. It is also less complex and there is one approach used empirical work of real environment to get optimal results [115]. Therefore, we can say that in the near future, providing service continuity through MIPv4 category under MIH will allow the operators to diversify their access networks due to the advantages of this category while MIPv6 category under MIH requires future work improvements in terms of VHO decision criteria, additional entities, complexity, diversity of RATs and evaluation using empirical work of real environment [115].

Chapter 4

Connection Failure and Signaling Cost Drawbacks in Heterogeneous Wireless Networks

4.1 Introduction

One challenge of wireless networks integration is the ubiquitous wireless access ability which provide the seamless handover for any moving device in heterogeneous wireless networks. This challenge is important as MUs are becoming increasingly demanding for services regardless of the technological complexities associated with it. To fulfil these requirements of seamless handover two VHO techniques were proposed independently by IEEE and 3GPP; namely, MIH and ANDSF, respectively. Each of them aims to provide information for selecting the most suitable target network from different types of technologies [104]. In this chapter, we present a comprehensive survey of VHO approaches designed to provide seamless VHO based on MIH and ANDSF for which we present their objectives and performances issues. The VHO approaches proposed in the literature are categorised into three groups based on MIH and ANDSF as published in [137]: ANDSF based VHO approaches, MIH based VHO approaches and MIH and ANDSF combination based VHO approaches.

The chapter begins with section 4.2, VHO approaches classifications based on MIH and ANDSF are presented into three categories. Then, a comparison between these categories is presented in section 4.3. In the last section 4.4, some conclusions are presented.

4.2 VHO Approaches Classifications Based on MIH and ANDSF

Although there are many existing VHO approaches have been proposed in the literature to reduce handover connection failure [126, 127, 128, 129, 130, 131, 132 and 133] and which have been surveyed in [134], highlights on [2, 112 and 135] as recent VHO decision algorithms have not been considered. A detailed survey of [2, 112] can be found in previous chapter (section 3.2.3.3.1). In [135], the authors proposed a new robust VHO algorithm in order to allow the MU to select a best RAT among heterogeneous wireless networks such as UMTS and WLAN scenario taking into account (RSS, velocity, duration, battery power, cost and bandwidth) and (cost, security, power consumption, network condition and network performance) in the initiation and decision phases to make VHO decision, respectively. The simulation results showed that the proposed algorithm outperformed the traditional algorithms in terms of handover connection failure, bandwidth utilisation rate and handover rate. The probability of handover connection failure occurs when the handover is initiated but a target network does not have sufficient resources to complete it (session rejection due to unavailable resources) or when the MU moves out of the coverage of a target network before the process is finalized [134, 136]. However, previous works in [126, 127, 128, 129, 130, 131, 132 and 133] have considered only the MU's moves as the handover connection failure factor while the other works in [2, 112 and 135] are content only with selecting one target RAT for the checking resources [146]. Therefore, in chapter 6 of this thesis, we focus on the session rejection due to unavailable resources for providing a lower probability of VHO connection failure while in this chapter we survey more VHO approaches and classify them into three main categories based on MIH and ANDSF in order to present their objectives, issues and evaluate their complexity of implementation. We identify three main categories as: ANDSF based VHO approaches, MIH based VHO approaches and MIH and ANDSF combination based VHO approaches.

4.2.1 ANDSF Category

As mentioned previously in chapter 3, the ANDSF is a mechanism provides a seamless VHO between different RATs and to mitigate the impacts of radio signals impairment between 3GPP and non-3GPP and it also works as a store of RATs information that is queried by the MU to make handover decision (e.g., neighbour cells, operator's policies and preferences, QoS and capabilities).

The ANDSF based VHO approaches includes new additional entities proposed in [68, 93] in order to provide seamless VHO integrated with ANDSF taking into account WiMAX and 3GPP scenario.

In [68], a new logical element is proposed named Forward Authentication Function (FAF), it is collocated with ANDSF and located in a target network. The FAF plays the role of target RAT to perform its functionalities; for example, if the MU moves toward 3GPP (E-UTRAN), the FAF emulates NodeB while if the MU moves toward WiMAX, the FAF emulates WiMAX BS. The FAF has two main goals; the first one, to enable the transmission from WiMAX to 3GPP (Authentication). The second one, to avoid direct link between 3GPP and WiMAX (i.e. avoid the WiMAX access scheduling measurement opportunities to the MU in order to measure neighbour 3GPP site) [68]. Nevertheless, the authors in [68] failed to tackle two vital aspects in the VHO procedure; the first one, a source network was not informed by the MU about its movement to a target network which resulted in packet losses and the second one, it lacked a releasing procedure for the resources of a network [104], this is shown in Figure.4.1. In [93], Data Forwarding Function (DFF) logical entity located in source network was proposed to solve the problems that were raised in [68], this is shown in Figure.4.2.

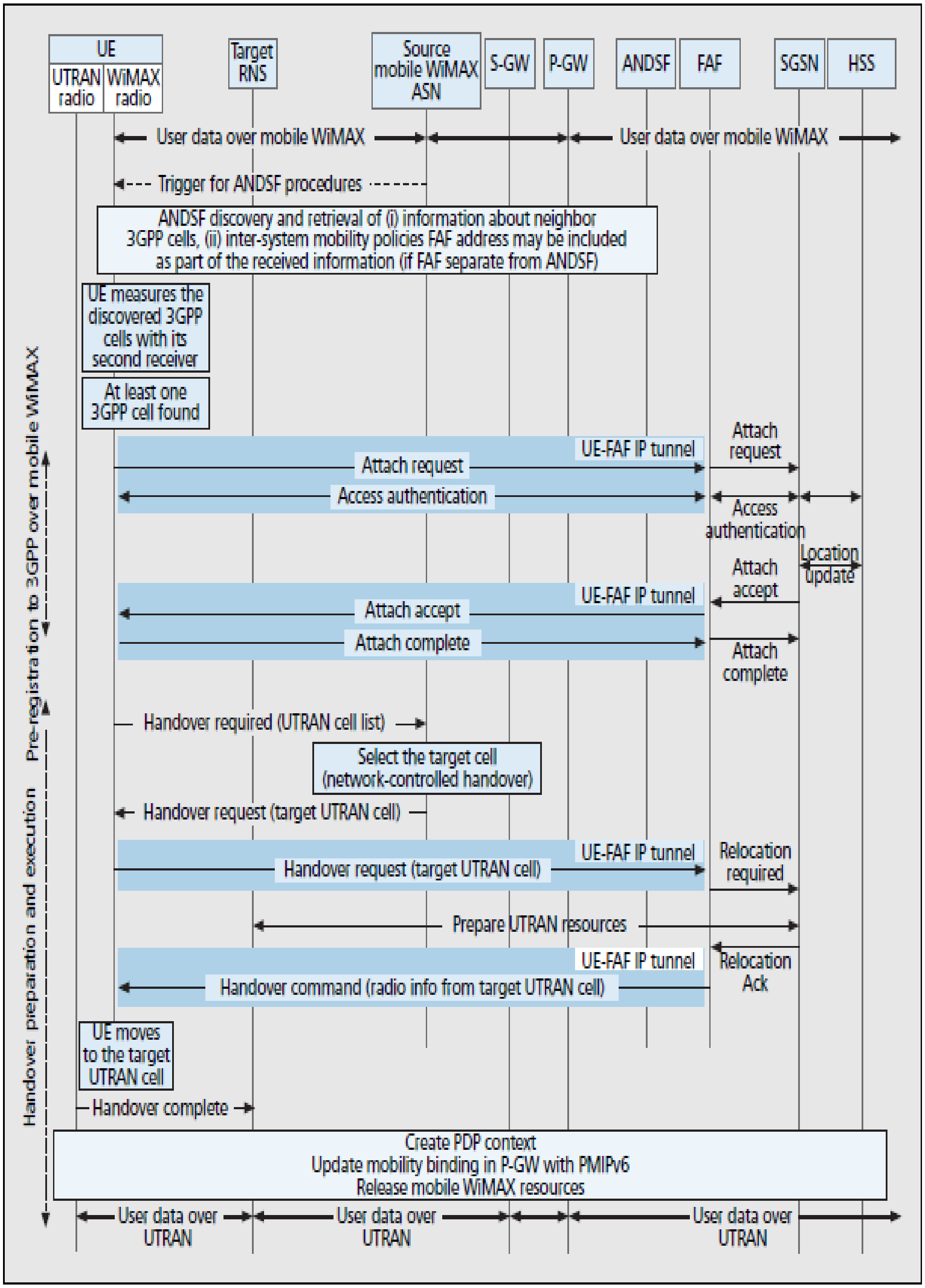

Figure 4.1: Seamless Single-Radio Handover from Mobile WiMAX to 3GPP Access [68]

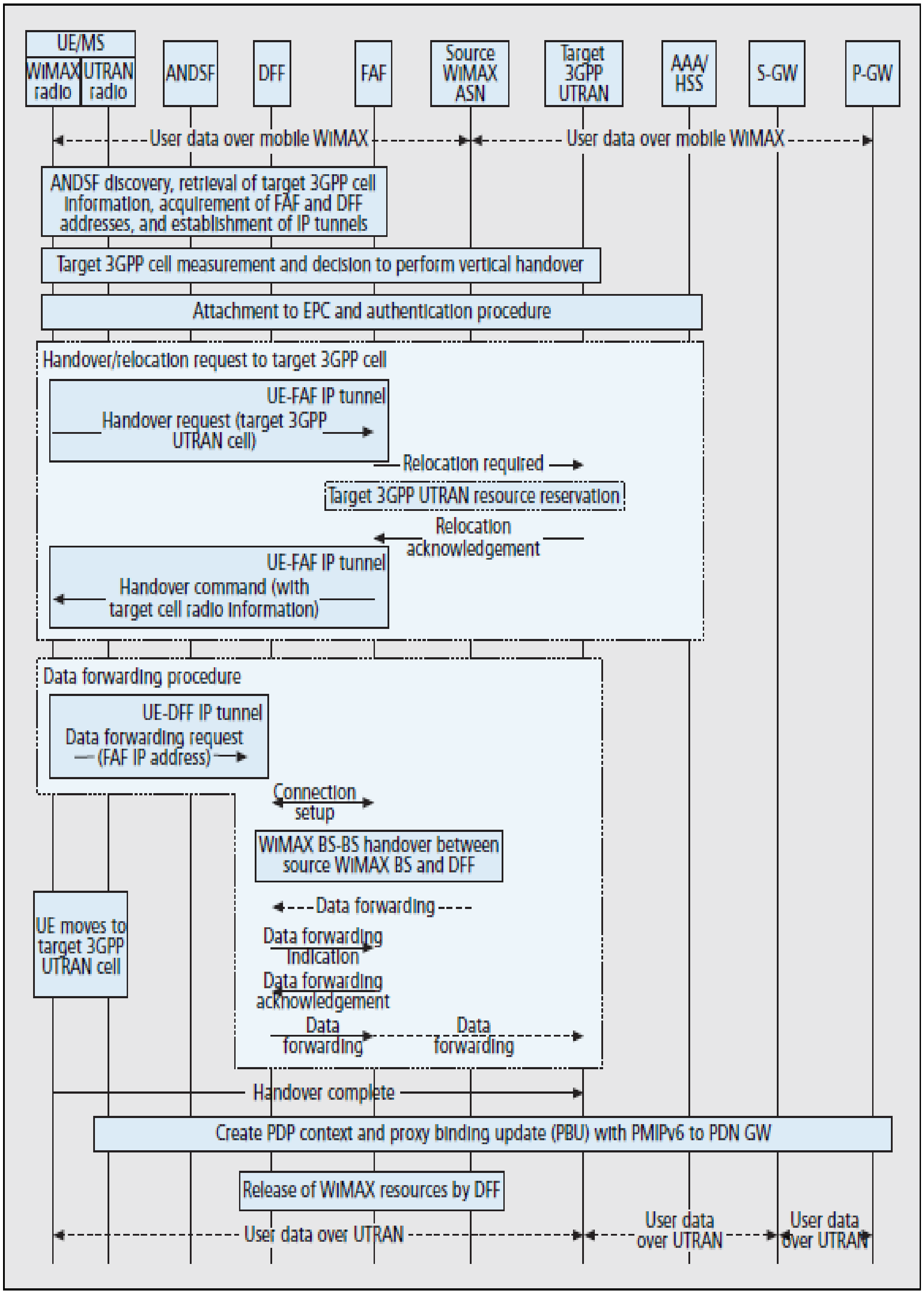

Figure 4.2: Signaling Flow of the Improved Vertical Handover from Mobile WiMAX to 3GPP UTRAN [93]

4.2.2 MIH Category

This category is primarily based on MIH to provide seamless VHO between different types of RATs scenarios [2, 3, 89, 94, 95, 110, 111, 112, 113, 114, 138 and 139]. A detailed survey of [2, 94, 110, 111, 112, 113 and 114] can be found in previous chapter of this thesis (section 3.2.3.3.1).

In [3], a new approach was proposed that was based on user's profile, a network information services and scoring mechanism to select the best RAT between Wi-Fi and UMTS scenario. The RSS parameter was considered to make VHO decision while CBR traffic was used to evaluate their work. The results showed an improved QoS [3].

In [89], middleware architecture was proposed in order to continue ongoing multimedia sessions that could be transferred seamlessly and securely between Wi-Fi to UMTS and UMTS to Wi-Fi scenarios. The SNR parameter was considered to make VHO decision. The handover latency represented the time elapsed between when a decision to handover was executed until the traffic was redirected to the new target network. Video traffic was used in order to evaluate the VHO latency and perceived video quality by simulation experiment. The results showed that when the VHO was based on the proposed MIH the handover latency was reduced while the perceived video quality was improved compared with a non-MIH [89].

In [95], five principles were proposed to support seamless VHO mobility to satisfy requirements of applications between WiMAX and GPRS scenario. The RSS parameter was considered to make the VHO decision. However, no performance evaluation or validation provided about their work.

In [138], new approach was proposed to select the best RAT with QoS between Wi-Fi and WiMAX scenario. The RSS parameter was considered to make VHO decision. Simulation experiments considering CBR traffic showed good results on handover performance [138].

In [139], a new approach was proposed to support seamless mobility while reducing handover latency and call dropping probability between Wi-Fi and WiMAX scenario. The RSS, MU's velocity, neighbour discovery unit and handover signaling latency were parameters considered to make VHO decision; however, no performance evaluation or validation provided about the work.

4.2.3 MIH and ANDSF Combination Category

Sections 4.2.1 and 4.2.2 have provided an overview of VHO approaches proposed in the literature based on MIH and ANDSF. It has been concluded that the main purpose of both MIH and ANDSF is to facilitate the VHO while the way to achieve this common goal is different. Table.4.1 shows the similarities and contrasts between them. The only similarity between MIH and ANDSF is the store of RATs information about the surrounding access networks which is queried by the MU to make handover decision while all the other parts are different, and therefore could complement one another if MIH and ANDSF are both deployed through the networks [104].

IEEE MIH		**3GPP ANDSF**
MIES **Events are sent between UE and network node**		The event reporting function of the EPC network is comparable to the MIES. It is located either in the Policy and Charging Enforcement Function (PCEF) or in the Bearer Binding and Event Reporting Function (BBERF) (depends on the deployed mobility protocol) and report events to the Policy and Charging Rules Function (PCRF). Both, the PCEF and the PCRF are network nodes.
MICS		The EPC has also a mechanism to reserve resources but the MICS provide a wider range of commands than the EPC.
MIIS	**The information services are similar to each other.**	Access network discovery information.
A mechanism similar to the inter system mobility policy is not supported within IEEE MIH		Inter system mobility policy.
A mechanism similar to the inter system routing policy is not supported within IEEE MIH		Inter system routing policy.

Table 4.1: Similarities and Contrasts of the Media Independent Handover (MIH) and Access Network Discovery and Selection Function (ANDSF) [104]

This category includes combination of MIH and ANDSF in order to improve VHO process taking into account WiMAX and LTE scenario.

In [104], combination between MIH and ANDSF was proposed; hence, there was no need for FAF and DFF to exist as in [93], besides, the MU obtained operator's policies from ANDSF which has the role of selecting a target network, this is shown in Figure.4.3. However, in [104], no evaluations or validations have been provided for the non exhaustive work which was complex as a result of combining MIH and ANDSF.

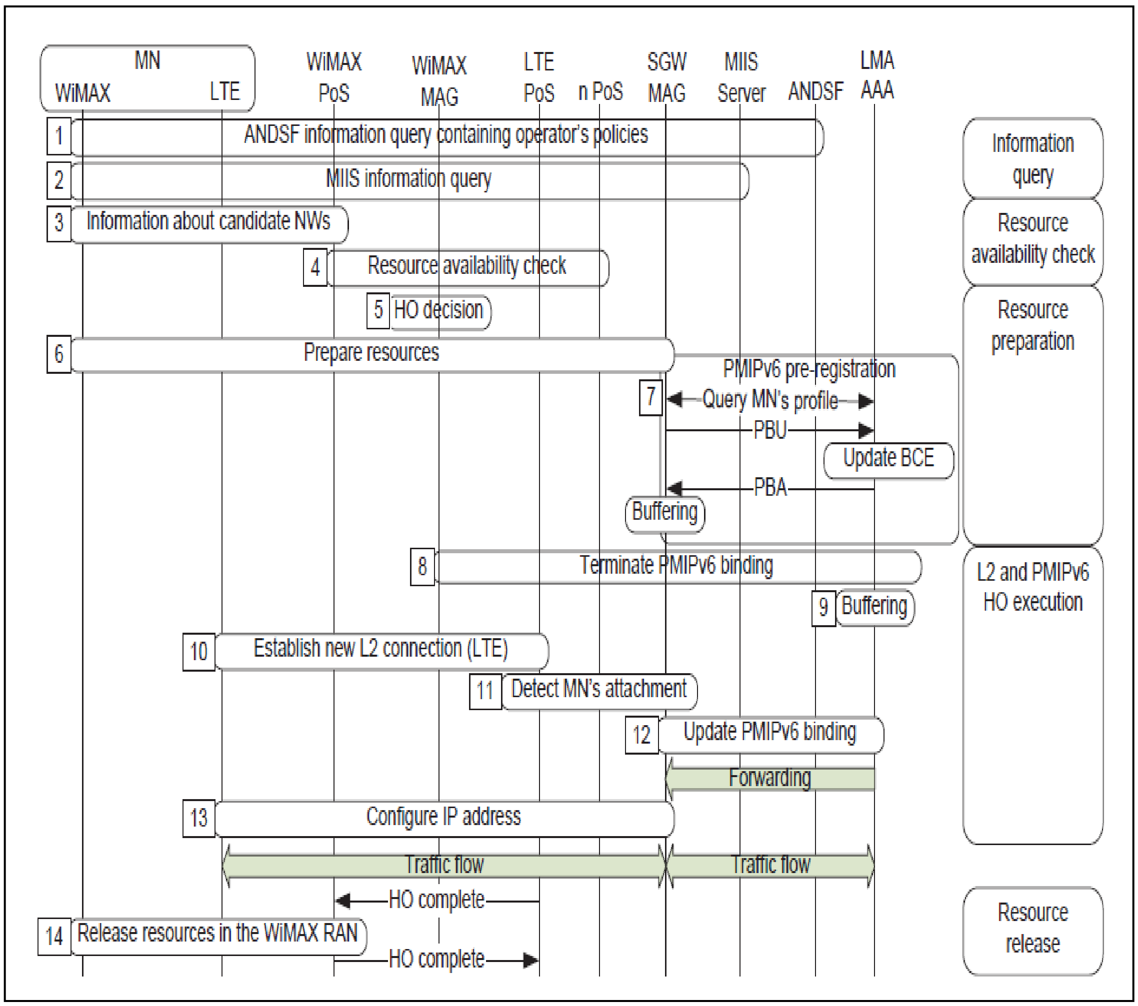

Figure 4.3: Handover Process with Media Independent Handover (MIH) and Access Network Discovery and Selection Function (ANDSF) Development [104]

4.3 Comparison of VHO Approaches Based on MIH and ANDSF

In sections 4.2.1, 4.2.2 and 4.2.3, we have discussed fifteen recent VHO studies found in the literature [2, 3, 89, 68, 93, 94, 95, 104, 110, 111, 112, 113, 114, 138 and 139] and classified them into three main categories based on their implementation of MIH and ANDSF in order to present their performances issues and characteristics. To provide comparison of the three main categories, we summarise their features with regard to seven aspects: main objective, input parameters for VHO decision, additional entity, complexity, traffic, evaluation method and applicable area, this is shown in Table.4.2.

Category	Main Objective	Input Parameters for VHO Decision	Additional Entity	Complexity	Traffic	Evaluation Method	Applicable Area
ANDSF	Minimal packet loss.	Not mentioned.	FAFand/or DFF.	Medium.	Video.	Simulation.	WiMAX-3GPP.
MIH	Minimal packet loss. Minimal latency. Minimal call dropping. Ongoing session. Best RAT.	Multiple parameters.	No need.	Low.	IPTV,VoIP CBR, FTP, Video.	Empirical. Testbed. Simulation. Analytical.	WiMAX-GPRS. Wi-Fi-UMTS. Wi-Fi-WiMAX. Wi-Fi, WiMAX and 3G. Wi-Fi, WiMAX and UMTS.
MIH& ANDSF	Minimal packet loss. Best RAT.	Not mentioned.	Combination (MIH/ANDSF).	High.	Not mentioned.	Not mentioned.	WiMAX-LTE.

Table 4.2: Comparative Summary of the Three Categories Based on MIH and ANDSF [137]

For the “Main Objective” criteria, the MIH category’s performance considers many vital parameters to provide seamless VHO (e.g., packet loss, latency and call dropping). While (MIH and ANDSF combination category) and (ANDSF category) are content with packet loss and best RAT.

In terms of "Input Parameters" for VHO decision, the MIH category presents approaches makes VHO decision based on various parameters such as RSS, link layer throughput and link quality. While the other categories do not mention the input parameters for VHO decision.

For "Complexity" and "Additional Entity", the MIH and ANDSF combination category scores high due to the combination of MIH and ANDSF. This followed by ANDSF category with medium complexity as new logical entities are required (FAF and/or DFF) while MIH category has low complexity as it does not require additional requirements (no additional cost).

In terms of "Evaluation Method" and "Traffic", there are various evaluation methods: empirical work of real environment, testbed, simulation experiment and analytical modelling. We notice that the MIH category evaluation method is mostly practical, it includes one empirical work and it considers various types of traffic (e.g., IPTV, VoIP and CBR). The ANDSF category is content with one work provides simulation using video traffic while MIH and ANDSF combination category have not considered these criteria on their work.

Finally, the "Applicable Area" for ANDSF category and the MIH and ANDSF combination category is between WiMAX-3GPP and WiMAX-LTE scenarios, respectively. While MIH category is applied to a variety of RATs combinations.

From the above discussion we conclude that any VHO procedure within MIH and/or ANDSF should take one of the following forms [137]:

VHO Procedure1; includes ANDSF, FAF and a VHO algorithm.

VHO Procedure2; includes ANDSF, FAF, DFF and a VHO algorithm.

VHO Procedure3; includes ANDSF, MIH and a VHO algorithm.

VHO Procedure4; includes MIH and VHO algorithm.

Procedure1 requires FAF as one additional entity for two reasons; the first one, to enable the transition from WiMAX to 3GPP (Authentication) and the second one, to avoid direct link between 3GPP and WiMAX (i.e. avoid the WiMAX access scheduling measurement opportunities to the MU in order to measure neighbour 3GPP sites). Procedure2 requires two additional entities (FAF and DFF) in order to provide seamless VHO integrated with ANDSF. Procedure3 includes the combination between MIH and ANDSF in order to provide seamless VHO without the additional entities (FAF and DFF); however, the combination results in high complexity. In Procedure4, the MIH does not require additional entities to provide seamless VHO mobility; hence, the majority of VHO approaches found in the literature are based on MIH. Although handover seamlessness generally means lower packet loss, minimal handover latency, lower signaling overheads and limited handover failures [140], the VHO approaches found in the literature concentrate primarily on packet loss and latency while the connection failure and the signaling cost, two of vital factors in providing seamless VHO, have not been considered thoroughly [137]. Therefore, concentrating on Procedure4 in order to produce a smart VHO algorithm taking into account the connection failure and the signaling cost factors will guarantee providing seamless VHO under MIH. In chapter 5 and chapter 6, we propose and evaluate a new approach concentrating on Procedure4 [137].

4.4 Chapter Summary

In this chapter, we have presented the fourth survey of the VHO techniques between MIH and ANDSF in order to identify more research problems. We have surveyed the VHO approaches proposed in the literature and classified them into three main categories based on MIH and ANDSF for which we have presented their objectives, issues and evaluated their complexity of implementation as published in [137]. The MIH does not require additional entities to provide seamless VHO mobility; hence, the majority of VHO approaches found in the literature are based on MIH. Although handover seamlessness generally means lower packet loss, minimal handover latency, lower signaling overheads and limited handover failures, the VHO approaches proposed in literature concentrate primarily on the packet loss and latency while the connection failure and the signaling cost, two of vital factors in providing seamless VHO, have not been considered thoroughly. Therefore, we have concluded in this survey [137] that it would be logical to concentrate on Procedure4 which is a combined MIH and VHO algorithm in order to produce a smart VHO algorithm taking into account the connection failure and the signaling cost factors to guarantee providing seamless VHO under MIH in heterogeneous wireless networks.

Chapter 5

New Procedure for Enhancing the VHO in Heterogeneous Wireless Networks

5.1 Introduction

This chapter presents our Imperative Alternative Media Independent Handover for Vertical Handover (I AM 4 VHO) approach which is divided into two main parts. The first part presents the proposed I AM 4 VHO procedure as published in [141, 142]. This procedure is designed for session mobility in Wi-Fi, WiMAX and UMTS heterogeneous wireless networks with minimal packet loss and latency. The second part presents the proposed I AM 4 VHO algorithm as published in [145, 146]. This algorithm is designed to give a lower probability of VHO connection failure and to reduce the signaling cost and the inevitable degradation in QoS. In this chapter, we present the proposed I AM 4 VHO procedure while the proposed I AM 4 VHO algorithm will be presented in chapter 6. Analysis and simulation of the proposed procedure show that the VHO packet loss and latency are significantly reduced compared with that found in the literature [141, 142].

The chapter is organised as follows: section 5.2 presents I AM 4 VHO approach. In sections 5.2.1, 5.2.1.1, 5.2.1.1.1 and 5.2.1.2, I AM 4 VHO procedure, analytical modelling of the proposed procedure, analytical results and discussions and simulation scenario, results and discussions are covered respectively. In the last section 5.3, some conclusions are presented.

5.2 New VHO Approach Based on MIH

MIH and ANDSF were proposed independently by IEEE and 3GPP, respectively. They enable a seamless VHO between different types of technologies such as Wi-Fi, WiMAX, UMTS and LTE, this is shown in Figure.5.1.

Figure 5.1: Various Radio Access Technologies (RATs) Integration Supported by MIH /ANDSF [92, 137]

In (chapter 4, [137]), we have surveyed the VHO approaches and classified them into three main categories based on MIH and ANDSF in order to present their objectives, issues and evaluate their complexity of implementation. Then, we have concluded in (chapter 4, [137]) that any VHO procedure within MIH and/or ANDSF should take one of the following forms:

VHO Procedure1; includes ANDSF, FAF and a VHO algorithm.

VHO Procedure2; includes ANDSF, FAF, DFF and a VHO algorithm.

VHO Procedure3; includes ANDSF, MIH and a VHO algorithm.

VHO Procedure4; includes MIH and VHO algorithm.

We propose I AM 4 VHO approach of loose coupling which could be applied in conjunction with MIPv4. This based on Procedure4 where MIH does not require additional entities and has better performance providing seamless VHO compared with IMS, (chapter 4, [137]) and (chapter 3, [109]), respectively; hence, the majority of approaches in the literature are based on MIH to provide seamless VHO mobility.

In (chapter 3, [88]), we have also concluded that a better performance is provided by loose coupling compared with tight coupling; therefore, the loose coupling is more suitable with MIH and contributes for enhancing its vital role in heterogeneous wireless network environment.

In addition, we have concluded in (chapter 3, [115]) that providing service continuity through MIPv4 category under MIH will allow the operators to diversify their access networks due to the advantages of this category while MIPv6 category under MIH requires future work improvements in terms of VHO decision criteria, additional entities, complexity, diversity of RATs and evaluation using empirical work of real environment.

Finally, in (chapter 4, [137]), we have concluded that the VHO approaches found in the literature concentrate primarily on packet loss and latency while the connection failure and the signaling cost, two of vital factors in providing seamless VHO, have not been considered thoroughly; therefore, it would be logical to concentrate on Procedure4 which is a combined MIH and VHO algorithm in order to produce a smart VHO algorithm taking into account the connection failure and the signaling cost factors to guarantee providing seamless VHO under MIH in heterogeneous wireless networks.

As a result of the conclusions above, the proposed approach is aimed to provide better performance (packet loss, latency and signaling cost), a lower probability of VHO connection failure, less complexity and an enhanced VHO compared with that found in the literature. It consists of a procedure which is implemented by an algorithm and provides the following [92]:

- Details on network operation in case of VHO initiated imperatively due to RSS going down or alternatively based on user's preferences (e.g., high data rate and low cost) taking into account higher priority to execute imperative session.
- VHO algorithm based on our approach reduces: **(a)** the VHO connection failure (probability of minimising VHO reject sessions) as a result of using the RATs list of priority. When the first choice from RATs list of priority could not be satisfied with available resources the Admission Control (AC) at destination PoS will automatically move to another RAT selection in the list in order to satisfy the requirements of this RAT selection and so on. **(b)** the signaling cost and the inevitable degradation in QoS as a result of avoiding unnecessary handover processes.
- No need to combine between ANDSF and MIH as in [104] as a result of assigning the operator's policies and preferences from PoS at the destination network.
- Better VHO performance with more soft (minimal packet loss) and faster (minimal latency) due to buffering new data packets earlier that comes from CN server after RAT has been checked by destination PoS.
- Dynamic Host Configuration Protocol (DHCP) server to distribute the Care of Address (CoA) to mitigate the load on PoS.

5.2.1 Imperative Alternative MIH for VHO (I AM 4 VHO) Procedure

We describe our procedure through VHO phases: Initiation, Decision and Execution [92], this is shown in Figure.5.2.

A. Initiation Phase

In this phase, while the MU is connected to a source network the VHO procedure will be triggered imperatively due to RSS going down or alternatively based on user's preferences (e.g., high data rate and low cost).

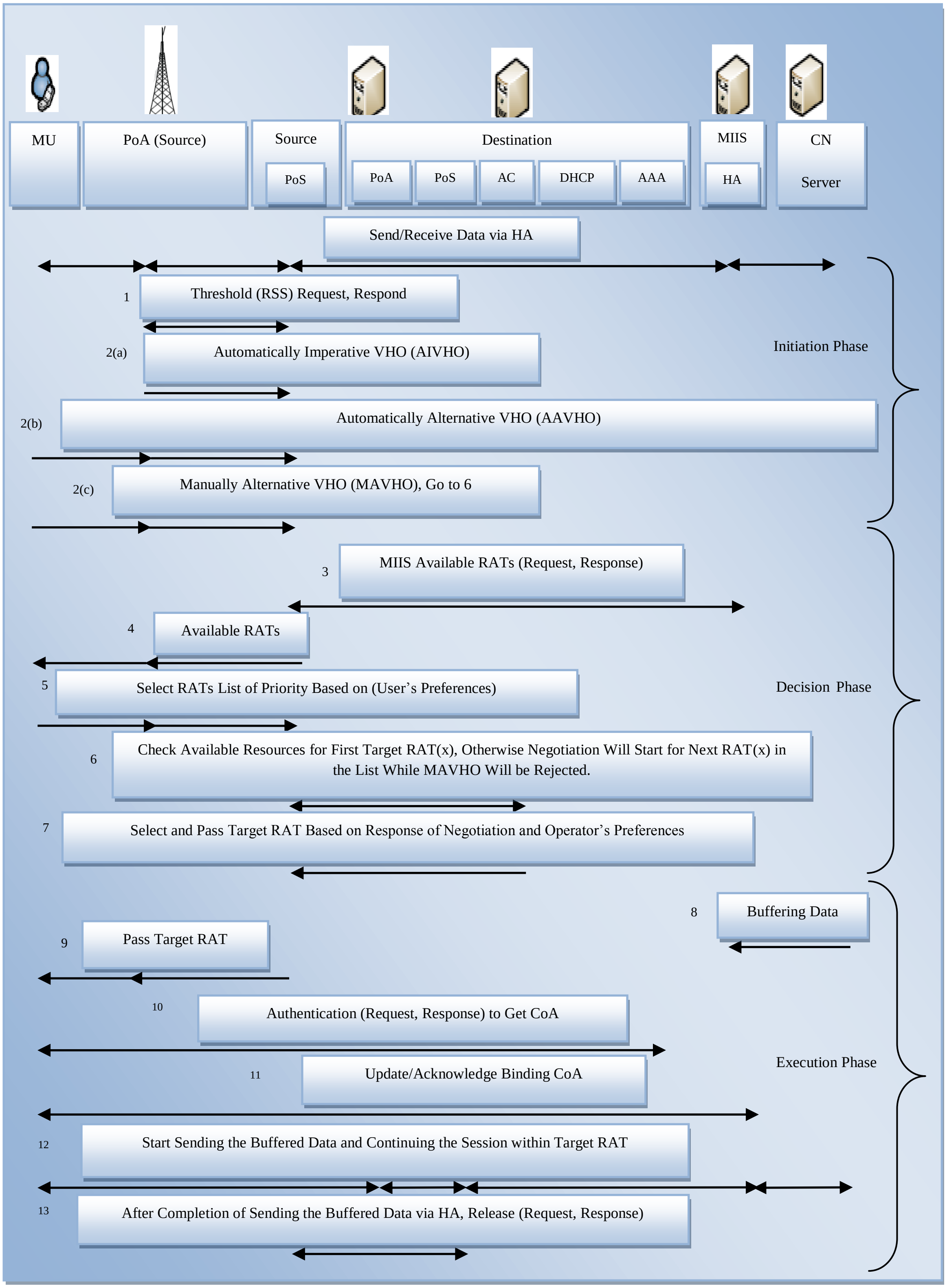

Figure 5.2: Imperative Alternative Media Independent Handover for Vertical Handover (I AM 4 VHO) Procedure [92]

B. Decision Phase

In this phase, as a result of triggering in the initiation phase, *MIIS Request/Response Available RATs* message will be responsible to pass available RATs to the MU via source network (PoA and PoS). In imperative session due to RSS going down the MU will select RATs list of priority based on user's preferences and then pass them to the destination PoS via source network whereas in alternative session the MU will select RATs list of priority based on user's preferences due to his/her profile change. When the first choice from RATs list of priority could not be satisfied with available resources, the AC at destination PoS will automatically move to another RAT selection in the list in order to satisfy the requirements of this RAT selection and so on. Once RAT of sufficient resources has been found, it will be checked by destination PoS whether it is compliant with the rules and preferences of operators. If that is available, the MIIS/HA will be informed to start early buffering for new data packets which are sent by CN server (Execution Phase).

C. Execution Phase

This phase based on MIPv4. The MU will be connected to target RAT to start its AAA with destination PoA and obtain CoA from DHCP. After that, *Update/Acknowledge binding* message notifies HA about the new CoA to start sending the buffered data and continuing the session within target RAT.

5.2.1.1 Analytical Modelling of the Proposed Procedure

We suggest that I AM 4 VHO procedure that is applied with MIH based on MIPv4 as published in [141, 142]. This will help the VHO between heterogeneous wireless networks such as Wi-Fi, WiMAX and UMTS to reduce packet loss and latency. We also define two main types of VHO and give priority to imperative sessions over alternative sessions. Figure.5.3 shows a diagram for the suggested I AM 4 VHO procedure.

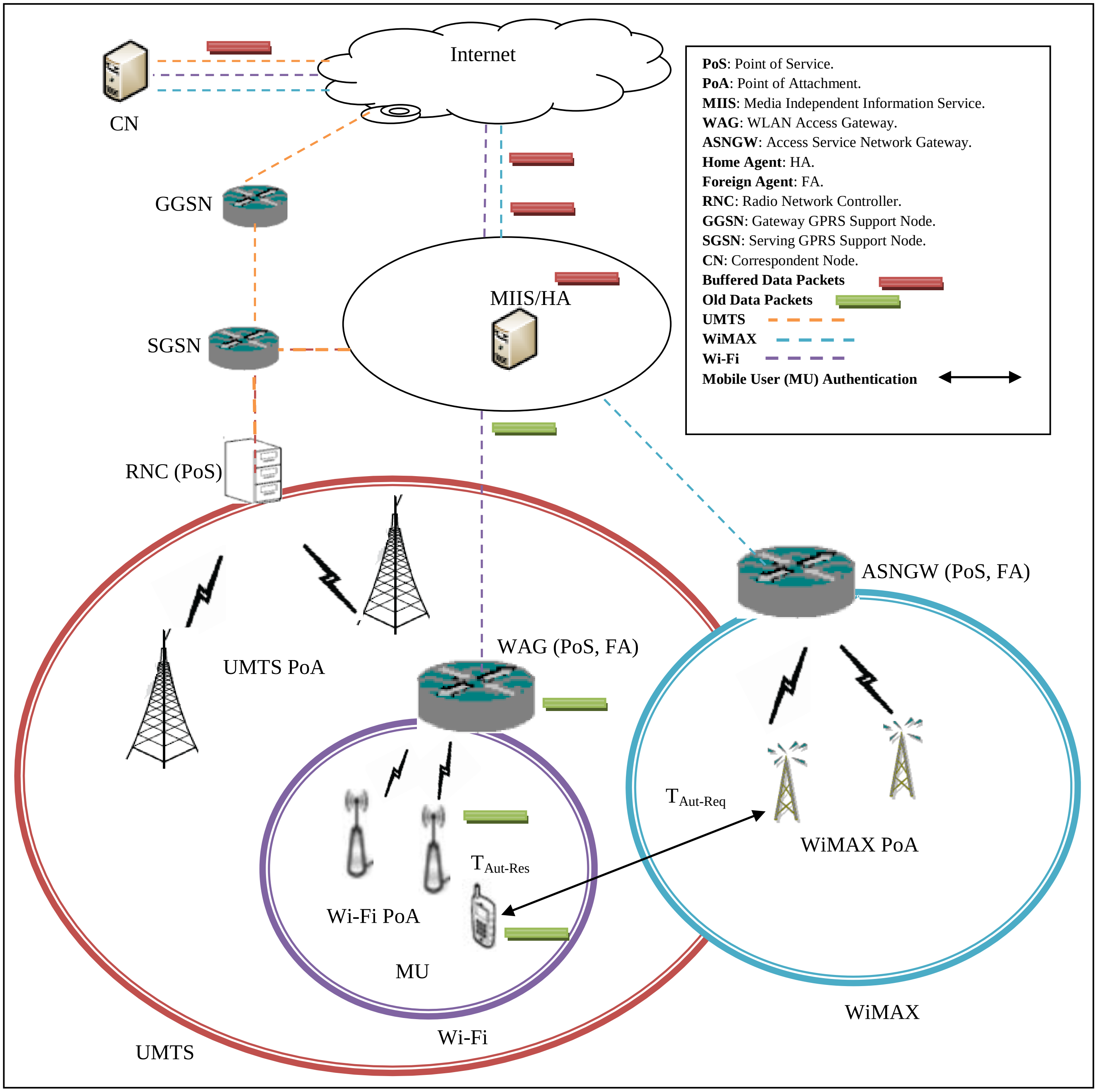

Figure 5.3: Diagram of Proposed Imperative Alternative Media Independent Handover for Vertical Handover (I AM 4 VHO) Procedure [141, 142]

For integration between these different RATs there are two main VHO interworking architectures. They are: loose coupling and tight coupling [58]. We select the loose coupling approach because the mobility management for loose coupling is based on MIP, and the probability of packet loss is less than tight coupling which is incurred it due to overload in UMTS core network [6], handover duration is equivalent with tight coupling at GGSN level approach where MIP is used [87] and modifications to the existing access network are not necessary as the case with tight coupling [100]. The HA is collocated with MIIS [2, 94] whereas Foreign Agents (FAs) are deployed in WLAN Access Gateway (WAG) and Access Service Network Gateway (ASN GW) in Wi-Fi and WiMAX networks, respectively. The PoS location is inside the access network for each RAT gateway (i.e. WAG, ASN GW and RNC in Wi-Fi, WiMAX and UMTS), respectively. Finally, the PoA location is inside NodeB, AP and BS for UMTS, Wi-Fi and WiMAX, respectively. In this modelling, we consider the handover from Wi-Fi to WiMAX network based on MIPv4.

There are three periods of time latency in our procedure associated with the three VHO types: Automatically Imperative VHO (AIVHO) session due to RSS going down, Automatically Alternative VHO (AAVHO) session due to user’s profile change and Manually Alternative VHO (MAVHO) session due to RAT is selected manually by the user, we refer them to the figure, table and text T_{AI},T_{AA},T_{MA}, respectively. This is shown in Figure.5.4 and notations in Table.5.1. In our analysis, we consider three VHO procedures between Wi-Fi and WiMAX: Proxy MIPv6 (PMIPv6), Proxy First MIPv6 (PFMIPv6) and IEEE 802.21-enabled PMIPv6 (MIH-enabled PMIPv6) [114]. We compare our procedure with the above procedures in terms of handover packet loss and latency.

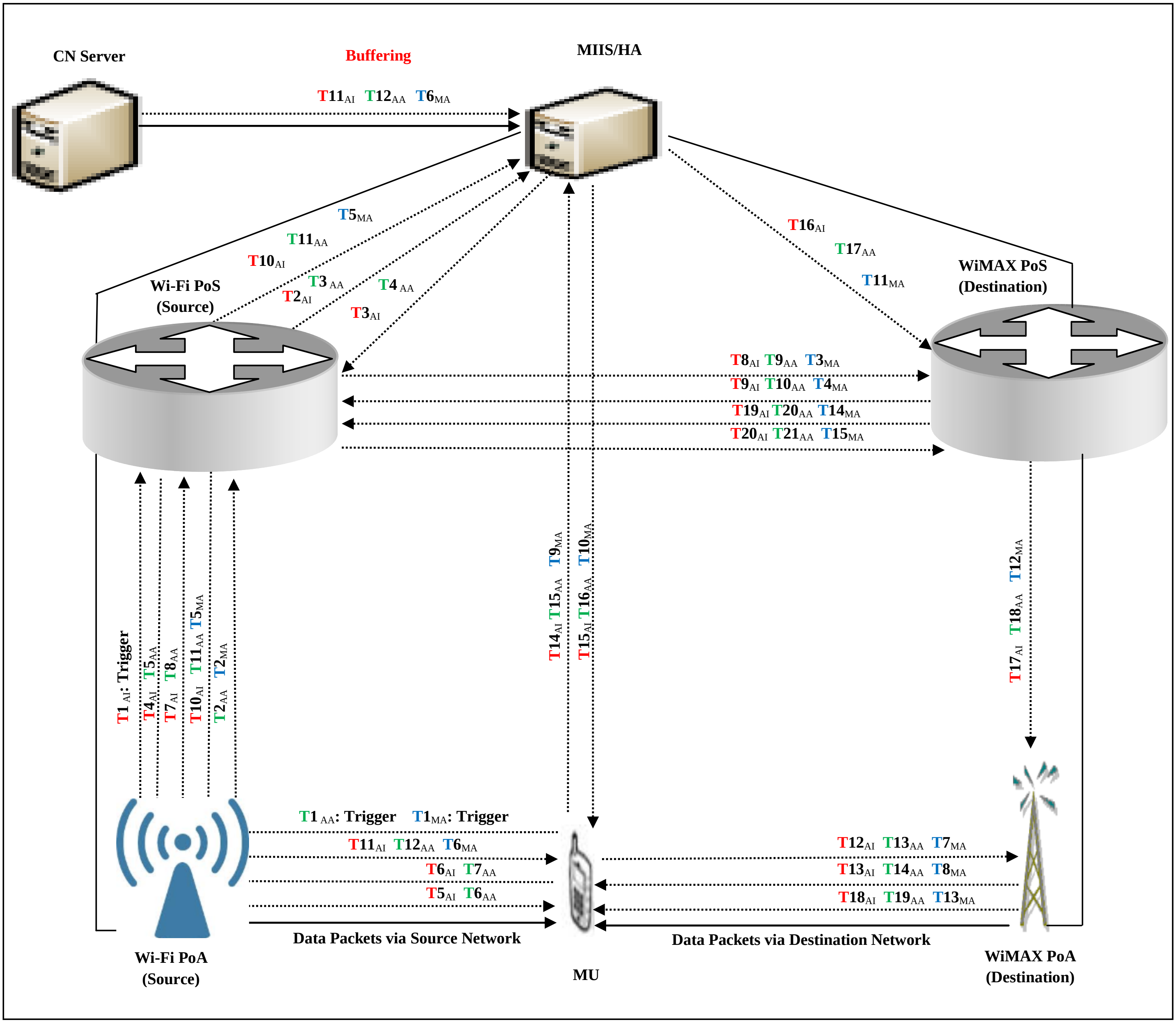

Figure 5.4: Time Signaling for Imperative Alternative Media Independent Handover for Vertical Handover (I AM 4 VHO) Procedure

Time Sequence			Signaling Sequence			Event
T_{AI}	T_{AA}	T_{MA}				
1	1	1	$T1_{AI}$			Automatically Imperative VHO (AIVHO) triggering.
			$T1_{AA}$			Automatically Alternative VHO (AAVHO) triggering.
			$T1_{MA}$			Manually Alternative VHO (MAVHO) triggering.
	2	2	$T2_{AA}$	$T2_{MA}$		AAVHO/MAVHO triggering pass to Wi-Fi PoA.
2	3		$T2_{AI}$	$T3_{AA}$		MIIS available RATs request.
3	4		$T3_{AI}$	$T4_{AA}$		MIIS available RATs response.
4	5		$T4_{AI}$	$T5_{AA}$		Pass RATs to Wi-Fi PoA.
5	6		$T5_{AI}$	$T6_{AA}$		Pass RATs to MU.
6	7		$T6_{AI}$	$T7_{AA}$		Pass RATs list of priority to Wi-Fi PoA.
7	8		$T7_{AI}$	$T8_{AA}$		Pass RATs list of priority to Wi-Fi PoS.
8	9	3	$T8_{AI}$	$T9_{AA}$	$T3_{MA}$	Pass RATs list of priority or RAT based on user selection to WiMAX PoS.
9	10	4	$T9_{AI}$	$T10_{AA}$	$T4_{MA}$	Pass target RAT to Wi-Fi PoS.
10	11	5	$T10_{AI}$	$T11_{AA}$	$T5_{MA}$	Notify MIIS server to start early buffering for new data packets which are sent by CN server and pass target RAT to Wi-Fi PoA concurrently.
11	12	6	$T11_{AI}$	$T12_{AA}$	$T6_{MA}$	Start buffering and pass target RAT to MU.
12	13	7	$T12_{AI}$	$T13_{AA}$	$T7_{MA}$	Authentication request with WiMAX PoA.
13	14	8	$T13_{AI}$	$T14_{AA}$	$T8_{MA}$	Authentication response from WiMAX PoA.
14	15	9	$T14_{AI}$	$T15_{AA}$	$T9_{MA}$	Binding request with HA.
15	16	10	$T15_{AI}$	$T16_{AA}$	$T10_{MA}$	Binding response from HA.
16	17	11	$T16_{AI}$	$T17_{AA}$	$T11_{MA}$	Release new data packets (buffering) to WiMAX PoS.
17	18	12	$T17_{AI}$	$T18_{AA}$	$T12_{MA}$	Pass new data packets to WiMAX PoA.
18	19	13	$T18_{AI}$	$T19_{AA}$	$T13_{MA}$	Pass new data packets to MU.
19	20	14	$T19_{AI}$	$T20_{AA}$	$T14_{MA}$	Release request with Wi-Fi PoS.
20	21	15	$T20_{AI}$	$T21_{AA}$	$T15_{MA}$	Release response from Wi-Fi PoA.

Table 5.1: Notations for Imperative Alternative Vertical Handover (I AM 4 VHO) Procedure Time Signaling

A. Latency

Vertical Handover latency (VHL) is the time taken for the MU to obtain a new IP address from a target network and register itself with HA [143]. During this process the MU does not receive any packets as a result of handover. The latency is the main cause of packet losses during handover so it needs to be minimised [140].

PMIPv6 Procedure

In PMIPv6 procedure, the MU attached to WiMAX after the MU was detached from Wi-Fi and Source-Mobile Access Gateway (S-MAG) simultaneously sent Proxy Binding Update (PBU) with the lifetime value of zero to Local Mobility Anchor (LMA). The *VHL* of PMIPv6 procedure (VHL_{PMIPv6}) is given by (5.1) [114]:

$$VHL_{PMIPv6} = 2(T_{MAG\text{-}LMA}) + T_{L2} + 4(T_{DOMAIN\text{-}AAA}) + T_{MU\text{-}AN} + T_{AN\ MAG} \quad (5.1)$$

Where $T_{MAG\text{-}LMA}$ is the latency between MAG and LMA, T_{L2} is the latency from when the MU is detached from AP to when the MU is attached to BS, $T_{DOMAIN\text{-}AAA}$ is the latency between entities in PMIPv6-Domain and AAA/MIIS server, $T_{MU\text{-}AN}$ is the latency between the MU and AP/BS and $T_{AN\text{-}MAG}$ is the latency between AP/BS and MAG.

PFMIPv6 Procedure

In PFMIPv6 procedure, the bi-directional tunnel between S-MAG and Target-MAG (T-MAG) utilised for sending and receiving handover initiate and handover acknowledge messages. The *VHL* of PFMIPv6 procedure ($VHL_{PFMIPv6}$) is given by (5.2) [114]:

$$VHL_{PFMIPv6} = 2(T_{MAG\text{-}LMA}) + T_{L2} + 2(T_{DOMAIN\text{-}AAA}) + T_{MU\text{-}AN} + T_{AN\text{-}MAG} \quad (5.2)$$

IEEE 802.21-enabled PMIPv6 Procedure

In IEEE 802.21-enabled PMIPv6 procedure, the *VHL* was reduced compared with PMIPv6 and PFMIPv6 procedures because the layer 2 (L2) attachment process and the

AAA process at T-MAG and LMA occurred before the MU was detached from Wi-Fi. The *VHL* of IEEE 802.21-enabled PMIPv6 procedure ($VHL_{802.21}$) is given by (5.3) [114]:

$$VHL_{802.21} = T_{AN\text{-}MAG} + T_{MU\text{-}AN} + 2(T_{MAG\text{-}LMA}) \quad (5.3)$$

I AM 4 VHO Procedure

In our procedure, after RAT has been checked by WiMAX PoS, concurrent notification informs both of MIIS/HA server to start buffering and Wi-Fi PoS to pass selected target RAT to Wi-Fi PoA (signaling $T10_{AI}$ *or* $T11_{AA}$ *or* $T5_{MA}$). After that, the Wi-Fi PoA sends target RAT to the MU for handover. The MU makes use of the buffering period to send *starts/ends authentication* messages with destination WiMAX PoA (signaling time of $T12_{AI}$ *or* $T13_{AA}$ *or* $T7_{MA}$) plus ($T13_{AI}$ *or* $T14_{AA}$ *or* $T8_{MA}$), respectively. Whereas the old data packets are still sent to the MU at the old IP address for a period of double signaling time of ($T10_{AI}$ *or* $T11_{AA}$ *or* $T5_{MA}$) plus ($T11_{AI}$ *or* $T12_{AA}$ *or* $T6_{MA}$). In other words, the MU will make authentication with destination WiMAX PoA before the last old data packets are received to the MU (signaling time of $T11_{AI}$ *or* $T12_{AA}$ *or* $T6_{MA}$). The *VHL* in our procedure ($VHL_{I\,AM\,4\,VHO}$) is given by (5.4) and (5.5) [141]:

$$VHL_{I\,AM\,4\,VHO} = (T14_{AI} \text{ or } T15_{AA} \text{ or } T9_{MA}) + (T15_{AI} \text{ or } T16_{AA} \text{ or } T10_{MA}) \quad (5.4)$$

This means $VHL_{I\,AM\,4\,VHO} = LTB + LTBA$ **(5.5)**

Where *LTB* is the latency of binding update and *LTBA* is the latency of binding acknowledgment with HA. Such that the registration time with HA in MIPv4 is given by (5.6) [144] which supports handovers between two adjacent RATs:

$$VHL_{I\,AM\,4\,VHO} = 2(S_{ctrl} / B_{wl}) + 2(L_{wl}) + PP_x \quad (5.6)$$

Where S_{ctrl} is the average size of a control message, B_{wl} is the bandwidth of the wireless link, L_{wl} is the latency of the wireless link and PP_x is the router or agent route lookup latency and packet processing latency.

B. Packet Loss

We need to compute the average number of packet loss in terms of packet loss ratio during handover session taking into account *VHL* from equation (5.1), (5.2), (5.3) and (5.6). Equation (5.7) shows percentage of packet loss while the MU receiving downlink real time IP packets [144]. It does not depend on the downlink bit rate or the length of the session [144]. Rather, it depends on cell residence time and the time taken to discover and complete a mobile IP registration where *Pkt_loss* is the percentage of packet loss, T_{agt_adv} is the mean period at which AP/BS sends agent advertisement over the wireless link and t_{cell} is the value of cell residence time [144].

$$Pkt\_loss = (1/2 * T_{agt\_adv} + VHL) / t_{cell} \quad (5.7)$$

C. Buffering

To estimate the size of the buffer for our procedure we have to compute the signaling time that is required after the buffer starts to receive new data packets by CN server until the buffer starts to release these data packets. As a result of notifying the MIIS/HA server to start buffering and passing target RAT information to source Wi-Fi PoA, the Time of the Buffering Signaling (TBS) is giving by (5.8) and (5.9):

$$TBS = (T11_{AI} \text{ or } T12_{AA} \text{ or } T6_{MA}) + (T12_{AI} \text{ or } T13_{AA} \text{ or } T7_{MA}) + (T13_{AI} \text{ or } T14_{AA} \text{ or } T8_{MA}) + (T14_{AI} \text{ or } T15_{AA} \text{ or } T9_{MA}) + (T15_{AI} \text{ or } T16_{AA} \text{ or } T10_{MA}) \quad (5.8)$$

This means $TBS = LRATMU + LAUTRT + LAUTRD + LTB + LTBA \quad (5.9)$

Where *LRATMU* is the latency of target RAT passed to the MU, *LAUTRT* is the latency of authentication request, *LAUTRD* is the latency of authentication respond, *LTB* is the latency of binding update and *LTBA* is the latency of binding acknowledgment with HA. Equation (5.10) gives the buffer size requirement in our procedure based on type of downloading application by CN server (e.g., IPTV and VoIP).

$$Buffer\ size = TBS * Data\ rate\ of\ application \quad (5.10)$$

5.2.1.1.1 Analytical Results and Discussions of the Proposed Procedure

Based on the analysis above, we evaluate and compare our procedure against three other procedures found in the literature in terms of handover packet loss and latency: PMIPv6, PFMIPv6 and IEEE 802.21-enabled PMIPv6 [114]. The parameters values used in this evaluation are adopted from [114, 144], this is shown in Table.5.2.

The results of equations (5.1), (5.2), (5.3) and (5.6) are shown in Figure.5.5 for *VHL* in PMIPv6, PFMIPv6, IEEE 802.21-enabled PMIPv6 and our procedure, respectively. It shows that our procedure scores a minimum latency of ($4.4 x 10^{-3}$ sec) compared with the other procedures. This is because the MU makes use of the data buffering period in MIIS/HA server to start/end authentication messages with WiMAX PoA to obtain CoA [141]. This means the time for registration with HA will represent the VHO latency ($VHL_{I\ AM\ 4\ VHO}$) [141].

The results of equation (5.7) shows percentage of the number of packet loss with respect to the total packet sent, this is shown in Figure.5.6. It illustrates our procedure with average packet loss of ($1.6 x 10^{-2}$) due to the reduced latency ($VHL_{I\ AM\ 4\ VHO}$) [141]. This is achieved by buffering of data in MIIS/HA server as shown in Figure.5.4.

Parameter	Value	Description
S_{ctrl}	400 bits.	Average size of a control message (agent advertisement, registration request/reply, path setup/acknowledgment).
L_{wl}	2 ms.	Latency of the wireless link (propagation latency and link layer latency).
PP_x	10^{-6} sec.	Router or agent route lookup latency and packet processing latency.
T_{agt_adv}	1 sec	Period at which AP/BS sends agent advertisement over the wireless link.
t_{cell}	Variable.	Cell residence time.
B_{wl}	2 Mps.	Bandwidth of the wireless link.
$T_{MAG\text{-}LMA}$	20 ms.	Latency between MAG and LMA.
$T_{MU\text{-}AN}$	10 ms.	Latency between MU and AP/BS.
$T_{AN\text{-}MAG}$	2 ms.	Latency between AP/BS and MAG.

Table 5.2: Input Parameters for Performance Evaluation of Analytical Modelling

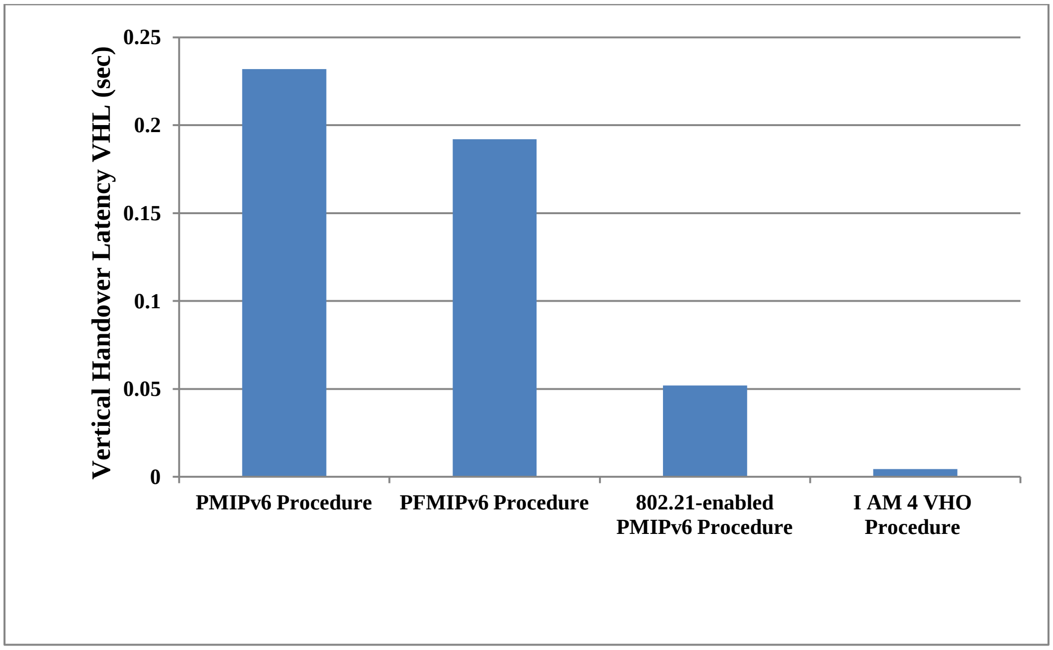

Figure 5.5: Comparison of Vertical Handover Procedures Performance Using Analytical Modelling Results (Latency)

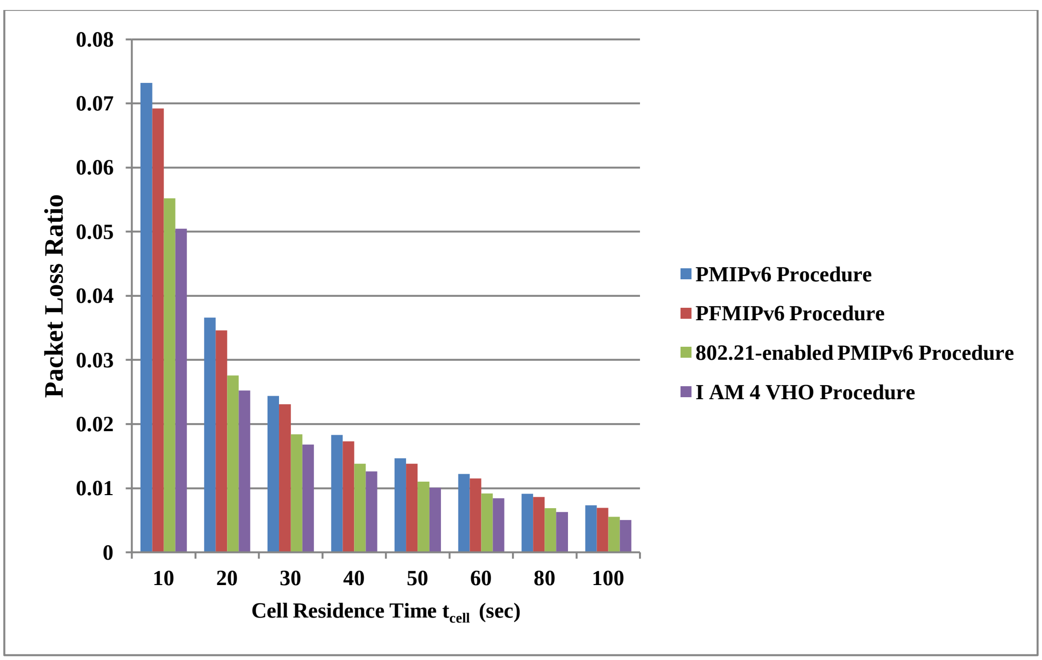

Figure 5.6: Comparison of Vertical Handover Procedures Performance Using Analytical Modelling Results (Packet Loss)

5.2.1.2 Simulation Scenarios, Results and Discussions of the Proposed Procedure

The packet loss and the latency are the major drawbacks in the execution phase where this phase is out of the scope of MIH (e.g., handover signaling, context transfer and packet reception) [103]. In section 5.2.1.1, the analysis shows that there are three periods of time latency in our procedure associated with the three VHO types are considered: T_{AI},T_{AA} and T_{MA}. It also shows that these periods of time latency have the same signaling time in the execution phase. Therefore, we have applied our procedure of loose coupling in conjunction with MIPv4 taking into account the handover signaling time in the execution phase and the RSS going down (T_{AI}) in order to make VHO decision. In OPNET simulation, we assume the MU originally is hosted by Wi-Fi and it has started moved toward the WiMAX and received VoIP traffic, this is shown in Figure.5.7. Detailed characteristics of the simulation parameters are explained in Table.5.3. After the implementation of our procedure in the specific scenario, Figure.5.8 and Figure.5.9 illustrate our procedure with average latency of ($2x10^{-5}$ sec) and zero packet loss, respectively [142]. The latency is the main cause of packet losses during handover [140]; therefore, the results obtained in this simulation and the analytical modelling show that the packet loss ratio improves as long as the latency reduced [142]. On the other hand, we can realise from Figure.5.8 and Figure.5.9 that the simulation and the analytical modelling results are not quite close. The reason for this is that some of the parameters which have been considered in the analytical modelling environment have not been considered in the simulation environment and vice versa. For example, in the analytical modelling, the results of the packet loss depended on the cell residence time and the time taken to discover and complete a mobile IP registration; they did not depend on the downlink bit rate or the length of the session. On the other side, the simulation has considered some of the parameters such as velocity, the thing which has not been considered in the analytical modelling.

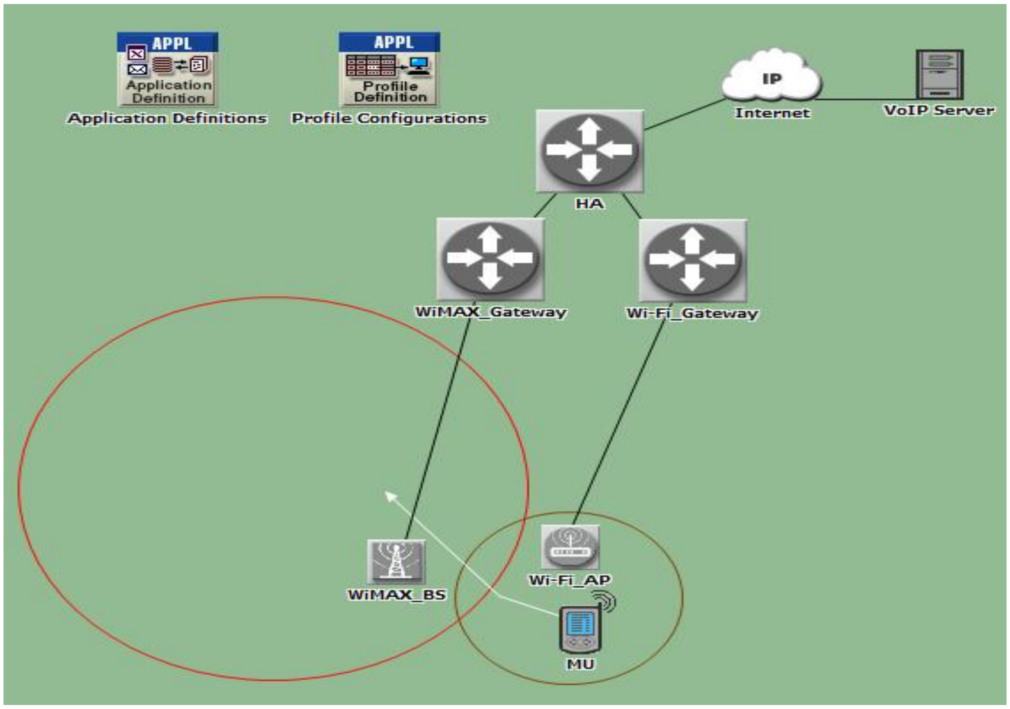

Figure 5.7: Simulation Diagram of Proposed Procedure from Wi-Fi to WiMAX

Name of the Parameter	**Value of the Parameter**
Simulation Duration	60 minute.
Path (Trajectory)	Linear.
Mobile User Velocity	10 Km/hr.
Traffic	VoIP.
WiMAX	
Cell Coverage	Ellipse, width=1000 m, height=1000 m.
Maximum Transmission Power	0.1 W.
Physical Profile Type	OFDM.
Receiver Sensitivity	-200 dBm.
Antenna Gain	15 dBi.
Wi-Fi	
Cell Coverage	Ellipse, width=450 m, height=450 m.
Transmit Power	0.0005 W.
Physical Profile	Direct sequence.
Packet Reception-Power Threshold	-95 dBm.
Data Rate	11 Mbps.

Table 5.3: Parameters for Performance Evaluation of Simulation Modelling

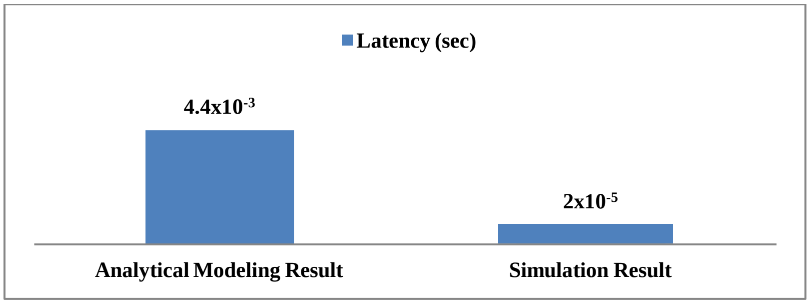

Figure 5.8: Comparison of the Proposed Vertical Handover Procedure Performance Using Simulation Result vs. Analytical Modelling Result (Latency)

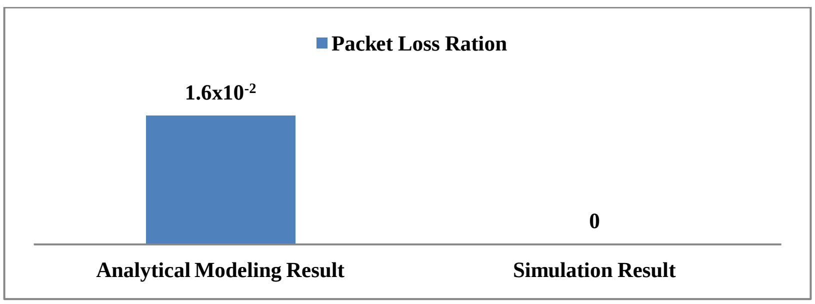

Figure 5.9: Comparison of the Proposed Vertical Handover Procedure Performance Using Simulation Result vs. Analytical Modelling Result (Packet Loss)

5.3 Chapter Summary

We have presented our approach based on the VHO approaches that have been studied in the literature. It consists of a procedure which is implemented by an algorithm. In this chapter, we have presented the proposed I AM 4 VHO procedure as the first part of our approach for providing seamless VHO in heterogeneous wireless network environment. Our procedure of loose coupling and MIPv4 provides early buffering for new data packets to minimise VHO packet loss and latency. Analysis and simulation of the proposed procedure show that the VHO packet loss and latency are significantly reduced compared with the three MIPv6 procedures found in the literature [141, 142].

Chapter 6

New Algorithm for Enhancing the VHO in Heterogeneous Wireless Networks

6.1 Introduction

In this chapter, we present the second part of our approach for providing seamless VHO in heterogeneous wireless network environment. This part presents the proposed I AM 4 VHO algorithm as published in [145, 146]. The algorithm is designed to give a lower probability of VHO connection failure and to reduce the signaling cost and the inevitable degradation in QoS. Analysis and simulation based performance evaluations demonstrate that the proposed algorithm reduces: **(a)** the probability of VHO connection failure as a result of using the optimum RATs list of priority and **(b)** the signaling cost and the inevitable degradation in QoS as a result of avoiding unnecessary handover processes [145, 146].

The chapter is organised as follows: In sections 6.2, 6.2.1, 6.2.1.1 and 6.2.2, I AM 4 VHO algorithm, analytical modelling of the proposed algorithm, analytical results and discussions and simulation scenarios, results and discussions. In the last section 6.3, some conclusions are presented.

6.2 Imperative Alternative MIH for VHO (I AM 4 VHO) Algorithm

Based on the explanation in (Chapter 5, 5.2.1.1), the algorithm to implement our procedure defines two main types of VHO: AIVHO session and Alternative VHO (AVHO) session. The AVHO consists of AAVHO session and MAVHO session, this is shown in Figure.6.1. Imperative session will have high priority; for example, if there are two VHO sessions at the same time, one due to RSS going down (imperative) and the other due to user's preferences (alternative), the first request will be responded to as high priority and the second request will be considered only if there is no any imperative VHO session under process, otherwise it has to wait in the queue. In AIVHO case, due to RSS going down the RATs list of priority based on user's preferences will be provided by the MU. When the first choice from RATs list of priority could not be satisfied with Sufficient of Resources (SoRs) the AC at destination PoS will automatically move to the next RAT in the list for satisfying the request and so on. Once RAT of sufficient resources has been found, it will be checked by the destination PoS as to whether it is compliant to the rules and preferences of operators, if that is available, the session will be accepted, otherwise the request will be returned to AC step to select the next RAT in list. Finally, the session will be rejected if there are no available resources for any RAT in the list. In AAVHO case, the MU will select target RATs list of priority based on user's preferences due to his/her profile change such as data rate and take the same path of imperative request. In MAVHO case, there is no need to have RATs list of priority step because RAT is selected manually by the user. Therefore, the session would be rejected if SoRs are not available for user's selection session.

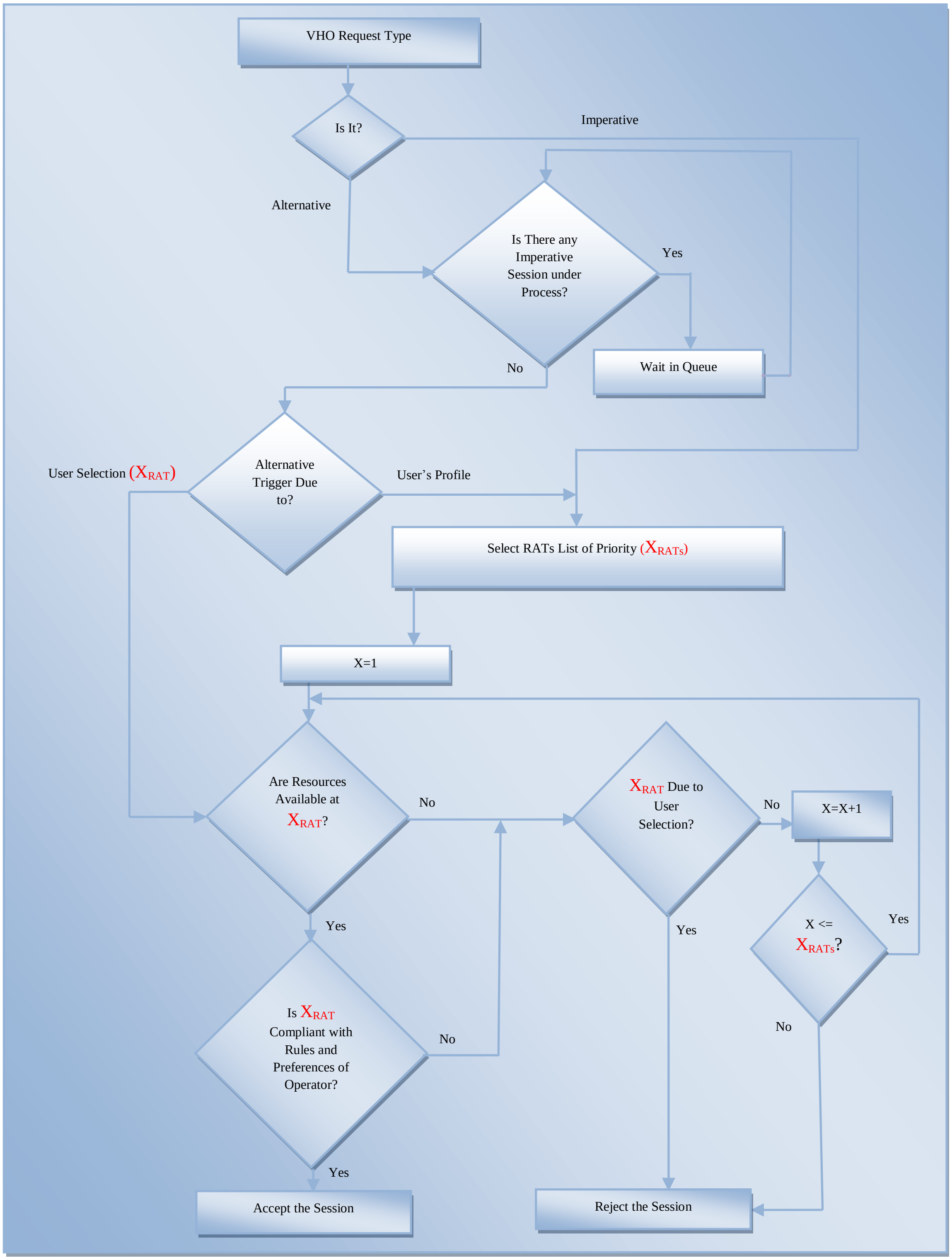

Figure 6.1: Imperative Alternative Media Independent Handover for Vertical Handover (I AM 4 VHO) Algorithm [92]

6.2.1 Analytical Modelling of the Proposed Algorithm

Many of VHO decision algorithm strategies surveyed in [64] used function based, user-centric, multiple attribute decision, fuzzy logic and neural networks based and context-aware strategies. We propose our VHO algorithm based on fuzzy logic which is a popular choice [64] due to its following features:

- It deals with imprecise data and multiple inputs parameters for making VHO decisions, it has high efficiency, it is flexible, supports non-real time and real time service, has a robust mathematical framework and eliminates the ping pong effect [64].
- It reduces unnecessary VHO, reduces signaling cost due to VHO processes and improves QoS due to VHO [5].

Our proposed VHO algorithm is composed of two main parts: Handover Initiation and Optimum RATs List of Priority as published in [145, 146], this is shown in Figure.6.2.

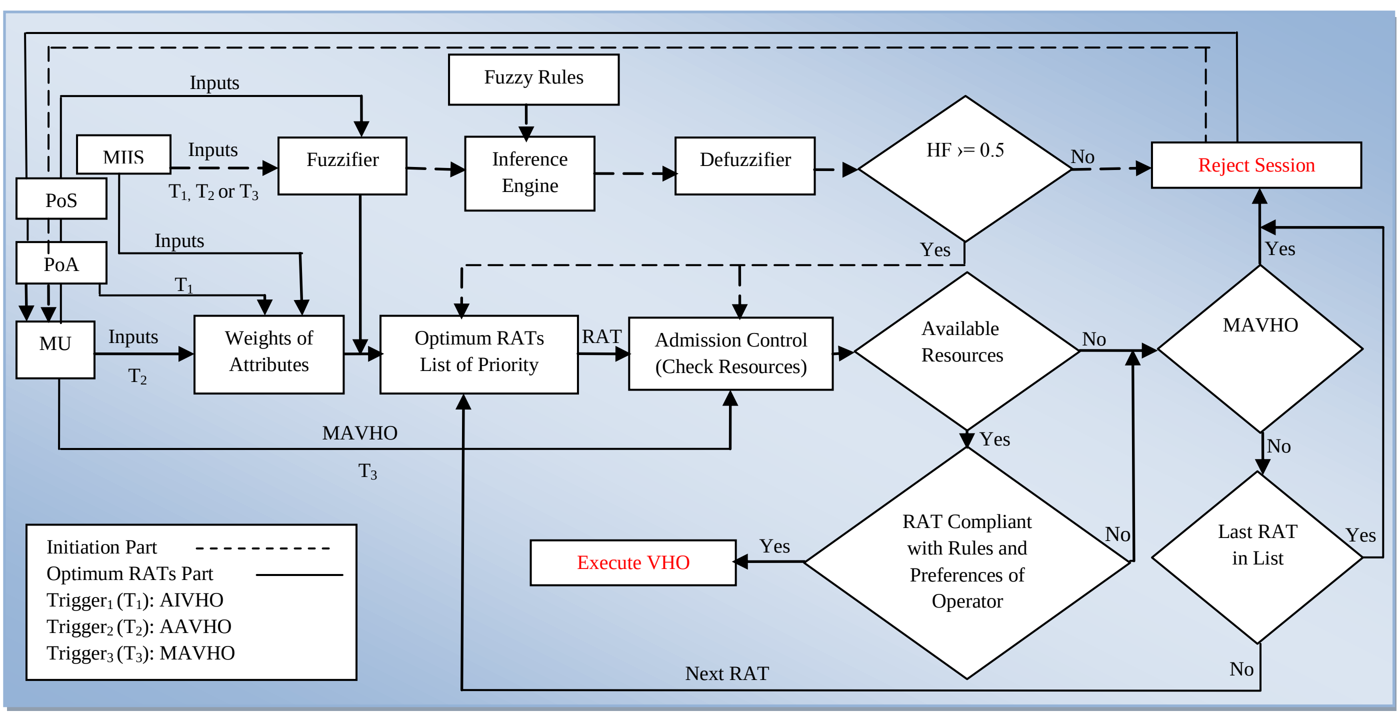

Figure 6.2: Handover Initiation and Optimum RATs Phases Using Mamdani Fuzzy Logic Inference System (FIS) [145, 146]

A. Handover Initiation

In this part, while the MU is connected to a source network the VHO will trigger due to: RSS going down (AIVHO), based on user's profile change (AAVHO) or based on user selection (MAVHO). A Mamdani Fuzzy logic Inference System (FIS) can be used for computing Handover Factor (HF) which determines whether VHO is required or not [5]. The first step is to take inputs and determine the degree to which they belong to each of the appropriate fuzzy sets via Membership Functions (MFs) - Gaussian functions are typically used as MFs [5]. In the modelling, we take into account four input parameters: RSS, data rate, coverage area and latency of a target network. The input is always a crisp value limited to the universe of discourse of the input variable and the output is a fuzzy degree of membership in the qualifying linguistic set between 0 and 1 [5]. The universe of discourse for the fuzzy variables RSS, data rate, network coverage area and network latency are (-78 dBm to -66 dBm, 0 Mbps to 60 Mbps, 0 Km to 50 Km and 0 ms to 200 ms), respectively such that the fuzzy set values for RSS consist of the linguistic terms: strong, medium and weak, data rate: high, medium and low, coverage area: very good, good and bad, latency: high, medium and low [5]. These sets are mapped to corresponding Gaussian MFs; after that, the fuzzy sets are fed into a fuzzy inference engine (IF-THEN) rules which are applied to obtain fuzzy decision sets, the output fuzzy decision sets are aggregated into a single fuzzy set and passed to the defuzzifier to be converted into a precise quantity (HF) [5]. The fuzzy set values for the output decision (HF) are: higher, high, medium, low and lower [5]. The universe of discourse for HF is defined from 0 to 1, with the maximum membership of the sets lower and higher at 0 and 1, respectively [5]. This is shown in Figure.6.3-Figure.6.7. In our algorithm, there are four fuzzy input variables and three fuzzy sets for each fuzzy variable so the maximum possible number of IF-THEN rules is $3^4 = 81$ such as [145]:

IF RSS is weak, and data rate is low, and network coverage area is bad, and network latency is high, THEN HF is lower.

IF RSS is weak, and data rate is low, and network coverage area is good, and network latency is medium, THEN HF is low.

IF RSS is medium, and data rate is medium, and network coverage area is good, and network latency is medium, THEN HF is medium.

IF RSS is strong, and data rate is very good, and network coverage area is good, and network latency is medium, THEN HF is high.

IF RSS is strong, and data rate is high, and network coverage area is very good, and network latency is low, THEN HF is higher.

The crisp HF computed after defuzzification is used to determine when a HF is required as follows:

IF HF >= 0.5, then initiate handover; otherwise reject session [145].

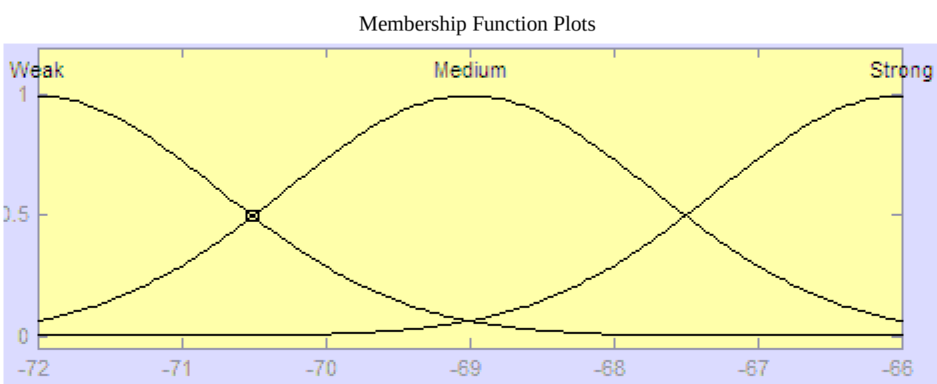

Figure 6.3: Input Variable “RSS”

Membership Function Plots

Figure 6.4: Input Variable "Data Rate"

Membership Function Plots

Figure 6.5: Input Variable "Coverage Area"

Membership Function Plots

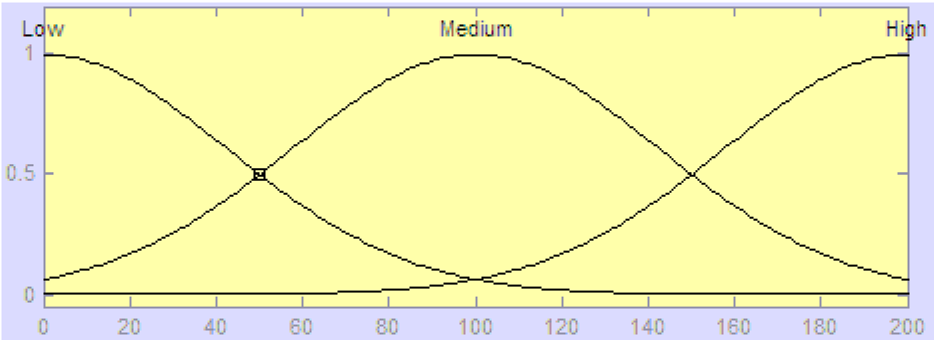

Figure 6.6: Input Variable "Latency"

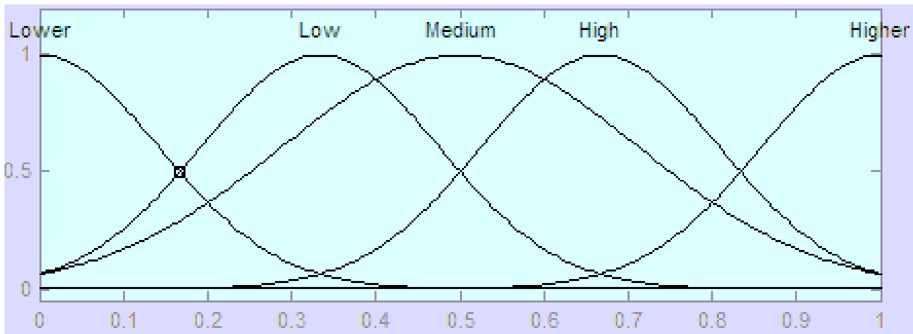

Figure 6.7: Output Variable "Handover Factor"

B. Optimum RATs List of Priority

In this part, the proposed algorithm reduces: **(a)** the VHO connection failure as a result of using the optimum RATs list of priority and **(b)** the signaling cost and the inevitable degradation in QoS as a result of avoiding unnecessary handover processes. Selecting the best RAT by Wireless Network Selection Function (WNSF) is optimised to network conditions, mobile conditions, user's preferences, QoS requirements and service cost [147]. The inputs parameters use for WNSF include good signal strength (S), high data rate (D), high network coverage area (CA), low network latency (L), high reliability (R), good security (E), low battery power requirement (P), good mobile terminal velocity (VL) and low service cost (SC) [147]. In MAVHO, there is no need to have RATs list of priority step because a target RAT will be selected manually by the user and such the session would be rejected if SoRs are not available for user's selection session [145].

The optimum wireless access network is computed by (6.1)-(6.6) and must satisfy: Maximize $f_i(\boldsymbol{u})$, $\boldsymbol{u}$ where $f_i(\boldsymbol{u})$ is the objective function evaluated for a network i and $\boldsymbol{u}$ is the vector of input parameters. The function f_i can be expressed as [147]:

$$f_i(\boldsymbol{u}) = f\,(S_i, D_i, CA_i, 1/L_i, R_i, E_i, 1/P_i, VL_i\ ,1/SC_i)$$

$$\sum_{i=1}^{6} w_X \, . \, N_f(X_i) + \sum_{i=1}^{3} w_Y \, . \, N_f(1/Y_i) \qquad \textbf{(6.1)}$$

Where $N_f(X)$ is the normalized function of the parameter X and w_X is the weight which indicates the importance of the parameter X, with $X_i = S_i, CA_i, D_i, R_i, E_i, VL_i$ and $Y_i = SC_i, P_i, L_i$. Normalization is needed to ensure that the sum of the values in different units is meaningful, a simple way to obtain $N_f(X)$ is normalization with respect to the maximum or minimum values of the real-valued parameters [147]. Therefore, we have (6.2) [147]:

$$f_i(x) = \sum_{i=1}^{6} w_X \, . \left(\frac{X_i}{X_{max}}\right) + \sum_{i=1}^{3} w_Y \, (Y_{min}/Y_i) \qquad \textbf{(6.2)}$$

Data from the system is fed into a fuzzifier to be converted into fuzzy sets. Suppose that $A = \{A_1, A_2, \ldots, A_j\}$ is a set of j alternatives and $C = \{C_1, C_2, \ldots, C_i\}$ is a set of i handover decision criteria (attributes) that can be expressed as fuzzy sets in the space of alternatives, the criteria are rated on a scale of *0* to *1*, the degree of membership of alternative A_j in the criterion C_i is denoted $\mu_{Ci}(A_j)$ and it is the degree to which alternative A_j satisfies this criterion [147]. A decision maker (e.g., MU) judges the criteria in pairwise comparisons [148] and assigns the values $a_{ij} = 1/a_{ji}$ using the judgment scale proposed by Saaty [149]. These are: 1 equal importance, 2 weak, 3 moderate importance, 4 moderate plus, 5 strong importance, 6 strong plus, 7 very strong, 8 very very strong and 9 extreme importance [145]. An $n \times n$ matrix B is constructed so that [147]:

$$b_{ii} = 1; (2) b_{ij} = a_{ij}, i \neq j; (3) b_{ji} = 1/b_{ij}$$

Using this matrix, the unit eigenvector V correspond to the maximum eigenvalue λ_{max} of B which is determined by the following equation [147]:

$$B.V = \lambda_{max} . V \qquad \textbf{(6.3)}$$

Finding the unit eigenvector *V* corresponding to the maximum eigenvalue of *B* produces the cardinal ratio scale of the compared attributes. The values of *V* are scaled for use as factors in weighting the membership values of each attribute by a scalar division of *V* by the sum of values of *V* to obtain a weighting matrix *W* [147]. In general, the fitness value for a network *i* is thus given by [147]:

$$f_i(x) = \sum_{j=1}^{n} w_j \,.\, \mu_{cj}(A_i) \qquad (6.4)$$

Where x is the vector of membership function values. The optimum wireless network is given by the optimisation problem [147]:

$$\max\ f_i\,(x) = \max\{\ \sum_{j=1}^{n} w_j \,.\, \mu_{cj}(A_i)\} \qquad (6.5)$$

Such that

$$0 \leq w_j \leq 1, and\ \sum_{j=1}^{n} w_j = 1 \qquad (6.6)$$

Probability of Minimising VHO Connection Failure

The probability of handover connection failure occurs when the handover is initiated but a target network does not have sufficient resources to complete it (session rejection due to unavailable resources) or when the MU moves out of the coverage of a target network before the process is finalized [134, 136]. However, previous works in [126, 127, 128, 129, 130, 131, 132 and 133] and which have been surveyed in [134] have considered only the MU's moves as the handover connection failure factor while the other works in [2, 112 and 135] are content only with selecting one target RAT for the checking resources [146]. In this chapter, giving more attention toward the session rejection due to unavailable resources as the handover connection failure factor is considered and the proposed algorithm performance with previous works found in the literature [2, 112 and 135] is compared.

We consider the situation in which there are three types of VHO triggers can be identified without background traffic: AIVHO, AAVHO and MAVHO. We refer to Alternative trigger (AAVHO/MAVHO) and Imperative trigger (AIVHO) as AA, MA and AI, respectively.

Let $Z = \{z_1, z_2, . . . , z_i\}$ and $Y = \{y_1, y_2, . . . , y_j\}$ be the sets of APs and BSs in a UMTS coverage area, respectively. Note that $i > 1$ and $j > 1$.

If the trigger is MA or based on selecting the best RAT as previous works, the probability of minimising VHO connection failure (p_2) is computed in [146] as follows:

$p_2(z_t) = p(z_i)$, z_t is only one target network selected (6.7)

$p_2(y_t) = p(y_j)$, y_t is only one target network selected (6.8)

Where p is the probability of available resources for any individual RAT.

If the trigger is AA or AI, the RATs list of priority should be $z_1, z_2, ..., z_i$ and/or $y_1, y_2, \dots, y_j$, the probability of minimising VHO connection failure (p_2) is computed in [146] as follows:

$$p_2(r_m \geq 1) = 1 - p_1(r_1 < 1), 1 - p_1(r_2 < 1), \dots, 1 - p_1(r_m < 1) \quad (6.9)$$

Where $p_1(r_m) = \binom{k}{r_m} p^{r_m} q^{k-r_m} = \frac{k!}{(k-r_m)!r_m!} p^{r_m} q^{k-r_m}$ (6.10)

Where p_1 is the probability of available resources for available RATs, k is number of available RATs, r is number of available successful RATs and q is probability of unavailable resources for any individual RAT.

6.2.1.1 Analytical Results and Discussions of the Proposed Algorithm

To ease our illustration, we just consider the situation in which there are two different RATs (UMTS and WiMAX). The UMTS covers whole analysis area as well as WiMAX(1) and WiMAX(2) partly overlay the service area. While the MU is currently connected to UMTS and downloading files, he has started moving toward the WiMAX hotspots area, this is shown in Figure.6.8. The MU is always in search for the high data rate, security, reliability, latency and cost of other RATs. This in turn means that data rate is extreme importance (9) over all other attributes. Security is very very strong (8) over all other attributes except the data rate. Reliability is very strong (7) over all other attributes except data rate and security. Latency is strong plus (6) over other attributes except data rate, security and reliability. Service cost is strong importance (5) over other attributes except data rate, security, reliability and latency. Finally, RSS, coverage area, mobile velocity and battery power requirement are equal importance (1).

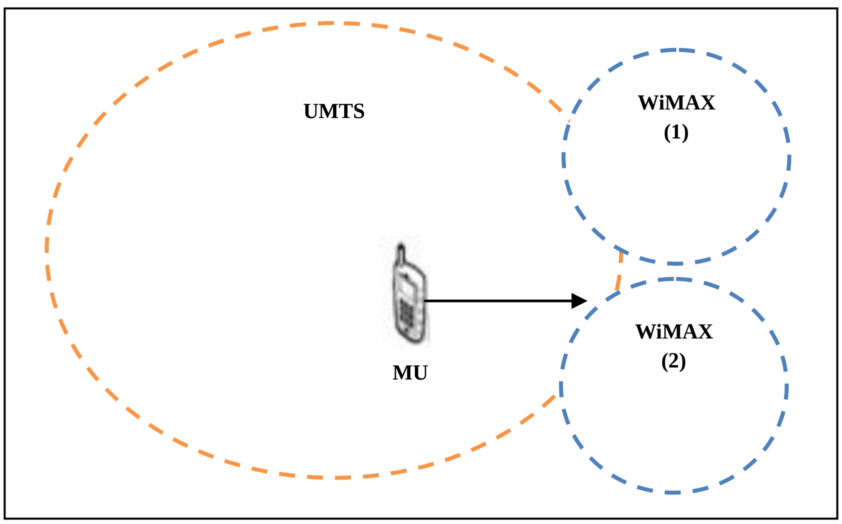

Figure 6.8: Radio Access Technologies (RATs) Coverage Area [145]

A. Handover Initiation

We first check to see whether the handover should be initiated by computing the HF. Suppose that the MU records the data values of RSS (dBm), data rate (Mbps), network coverage area (m) and network latency (ms) as {-67.3, 48.8, 47.9, 56.5} and {-67.01, 48.6, 47.6, 55.8}for WiMAX(1) and WiMAX(2), respectively [5]. These set of values are fed into FIS and we obtain HF values 0.57 and 0.58, thus indicating the need to handover either to WiMAX(1) or WiMAX(2) for the downloading files service [145].

B. Optimum RATs List of Priority

The second stage of VHO decision algorithm is to compute the WNSF for all RATs. The MU proceeds to gather data on all required parameters. The matrix *B* and weighting matrix *W* are indicated below [145]:

$$B = \begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \\ C_6 \\ C_7 \\ C_8 \\ C_9 \end{array} \begin{array}{c} \begin{array}{ccccccccc} C_1 & C_2 & C_3 & C_4 & C_5 & C_6 & C_7 & C_8 & C_9 \end{array} \\ \left(\begin{array}{ccccccccc} 1 & 1/9 & 1 & 1/6 & 1/7 & 1/8 & 1 & 1 & 1/5 \\ 9 & 1 & 9 & 9 & 9 & 9 & 9 & 9 & 9 \\ 1 & 1/9 & 1 & 1/6 & 1/7 & 1/8 & 1 & 1 & 1/5 \\ 6 & 1/9 & 6 & 1 & 1/7 & 1/8 & 6 & 6 & 6 \\ 7 & 1/9 & 7 & 7 & 1 & 1/8 & 7 & 7 & 7 \\ 8 & 1/9 & 8 & 8 & 8 & 1 & 8 & 8 & 8 \\ 1 & 1/9 & 1 & 1/6 & 1/7 & 1/8 & 1 & 1 & 1/5 \\ 1 & 1/9 & 1 & 1/6 & 1/7 & 1/8 & 1 & 1 & 1/5 \\ 5 & 1/9 & 5 & 1/6 & 1/7 & 1/8 & 5 & 5 & 1 \end{array}\right) \end{array} \Longrightarrow V = \begin{pmatrix} -0.0295 \\ -0.8550 \\ -0.0295 \\ -0.1293 \\ -0.2316 \\ -0.4352 \\ -0.0295 \\ -0.0295 \\ -0.0762 \end{pmatrix} \Longrightarrow W = \begin{pmatrix} 0.0159 \\ 0.4633 \\ 0.0159 \\ 0.0700 \\ 0.1255 \\ 0.2358 \\ 0.0159 \\ 0.0159 \\ 0.0412 \end{pmatrix}$$

Membership values used in this evaluation are adopted from [5] and the attribute weights and the membership values of the three available networks for the attributes are summarised in the Table.6.1. Using the attribute weights, we define the WNSF as:

$f_i(x)$= (0.0159) * x(1) + (0.4633) * x(2) + (0.0159) * x(3) + (0.0700) * x(4) + (0.1255) * x(5) + (0.2358) * x(6) + (0.0159) * x(7) + (0.0159) * x(8) + (0.0412) * x(9)

Evaluating the function using the membership values x(i) for the available networks are scored [145]:

f_{UMTS}= (0.0159) * (0.8125) + (0.4633) * (0.0994) + (0.0159) *(0.2027) + (0.0700) * (0.5949) + (0.1255) * (0.9000) + (0.2358) * (0.8985) + (0.0159) * (0.7998) + (0.0159) * (0.8972) + (0.0412) * (0.5982)

$f_{WiMAX(1)}$= (0.0159) * (0.8945) + (0.4633) * (0.9000) + (0.0159) * (0.8039) + (0.0700) * (0.7831) + (0.1255) * (0.9000) + (0.2358) * (0.8938) + (0.0159) * (0.7484) + (0.0159) * (0.5000) + (0.0412) * (0.8300)

$f_{WiMAX(2)}$= (0.0159) * (0.9000) + (0.4633) * (0.9000) + (0.0159) * (0.8879) + (0.0700) * (0.8865) + (0.1255) * (0.8898) + (0.2358) * (0.8993) + (0.0159) * (0.6552) + (0.0159) * (0.5000) + (0.0412) * (0.8500)

f_{UMTS}= 0.479, $f_{WiMAX(1)}$= 0.876, $f_{WiMAX(2)}$= 0.884.

Since WiMAX(2) has scored the highest value for WNSF as shown in Figure.6.9, it is best to handover from UMTS to WiMAX(2) by passing WiMAX(2) to AC for checking available resources. When the first choice from RATs list of priority (WiMAX(2)) could not be satisfied with SoRs the AC at destination PoS will automatically move to the next RAT (WiMAX(1)) in the list for satisfying the request. Once RAT of resources has been found, it will be checked by the destination PoS whether it is compliant to the rules and preferences of operators. If that is available, the session will be accepted, otherwise the request will be returned to AC step to select a next RAT in the list. Finally, the session will be rejected if there are no available resources for any RAT in the list.

Criteria		Weights of Attributes	Membership Values		
			UMTS	WiMAX(1)	WiMAX(2)
RSS	C_1	0.0159	0.8125	0.8945	0.9000
Data Rate	C_2	0.4633	0.0994	0.9000	0.9000
Network Coverage	C_3	0.0159	0.2027	0.8039	0.8879
Network Latency	C_4	0.0700	0.5949	0.7831	0.8865
Reliability	C_5	0.1255	0.9000	0.9000	0.8898
Security	C_6	0.2358	0.8985	0.8938	0.8993
Power Requirement	C_7	0.0159	0.7998	0.7484	0.6552
Mobile Velocity	C_8	0.0159	0.8972	0.5000	0.5000
Service Cost	C_9	0.0412	0.5982	0.8300	0.8500
WNSF Values			0.479	0.876	**0.884**

Table 6.1: Performance Evaluation for Optimum RATs List of Priority

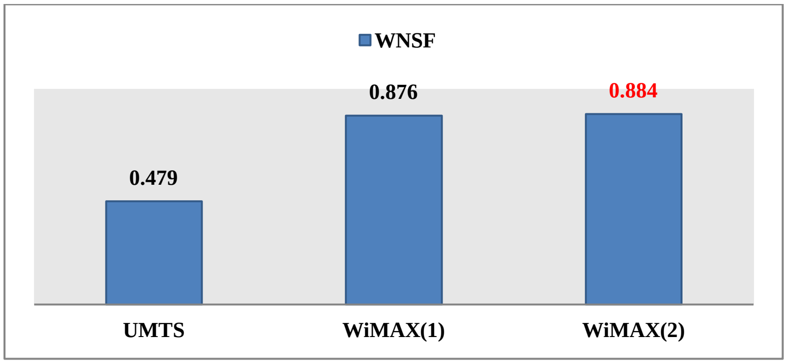

Figure 6.9: Wireless Network Selection Function (WNSF) Values

Probability of Minimising VHO Connection Failure

To investigate probability of minimising VHO connection failure thoroughly, we assume set of variables of p (0.1, 0.2, 0.3, ... , 0.9) as shown in Figure.6.10-Figure.6.18, respectively. It can be seen from the figures that the probability of minimising VHO connection failure (p_2) is improved with the increasing number of RATs in RATs list of priority compared with previous works in [2, 112 and 135] which are content only with selecting one target RAT for the checking resources [146].

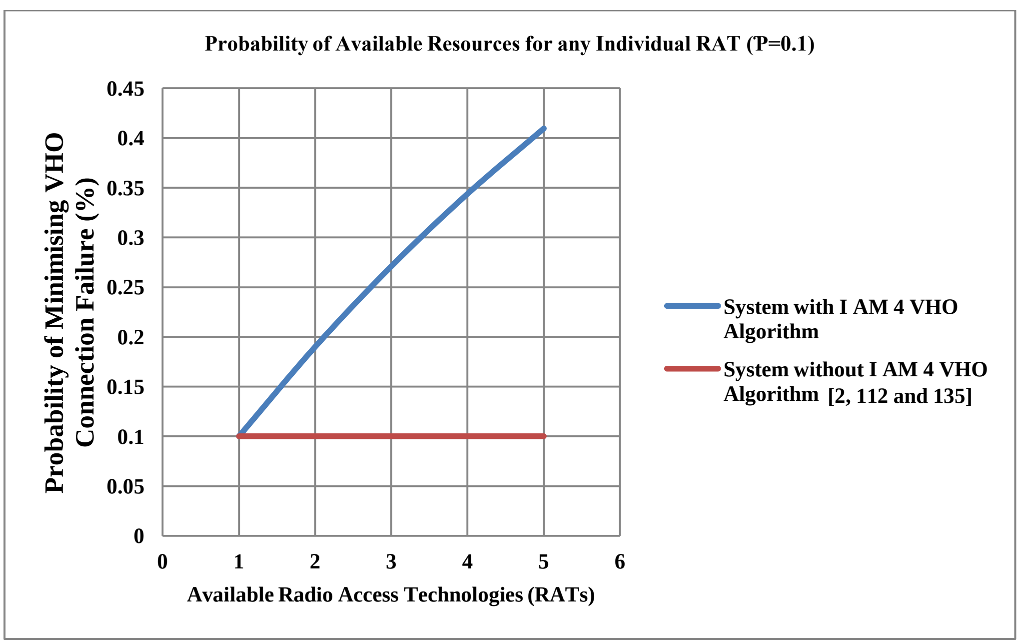

Figure 6.10: Comparison of Probability of Minimising VHO Connection Failure Algorithms (p = 0.1)

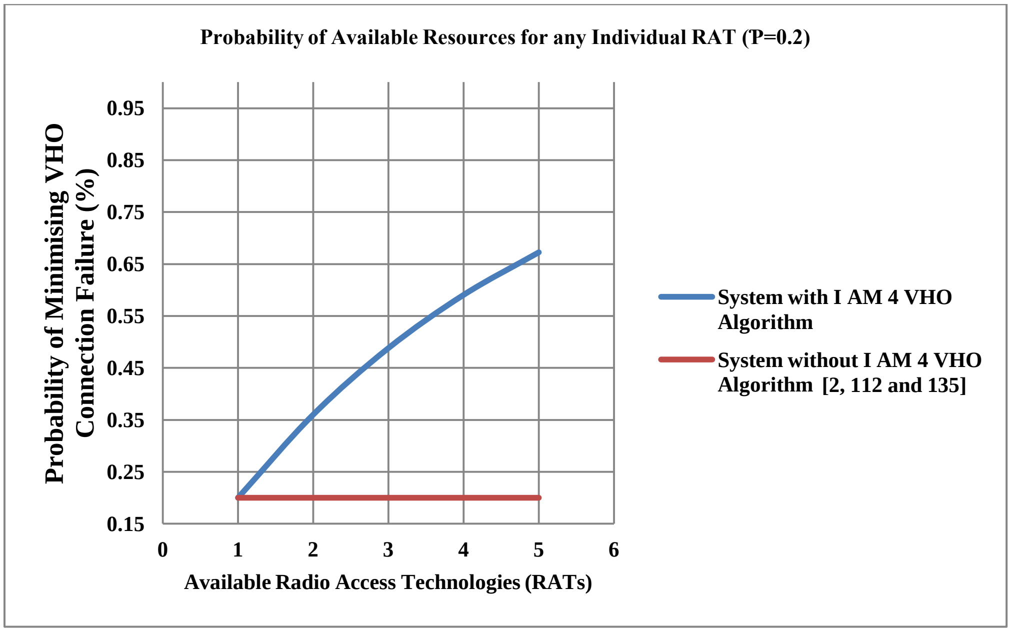

Figure 6.11: Comparison of Probability of Minimising VHO Connection Failure Algorithms (p = 0.2)

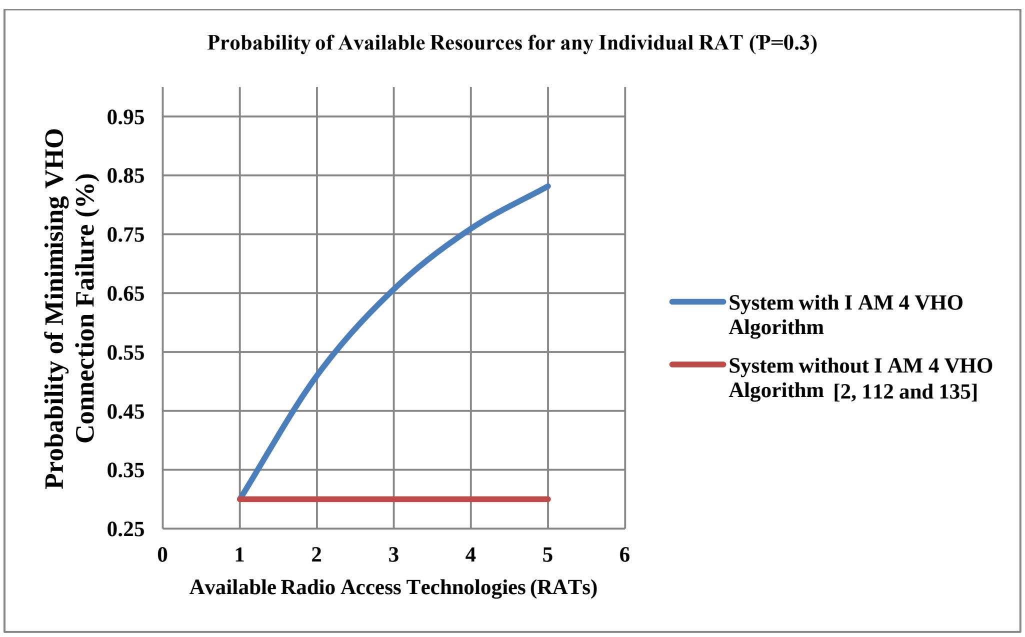

Figure 6.12: Comparison of Probability of Minimising VHO Connection Failure Algorithms (p = 0.3)

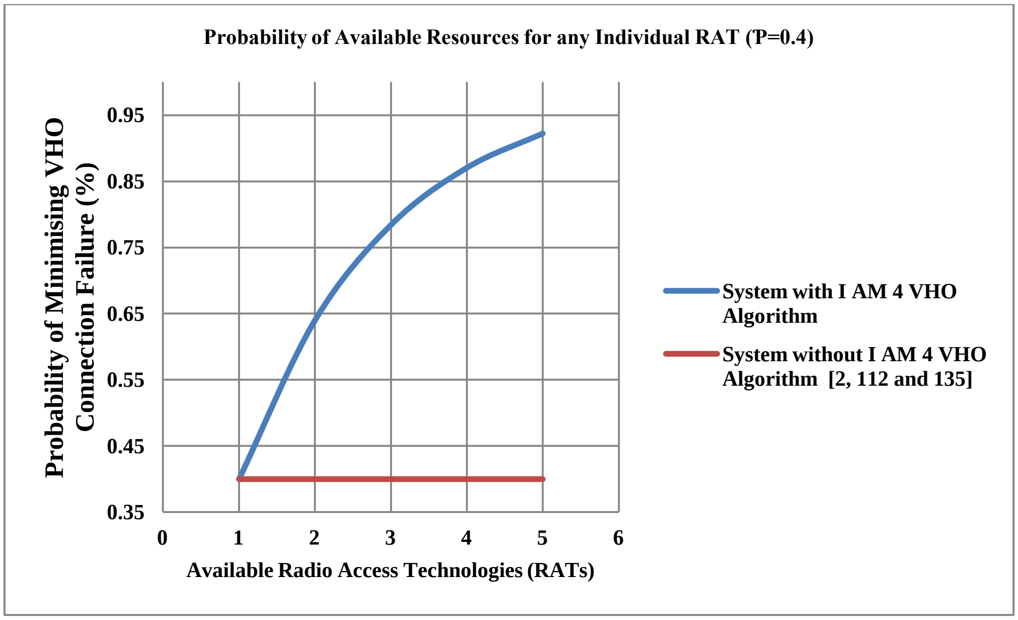

Figure 6.13: Comparison of Probability of Minimising VHO Connection Failure Algorithms (p = 0.4)

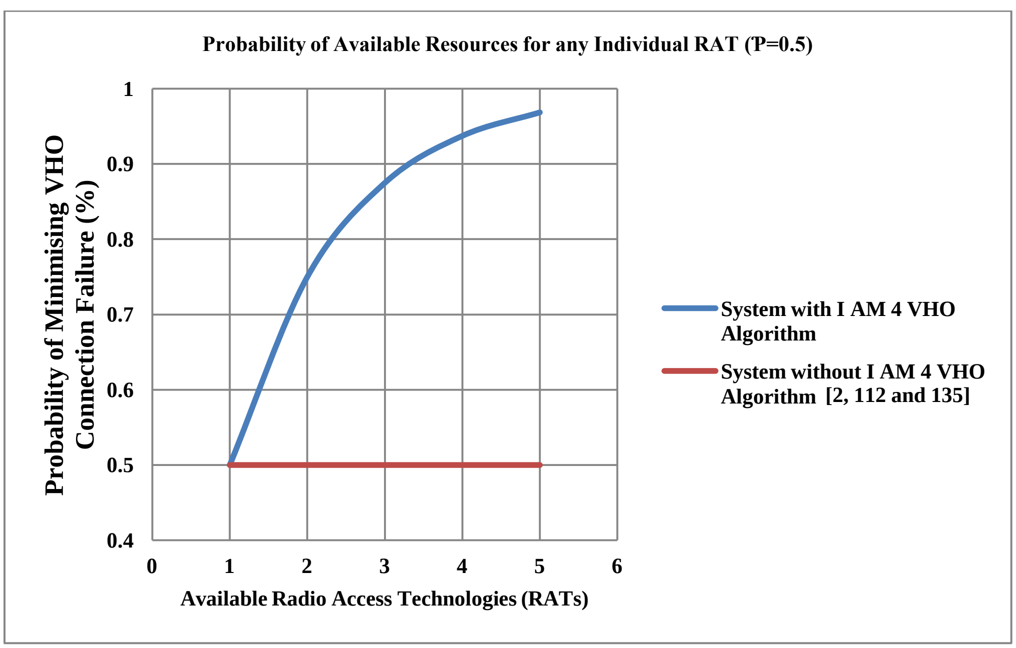

Figure 6.14: Comparison of Probability of Minimising VHO Connection Failure Algorithms (p = 0.5)

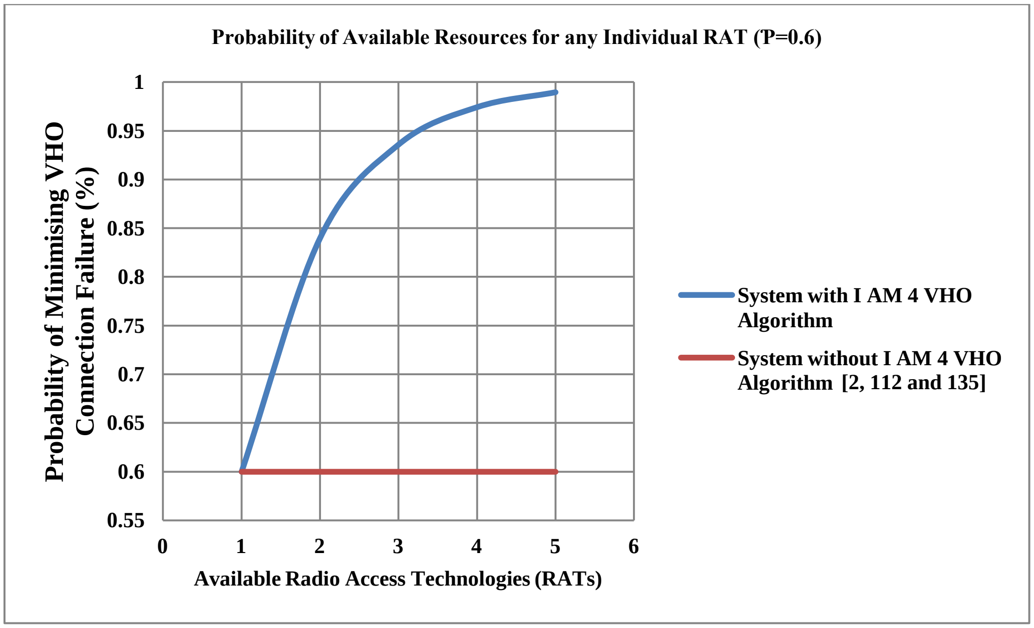

Figure 6.15: Comparison of Probability of Minimising VHO Connection Failure Algorithms (p = 0.6)

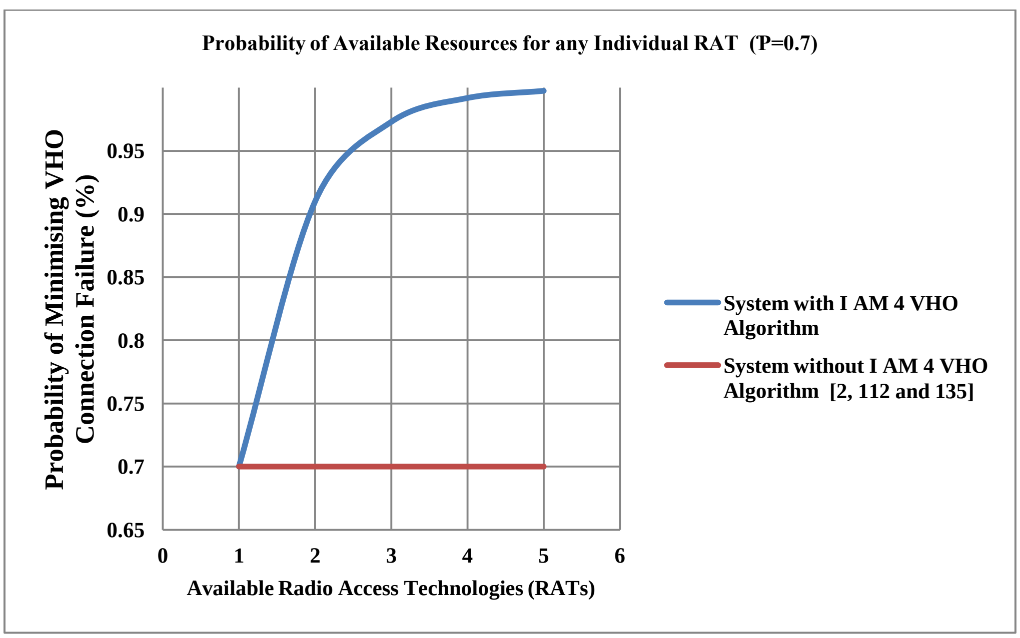

Figure 6.16: Comparison of Probability of Minimising VHO Connection Failure Algorithms (p = 0.7)

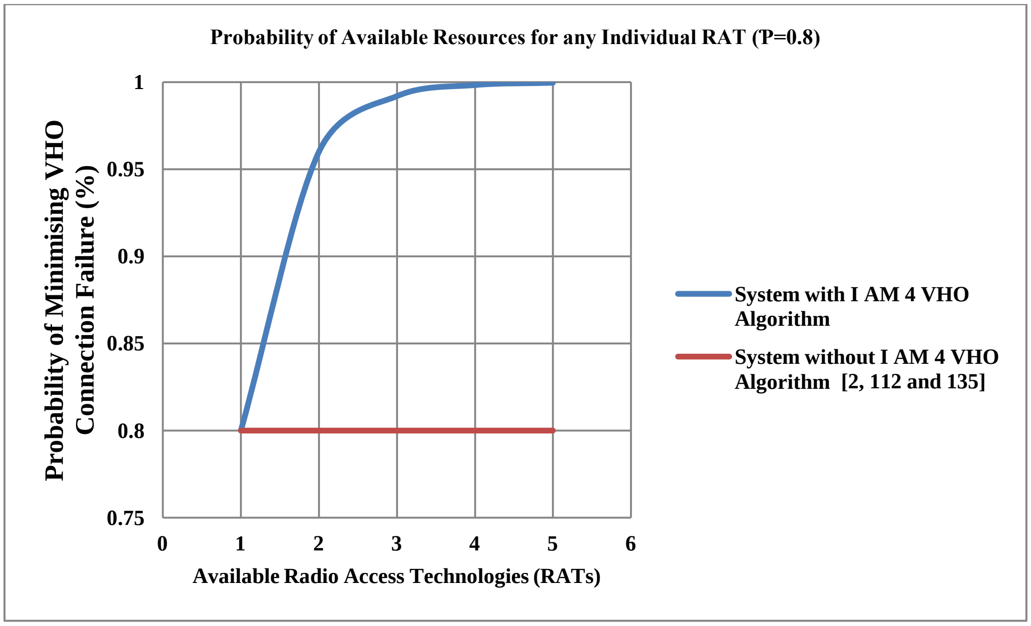

Figure 6.17: Comparison of Probability of Minimising VHO Connection Failure Algorithms (p = 0.8)

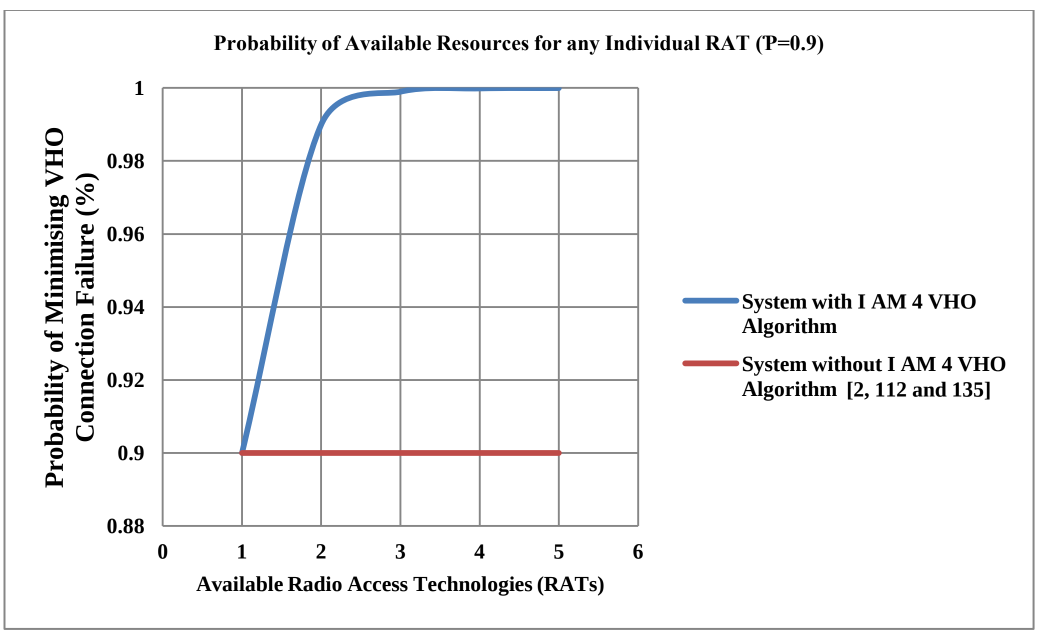

Figure 6.18: Comparison of Probability of Minimising VHO Connection Failure Algorithms (p = 0.9)

6.2.2 Simulation Scenarios, Results and Discussions of the Proposed Algorithm

The performance of the proposed algorithm is evaluated by simulation using MATLAB. In our illustration, we consider the situation in which there are three scenarios without background traffic: AIVHO, AAVHO and MAVHO. Two different RATs in these scenarios are considered: The UMTS covers most of simulation area as well as WiMAX(1) and WiMAX(2) partly overlay at the end of UMTS where the MU always operates on UMTS network, this is shown in Figure.6.8. We refer to Alternative trigger (AAVHO/MAVHO) and Imperative trigger (AIVHO) as 1 and 0, respectively. While 2 for not required session due to HF less than 0.5, this is shown in Table.6.2. We compare our algorithm performance with previous works in [2, 112 and 135] which are content only with selecting one target RAT for the checking resources [146].

Scenario	Trigger		RSS (dBm)	Data Rate (Mbps)	Network Coverage Area (Km)	Latency (ms)	Output (HF)	Output Notation
1	AIVHO (RSS Going Down)	UMTS	-67	29	25	100	0.432	2
		WiMAX(1)	-67	46	39	143	0.503	0
		WiMAX(2)	-70	25	29	136	0.477	2
2	AAVHO (User's Profile Change)	UMTS	-67	33	39	143	0.487	2
		WiMAX(1)	-67	46	29	38	0.522	1
		WiMAX(2)	-67	55	38	53	0.591	1
3	MAVHO (User Selection)	UMTS	-69	43	18	56	0.508	1
		WiMAX(1)	-70	18	14	173	0.395	2
		WiMAX(2)	-69	20	18	149	0.464	2

Table 6.2: Initiation Phase Scenarios and Results

Scenario 1 (Imperative VHO): Automatic

The MU starts moving out of the coverage of UMTS due to RSS going down, the handover takes place to available RAT either WiMAX(1) or WiMAX(2) to keep the session going.

Table.6.2 shows that the VHO is possible to WiMAX(1) only because of its HF being above 0.5 (0.503) while it is not possible to UMTS and WiMAX(2) as their HF are less than 0.5 (0.432, 0.477) [145], respectively.

Scenario 2 (Alternative VHO): Automatic

As the MU starts moving into WiMAX(1) and WiMAX(2) coverage, it could automatically change its connection into one of them to keep the session depending on the user's profile.

Table.6.2 shows that the VHO is possible to WiMAX(1) and WiMAX(2) since their HF are 0.522 and 0.591, respectively while it is not possible to UMTS due to its low HF (0.487) [145].

Scenario 3 (Alternative VHO): Manual

As the MU starts moving into WiMAX(1) and WiMAX(2) coverage, it could manually change its connection into one of them to keep the session depending on the user selection.

Table.6.2 shows that the VHO is possible just to UMTS due to its HF (0.508) while it is not possible to WiMAX(1) and WiMAX(2) as their HF are less than 0.5 (0.395, 0.464) [145], respectively.

Discussions

From the simulation results presented above and as shown in Table.6.3, the following observations can be made:

- In scenario 1, the probability of minimising VHO connection failure of our algorithm is equal to previous works as shown in Figure.6.19 due to the RATs list of priority step in our algorithm is inactive where there is only one RAT (WiMAX(1)) qualified to initiate the optimised RATs list of priority [145].

- In scenario 2, as there are more than one RAT qualified to initiate the optimised RATs list of priority, the probability of minimising VHO connection failure in our algorithm is (75%) whereas previous works [2, 112 and 135] scores (50%) because they are content only with selecting one target RAT for the checking resources [145], this is shown in Figure.6.20.
- Scenario 3 avoids the VHO to WiMAX(1) and WiMAX(2) and staying in UMTS will guarantee reducing of the signaling cost and the inevitable degradation in QoS as a result of avoiding unnecessary handover processes [145].

Scenario	System with I AM 4 VHO Algorithm	System without I AM 4 VHO Algorithm
(1) Probability of Minimising VHO Connection Failure	50%.	50%.
(2) Probability of Minimising VHO Connection Failure	75%.	50%.
(3) (a) Unnecessary VHO	Avoided.	2.
(b) VHO Signaling Cost Due to Unnecessary VHO	Avoided.	Incurred.
(c) Inevitable Degradation in QoS Due to Unnecessary VHO	Avoided.	Incurred.

Table 6.3: Optimum Radio Access Technologies List of Priority Phase Scenarios and Results

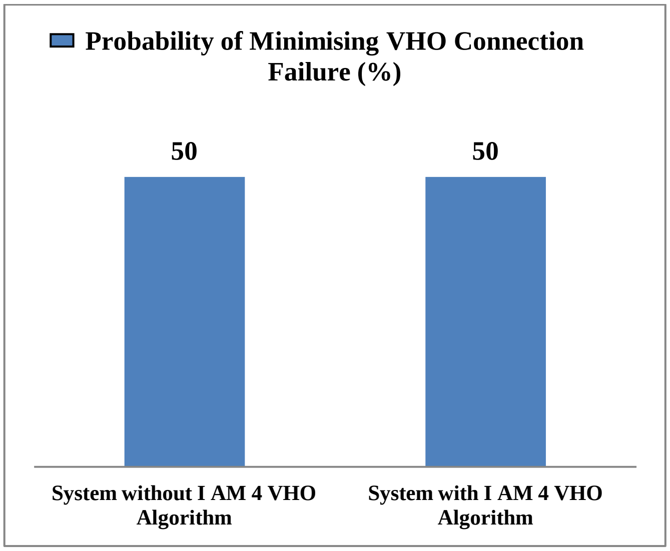

Figure 6.19: Scenario 1: Probability of Minimising VHO Connection Failure

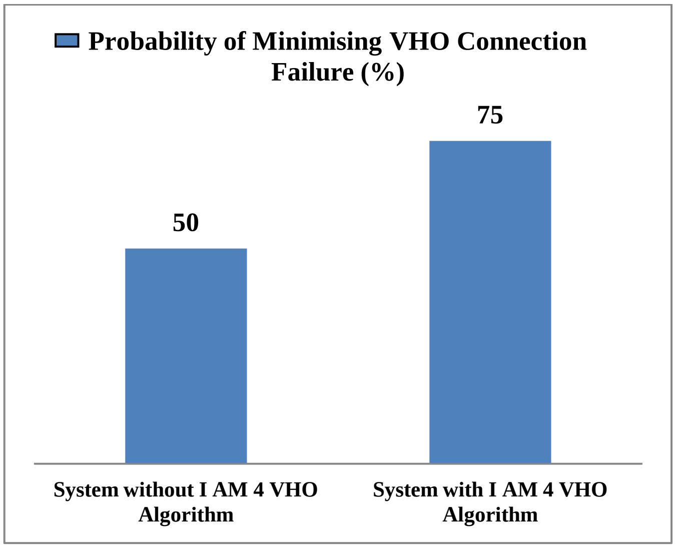

Figure 6.20: Scenario 2: Probability of Minimising VHO Connection Failure

6.3 Chapter Summary

In this chapter, we have presented the proposed I AM 4 VHO algorithm as the second part of our approach for providing seamless VHO in heterogeneous wireless network environment. Our algorithm is composed of two main parts: Handover Initiation and Optimum RATs list of priority. The first part includes two main types of VHO and gives priority to imperative sessions over alternative sessions. This part is also responsible for deciding when and where to perform the handover by choosing the best RATs from the multiple ones available. Then, it passes them to the decision phase. This results in reducing the signaling cost and the inevitable degradation in QoS as a result of avoiding unnecessary handover processes. The second part defines RATs list of priority to minimise VHO connection failure. Analysis and simulation based performance evaluations demonstrate that the proposed algorithm outperforms the traditional algorithms in terms of: **(a)** the probability of VHO connection failure as a result of using the optimum RATs list of priority and **(b)** the signaling cost and the inevitable degradation in QoS as a result of avoiding unnecessary handover processes [145, 146].

Chapter 7

Conclusions and Future Work

7.1 Introduction

This final chapter closes the thesis by presenting the summary of the work and describing the key contributions. It also describes possible areas for future work.

7.2 Outcomes of the Research Study (Conclusions)

The focus of the research project presented in this thesis is to develop a VHO approach to optimise the performance of VHO in heterogeneous wireless network environment. We have highlighted the main theme of this research study and shown how it has succeeded in answering and addressing the research problems through the following questions as they are shown in Figure.7.1:

A. How Have the Key Research Problems Been Identified?

In order to identify the research problems accurately, four surveys have been presented and published about the VHO approaches found in the literature (chapter 3, [88, 109 and 115]) and (chapter 4, [137]). In these surveys, we have classified the VHO approaches into categories based on the available VHO techniques for which we have presented their objectives and performances issues.

In (chapter 3, [88]), we have surveyed two main VHO interworking architectures: loose coupling and tight coupling and highlighted their objectives, features and challenges. A fair comparison has been made based on their performance in terms of latency, probability of packet loss, mobility management, congestion, complexity, overload, additional modification requirement and additional cost requirement.

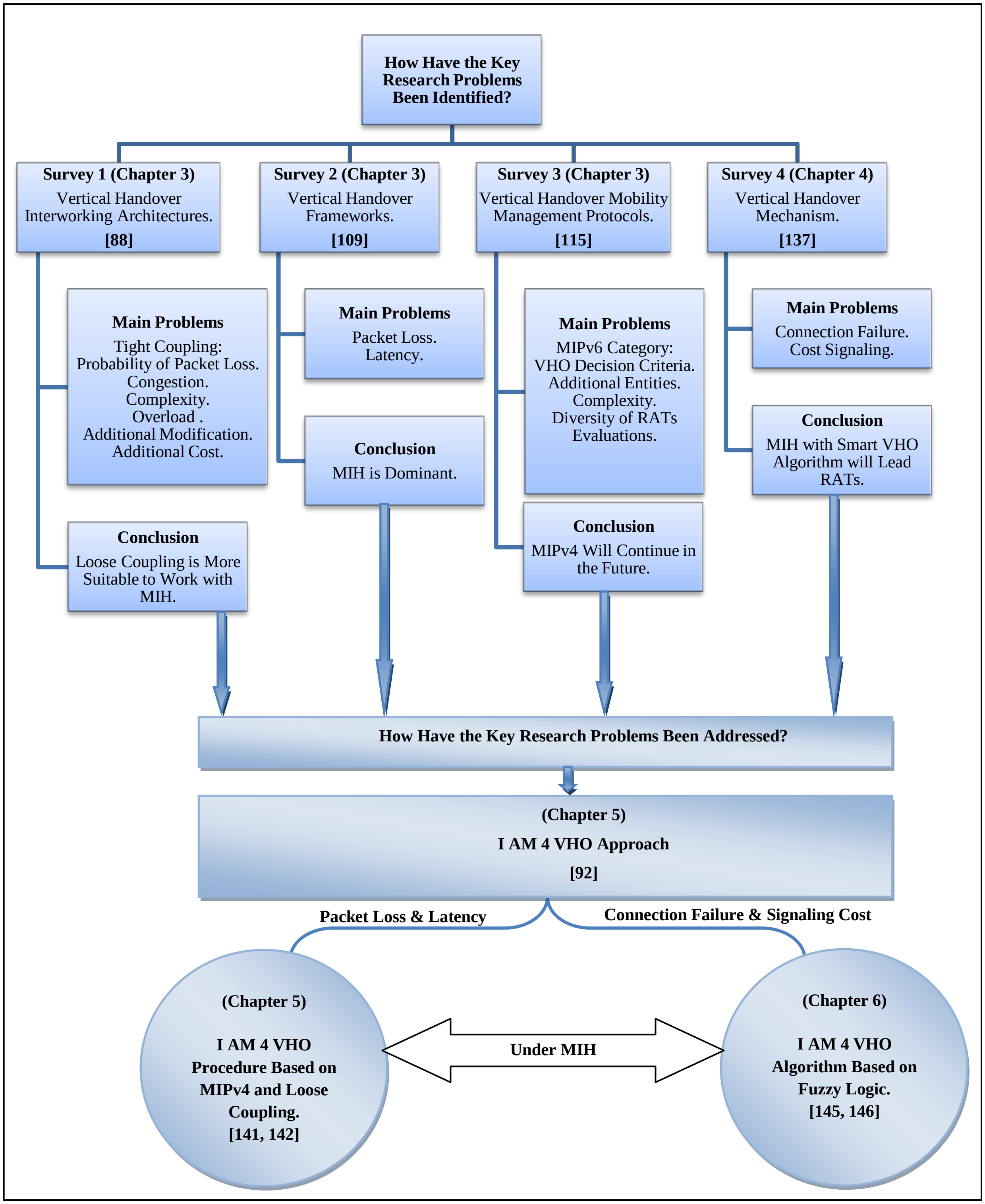

Figure 7.1: The Outline of the Thesis Structure

A better performance is provided by loose coupling compared with tight coupling; therefore, it has been concluded in (chapter 3, [88]) that the loose couple VHO interworking architecture is more suitable to work with MIH and enhance its vital role in heterogeneous wireless network environment while the tight coupling with MIH requires future work improvements in terms of probability of packet loss, congestion, complexity, overload, additional modification and additional cost.

In (chapter 3, [109]), we have presented a comprehensive survey of VHO approaches designed to provide seamless VHO based on MIH and IMS frameworks. To offer a systematic and exhaustive comparison in this survey, we have presented two types of comparison: a comparison between the frameworks (MIH and IMS) and a comparison between the four categories based on these frameworks (MIH based category, IMS based category, MIP under IMS based category and MIH and IMS combination based category). In order to provide a comparison of the two frameworks, we have summarised their specifications on fourteen aspects: producer, released, mobility management protocol, legacy RATs, security, implementation of the decision algorithm, wired and wireless multimedia service, available RATs provider, available RATs provider capability, upgrade, additional cost, components, battery consumptions (MU) and receivers (MU). In order to provide a comparison of the four categories, we have summarised their features with regard to eight aspects: objective, VHO decision criteria, applicable area, additional entity, cost, complexity, evaluation method and traffic. It has been concluded in (chapter 3, [109]) that the MIH is the dominant category due to its characteristics for providing seamless VHO compared with IMS framework (i.e. MIH is more flexible and has better performance).

In (chapter 3, [115]), We have presented a comprehensive survey of VHO approaches designed to provide seamless VHO based on mobility management protocols (MIPv4 and MIPv6) under MIH. We have summarised their features with regard to eight aspects: main objective, input parameters for VHO decision, additional entity, additional cost, complexity, traffic, evaluation method and applicable area. The conclusion in (chapter 3, [115]) has indicated that, in the near future, providing service continuity through MIPv4 category under MIH will allow the operators to diversify their access networks due to the advantages of this category while MIPv6 category under MIH requires future work improvements in terms of VHO decision criteria, additional entities, complexity, diversity of RATs and evaluation using empirical work of real environment.

In (chapter 4, [137]), we have presented a comprehensive survey of VHO approaches designed to provide seamless VHO based on MIH and ANDSF. To offer a systematic comparison, the VHO approaches are categorised into three groups based on MIH and ANDSF: ANDSF based VHO approaches, MIH based VHO approaches and MIH and ANDSF combination based VHO approaches. We have summarised their features with regard to seven aspects: main objective, input parameters for VHO decision, additional entity, complexity, traffic, evaluation method and applicable area. The conclusion in (chapter 4, [137]) has indicated that the VHO approaches concentrate only on the packet loss and latency while the connection failure and the signaling cost, two of vital factors in providing seamless VHO, have not been considered thoroughly; therefore, it would be logical to concentrate on Procedure4 which is a combined MIH and VHO algorithm in order to produce a smart VHO algorithm taking into account the connection failure and the signaling cost factors to guarantee providing seamless VHO under MIH in heterogeneous wireless networks.

B. How Have the Key Research Problems Been Addressed?

As a result of the conclusions in the surveys above (chapter 3, [88, 109 and 115]) and (chapter 4, [137]), chapter 5 and chapter 6 have considered and addressed equitably four main VHO mobility elements which are responsible to provide seamless VHO in heterogeneous wireless network environment as follows:

- Reduce VHO latency.
- Reduce VHO packet loss.
- Reduce probability of VHO connection failure (probability of minimising VHO reject sessions).
- Reduce signaling cost due to VHO processes.

To tackle the above requirements, our approach has been presented which is divided into two main parts as published in [92]. The first part presents the proposed I AM 4 VHO procedure as published in [141, 142]. This procedure is designed for session mobility in Wi-Fi, WiMAX and UMTS heterogeneous wireless networks with minimal packet loss and latency. Analysis and simulation of the proposed procedure show that our procedure provides lowest handover packet loss and latency compared with that found in the literature [141, 142].

The second part presents the proposed I AM 4 VHO algorithm as published in [145, 146]. This algorithm is designed for reducing: **(a)** the probability of VHO connection failure as a result of using the optimum RATs list of priority and **(b)** the signaling cost and the inevitable degradation in QoS as a result of avoiding unnecessary handover processes. Our analysis and simulation results show that our algorithm outperforms previous works found in the literature in terms of connection failure, unnecessary handover, signaling cost and degradation in QoS [145, 146]. Finally, we conclude that our research methodology for solving the problems mentioned is valid.

7.3 Future Work

As we have shown in previous Chapters, various issues have been raised that have yet to be addressed. Besides, fascinating new opportunities for improving research activity in VHO have been created. Some of the most interesting problems are discussed below.

- As a result of the conclusion in (chapter 3, [88]), the loose couple VHO interworking architecture is more suitable to work with MIH and enhance its vital role in heterogeneous wireless network environment due to its characteristics while the tight coupling requires future improvements in terms of probability of packet loss, congestion, complexity, overload, additional modification and additional cost.

- As a result of the conclusion in (chapter 3, [109]), the MIH is the dominant category for performing VHO while the other categories (IMS based category, MIP under IMS based category and MIH and IMS combination based category) require further improvements in terms of two vital parameters that make VHO seamless (packet loss and latency), VHO decision criteria, additional entities, complexity, diversity of RATs and evaluation using empirical work of real environment.

- As a result of the conclusion in (chapter 3, [115]), the MIPv4 category under MIH could continue in the future due its characteristics and performances which are: **(a)** mostly in practical, such that one of them was empirical work of real environment **(b)** less complex **(c)** implement three types of RATs and **(d)** multiple parameters for VHO decision making are considered while MIPv6 category under MIH requires future work improvements on its characteristics and performances issues.

- The scenarios presented in the analytical modelling and in the simulation environment for our approach of the procedure and the algorithm, chapter 5 (5.2.1.1, 5.2.1.1.1 and 5.2.1.2) and chapter 6 (6.2.1, 6.2.1.1 and 6.2.2), respectively are between two types of RATs. A much more sophisticated and intrinsic scenarios are required which would take into account a wider array of parameters and MUs to make a more intelligent and optimised network selection.

In addition, analysis and simulation results on the VHO signaling cost and the inevitable degradation in QoS as a result of avoiding unnecessary handover processes is another interesting potential area for further research.

- The performance of our approach of the procedure and the algorithm has been validated through OPNET and MATLAB simulations, respectively. However, getting results through simulation tool have two main concerns: accuracy and scalability [150]. Therefore, it would be preferable to develop an implementation to practical experiment for evaluating real-world deployments such as the previous work found in the literature [2]. In this work [2], the authors' proposal was implemented in real environment by Meditel Telecommunication operator in Morocco which provided hardware configuration for session mobility in Wi-Fi, WiMAX and 3G, MIH server and MU (Toshiba laptop Pentium IV, runs on Linux Ubuntu) equipped with three access interfaces. As a result, our approach could be implemented in real environment as it deals with the same previous work environment [2] in terms of number and types of RATs, MIH server and mobility management protocol (MIPv4). However, it would be logical to carry out our approach with Smartphones devices instead of laptops due to two main reasons. The first one is the recent statistic shown in [151], according to which "The mobile video will increase 25-fold between 2011 and 2016, accounting for over 70% of total mobile data traffic by 2016". The second reason is that the practical experiments studies which have been already implemented, have almost exclusively depended on laptops [152].

References

[1] Our vision: Committed to connecting the world. (04/08/2011). International Telecommunication Union (ITU). Retrieved 20 May, 2014, from http://www.itu.int/en/about/Pages/vision.aspx.

[2] Angoma, B.; Erradi, M.; Benkaouz, Y.; Berqia, A.; Akalay, M.C.;, "HaVe-2W3G: A Vertical Handoff Solution between WLAN, WiMAX and 3G Networks," *7th International Wireless Communications and Mobile Computing Conference 2011 (IWCMC 2011)*, 4-8 Jul 2011, pp. 101-106.

[3] Haji, A.; Ben Letaifa, A.; Tabbane, S.;, "Integration of WLAN, UMTS and WiMAX in 4G," *16th International Conference Electronics, Circuits, and Systems 2009 (ICECS 2009)*, 13-16 Dec 2009, pp. 307-310.

[4] Akkari, N.; Tohme, S.;, "Introducing Intelligent Vertical Handover in Next Generation Networks," *International Conference Signal Processing and Communications 2007 (ICSPC 2007)*, 24-27 Nov 2007, pp. 728-731.

[5] Nkansah-Gyekye, Y.; Agbinya, J.I.;, "A Vertical Handoff Decision Algorithm for Next Generation Wireless Networks," *3rd International Conference on Broadband Communications, Information Technology & Biomedical Applications*, 23-26 Nov 2008, pp. 358-364.

[6] Benoubira, S.; Frikha, M.; Tabbane, S.;, "Hierarchical Mobile IPv6 Based Architecture for Heterogeneous Wireless Networks Interworking," *3rd International Conference on Communication Software and Networks 2011 (ICCSN 2011)*, 27-29 May 2011, pp. 422-426.

[7] Guifen, G.; Guili, P.;, "The Survey of GSM Wireless Communication System," *International Conference on Computer and Information Application 2010 (ICCIA 2010)*, 3-5 Dec 2010, pp. 121-124.

[8] Kazemi, R.; Mosayebi, R.; Etemadi, S.M.; Boloursaz, M.; Behnia, F.;, "A Lower Capacity Bound of Secure End to End Data Transmission via GSM Network," *6th International Symposium on Telecommunications 2012 (IST 2012)*, 6-8 Nov 2012, pp. 1015-1020.

[9] Tae, S.K., Soo, W.K.;, "A Method for Reducing a Bumblebee Noise Generated by a GSM Technology in a Smartphone," *12th International Conference on Intelligent Systems Design and Applications 2012 (ISDA 2012),* 27-29 Nov 2012, pp. 927-930.

[10] Femandez, R.T.; Preciado Velasco, J.E.;, "From GSM Toward UMTS: A Radio Interface for Multimedia Services Transmission," *International Telecommunications Symposium 1998 (ITS 1998),* vol. 2, 9-13 Aug 1998, pp. 388-393.

[11] Hanzo, L & Stefanov, J. (1992). The Pan-European Digital Cellular Mobile Radio System-known as GSM:1st. In Steele, R (Ed), *Mobile Radio Communications* (pp. 677-773). UK: IEEE Press-Pentech Press.

[12] Hoff, S.; Meyer, M.; Schieder, A.;, "A Performance Evaluation of Internet Access via the General Packet Radio Service of GSM," *48th Vehicular Technology Conference 1998 (VTC 1998),* vol. 3, 18-21 May 1998, pp. 1760-1764.

[13] Yi, B.L.; Yieh, R.H.; Yuan, KC.; Imrich, C.;, "Mobility Management: from GPRS to UMTS," *Wireless Communications and Mobile Computing,* vol. 1, no. 4, 2001, pp. 339-359.

[14] Darnbrough, J.;, "Market Aspects of UMTS," *IEE Colloquium on Personal Communications in the 21st Century (I),* 5 Feb 1998, pp. 1-26.

[15] Shaikh, F. (Jan 2010). *Intelligent Proactive Handover and QoS Management using TBVH in Heterogeneous Networks*. (PhD thesis), University of Middlesex.

[16] Longoni, F., Lansisalmi, A & Toskala, A. (2004). Radio Access Network Architecture. In Harri, H & Antti, T (Eds), *WCDMA for UMTS:Radio Access for Third Generation Mobile Communications* (3rd ed.) (pp. 106-129). England: John Wiley & Sons Ltd.

[17] Leroy, S.; Bos, L.; De Vriendt, J.;, "End-to-End UMTS Quality of Service Architecture for the Support of Real-Time IP Multimedia Services in UMTS R5," *3rd International Conference on 3G Mobile Communication Technologies,* 8-10 May 2002, pp. 234-238.

[18] Khan, A.; Sun, L.; Ifeachor, E.;, "Learning Models for Video Quality Prediction over Wireless Local Area Network and Universal Mobile Telecommunication System Networks," *IET Communications,* vol. 4, no. 12, 13 Aug 2010, pp. 1389-1403.

[19] Popova, L.; Herpel, T.; Koch, W.;, "Improving Downlink UMTS Capacity by Exploiting Direct Mobile-to Mobile Data Transfer," *5th International Symposium on Modeling and Optimization in Mobile, Ad Hoc and Wireless Networks and Workshops*, 16-20 Apr 2007, pp. 1-8.

[20] Feng, R.; Song, J.;, "Some QoS Issues in *3G* Wireless Networks," *Region 10 Conference on Computers, Communications, Control and Power Engineering*, vol. 2, 28-31 Oct 2002, pp. 724-727.

[21] Dingyong, G.; Bo, W.; Shiqi, W.;, "An Optimized Transmission Scheme for UMTS Streaming Services," *International Conference on Communications, Circuits and Systems 2004 (ICCCAS 2004)*, vol. 1, 27-29 Jun 2004, pp. 394-397.

[22] Shen, Q.; Shen, R.; Wang, L.;, "QoS Guaranteeing during UMTS Packet Domain Handover," *4th International Conference on Parallel and Distributed Computing, Applications and Technologies 2003 (PDCAT 2003)*, 27-29 Aug 2003, pp. 387-390.

[23] Wang, H.; Prasad, D.; Teyeb, O.; Schwefel, H.P.;, "Performance Enhancements of UMTS Networks using End to End QoS Provisioning," *International Symposium on Wireless Personal Multimedia Communications*, Aalborg, Denmark, Sep 18-22, 2005.

[24] Harri, H & Antti, T. (2000). *WCDMA for UMTS: Radio Access for Third Generation Mobile Communications* (1st ed.). USA: John Wiley & Sons.

[25] Shreevastav, R.; McGoldrick, C.; Huggard, M .;, "Delivering Improved QoS and Cell Throughput in UMTS Based HSDPA Networks," *International Symposium on a World of Wireless, Mobile and Multimedia Networks & Workshops, 2009 (WoWMoM 2009)*, 15-19 Jun 2009, pp. 1-9.

[26] Piamrat, K.; Singh, K.D.; Ksentini, A.; Viho, C.; Bonnin, J.;, "QoE- Aware Scheduling for Video-Streaming in High Speed Downlink Packet Access," *Wireless Communications and Networking Conference 2010 (WCNC 2010),* 18-21 Apr 2010, pp. 1-6.

[27] Rabbani, M.G.; Kamruzzaman, J.; Gondal, I.; Ahmad, I.;, "A new Resource Distribution Model for Improved QoS in an Integrated WiMAX/WiFi Architecture," *7th International Wireless Communications and Mobile Computing Conference 2011 (IWCMC 2011),* 4-8 Jul 2011, pp. 266-271.

[28] Villacis, D.; Acosta, F.R.; Lara Cueva, R.A.;, "Performance Analysis of VoIP Services over WiFi-Based Systems," *Colombian Conference on Communications and Computing 2013 (COLCOM 2013),* 22-24 May 2013, pp. 1-6.

[29] Datar, R.V.;, "WiFi and WiMAX-Break through in Wireless Access Technologies," *IET International Conference on Wireless, Mobile and Multimedia Networks*, 11-12 Jan 2008, pp. 141-145.

[30] Cisco and/or its affiliates. (2012). *White Paper on Architecture for Mobile Data Offload over Wi-Fi Access Networks* (pp. 1-23). USA: Cisco.

[31] Brevi, D.; Pilosu, L.; Fileppo, F.; Scopigno, R.;, "Viability and Guidelines for the Effective Integration of Consumer WiFi in Industrial Plants," *International Congress on Ultra Modern Telecommunications and Control Systems and Workshops 2010 (ICUMT 2010),* 18-20 Oct 2010, pp. 232-239.

[32] Zhou, X.; Li, C.; Liu, P.;, "Application Research of 802.11-Based Wireless Network in the Library," *International Conference on E-Health Networking, Digital Ecosystems and Technologies 2010 (EDT 2010),* vol. 1, 17-18 Apr 2010, pp. 272-275.

[33] Zhenxia, Z.; Pazzi, R.W.; Boukerche, A.;, "Design and Evaluation of a Fast Authentication Scheme for WiFi-Based Wireless Networks," *International Symposium on a World of Wireless Mobile and Multimedia Networks 2010 (WoWMoM 2010),* 14-17 Jun 2010, pp. 1-6.

[34] Cooklev, T. (2004). The IEEE Standard for WLAN: IEEE 802.11. In Jennifer, L (Ed), *Wireless Communication Standards:A Study of IEEE 802.11, 802.15, 802.16* (pp. 45-132). US*:* Wiley-IEEE Standards Association.

[35] Torad, M.; El Qassas, A.; Al Henawi, H.;, "Comparison between LTE and WiMAX Based on System Level Simulation Using OPNET Modeler (Release 16)," *28th National Radio Science Conference 2011 (NRSC 2011)*, 26-28 Apr 2011, pp. 1-9.

[36] David, M.S.; Jose, F.M.; Jorge, C.P.; Daniel, C.; Salvador, G.; Narc´ıs, C.;, "On the Way Towards Fourth-Generation Mobile:3GPP LTE and LTE-Advanced," *Journal on Wireless Communications and Networking*, vol. 2009, no. 4, 2009, pp. 1-10.

[37] Chang, J.M.; Abichar, Z.; Chau-Yun, H.;, "WiMAX or LTE: Who Will Lead the Broadband Mobile Internet?," *IT Professional*, vol. 12, no. 3, May-Jun 2010, pp. 26-32.

[38] Seddigh, N.; Nandy, B.; Makkar, R.; Beaumont, J.F.;, "Security Advances and Challenges in 4G Wireless Networks," *8th Annual International Conference on Privacy Security and Trust 2010 (PST 2010)*, 17-19 Aug 2010, pp. 62-71.

[39] Sengar, S.S.; Tyagi, N.; Singh, A.P.;, "A Survey on WiMAX-3G interworking," *3rd International Conferenceon Communication Software and Networks 2011 (ICCSN 2011)*, 27-29 May 2011, pp. 54-58.

[40] Ahmadi, S.;, "An Overview of Next-Generation Mobile WiMAX Technology," *IEEE Communication Magazine*, vol. 47, no. 6, Jun 2009, pp. 84-98.

[41] Papapanagiotou, I.; Toumpakaris, D.; Jungwon, L.; Devetsikiotis, M.;, "A Survey on Next Generation Mobile WiMAX Networks: Objectives, Features and Technical Challenges," *IEEE Communications Surveys & Tutorials*, vol. 11, no. 4, Fourth Quarter 2009, pp. 3-18.

[42] Murawwat, S.; Javaid, T.;, "Speed & Service Based Handover Mechanism for Cellular WiMAX," *2nd International Conference on Engineering and Technology 2010 (ICCET 2010)*, vol. 1, 16-18 Apr 2010, pp. 418-422.

[43] Rajiv, C.; Rajesh, K.;, "QoS Support in Wi-Fi, WiMAX & UMTS Technologies," *International Journal of Electronics & Communication Technology 2011 (IJECT 2011)*, vol. 2, no. 3, Sep 2011, pp. 176-179.

[44] Murawwat, S.; Aslam, S.; Saleemi, F.;, "Urgency and Proficiency Based Packet Scheduling & CAC Method for IEEE 802.16," *5th International Conference on Wireless Communications, Networking and Mobile Computing 2009 (WiCom 2009)*, 24-26 Sep 2009, pp. 1-4.

[45] Anand, S.V.;, "Qos Based Handover Layer for a Multi-RAT Mobile Terminal in UMTS and Wi-MAX Networks," *3rd International Conference on Communication Systems Software and Middleware and Workshops 2008 (COMSWARE 2008)*, 6-10 Jan 2008, pp. 472-479.

[46] Talukdar, A.; Mondal, B.; Cudak, M.; Ghosh, A.; Fan, Wang.;, "Streaming Video Capacity Comparisons of Multi-Antenna LTE Systems," *71st Vehicular Technology Conference 2010 (VTC 2010-Spring)*, 16-19 May 2010, pp. 1-5.

[47] Yahiya, T.A.; Chaouchi, H.;, "On the Integration of LTE and Mobile WiMAX Networks," *19th International Conference on Computer Communications and Networks 2010 (ICCCN 2010)*, 2-5 Aug 2010, pp. 1-5.

[48] Hui, S.Y.; Yeung, K.H.;, "Challenges in the Migration to 4G Mobile Systems," *IEEE Communications Magazine*, vol. 41, no. 12, Dec 2003, pp. 54-59.

[49] Xie, B.; Kumar, A.; Agrawal, D.P.;, "Enabling Multiservice on 3G and Beyond: Challenges and Future Directions," *IEEE Wireless Communications*, vol. 15, no. 3, Jun 2008, pp. 66-72.

[50] Mccann, S.; Groting, W.; Pandolfi, A.; Hepworth, E.;, "Next Generation Multimode Terminals," *5th International Conference on 3G Mobile Communication Technologies*, 2004, pp. 143-147.

[51] 3GPP TR 25.814 v7.1.0, "Physical Layer Aspects for Evolved Universal Terrestrial Radio Access (UTRA) Release 7".

[52] Khan, M.M.A.; Ismail, M.F.; Dimyati, K.;, "Seamless Handover between WiMAX and UMTS," *9th Malaysia International Conference on Communications 2009 (MICC* 2009*)*, 15-17 Dec 2009 pp. 826-830.

[53] Alkhayat, I.; Kumar, A.; Elmaghraby, A.;, "Seamless Connectivity Scheme for Heterogeneous Wireless Networks," *International Symposium on Signal Processing and Information Technology 2008 (ISSPIT 2008),* 16-19 Dec 2008, pp. 363-368.

[54] Ben-Jye, C.; Jun-Fu, C.;, "Cross-Layer-Based Adaptive Vertical Handoff With Predictive RSS in Heterogeneous Wireless Networks," *IEEE Transactions on Vehicular Technology,* vol. 57, no. 6, Nov 2008, pp. 3679-3692.

[55] The Mobile Broadband Standard. (Jun/2013). 3rd Generation Partnership Project (3GPP). Retrieved 27 May, 2014, from http://www.3gpp.org/technologies/keywords-acronyms/97-lte-advanced.

[56] Fangmin, X.; Luyong, Z.; Zheng, Z.;, "Interworking of Wimax and 3GPP Networks Based on IMS [IP Multimedia Systems (IMS) Infrastructure and Services]," *IEEE Communications Magazine*, vol. 45, no. 3, Mar 2007, pp. 144-150.

[57] Lin, M.; Lanlan.; R.;, "An End-to-End QoS Frame in Multimedia Provision for Tight-Coupled Interworking of IMS and WiMAX," *International Conference on Networking, Sensing and Control 2008 (ICNSC 2008),* 6-8 Apr 2008, pp. 1153-1157.

[58] Sgora, A.; Vergados, D.D.;, "IMS Mobility Management in Integrated WiMAX-3G Architectures," *14th Panhellenic Conference on Informatics 2010 (PCI 2010)*, 10-12 Sep 2010, pp. 170-174.

[59] Quoc-Thinh, N.V.; Fiat, L.; Agoulmine, N.;, "An Architecture for UMTS-WIMAX Interworking," *1st International Workshop on Broadband Convergence Networks 2006 (BCN 2006)*, 7-7 Apr 2006, pp. 1-10.

[60] Nguyen-Vuong, QT.; Agoulmine, N.; Ghamri-Doudane, Y.;, "Terminal-Controlled Mobility Management in Heterogeneous Wireless Networks," *IEEE Communication Magazine*, vol. 45, no. 4, Apr 2007, pp. 122- 129.

[61] Lampropoulos, G.; Passas, N.; Kaloxylos, A.; Merakos, L.;, "A Flexible UMTS/WLAN Architecture for Improved Network Performance", *Wireless Personal Communications Journal*, vol. 43, no. 3, Nov 2007, pp. 889- 906.

[62] Louta, M.; Zournatzis, P.; Kraounakis, S.; Sarigiannidis, P.; Demetropoulos, I.;, "Towards Realization of the ABC Vision: A Comparative Survey of Access Network Selection," *Symposium on Computers and Communications(ISCC)*, 28 Jun 2011-1 Jul 2011, pp. 472-477.

[63] Zekri, M.; Jouaber, B.; Zeghlache, D.;, "Context Aware Vertical Handover Decision Making in Heterogeneous Wireless Networks," *35th Conference on Local Computer Networks 2010 (LCN 2010)*, 10-14 Oct 2010, pp. 764-768.

[64] Meriem, K.; Brigitte, K.; Guy, P.;, "An Overview of Vertical Handover Decision Strategies in Heterogeneous Wireless Networks," *Computer Communications*, vol. 31, no. 10, 25 Jun 2008, pp. 2607-2620.

[65] Stevens-Navarro, E.; Wong, V.W.S.;, "Comparison between Vertical Handoff Decision Algorithms for Heterogeneous Wireless Networks," *63rd Vehicular Technology Conference (VTC 2006)*, vol. 2, 7-10 May 2006, pp. 947-951.

[66] Chan, P.M.L.; Sheriff, R.E.; Hu, Y.F.; Conforto, P.; Tocci, C.;, "Mobility Management Incorporating Fuzzy Logic for Heterogeneous a IP Environment," *IEEE Communications Magazine*, vol. 39, no. 12, Dec 2001, pp. 42-51.

[67] Chen, W.T.; Liu, J.C.; Huang, H.K.;, "An Adaptive Scheme for Vertical Handoff in Wireless Overlay Networks," *10th International Conference on Parallel and Distributed Systems 2004 (ICPADS 2004)*, 7-9 Jul 2004, pp. 541- 548.

[68] Taaghol, P.; Salkintzis, A.; Iyer, J.;, "Seamless Integration of Mobile WiMAX in 3GPP Networks," *IEEE Communications Magazine*, vol. 46, no. 10 , Oct 2008, pp. 74-85.

[69] Bari, F.; Leung, V.C.M.;, "Automated Network Selection in a Heterogeneous Wireless Network Environment," *IEEE Network*, vol. 21, no. 1, Jan-Feb 2007, pp. 34-40.

[70] Charilas, D.; Markaki, O.; Nikitopoulos, D.; Theologou, M.;, "Packet Switched Network Selection with the Highest QoS in 4G Networks," *Computer Networks*, vol. 52, no. 1, Jan 2008, pp. 248-258.

[71] Yiping, C.; Yuhang, Y.;, "A New 4G Architecture Providing Multimode Terminals Always Best Connected Services," *IEEE Wireless Communications*, vol. 14, no. 2, Apr 2007, pp. 36-41.

[72] Ormond, O.; Murphy, J.; Muntcan, G.M.;, "Utility-Based Intelligent Network Selection in Beyond 3G Systems," *International Conference on Communications*, vol. 4, Jun 2006, pp. 1831-1836.

[73] Nguyen-Vuong, Q.T.; Agoulmine, N.; Ghamri-Doudane, Y.;, "A User Centric and Context-Aware Solution to Interface Management and Access Network Selection in Heterogeneous Wireless Environments," *Computer Networks*, vol. 52, no. 18, Dec 2008, pp. 3358-3372.

[74] Zhang, W.; Jaehnert, J.; Dolzer, K.;, "Design and Evaluation of a Handover Decision Strategy for 4th Generation Mobile Networks," *57th Semiannual Vehicular Technology Conference 2003 (VTC 2003-Spring)*, vol. 3, 22-25 Apr 2003, pp. 1969–1973.

[75] Wei, Q.; Farkas, K.; Prehofer, C.; Mendes, P.; Plattner, B.;, "Context Aware Handover Using Active Network Technology," *Computer Networks*, vol. 50, no. 15, Oct 2006, pp. 2855–2872.

[76] Ahmed, T.; Kyamakya, K.; Ludwig, M.;, "A Context-Aware Vertical Handover Decision Algorithm for Multimode Mobile Terminals and its Performance," *Euro American Conference on Telematics and Information Systems 2006 (EATIS 2006)*, 7-10 Feb 2006, pp. 19–28.

[77] Bernaschi, M.; Cacace, F.; Pescape, A.; Za, S.;, "Analysis and Experimentation over Heterogeneous Wireless Networks," *1st International Conference on Testbeds and Research Infrastructures for the Development of Networks and Communities 2005 (Tridentcom 2005)*, 23-25 Feb 2005, pp. 182–191.

[78] Artemis, A.K.; Evgenia, F.A.; Konstantinos, P.D.; Michael, E.T.;, "Terminal Management and Intelligent Access Selection in Heterogeneous Environments," *Mobile Networks and Applications*, vol. 11, no. 6, Dec 2006, pp. 861-871.

[79] Nasser, N.; Hasswa, A.; Hassanein, H.;, "Handoffs in Fourth Generation Heterogeneous Networks," *IEEE Communications Magazine* no. 10, vol. 44, Oct 2006, pp. 96–103.

[80] Yan, X.; Ahmet Şekercioğlu, Y.; Narayanan, S.;, "A Survey of Vertical Handover Decision Algorithms in Fourth Generation Heterogeneous Wireless Networks," *Computer Networks*, vol. 54, no. 11, 2 Aug 2010, pp. 1848-1863.

[81] McNair, J.; Fang, Z.;, "Vertical Handoffs in Fourth-Generation Multinetwork Environments," *IEEE Wireless Communications*, vol. 11, no. 3, Jun 2004, pp. 8-15.

[82] Farhan, S.; Sherali, Z.;, "Mobility Management Across Hybrid Wireless Networks: Trends and challenges," *Computer Communications*, vol. 29, no. 9, May 2006, pp. 1363-1385.

[83] Cheng-Mu, Shiao.; Ruey-Rong, Su.; I-Shyan, Hwang.; Bor-Jiunn, Hwang.;, "Performance Analysis of Algorithms with Multiple Attributes for Adaptive Call

Admission Control in Heterogeneous Wireless Networks," *10th International Symposium on Pervasive Systems, Algorithms, and Networks 2009 (ISPAN 2009)*, 14-16 Dec 2009, pp. 303-308.

[84] Zekri, M.; Jouaber, B.; Zeghlache, D.;, "On the Use of Network QoS Reputation for Vertical Handover Decision Making," *IEEE GLOBECOM Workshops 2010 (GC Wkshps 2010)*, 6-10 Dec 2010, pp. 2006-2011.

[85] ETSI TR 101 957. (2001). *Technical Report on Broadband Radio Access Networks (BRAN); HIPERLAN Type 2; Requirements and Architectures for Interworking between HIPERLAN/3 and 3rd Generation Cellular Systems* (pp. 1-56). France: ETSI.

[86] Salkintzis, A.K.; Fors, C.; Pazhyannur, R.;, "WLAN-GPRS Integration for Next-Generation Mobile Data Networks," *IEEE Wireless Communication*, vol. 9 ,no. 5, Oct 2002, pp. 112-124.

[87] Ronald, B. (2009). Integration of Heterogeneous Wireless Access Networks. In Ekram, H (Ed), *Heterogeneous Wireless Access Networks Architectures and Protocols* (pp. 1-18). US: Springer.

[88] Khattab, O.; Alani, O.;, "An Overview of Interworking Architectures in Heterogeneous Wireless Networks: Objectives, Features and Challenges," *10th International Network Conference 2014 (INC 2014)*, 8-10 Jul 2014, pp. 71-79.

[89] Rodriguez, J.; Tsagaropoulos, M.; Politis, I.; Kotsopoulos, S.; Dagiuklas, T.;, "A Middleware Architecture Supporting Seamless and Secure Multimedia Services Across an Intertechnology Radio Access Network," *IEEE Wireless Communications*, vol. 16, no. 5, Oct 2009, pp. 24-31.

[90] Johann, M.B.; Carlos, T.C.; Juan-Carlos, C.; Pietro, M.;, "Review: An Overview of Vertical Handover Techniques: Algorithms, Protocols and Tools," *Computer Communication*, vol. 34, no. 8, 1 Jun 2011, pp. 985-997.

[91] 3GPP. (16/05/2013). IEEE 802.21. Retrieved 18 May, 2013, from http://www.3gpp.org/ftp/Specs/html-info/24312.htm.

[92] Khattab, O.; Alani, O.;, "I AM 4 VHO: New Apprach to Improve Seamless Vertical Handover in Heterogeneous Wireless Networks," *International Journal of Computer Networks & Communications (IJCNC)*, vol. 5, no. 3, May 2013, pp. 53-63.

[93] Song, W.; Jong-Moon, C.; Daeyoung, L.; Chaegwon, L.; Sungho, C.; Taesun,Y.;, "Improvements to Seamless Vertical Handover between Mobile WiMAX and 3GPP UTRAN through the Evolved Packet Core," *IEEE Communications Magazine* ,vol. 47, no. 4, Apr 2009, pp. 66-73.

[94] Neves, P.; Soares, J.; Sargento, S.;, "Media Independent Handovers:LAN, MAN and WAN Scenarios," *IEEE GLOBECOM Workshops*, 30 Nov 2009–4 Dec 2009, pp. 1-6.

[95] Lampropoulos, G.; Salkintzis, A.K.; Passas, N.;, "MediaIndependent Handover for Seamless Service Provision in Heterogeneous Networks," *IEEE Communication Magazine*, vol. 46, no. 1, Jan. 2008, pp. 64-71.

[96] IEEE Draft Standard for Local and Metropolitan Area Networks: Media Independent Handover Services, *IEEE Unapproved Draft Std P802.21/D10.0*, Apr 2008.

[97] Pontes, A.; Dos Passos Silva, D.; Jailton, J.; Rodrigues, O.; Dias, K.L.;, "Handover Management in Integrated WLAN and Mobile WiMAX Networks," *IEEE Wireless Communications*, vol. 15, no. 5, Oct 2008, pp. 86-95.

[98] Corujo, D.; Guimaraes, C.; Santos, B.; Aguiar, R.L.;, "Using an Open-Source IEEE 802.21 Implementation for Network-Based Localized Mobility Management," *IEEE Communications Magazine*, vol. 49, no. 9, Sep 2011, pp. 114-123.

[99] Tamijetchelvy, R.; Sivaradje, G.;, "An Optimized Fast Vertical Handover Strategy for Heterogeneous Wireless Access Networks Based on IEEE 802.21

Independent Handover Standard," 4^{th} *International Conference on Advanced Computing 2012 (ICoAC 2012),* 13-15 Dec 2012, pp. 1-7.

[100] Kassab, M.; Bonnin, J.M.; Belghith, A.;, "Technology Integration Framework for Fast and Low Cost Handovers-Case Study:WiFi–WiMAX Network," *Journal of Computer Systems, Networks, and Communications,* vol. 2010, no. 9, Jan 2010, pp. 1-21.

[101] Vetrivelan, P.; Narayanasamy, P.;, "SMIRT with Call Admission Control (CAC) Based Vertical Handover Decision for Seamless Mobility in Multi-Access 4G Heterogeneous Wireless Overlay Networks," *International MultiConference of Engineers and computer Scientists (IMECS 2012)*, vol. 1, 14-16 Mar 2012, pp. 345.

[102] Miriam, T.; Ahutosh, D.; Yuu-Heng, C.; Subir, D.; Donald, B.; Maya, Y.; David, F.; Yoshihiro, O.; Victor, F.; Kenichi, T.;, "Realization of IEEE 802.21 Services and Preauthentication Framework," 5^{th} *International Conference on Testbeds and Research Infrastructures for the Development of Networks & Communities and Workshops*, Apr 6-8 2009, pp. 1-10.

[103] IEEE 802.21 Tutorial. (2006). IEEE 802.21. Retrieved 20 May, 2014, from http://www.ieee802.org/21/.

[104] Frei, S.; Fuhrmann, W.; Rinkel, A.; Ghita, B.V.;, "Improvements to Inter System Handover in the EPC Environment," 4^{th} *IFIP International Conferenceon on New Technologies, Mobility and Security 2011 (NTMS 2011)*, 7- 10 Feb 2011, pp. 1-5.

[105] Bakmaz, B.; Bojkovic, Z.; Bakmaz, M..;, "Internet Protocol Multimedia Subsystem for Mobile Services," 14^{th} *International Workshop on Systems, Signals and Image Processing and 6th EURASIP Conference Focused on Speech and Image Processing, Multimedia Communications and Services*, 27-30 Jun 2007, pp. 339-342.

[106] Youngsuk, L.; Namhi, K.; Seokkap, K.; Younghan, K.;, "An Efficient QoS Control Mechanism for IMS Based Convergence Network," 2^{nd} *International*

Workshop on Broadband Convergence Networks 2007 (BcN 2007), 21-21 May 2007, pp. 1-12.

[107] Qadeer, M.A.; Khan, A.H.; Ansari, J.A.; Waheed, S.;, "IMS Network Architecture," *International Conference on Future Computer and Communication 2009 (ICFCC 2009),* 3-5 Apr 2009, pp. 329-333.

[108] Fernandes, S.; Karmouch, A.;, "Vertical mobility Management Architectures in Wireless Networks: A comprehensive Survey and Future Directions," *IEEE Communications Surveys & Tutorials*, vol. 14, no. 1, pp. 45–63, 2012.

[109] Khattab, O.; Alani, O.;, "A Survey on Media Independent Handover (MIH) and IP Multimedia Subsystem (IMS) in Heterogeneous Wireless Networks," *International Journal of Wireless Information Networks (IJWIN),* Springer, vol. 20, no. 2, Jun 2013, pp. 215-228.

[110] Kim, J.M & Jang, J.W. (2007). Low Latency Vertical Handover Using MIH L2-Trigger Algorithm in Mobile IP Networks. In Stojmenovic, I, Thulasiram, R, Yang, L, Jia, W, Guo, M & De Mello, R (Eds.), *Parallel and Distributed Processing and Applications* (pp. 707-718). Berlin: Springer.

[111] Kim, H.H.; Park, S.C.; KYU YI, M.;, "Fast-Handover Mechanism between 802.11 WLAN and 802.16 WiMax with MIH in PMIPv6," *4th International Conference on Ubiquitous Information Technologies & Applications 2009 (ICUT 2009),* 20-22 Dec 2009, pp. 1-6.

[112] Marquez-Barja, J.; Calafate, C.T.; Cano, J.C.; Manzoni, P.;, "Evaluation of a Technology-Aware Vertical Handover Algorithm Based on the IEEE 802.21 Standard," *Wireless Communications and Networking Conference 2011 (WCNC 2011)*, 28-31Mar 2011, pp. 617-622.

[113] Capela, N.; Soares, J.; Neves, P.; Sargento, S.;, "An Architecture for Optimized Inter-Technology Handovers: Experimental Study," *IEEE International Conference on Communications 2011 (ICC 2011)*, 5-9 Jun 2011, pp. 1-6.

[114] Heecheol, S.; Jongjin, K.; Jaeki, L.; Hwang, S.L.;, "Analysis of Vertical Handover Latency for IEEE 802.21-Enabled Proxy Mobile IPv6," *13th International Conference on Advanced Communication Technology (ICACT 2011)*, 13-16 Feb 2011, pp. 1059-1063.

[115] Khattab, O.; Alani, O.;, "Survey on Media Independent Handover (MIH) Approaches in Heterogeneous Wireless Networks," *19th European Wireless 2013 (EW 2013)*, 16-18 Apr 2013, pp. 1-5.

[116] Gundavelli, S.; Leung, K.; Devarapalli, V.; Chowdhury, K.; Patil, B.;, Proxy Mobile IPv6, *IETF RFC 5213*, Aug. 2008.

[117] IEEE Standard for Local and Metropilitan Area Networks-Part 21: Media Independent Handover, *IEEE Std 802.21-2008*, Jan 2009, pp. 1-301.

[118] Munasinghe, K.; Jamalipour, A.;, "Interworking of WLAN-UMTS Networks: an IMS-Based Platform for Session Mobility," *IEEE Communications Magazine*, vol. 46, no. 9, Sep 2008, pp. 184-191.

[119] Munir, A.; Gordon-Ross, A.;, "SIP-Based IMS Signaling Analysis for WiMax-3G Interworking Architectures," *IEEE Mobile Computing, Transactions*, vol. 9, no. 5, May 2010, pp. 733-750.

[120] Nithyanandan, L.; Parthiban, I.;, "Seamless Vertical Handoff in Heterogeneous Networks Using IMS Technology," *International Conference on Communications and Signal Processing 2012 (ICCSP 2012)*, 4-5 Apr 2012, pp. 32-35.

[121] Lifeng, L.; Gang, L.;, "Cross-Layer Mobility Management Based on Mobile IP and SIP in IMS," *WiCom International Conference on Wireless Communications, Networking and Mobile Computing*, 21-25 Sep 2007, pp. 803-806.

[122] Munasinghe, K.S.; Jamalipour, A.;, "Interworked WiMAX-3G Cellular Data Networks: An architecture for Mobility Management and Performance Evaluation," *IEEE Wireless Communications Transactions*, vol. 8, no. 4, Apr 2009, pp. 1847-1853.

[123] Alamri, N.M.; Adra, N.;, “Integrated MIP-SIP for IMS-Based WiMAX-UMTS Vertical Handover,” *19th International Conference on Telecommunications 2012 (ICT 2012)*, 23-25 Apr 2012, pp. 1-6.

[124] Boutabia, M.; Abd-Elrahman, E.; Afifi, H.;, “A Hybrid Mobility Mechanism for Heterogeneous Networks in IMS,” *International Conference on Multimedia and Expo 2010 (ICME 2010)*, 19-23 Jul 2010, pp. 1570-1575.

[125] Tsagkaropoulos, M.; Politis, I.; Tselios, C.; Dagiuklas, T.; Kotsopoulos, S.;, “Service Continuity over Intertechnology RATs,” *16th International Workshop on Computer Aided Modeling and Design of Communication Links and Networks 2011 (CAMAD 2011)*, 10-11 Jun 2011, pp. 117-121.

[126] Pahlavan, K.; Krishnamurthy, P.; Hatami, A.; Ylianttila, M.; Makela, J.; Pichna, R.; Vallstron, J.;, “Handoff in Hybrid Mobile Data Networks,” *IEEE Personal Communcation*, vol. 7, no. 2, Apr 2000, pp. 34–47.

[127] Ylianttila, M.; M¨akel¨a, J.; Pahlavan, K.;, “Analysis of Handoff in a Location-Aware Vertical Multi-Access Network,” *Computer Network*, vol. 47, no. 2, Feb 2005, pp. 185–201.

[128] Emmelmann, M.; Langg¨aertner, T .; Sonnemann, M.;, “System Design and Implementation of Seamless Handover Support Enabling Real-Time Telemetryhighly Mobile Users,” *6th ACM international symposium on Mobility management and wireless access*, 2008, pp. 1–8.

[129] Haider, A.; Gondal, I.; Kamruzzaman, J.;, “Dynamic Dwell Timer for Hybrid Vertical Handover in 4g Coupled Networks,” 73rd *Vehicular Technology Conference (VTC Spring)*, 2011, pp. 1–5.

[130] Saxena, N.; Roy, A.;, “Novel Framework for Proactive Handover with Seamless Multimedia over WLANS,” *IET Communications* , vol. 5, no. 9, Jun 2011, pp. 1204 – 1212.

[131] Li, D.; Van Lil, E.; Van de Capelle, A.;, "Improving Slow-Start Based Probing Mechanisms for Flow Adaptation after Handovers," Computer Network, vol. 56, no. 1, Jan 2012, pp. 329–344.

[132] Mohanty, S.; Akyildiz, I.;, "A cross-Layer (layer 2 + 3) Handoff Management Protocol for Next-Generation Wireless Systems," *IEEE Transactions on Mobile Computing*, vol. 5, no. 10, Oct 2006, pp. 1347-1360.

[133] Becvar, Z.; Mach, P.; Simak, B.;, "Improvement of Handover Prediction in Mobile WIMAX by Using Two Thresholds," *Computer Network*, vol. 55, no. 16, Nov 2011, pp. 3759–3773.

[134] Ahmed, A.; Boulahia, L.; Gaiti, D.;, "Enabling Vertical Handover Decisions in Heterogeneous Wireless Networks: A State-of-the-Art and A Classification," *IEEE Communications Surveys & Tutorials*, vol. PP, no. 99, 2013, pp. 1-36.

[135] Daojing, H.; Caixia, Chi, Sammy, C.; Chun, C, Jiajun, B.; Mingjian, Y.;, "A Simple and Robust Vertical Handoff Algorithm for Heterogeneous Wireless Mobile Networks," *Wireless Personal Communications*, vol. 59, no. 2, 2011, pp 361-373.

[136] Issaka, H.A.; Li, R.; Zeng, F.;, "Handover Necessity Estimation for 4G Heterogeneous Networks," *International Journal of Information Sciences and Techniques (IJIST)*, vol. 2, no.1, Jan 2012, pp. 1-13.

[137] Khattab, O.; Alani, O.;, "A Survey on MIH vs. ANDSF: Who Will Lead the Seamless Vertical Handover Through Heterogeneous Networks?," *International Journal of Future Generation Communication and Networking (IJFGCN)*, vol. 6, no. 4, Aug 2013, pp. 1-11.

[138] Jong, K.M.; Woo, S.S.; Ho, R.B.;, "A New Approach Network Selection with MIH between WLAN and WMAN", *4th International Conference on Computer Sciences and Convergence Information Technology 2009 (ICCIT 2009)*, 24-26 Nov 2009, pp. 751-755.

[139] Mansor, S.; Chee, W.T.;, "Mobility Management in Heterogeneous Wireless Access Network with IEEE 802.21 Services," *2nd International Conference on Computer and Network Technology 2010 (ICCNT 2010)*, 23-25 Apr 2010, pp. 110-114.

[140] Liyan, Z.; Li Jun, Z & Samuel, P. (2011). Performance Analysis of Seamless Handover in Mobile IPv6-Based Cellular Network. In Agassi, M (Ed), *Cellular Networks - Positioning, Performance Analysis and Reliability* (pp. 305-330). Croatia: InTech.

[141] Khattab, O.; Alani, O.;, "Mobile IPv4 Based Procedure for Loose Coupling Architecture to Optimise Performance in Heterogeneous Wireless Networks," *International Journal of Computer Networks and Wireless Communications (IJCNWC)*, vol. 3, no. 1, Feb 2013, pp. 56-61.

[142] Khattab, O.; Alani, O.;, "Simulation of Performance Execution Procedure to Improve Seamless Vertical Handover in Heterogeneous Networks," *International Journal of Advanced Computer Science and Applications (IJACSA)*, vol. 5, no. 6, Jun 2014, pp. 109-113.

[143] Haseeb, S.; Ismail, A.F.;, "Handoff Latency Analysis of Mobile IPv6 Protocol Variations," *Computer Communications*, vol. 30, no. 4, 26 Feb 2007, pp. 849-855.

[144] Stephane, A.; Aghvami, A.H.;, "Fast Handover Schemes for Future Wireless IP Networks: a Proposal and Analysis," *Vehicular Technology Conference*, 2001. vol. 3, May 2001, pp. 2046-2050.

[145] Khattab, O.; Alani, O.;, "Algorithm for Seamless Vertical Handover in Heterogeneous Mobile Networks," *IEEE Technically Co-Sponsored Science and Information Conference (SAI 2014)*, 27-29 Aug 2014, pp. 1-8.

[146] Khattab, O.; Alani, O.;, "The Design and Calculation of Algorithm for Optimising Vertical Handover Performance," *9th IEEE/IET International Symposium on*

Communication Systems, Networks and Digital Signal Processing 2014 (CSNDSP 2014), 23-25 Jul 2014, pp. 421-426.

[147] Nkansah-Gyekye, Y.; Agbinya, J.I.;, "Vertical Handoff Decision Algorithm for UMTS-WLAN," *AusWireless 2nd International Conference on Wireless Broadband and Ultra Wideband Communications*, 27-30 Aug 2007, pp. 37.

[148] Yager, R.R.;, "Multiple Objective Decision Making using Fuzzy Sets," *International Journal of Man-Machine Studies*, vol. 9, 1977, pp. 375-382.

[149] Saaty, T.;, "Hierarchy Process," *International Journal of Services Sciences*, vol. 1, no. 1, 2008, pp. 83-98.

[150] Henri, K.; Arnaud, G.; Arnaud, L.; Martin, Q.; Frédéric, S.;, "Versatile, Scalable, and Accurate Simulation of Distributed Applications and Platforms," *Journal of Parallel and Distributed Computing*, vol. 74, no. 10, Jul 2014, pp. 2899-2917.

[151] Yonggang, W.; Xiaoqing, Z.; Rodrigues, J.J.P.C.; Chang, W.C.;, "Cloud Mobile Media: Reflections and Outlook," *IEEE Transactions on Multimedia*, vol. 16, no. 4, Jun 2014, pp. 885-902.

[152] Soderman, P.; Eklund, J.; Grinnemo, K.J.; Hidell, M.; Brunstrom, A.;, "Handover in the Wild: The Feasibility of Vertical Handover in Commodity Smartphones," *IEEE International Conference on Communications2013 (ICC 2013)*, 9-13 Jun 2013, pp. 6401-6406.