

NETWORK ACCESS SELECTION IN HETEROGENEOUS WIRELESS NETWORKS



This dissertation is submitted

By:

Olugbenga Adekunle TAIWO

In partial fulfillment of the academic requirements

for the degree of

Master of Science (MSc.) in Electrical Engineering

In the Faculty of Engineering and the Built Environment

University of Cape Town

December 2013

The copyright of this thesis vests in the author. No quotation from it or information derived from it is to be published without full acknowledgement of the source. The thesis is to be used for private study or non-commercial research purposes only.

Published by the University of Cape Town (UCT) in terms of the non-exclusive license granted to UCT by the author.

As the candidate's supervisor, I have approved this dissertation for submission.

Name: Dr. Olabisi Emmanuel FALOWO

Signed: _____

Date: _____

University of Cape Town

Declaration

I hereby declare that: (1) the above thesis is my own unaided work, both in conception and execution, and that apart from the normal guidance of my supervisor, I have received no assistance apart from that stated below; (2) except as stated below, neither the substance or any part of the thesis has been submitted in the past, or is being, or is to be submitted for a degree in the University or any other University.

I am now presenting the dissertation for examination for the Degree of MSc. (Eng.) in Electrical Engineering. I also grant the University free license to reproduce the above dissertation in whole or in part, for the purpose of research.

Olugbenga Adekunle TAIWO

Name

27th March 2014

Date

University of Cape Town

Abstract

In heterogeneous wireless networks (HWNs), both single-homed and multi-homed terminals are supported to provide connectivity to users. A multiservice single-homed multi-mode terminal can support multiple types of services, such as voice call, file download and video streaming simultaneously on any one of the available radio access technologies (RATs) such as Wireless Local Area Network (WLAN), and Long Term Evolution (LTE). Consequently, a single-homed multi-mode terminal having multiple on-going calls may need to perform a vertical handover from one RAT to another. One of the major issues in HWNs is how to select the most suitable RAT for multiple handoff calls, and the selection of a suitable RAT for multiple-calls from a single-homed multi-mode terminal in HWNs is a group decision problem. This is because a single-homed multi-mode terminal can connect to only one RAT at a time, and therefore multiple handoff calls from the terminal have to be handed over to the same RAT. In making group decision for multiple-calls, the quality of service (QoS) requirements for individual calls needs to be considered. Thus, the RAT that most satisfies the QoS requirements of individual calls is selected as the most suitable RAT for the multiple-calls.

Whereas most research efforts in HWNs have concentrated on developing vertical handoff decision schemes for a single call from a multi-mode terminal, not much has been reported in the literature on RAT-selection for multiple-calls from a single-homed multi-mode terminal in next generation wireless networks (NGWNs). In addition, not much has been done to investigate the sensitivity of RAT-selection criteria for multiple-calls in NGWNs. Therefore, this dissertation addresses these issues by focusing on following two main aspects: (1) comparative analysis of four candidate multi-criteria group decision-making (MCGDM) schemes that could be adapted for making RAT-selection decisions for multiple-calls, and (2) development of a new RAT-selection scheme named the consensus RAT-selection model.

In comparative analysis of the candidate RAT-selection schemes, four MCGDM schemes namely: distance to the ideal alternative-group decision making (DIA-GDM), multiplicative exponent weighting-group decision making (MEW-GDM), simply additive weighting-group decision making (SAW-GDM), technique for order preference by similarity to Ideal solution-group decision making (TOPSIS-GDM) are considered. The performance of the multiple-calls RAT-selection schemes is evaluated using the MATLAB simulation tool. The results

show that DIA-GDM and TOPSIS-GDM schemes are more suitable for multiple handoff calls than SAW-GDM and MEW-GDM schemes. This is because they are consistent and less-sensitive in making RAT-selection decision than the other two schemes, with regards to RAT-selection criteria (service price, data rate, security, battery power consumption and network delay) in HWNs.

In addition, the newly developed RAT-selection scheme incorporates RAT-consensus level for improving RAT-selection decisions for multiple-calls. Numerical results conducted in MATLAB validate the effectiveness and performance of the newly proposed RAT-selection scheme for multiple-calls in HWNs.

University of Cape Town

Acknowledgements

It is with great pleasure that I express my sincere gratitude to my supervisor, Dr. Olabisi E. Falowo, for his guidance and support at each stage of my research. This dissertation represents a great deal of time and dedication not only from me, but also from my supervisor. I am grateful to him for opening the door for me to carry out research in the field of radio access networks and radio resource management, as well as providing many opportunities for growth in the telecommunication industry. I am greatly pleased to have worked under him.

I am grateful to Mrs. Funmi Oni, Mr. Olubunmi Aro, Mr. Abiodun Adebajo, Mr. Muyideen Ojora, Miss Elizabeth Monday and Mr. Muyiwa Taiwo for their advice, support and concern toward my studies. I also appreciate the support of Mr. Samuel Falowo and Miss Bukky Awodele for their constructive criticism and proof reading this dissertation. I am grateful to the members of Communication Research Group, University of Cape Town for the constructive criticism and technical support throughout my studies.

I express my deepest thanks to my parents Mr. & Mrs. Taiwo for their prayers, love, support, and encouragement during my Masters studies. Special thanks to my uncle, brothers and sisters for their constant support, love, encouragement, and sacrifice.

Lastly and most importantly, I thank Almighty God for his grace, mercy and the gift of life.

Table of Contents

Declaration	iii
Abstract	iv
Acknowledgements	vi
Table of Contents	vii
List of Figures.....	x
List of Tables	xii
Acronyms.....	xiv
Chapter 1 Introduction	1
1.1 Problem Statement	3
1.2 Research Questions.....	4
1.3 Research Objectives.....	4
1.4 Scope and Limitation of Research.....	4
1.5 Contributions	5
1.5.1 Comparative analysis of four candidates that could be modified for MCGDM Schemes for multiple-calls from a single-homed multi-mode terminal in HWNs	5
1.5.2 Develop a New RAT-selection Scheme to Solve the Group Decision Problem in HWNs.....	5
1.5.3 Use of a Range of Preference Values per Criterion for RAT-selection.....	6
1.6 Dissertation Outline	6
Chapter 2 Background and Literature Review	8
2.1 Introduction	8
2.2 Overview of Next Generation Wireless Networks.....	8
2.3 Heterogeneous Wireless Networks	11
2.3.1 Motivation for Heterogeneous Wireless Networks	13
2.4 Issues in Heterogeneous Wireless Networks	13
2.4.1 Common Billing Platform Issue	13
2.4.2 Integration of RATs	14
2.4.3 Service Continuity	14
2.4.4 Network Security	14
2.4.5 Appropriate RAT-selection Scheme	15
2.5 Radio Resource Management in the Heterogeneous Wireless Networks.....	15
2.5.1 Independent Radio Resource Management.....	15
2.5.2 Joint Radio Resource Management	16
2.6 Joint Call Admission Control Algorithm	17
2.6.1 Network Load-based JCAC Algorithm.....	18

2.6.2	<i>Path Loss-based JCAC Algorithm</i>	19
2.6.3	<i>Layer-based JCAC Algorithm</i>	19
2.6.4	<i>Service Cost-based JCAC Algorithm</i>	19
2.6.5	<i>Random-based JCAC Algorithm</i>	19
2.6.6	<i>Service Class-based JCAC Algorithm</i>	20
2.6.7	<i>Utility-based JCAC Algorithm</i>	20
2.6.8	<i>Non-computational Intelligence-based JCAC Algorithm</i>	20
2.6.9	<i>Computational Intelligence-based JCAC Algorithm</i>	21
2.7	The Prerequisites of JCAC Algorithms in Heterogeneous Wireless Networks	22
2.7.1	<i>Multiple-calls QoS</i>	22
2.7.2	<i>Simplicity</i>	23
2.7.3	<i>High-execution Speed</i>	23
2.7.4	<i>Efficiency</i>	23
2.7.5	<i>Scalability</i>	23
2.7.6	<i>Stability</i>	24
2.8	Next Generation Mobile Terminals (Terminal Heterogeneity)	24
2.8.1	<i>Classification of Mobile Terminals Capabilities</i>	24
2.9	Related Works on RAT-selection in Heterogeneous Wireless Networks	25
2.10	Chapter Summary	31
<u>Chapter 3 Comparative Analysis of Multi-Criteria Group Decision-Making Schemes for Multiple-calls</u>		<u>33</u>
3.1	Introduction	33
3.2	RAT-selection Criteria in Heterogeneous Wireless Networks	34
3.3	Multi-Criteria RAT-selection Problem Definition	35
3.4	Conversion of Linguistic Terms to Crisp Values	37
3.5	Adapted Multi-Criteria Group Decision-making and Procedures	37
3.5.1	<i>Simply Additive Weighting-Group Decision-making</i>	38
3.5.2	<i>Multiplicative Exponent Weighting-Group Decision-making</i>	41
3.5.3	<i>Technique for Order Preference by Similarity to Ideal Solution-Group Decision making</i>	41
3.5.4	<i>Distance to the Ideal Alternative-Group Decision-making</i>	43
3.6	Numerical Simulations and Results	44
3.6.1	<i>RAT-selection Sensitivity Analysis</i>	45
3.7	Chapter Summary	49
<u>Chapter 4 Consensus RAT-selection Scheme for Making RAT-selection Decisions for Multiple Handoff calls in Heterogeneous Wireless Networks</u>		<u>50</u>
4.1	Introduction	50
4.2	Consensus RAT-selection Scheme Concepts for RAT-selection in Heterogeneous Wireless	

Networks	51
4.3 Fuzzy Preference Relations for RAT-selection in Heterogeneous Wireless Networks.	53
4.4 Consensus RAT-selection Scheme for Making Group Decision in Heterogeneous Wireless Networks	54
<i>4.4.1 RAT-selection Problem Statement in Heterogeneous Wireless Networks</i>	<i>55</i>
4.5 Numerical Example of Application of Consensus Scheme for RAT-selection for Multiple-calls in a Heterogeneous Wireless Network	56
<i>4.5.1 Rules and Directions Governing Change of Preference to RAT-selection Criteria in Heterogeneous Wireless Networks</i>	<i>66</i>
<i>4.5.2 Second-iteration for Consensus RAT-selection Decisions.....</i>	<i>66</i>
<i>4.5.3 Third Consensus RAT-selection Decisions for a group of Multiple-calls in HWNs.....</i>	<i>74</i>
<i>4.5.4 Analysis of Proximity measures for Selective Subset of a Group of Handoff -calls in a Heterogeneous Wireless Network</i>	<i>86</i>
4.6 Chapter Summary	87
<u>Chapter 5 Conclusion and Future Work.....</u>	<u>88</u>
5.1 Summary of Contributions.....	88
5.2 Recommendations and Future Work.....	89
<u>References.....</u>	<u>91</u>

List of Figures

Figure 1.1: RAT-selection Problem for a Group of Handoff calls in an HWN	2
Figure 2.1: An Example of Homogeneous Wireless Network.....	12
Figure 2.2: Three Mobile Terminals having Simultaneous Connections in an HWN..	12
Figure 2.3: An Example of an Independent Radio Resource	16
Figure 2.4: Joint Radio Resource Management in an HWN.....	16
Figure 2.5: Basic Components of JCAC Algorithms.	17
Figure 2.6: Fuzzy Logic Diagram.	21
Figure 2.7: The Prerequisites of the JCAC Algorithm in HWNs.....	22
Figure 3.1: RAT-selection Connection of Multi-criteria to four candidate RATs in HWNs.	34
Figure 3.2: Service price Sensitivity on RAT-selection for Multiple-calls in HWNs.	45
Figure 3.3: Data rate Sensitivity on RAT-selection for Multiple-calls in HWNs.....	46
Figure 3.4: Security Sensitivity on RAT-selection for Multiple-calls in HWNs.	47
Figure 3.5: Battery Power-consumption Sensitivity on RAT-selection for Multiple- calls in HWNs.	47
Figure 3.6: Network delay Sensitivity on RAT-selection for Multiple-calls in HWNs.	48
Figure 4.1: A Flow Chart of Consensus RAT-selection Scheme Decisions in HWNs.	52
Figure 4.2: Criteria threshold for a Group of Multiple Handoff Calls in HWNs (First- Proximity Decision).....	65
Figure 4.3: Criteria threshold for Group of Multiple Handoff Calls in HWNs (Second- Proximity Decisions).	73
Figure 4.4: Criteria threshold for Group of Multiple Handoff Calls in HWNs (Third- Proximity Decision).....	81

Figure 4.5: Consensus RAT-selection Decisions for a Group of Multiple-calls in HWNs (User-1).	83
Figure 4.6: Consensus Ranking Decisions for a Group of Multiple-calls in HWNs. .	84
Figure 4.7: Number of Consensus Decisions for a Group of Multiple Handoff Calls in HWNs.	84
Figure 4.8: Consensual RAT-selection Decisions in HWNs.	85
Figure 4.9: A Subset Selection of a Group of Handoff-calls from a Single-homed Multi-mode Terminal in an HWN.	86

University of Cape Town

List of Tables

Table 2.1: Summarizes the above-mentioned Network in Wireless Networks.	11
Table 3.1: Example of Users' Specified Weights for Criteria per Service Class.	36
Table 3.2: User Service Scales.	37
Table 3.3: RAT-selection Criteria for Handoff Multiple-calls.	39
Table 3.4: User Assigned Weights.	44
Table 4.1: Fuzzy Linguistic Conversion Scales.	53
Table 4.2: Linguistic Preferences for a Group of Multiple-calls in HWNs.	57
Table 4.3: Crisp Value for a Group of Multiple-calls Preferences in HWNs.	57
Table 4.4: RAT-selection Criteria for Handoff Multiple-calls.	58
Table 4.5: Overall Performance Scores of Multiple Handoff Calls in HWNs.	60
Table 4.6: Analytic Hierarchy Process Pairwise Comparison of four RATs for Voice call.	61
Table 4.7: Analytic Hierarchy Process Pairwise Comparison of four RATs for File download.	61
Table 4.8: Analytic Hierarchy Process Pairwise Comparison of four RATs for Video streaming.	61
Table 4.9: Linguistic Preferences for a Group of Multiple-calls in HWNs.	67
Table 4.10: Crisp Value for a Group of Multiple-calls Preferences in HWNs.	67
Table 4.11: Overall Performance Scores of Multiple Handoff Calls in HWNs.	68
Table 4.12: Analytic Hierarchy Process Pairwise Comparison of four RATs for Voice call.	69
Table 4.13: Analytic Hierarchy Process Pairwise Comparison of four RATs for File download.	69
Table 4.14: Analytic Hierarchy Process Pairwise Comparison of four RATs for Video streaming.	69
Table 4.15: Linguistic Preferences for a Group of Multiple-calls in HWNs.	74

Table 4.16: Crisp Value for a Group of Multiple-calls Preferences in HWNs.	75
Table 4.17: Overall Performance Score of Multiple Handoff Calls in HWNs.	76
Table 4.18: Analytic Hierarchy Process Pairwise Comparison of four RATs for Voice call.	77
Table 4.19: Analytic Hierarchy Process Pairwise Comparison of four RATs for File download.	77
Table 4.20: Analytic Hierarchy Process Pairwise Comparison of four RATs for Video streaming.	77
Table 4.21: Ranking Order of RAT-selection in HWNs.	82

University of Cape Town

Acronyms

2G	Second Generation
3G	Third Generations
4G	Fourth Generations
AHP	Analytic Hierarchy Process
ANP	Analytical Network Process
BBU	Basic Bandwidth Unit
CDMA	Code Division Multiple Access
DIA	Distance to Ideal Alternative
DIA-GDM	Distance to the Ideal Alternative-Group Decision Making
EDGE	Enhanced Data rate for Global Evolution
ELECTRE	Elimination and Choice Translating Priority
E-SAW	Enhanced-Simple Additive Weighting
FAHP	Fuzzy Analytic Hierarchy Process
FANP	Fuzzy Analytical Network Process
Gbps	Gigabit per second
GRA	Grey Relational Analysis
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
HWNs	Heterogeneous Wireless Networks
IRRM	Independent Radio Resource Management
JCAC	Joint Call Admission Control
JRRM	Joint Pool of Radio Resources Management
Kbps	Kilobit per second
KPI	Key Performance Index
LB	Load Balancing

LOWA	Linguistic Ordered Weighted Averaging
LTE	Long-time Evolution
MADM	Multi-attribute Decision Making
Mbps	Mega bit per second
MCDM	Multi-criteria Decision Making
MCGDM	Multi-criteria Group Decision-making
MEW	Multiplicative Exponent Weighting
MEW-GDM	Multiplicative Exponent Weighting-Group Decision Making
MMS	Multimedia Message Service
NGWNs	Next Generation Wireless Networks
NIA	Negative Ideal Alternative
OWA	Ordered Weighted Averaging
PIA	positive Ideal Alternative
QOE	Quality of Experience
QoS	Quality of Service
RATs	Radio Access Technologies
RAT-selection	Radio Access Technology Selection
RW	Random Weighting
SAW	Simple Additive Weighting
SAW-GDM	Simply Additive Weighting-Group Decision Making
SES-CH	Call Change
SM	Similarity Matrix
SMS	Short Message Service
TDMA	Time Division Multiple-access
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
TOPSIS-GDM	Technique for Order Preference by Similarity to Ideal Solution-Group

	Decision Making
UMTS	Universal Mobile Telecommunications System
VASs	Value Added Services
VHA	Vertical Handover Algorithm
VIKOR	ViseKriterijumska Optimizacija I Kompromisno Resenje
VOIP	Voice over Internet protocol
W	Weight Vector
W-CDMA	Wideband-Code Division Multiple Access
Wi-Fi	Wireless-Fidelity
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
WMC	Weighted Markov Chain
WP	Weighted Product

Chapter 1 Introduction

In recent years, the wireless communication industry has become a global market where evolving and emerging value added services (VASs), such as multimedia and voice over internet protocol (VOIP) are being developed to provide better service to end users. Moreover, the current transition in the wireless communication industry has led to an increase in the number of handheld devices. These devices are used to access seamless and ubiquitous services on different radio access technologies (RATs) such as Wireless-Fidelity (Wi-Fi), Universal Mobile Telecommunications Systems (UMTS), and Long Term Evolution (LTE) systems. This transition has led to a shift in paradigm where users are not passive to the network, but are being involved to determine what they want from the network by allocating a range of preferences to the criteria used for RAT-selection [1]. Even at that, users' demands for "always best connected" ubiquitous services are increasing on a daily basis [2].

Therefore, it is envisioned that heterogeneous wireless networks (HWNs) will provide the platform where network services are provided for user's at any given time, and in any place [3]. This is because HWNs has the capability to aggregate the pool of radio resources from different RATs. On the other hand, the traditional homogeneous wireless network is limited in coverage and capacity, and therefore may not provide the QoS required for subscribed services due to the confinement of users' devices to a single-RAT [4]. Whereas in HWNs, the pool of radio resources is utilized efficiently with the advances in mobile devices (i.e., terminal multimodal capability).

Terminal heterogeneity refers to a combination of built-in modality features such as number of networks supported, homing capability, energy consumption rate, portability/weight, complexity, display size, etc. [5]. A multi-mode mobile device has more than one network interface and its can connect to one or more RATs sequentially or simultaneously, and is capable of communicating with existing wireless access network protocol [1]. In next generation wireless networks (NGWNs), it is envisaged that multi-mode terminals will not be fully controlled by the operators or the service providers but will be able to select the most suitable RAT that best satisfies the user's preferences.

A multi-mode terminal that has the capability to connect to different RATs, but one at a time, is referred to as a single-homed terminal, while a terminal that can connect to two or more RATs simultaneously is called a multi-homed terminal.

In HWNs, user mobility is dynamic, which often leads to vertical handoff of on-going calls

(single or multiple-calls) that have been initiated on a single-homed multi-mode terminal to any of the available RATs, in order to maintain seamless connection. The process of moving the on-going calls from one RAT to another dissimilar RAT is referred to as vertical handoff [6], [7]. Vertical handoff occur when a user initiates a new call on a mobile device, which already have an on-going call and well connected to a particular RAT (e.g. Wi-Fi), the current RAT (e.g. Wi-Fi) may no longer be suitable for the two calls (the incoming-call and the on-going-call). Therefore, this situation may necessitate the need for vertical handover of the entire on-going multiple-calls to another RAT (e.g. UMTS network). Moreover, a vertical handoff may take place when a user moves away from the coverage area of the attached network (Wi-Fi) to another network coverage area (LTE network).

However, the selection of a suitable RAT for a group of handoff calls from a single-homed multi-mode terminal has been a major issue in the wireless communication industry. This is because the RATs in HWNs have different features and properties that make it difficult for the mobile terminal to select the most suitable RAT. Therefore, the selection of a suitable RAT for a group of handoff calls in HWNs is a group decision problem. A group decision handoff problem refers to a course of action where the handoff selection process involves a group of calls selecting the most suitable RAT amongst the existing RATs in HWNs. The handoff calls, for example, may be voice call, file download and video streaming. Figure 1.1 illustrates the problem of RAT-selection for a group of handoff calls from a single-homed multi-mode terminal in an HWN.

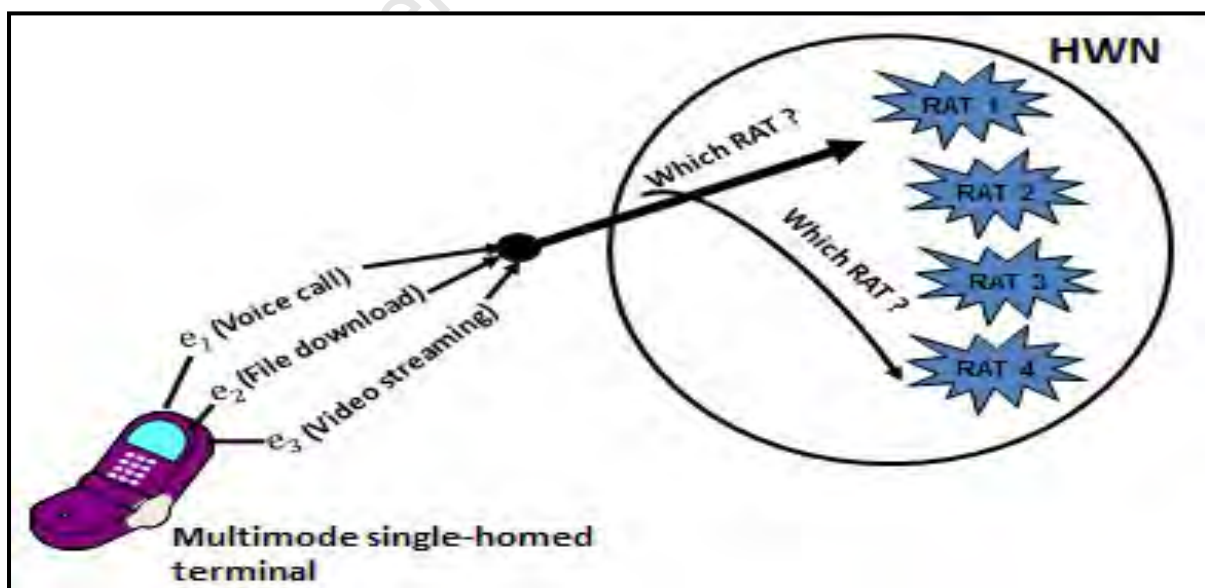


Figure 1.1: RAT-selection Problem for a Group of Handoff calls in an HWN.

As shown in Figure 1.1, a vertical handoff is required for the group of calls because user's mobility is dynamic (i.e., users can move from one coverage area to another). Efficient RAT-selection for a single call has been a prominent area of interest for several researchers because of the scarce radio resources and the cost implications of spectrums that are involved in the decision process [8], [9], [10].

Solving a group decision problem for handoff calls in HWNs is more complicated, and various decision issues must be considered. Such decision issues include, but are not limited to: (1) preference evaluation and preference representation structure, (2) RAT-selection criteria and range of selection-criteria preferences for a set of criteria, (3) prioritization of call and assignment of priority weight to different service classes, and (4) the use of an appropriate multi-criteria group decision-making (MCGDM) scheme for making RAT-selection decisions.

In such decision issues, the aim is to find the most suitable RAT for a group of calls. Therefore, it is essential for the operators and service providers to implement a suitable scheme on their networks in order to select the appropriate RAT, as well as to manage the joint pool of different radio resources efficiently to provide better service to end users.

1.1 Problem Statement

A number of schemes have been proposed for making RAT-selection decisions in HWNs. These schemes have been primarily designed for making RAT-selection decisions for a single call from a mobile terminal in HWNs. Therefore, they are not suitable for making RAT-selection decisions for multiple handoffs calls in HWNs because the problem of RAT-selection for multiple-calls from a single-homed multi-mode terminal is a group decision problem.

Thus, this shows that in the existing schemes there are unresolved issues in making RAT-selection decisions for multiple handoffs calls in HWNs. Therefore, the use of group decision making schemes is required to solve the problem of making RAT-selection decisions for multiple handoffs calls from a single-homed multi-mode terminal in HWNs.

Group decision-making schemes are used to solve the preference of multi-criteria and the disparity of QoS requirements for multiple handoff calls. This is achieved by using a coherent group decision to combine all requirements into collective QoS requirements before selecting the RAT that best offers the collective requirements for the group of multiple-calls from a

single-homed multi-mode terminal in HWNs.

1.2 Research Questions

The research questions addressed in this dissertation can be summarized as follows:

- ❖ How can operators and service providers select the most suitable MCGDM scheme for RAT-selection in HWNs?
- ❖ How can a RAT-selection algorithm ensure that the QoS requirements for individual calls in a group of multiple-calls from a single-homed multi-mode terminal are satisfied by the selected RAT?

1.3 Research Objectives

The objectives of the dissertation are to address the RAT-selection problem for a group of handoff calls from a single-homed multi-mode terminal in the HWNs. Furthermore, it investigates the sensitivity of five chosen criteria in making RAT-selection decisions for multiple-calls in a four-RAT HWN. The modified MCGDM schemes are: (1) simply additive weighting-group decision making (SAW-GDM), (2) multiplicative exponent weighting-group decision making (MEW-GDM), (3) technique for order preference by similarity to ideal solution-group decision making (TOPSIS-GDM), and (4) distance to the ideal alternative-group decision making (DIA-GDM). In addition, the study introduces a new concept on how to reach a consensus among a group of handoff calls from a single-homed multi-mode terminal for selecting the most suitable RAT in HWNs.

The specific objectives of the dissertation are to:

- ❖ Perform a comparative analysis of four candidate MCGDM schemes for making RAT-selection decisions for a group of handoff calls in an HWN.
- ❖ Develop a new RAT-selection scheme to address the group-call decision problems in HWNs, and as well evaluate its performance.

1.4 Scope and Limitation of Research

The dissertation addresses the group decision problem of RAT-selection when a single-homed multi-mode terminal is being used in HWNs. However, RAT selection for multi-homed terminals has not been considered in the dissertation.

1.5 Contributions

The main research contributions of this dissertation are:

1.5.1 Comparative analysis of four candidates that could be modified for MCGDM Schemes for multiple-calls from a single-homed multi-mode terminal in HWNs

Four adapted MCGDM candidate schemes for making RAT-selection decisions for a group of handoff calls are analyzed in terms of criteria sensitivities in order to determine the most suitable MCGDM scheme. Criterion sensitivity is a measure of how a particular criterion type affects the choice of a RAT for a group of handoff calls. The adapted MCGDM schemes compared in this dissertation are simply additive weighting-group decision making (SAW-GDM), multiplicative exponent weighting-group decision making (MEW-GDM), techniques for order preference by similarity to ideal solution-group decision making (TOPSIS-GDM), and distance to the ideal alternative-group decision making (DIA-GDM).

1.5.2 Develop a New RAT-selection Scheme to Solve the Group Decision Problem in HWNs

The consensus RAT-selection scheme is proposed to address the group decision problem of RAT-selection for a group of calls using a single-homed multi-mode terminal in HWNs. The proposed scheme works by using the fuzzy preference relation to express the calls' preferences on RAT-selection criteria. A call preference is defined as the weights specified by the user to different RAT-selection criteria. This model is different from the existing schemes for RAT-selection. This is because it makes use of "consensus measures that are based on soft coincidence among preferences" to determine the most suitable RAT for the group of multiple-calls in an HWN.

The new RAT-selection scheme is proposed because a group of handoff calls requires a high degree of QoS level in HWNs. This approach improves the users' QoE and service satisfaction when using a single-homed multi-mode terminal in HWNs. It also helps to reduce the overall call dropping probability during the handoff process of a group of multiple-calls in HWNs. In addition, the consensus RAT-selection scheme evaluates the RAT-selection when a user assigns a fixed preference to selection criteria and compares it to that of dynamic range

of preferences for multiple on-going calls from a single-homed multi-mode terminal in an HWN.

1.5.3 Use of a Range of Preference Values per Criterion for RAT-selection

Existing RAT-selection algorithms use a single preference value per criterion. This dissertation proposes the use of a range of preference values per criterion. Therefore, users can configure their mobile terminals to choose the most suitable preference value within the specified range of preference values per criterion.

➤ Conference Publication

- (1) O. A. Taiwo and O. E. Falowo, "Comparative Analysis of Algorithms for Making Multiple-calls Handover Decisions in Next Generation Wireless Networks" (To appear in the proceedings of IEEE Africa Conference (IEEE-AFRICON), Mauritius, 9-12 September 2013).

1.6 Dissertation Outline

The remainder of this dissertation is structured as follows:

Chapter 2 presents the background and literature reviews of this study. The background of NGWNs are discussed in detail which includes the following: the limitations of a single radio access technology for high bandwidth-consuming services in HWNs, motivation for an HWN platform, challenges of HWNs, radio resource management in the NGWNs, joint call admission control schemes, prerequisites of joint schemes in HWNs, next generation mobile terminals (multi-mode terminals) and classification of the mobile terminals capabilities. Also, literature reviews of related works on RAT-selection in HWNs are discussed.

Chapter 3 presents the procedures for the four candidate MCGDM schemes namely: SAW-GDM, MEW-GDM, TOPSIS-GDM and DIA-GDM that may be used for RAT-selection for a group of handoff calls from a single-homed multi-mode terminal in an HWN. It further presents the sensitivity analysis of the four candidate MCGDM schemes. The results obtained show the performance of the MCGDM candidates for RAT-selection in a HWN.

Chapter 4 presents the newly proposed scheme named consensus RAT-selection. Consensus RAT-selection scheme procedures are discussed in detail and includes the following: the concepts used for selecting the most suitable RAT in HWNs, fuzzy preference relations for the RAT-selection decision, consensus making for group decision of multiple-calls, and rules

and directions governing change of preference to RAT-selection criteria in HWNs.

Finally, chapter 5 summarizes the contributions of the dissertation on sensitivity analysis of four candidate MCGDM schemes for multiple-calls handoff decisions for a group of multiple-calls from a single-homed multi-mode terminal in HWNs, and the newly proposed scheme named consensus RAT-selection. It also highlights some recommendations, and suggests areas for future study.

University of Cape Town

Chapter 2 Background and Literature Review

2.1 Introduction

The previous chapter has highlighted the group decision problem in HWNs with emphasis on how to select a suitable RAT for a group of handoff calls when a single-homed multi-mode terminal is being used in the HWNs.

This chapter provides the overview of the evolution of NGWNs, and particularly the key concepts on why a single RAT cannot meet the QoS requirements of all services at all times. It also highlights the flexible connection of mobile terminal in HWNs and its pending issues. Next, radio resource management in HWNs is discussed, followed by a discussion on the next generation mobile terminals (multi-mode terminals). Finally, relevant works are discussed as well.

2.2 Overview of Next Generation Wireless Networks

In NGWNs, single-homed multi-mode terminals are supported to provide connectivity to users. This type of terminal modality can access one, two or more classes of calls, such as voice call, file download and video streaming on any of the available RATs (i.e., Wi-Fi, LTE, and WLAN) in an HWN. Similarly, it is expected that the rates of demand for high consuming service (call) will increase exponentially, such that a single-RAT resource from a homogeneous wireless network may not be able to provide the required bandwidth [11]. This is because in a homogeneous wireless network, service (call) is often rendered through the use of a single-RAT that is limited in capacity and coverage [10], [11]. This poses a drawback in terms of overall call blocking/dropping probability experienced on the network, and thereby contributes to poor QoS delivery to network users.

However, the problems encountered in homogeneous wireless networks have led several researchers to propose solutions to solve the problems of high consuming bandwidth service through the advances from one network generation to another network generation.

For example, in second generation (2G) mobile telecommunications technology, voice call is supported with 8 time slots in the time division multiple-access (TDMA) mode, and it makes use of a 200 KHz carrier in 900/1800 MHz bands. Nevertheless, the high consuming bandwidth service cannot be provided and the overall call dropping probability remains high. This is because of its limitation in terms of radio resource capacity, which then gives rise to

an extension to the 2G network known as general packet radio service (GPRS).

GPRS was developed as the add-on network for the 2G network. This type of network can also be referred to as 2.5G. The 2.5G network is a packet oriented data service network that has the capability to provide attractive services, such as the short message service (SMS) and multimedia message service (MMS). These services are provided through the packet switched network. Even at that, 2.5G network has its own limitations in terms of capacity and coverage. Therefore, the high consuming bandwidth services are compromised and the overall call blocking/dropping probability remains high as well [12].

In light of the 2.5G limitation, an alternative enhanced technology has been developed as a solution called enhanced data rate for global evolution (EDGE). The EDGE is referred as 2.75G network. The 2.75G can provides a high consuming service with a bandwidth up to 236 kbit/s (with end-to-end latency of less than 150 ms) using 4 timeslots in packet mode, and it is considered a pre-3G radio technology. Also, it is backward-compatible with 2G and 2.5G networks. Nevertheless, poor signal quality, high latencies of packet-based services and high call blocking/dropping probability are experienced as well.

These limitations bring about the third generation (3G) of mobile telecommunications technology. The 3G network has a higher spectrum packet-based service and the capacity to support more than one class of calls (voice call and data) at the same time from different terminal modalities (single-homed and multi-homed).

Furthermore, the 3G mobile telecommunications technology can be classified into two broad standards. They are the universal mobile telecommunications system (UMTS) and code division multiple access (CDMA2000). These standards are based on wideband-CDMA (W-CDMA) technologies. The W-CDMA provides better coverage with flexible resource allocation to users. However, W-CDMA is faced with a number of pressing challenges. One of the challenges is referred to as "cell breathing" [13], [14].

Cell breathing occurs when the numbers of users that are currently using the radio resources are more than the capacity, the serving cell becomes heavily loaded and the coverage surface area shrinks [13]. The problem of cell breathing is regarded to be a major shortcoming of 3G technology. In that light, a temporary solution was proposed to utilize a mechanism that redirects some of the on-going services (calls) or traffic to neighboring cells [15]. The neighboring cells are considered / assumed to have a lighter load with more capacity in order to prevent the cell breathing problem. This type of solution is referred to as load balancing

(LB) [15].

However, from the above network generations of mobile telecommunications technology (2G, 2.5G, 2.75G and 3G), it can be inferred that no single-RAT from the network generations of mobile telecommunications technology is suitable to guarantee users with adequate QoS, reduce new call blocking/handoff call probability, as well as improve the average system utilization.

A possible way to solve these problems is to utilize HWNs to provide adequate resources, because of its capabilities to aggregate different radio resources from more than one RAT, which are of different technologies. Therefore, HWNs enhance the user QoE and service satisfaction by connecting the user terminal to any available RAT. This helps to utilize the pool of radio resources for a variety of services (calls).

To do so, the 4G of mobile telecommunications technology provides the platform where different RATs complement one another in a flexible manner in terms of merits and demerits through their heterogeneity [8]. It provides an optimum data rate of about 100Mbps on motion and 1000Gbps at stationary mode with the tendency of reducing the overall call dropping probability. It also provides the necessary bandwidth requirements for calls because of the aggregation of resources, and enables pervasive computing in which simultaneous connections to multiple network resources are possible.

Currently, there are two technology candidates for 4G network, LTE and worldwide interoperability for microwave access (WiMAX) [16]. The two candidate technologies provide the following features and benefits. They include: (1) cost effective service, (2) support both scalable and non-scalable services such as multimedia and voice call respectively, (3) wide area coverage, (4) service portability, (5) high throughput, (6) IP based mobile system based, (7) better scheduling and call admission control techniques, (8) adaptive modulation and power control, and (7) seamless switching, and a variety of QoS driven services.

With all these promising features and benefits of 4G network. Thus, 4G network faces the problem of frequent handoff of call (Ping-Pong handoff of call) [17]. The Ping-Pong handoff of call has the tendency of affecting the average system utilization, the provision QoS of all accepted calls and increases the number of handoff probability ratio on the network [18].

Table 2.1 illustrates the overview of above-mentioned network generations in wireless communications.

Table 2.1: Summarizes the above-mentioned Network in Wireless Networks.

Network Generations	2G			3G	4G
	2G	2.5G	2.75G		
Transmission method	Digital			Digital	Digital
Service types	Voice call and short message service (SMS)	SMS, multimedia message service (MMS), Mobile Internet, Voice call,	Voice call, data, video streaming, audio streaming, SMS, MMS, mobile TV, and mobile internet	Audio streaming, SMS, Data, video streaming, MMS, Voice call, mobile TV (with high definition), and mobile internet, 3D-TV	
Data rate	Up to 48.6kb/s	384kb/s	Up to 2 Mb/s	Up to 1Gb/s	
Mobility	Medium			High	Very high

As mentioned above, the terminal heterogeneity refers to a combination of terminals with different capabilities for selecting the most suitable RAT for multiple-calls in HWNs.

2.3 Heterogeneous Wireless Networks

As mentioned above, multi-mode terminals can either be single-homed or multi-homed. A single-homed multi-mode terminal can only be connected to one RAT at a time, whereas a multi-homed terminal can connect to two or more RATs simultaneously, and are therefore more flexible with regard to radio resource allocation [19].

Figure 2.1 shows an example where a mobile terminal is confined to a single-RAT in a homogeneous wireless network. Although the mobile terminal has the capacity to connect and access resources from more than one RAT simultaneously, this is not possible due to the

homogeneous network constraint. Therefore, the number of blocking/dropping call probability may increase in a homogeneous wireless network compared to that of HWNs [4], [5], [20].

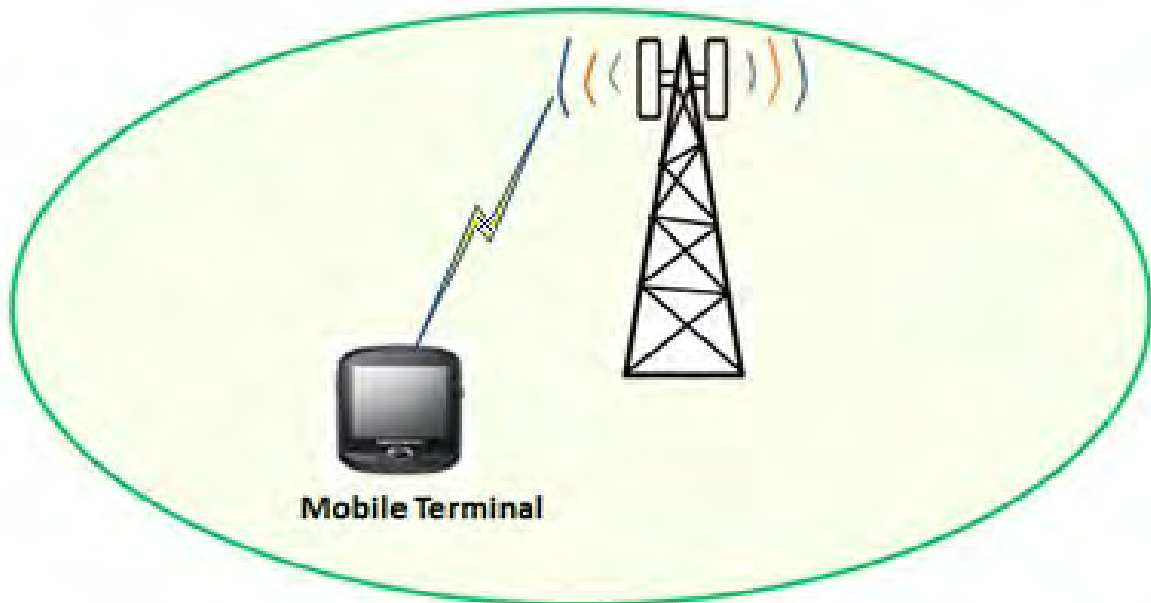


Figure 2.1: An Example of Homogeneous Wireless Network.

Figure 2.2, illustrates three mobile terminals connecting to more than one RAT at the same time in an HWN.

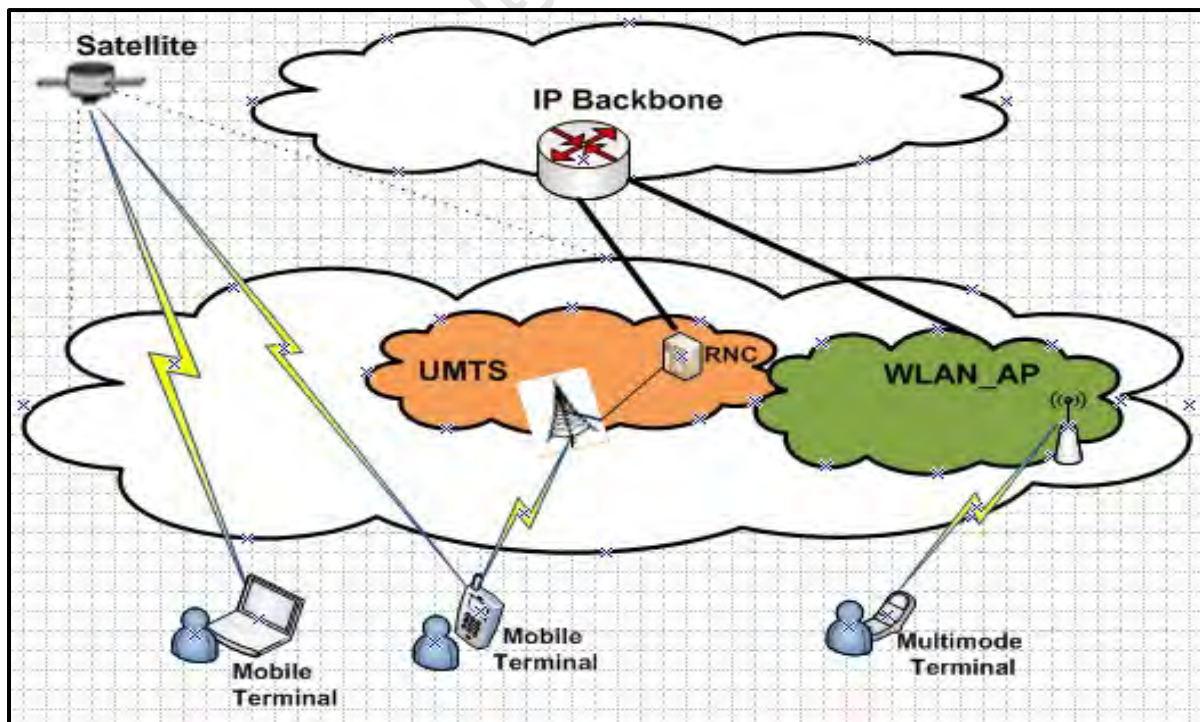


Figure 2.2: Three Mobile Terminals having Simultaneous Connections in an HWN.

This type of connection allows users to access multiple networks because the mobile terminals have more than one network interface. Therefore, the call blocking/dropping probability is reduced in HWNs. The next subsection explains the motivation for HWNs and its challenges.

2.3.1 Motivation for Heterogeneous Wireless Networks

One of the motivations for HWNs in wireless communication is to ensure that all the mobile network resources are aggregated to provide seamless communications, adaptive QoS and enrich services to users, as well as to improve the overall satisfaction and the resource utilization. To do so, there exist some issues that might mitigate this drive in HWNs. These issues are explained in the next section.

2.4 Issues in Heterogeneous Wireless Networks

As mentioned in 2.3.1, there exist some pending issues which can affect the motivation for HWNs. These issues could be classified into five groups, namely a common billing platform, integration of RATs, service continuity, network security, and the use of an appropriate RAT-selection scheme. Each of the issues is explained in subsections that follow:

2.4.1 Common Billing Platform Issue

The joint pool of radio resources from different RATs allows the operators and content providers to provide new and exciting products and services which are cost effective and affordable for users. These products and services may be referred to as value added services (VASs). Having said this, the service charge for the VASs may vary from one RAT to another in HWNs. Therefore, a different cost will be charged for the same service content (call) based on the selected RAT in HWNs.

However, having cost effective products and services may be hampered due to different billing charged for the same service content across the RATs in HWNs. Furthermore, having a common or unified billing platform for different RATs has been a major problem in HWNs [4]. Common billing platform stands for a billing system where a user is charged with a single bill across the available RATs for service contents in HWNs.

2.4.2 Integration of RATs

In HWNs, a number of RATs have different merits and demerits which range from coverage dimensions, security levels, power consumption rate, capacity, service cost, data rate, etc. Each of the RATs has been designed to have its own unique properties, which differ from one another. Even at that, integrating and selecting the best matching RATs that are suitable for network coupling in HWNs has been a challenge because of the individual demerits [21].

2.4.3 Service Continuity

Service continuity ensures that seamless connections of on-going calls are guaranteed at all times on the networks. However, due to the users' mobility, the on-going calls may need to handoff from the current RAT to another. The handoff can be classified into two types: horizontal and vertical handoff [22]. The horizontal handoff occurs between the same mobile communications technology (e.g., GSM to GSM). In contrast, vertical handoff takes place between different mobile communications technologies (e.g., WLAN to GSM or GSM to WLAN) [23].

Most often, the seamless connectivity for a group of calls is cut off when users move away from the coverage area of a network (WLAN) that has larger bandwidth to a network (GSM) which has a lower bandwidth. This compromises the "always best connected" service and also results in undesirable dropping of the on-going group of calls in HWNs.

2.4.4 Network Security

One of the benefits of HWNs is to provide ubiquitous connection to users at any time, and in anyplace from the coupled RATs. Most times, if not all, the network security of the integrated RATs remains as a great challenge, because of the disparity in security levels. The security levels vary from one RAT to another RAT; some have robust designs for layer 1 and layer 2 networks, while others have weak security features. To some extent, the benefit of integrating different RATs in HWNs may not be achieved in adequacy, if the security issue is not solved [24]. For instance, considering a network where two integrated RATs such as UMTS and WLAN are coupled to provide "always best connected" service to users. As aforementioned, each of the RATs has its own security levels; the security design for UMTS is very robust compared to WLAN. This type of network exposes the entire network of elements to

intrusion by other parties because the WLAN security design is loose, which therefore poses a security challenge in HWNs.

2.4.5 Appropriate RAT-selection Scheme

For efficient management of the joint pool of radio resources in HWNs, it is necessary for operators and other service providers to implement the appropriate RAT-selection scheme that is suitable for various call flows in HWNs. To do so, the problem of how to select the most suitable RAT for single call and multiple-calls from the available RATs needs to be solved accordingly.

2.5 Radio Resource Management in the Heterogeneous Wireless Networks

In HWNs, radio resource management is used to manage the joint pool of radio resources for the purpose of achieving optimal network performance in the paradigm of "always best connected" of users' service request to the available RATs at all times, in any place and anyhow [2]. The radio resource management can be classified into two parts, namely the independent radio resource and joint radio resource managements. The next subsection explains each of the radio resource management respectively.

2.5.1 Independent Radio Resource Management

In independent radio resource management (IRRM), each RAT manages its radio resources. This method of resource management may not provide adequate QoS for multiple-calls in HWNs, especially during peak periods. In addition, the following disadvantages are associated with the IRRM as listed below:

- ❖ Underutilization of the available resource is experienced.
- ❖ High blocking/dropping probability is experienced.
- ❖ It limits the overall revenue of operators and other service providers.
- ❖ It limits the coverage area/coverage footprint.
- ❖ It restricts users to a single-RAT.

Figure 2.3, shows an example where the individual RAT resource is been managed by IRRM in an HWN [4].

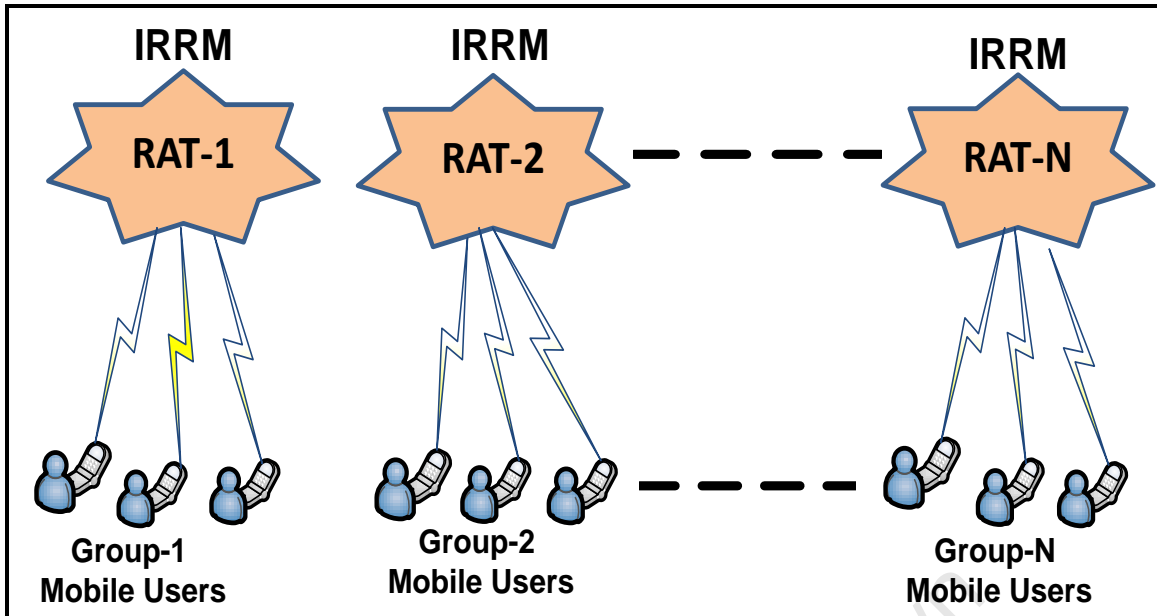


Figure 2.3: An Example of an Independent Radio Resource.

As shown in Figure 2.3, an IRRM may not be suitable for multiple-calls in HWNs.

2.5.2 Joint Radio Resource Management

The joint radio resource management (JRRM) provides the means where the pool of resources from different RATs in HWNs could be managed. Several researchers have considered JRRM as an efficient system [25], [26]. Figure 2.4, illustrates how the available resources from different RATs are been managed in an HWN [4].

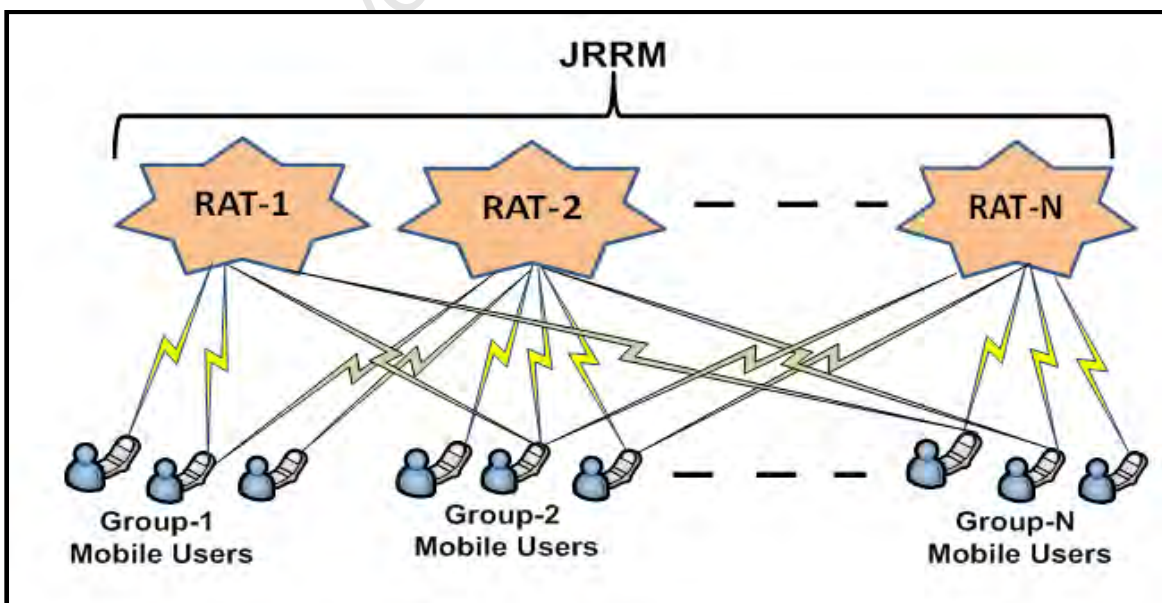


Figure 2.4: Joint Radio Resource Management in an HWN.

On the other hand, the JRRM offers the operators and service providers means to provide "always best connected" ubiquitous service to their respective subscribers, where the subscribed services receive the required amount of resources from the network [3]. This improves the network performance. Network performance refers to measures used to determine the level of users' satisfaction on the QoS of product and service contents from operators and service providers' networks.

Furthermore, in HWNs, it is important to manage the radio resource judiciously due to its scarcity, and it also costs a large sum of money to purchase or lease from the appropriate authority [27].

Therefore, a number of JRRM algorithms have been proposed by several researchers for resource management in HWNs. Examples are the joint call admission control (JCAC) algorithm, resource allocation/scheduling algorithms and the congestion/load control and power control algorithm [4], [28]. This dissertation only reviews the JCAC algorithms for RAT-selection in HWNs.

2.6 Joint Call Admission Control Algorithm

The JCAC algorithms consist of two components, namely call admission decision and RAT selection decision. The call admission decision determines whether an incoming call or handoff call will be accommodated into the network or not, while the RAT selection decision performs the function of selecting the most suitable RAT for the incoming call or handoff call in HWNs. Figure 2.5 shows the basic components of JCAC algorithms [4].

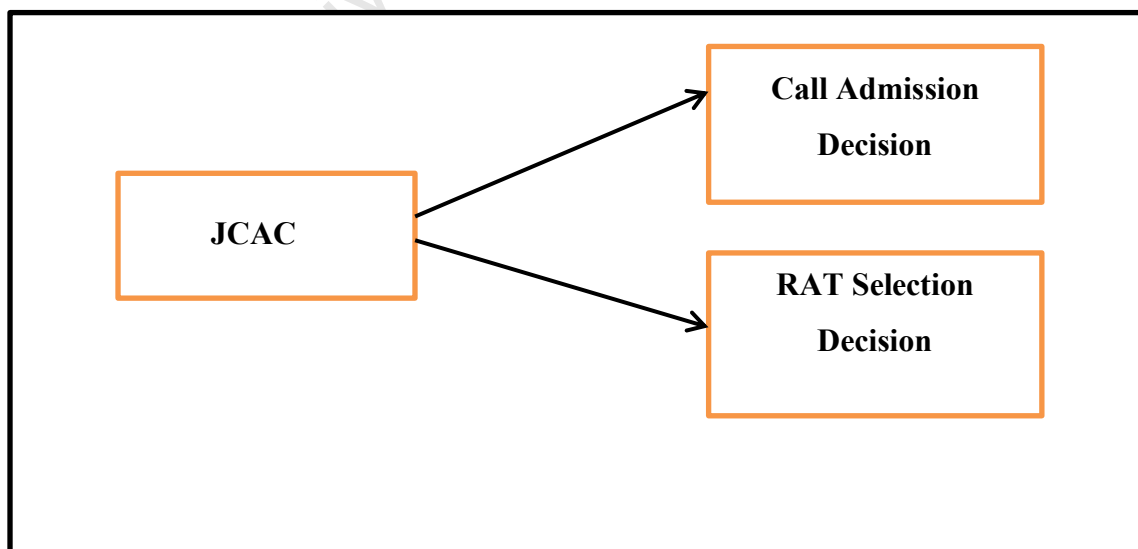


Figure 2.5: Basic Components of JCAC Algorithms.

However, the JCAC algorithms need to ensure that the QoS commitment to the incoming call and other existing on-going calls is not violated and as well, determines the appropriate RAT in the shortest possible time [29]. The JCAC algorithms can be grouped into two main classes, namely single-criterion and multiple-criteria selections.

A single-criterion JCAC algorithm selects the preferred-RAT for the incoming call or handoff call based on one criterion only, whereas, the multiple-criteria JCAC algorithms base the selection decision on two or more criteria/parameters in HWNs. The essence of using multiple-criteria JCAC algorithms in HWNs is to improve the QoS connection level and the QoE users derive from their subscribed services in HWNs [9], [30]. Examples of JCAC algorithm classification are stated in the following subsections.

2.6.1 Network Load-based JCAC Algorithm

A network load-based JCAC algorithm is used to balance the traffic load evenly amongst the available RATs by preventing a particular RAT from being over-utilized in an HWN [31]. Furthermore, the network load-based JCAC algorithm ensures that the incoming calls and handoff calls are accepted into the least loaded RAT in HWNs. Additionally, the network load-based JCAC algorithm can be classified into four types: user preference, non-user preference, force-based and unforced-based.

The user preference network load JCAC algorithm considers the user preference before the on-going calls are admitted into the most suitable RAT, while the non-user preference load JCAC does not consider the user preference in HWN [4].

On the other hand, the forced-based JCAC algorithm moves a portion of the on-going calls from a highly-loaded RAT to a less-loaded RAT when the differential load between the two networks is above a certain threshold in HWN. This is called call reassignment. Whereas, the unforced load-based JCAC algorithm is carried out only during the admission of a new call or necessary vertical handoff call (i.e., a vertical handoff that occurs when an active mobile terminal is moving outside the coverage area of the current RAT). The new or vertical handoff call is then admitted into the least loaded RAT among the available RATs in HWNs [32].

A major advantage of the network load-based algorithm is high network stability due to even distribution of loads in HWNs. However, the network load-based JCAC algorithm is a network-centric scheme and therefore may not be suitable for RAT-selection in HWNs [15].

2.6.2 Path Loss-based JCAC Algorithm

In HWNs, the path loss-based JCAC algorithm admits calls into the most suitable RAT based on path loss measurements and it takes the cells status of all the available RATs into consideration when making RAT-selection decisions in HWNs. The path loss-based JCAC algorithm bases its decisions on the received signal strength, and the received power link.

The advantage of using a path loss-based JCAC algorithm for RAT-selection is based on higher throughput and lower bit error rate. Even at that, this algorithm is susceptible to frequent vertical handoff in HWNs, and thereby is not suitable for RAT-selection decisions due to the ping pong of calls in HWNs [4].

2.6.3 Layer-based JCAC Algorithm

A layer-based JCAC algorithm allocates incoming or handoff calls from a mobile terminal into a specific layer. However, when the specified layer cannot accommodate the incoming or handoff calls, the layer-based JCAC algorithm tries to admit the calls in the next available layer, or else the calls are dropped [4].

The advantage of the layer-based JCAC algorithm is that it is simple to implement for RAT-selection in HWNs. However, the layer-based JCAC algorithm leads to highly unbalanced network loads.

2.6.4 Service Cost-based JCAC Algorithm

The service price-based JCAC algorithm differs from the mentioned above schemes because it admits incoming calls and handoff calls from a mobile terminal into the least expensive RAT amongst available RATs in HWNs. This algorithm helps the users to incur the least possible charge because the service cost differs from one RAT to another in HWNs [33].

In addition, each RAT has different service costs in terms of spectrum license fees, cost of equipment, and cost of maintenance. However, the service price-based JCAC algorithm can lead to a highly unbalanced network load and waste of scarce resource in HWNs.

2.6.5 Random-based JCAC Algorithm

The random-based JCAC algorithm randomly admits an incoming call or handoff call into

one of the available RATs in HWNs. The advantage of this algorithm is because it is based on the fact that the implementation is very simple [34].

However, when the selected RAT has no sufficient resources to accommodate the call, the call is blocked or dropped. Moreover, users may experience high call blocking/dropping probability, and this may lead to poor key performance index (KPI) of the network. Therefore, the random-based JCAC algorithm is not suitable for RAT-selection in HWNs.

2.6.6 Service Class-based JCAC Algorithm

The service-class based JCAC algorithm accepts the users' calls into a defined or specified RAT based on the class of the service, such as voice call, video streaming, audio streaming, file download, etc. in HWNs [4]. The algorithm ensures that incoming calls such as voice calls or video streaming is admitted into the appropriate RAT. For example, consider a scenario where operators and service providers implement a service class-based JCAC algorithm for RAT-selection in HWNs that consist of two RATs (i.e., GSM and UMTS). In this case, the GSM network will be suitable and be selected as the preferred network for the voice call, while the UMTS will be preferred for the video streaming. This is because the GSM does not have the capability to provide the QoS requirements for video streaming. However, the UMTS can support both the voice call and the video streaming in HWNs.

The advantage of the service class-based JCAC algorithm is that the best matching RAT is always selected for new calls and handoff calls in HWNs [4]. Even at that, the service-class based JCAC algorithm is limited because vertical handoff is not possible in HWNs, and this may lead to high blocking/dropping of calls in HWNs.

2.6.7 Utility-based JCAC Algorithm

The utility-based JCAC algorithm performs a RAT-selection decision in HWNs based on utility or fitness factors [10]. This algorithm is highly efficient for RAT-selection of new calls or handoff calls from a mobile terminal in an HWN environment. However, the utility-based JCAC algorithm is very difficult to implement in a network.

2.6.8 Non-computational Intelligence-based JCAC Algorithm

The non-computational intelligence-based JCAC algorithm works by accepting the incoming

call from a mobile terminal into a specific RAT based on some cost functions using multi-criteria requirements in HWNs. The advantage of this algorithm is that it improves both the QoS and the user satisfaction in HWNs.

However, the non-computational intelligence-based JCAC algorithm has a shortcoming in terms of high computational overheads [8]. Therefore, this algorithm is not suitable for RAT-selection in HWNs [27].

2.6.9 Computational Intelligence-based JCAC Algorithm

In HWNs, the computational intelligence-based JCAC algorithm such as fuzzy logic and fuzzy MADM techniques are used to accommodate new calls and handoff calls into a specific RAT in HWNs [29]. For example, fuzzy logic involves the use of multiple input data, which are processed into multiple output information. Moreover, fuzzy logic is made up of four components (i.e., fuzzifier, inference engine, fuzzy based rules and defuzzifier) as shown in Figure 2.6 [4].

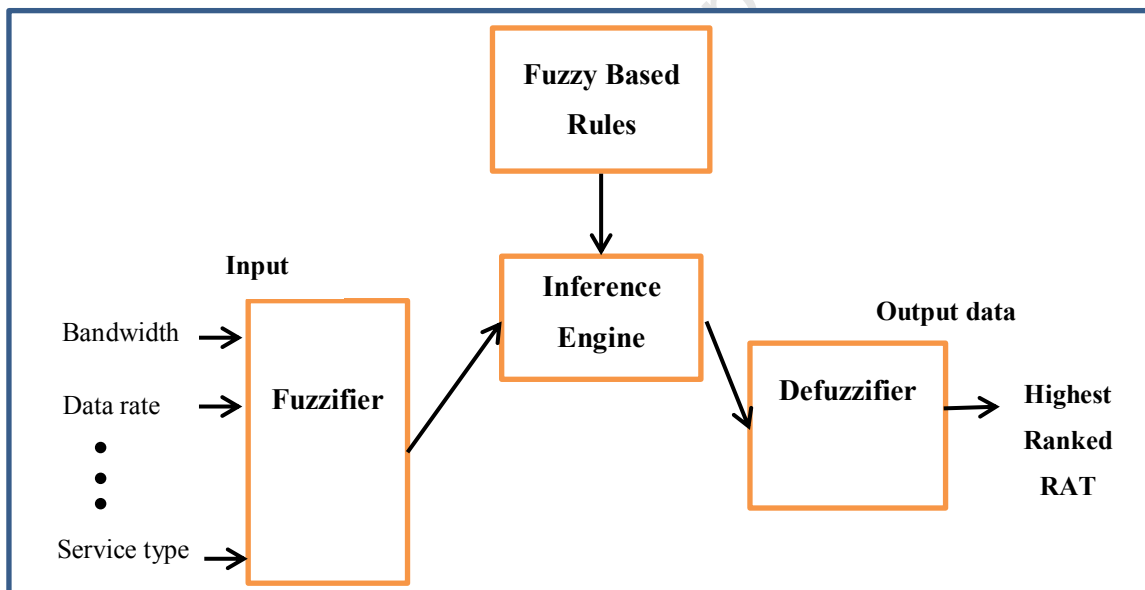


Figure 2.6: Fuzzy Logic Diagram.

Figure 2.6 shows that the fuzzifier is used to define the entry point for input data. This input data may be in terms of bandwidth, power consumption, data rate, call types, QoS, service price, etc., while, the inference engine deals with each subset of the fuzzy that are defined in HWNs. In addition, the inference engine makes use of the fuzzy based rules to perform RAT-selection decisions in HWNs. These fuzzy based rules only deal with “If then” rules. On the other hand, the defuzzifier is used to convert the output from the inference engine to a value that varies within the range of {0 to 1}. Therefore, the RAT with the highest output value is

then selected as the most preferred RAT amongst the available RATs in HWNs [11].

The disadvantage of the computational intelligence-based JCAC is the problem of high computational overheads in HWNs.

2.7 The Prerequisites of JCAC Algorithms in Heterogeneous Wireless Networks

In HWNs, the JCAC algorithms need to meet certain prerequisites before the most suitable RAT from a mobile terminal is selected among available RATs in HWNs. These prerequisites are shown in Figure 2.7 as: multiple-sessions QoS, simplicity, high-execution speed, efficiency, scalability and stability.

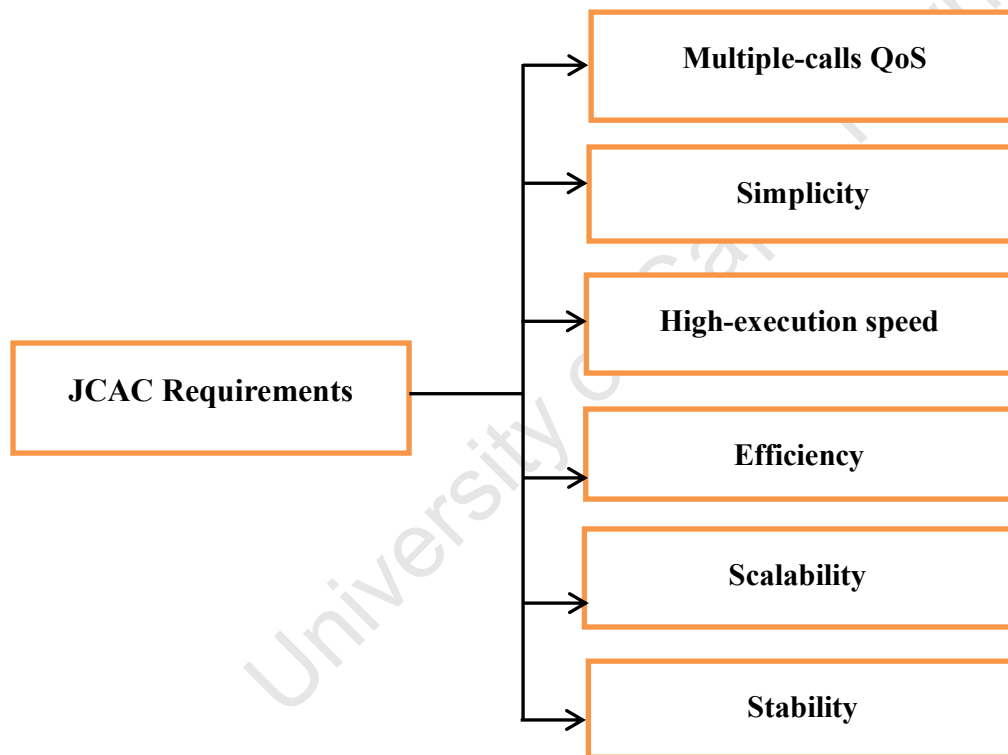


Figure 2.7: The Prerequisites of the JCAC Algorithm in HWNs.

2.7.1 Multiple-calls QoS

One of the important features of HWNs is to support groups of multiple-calls from any type of multi-homed device such as single-homed multi-mode and multi-homed multi-mode. Thus, supporting multiple-calls in HWNs will enhance the users' satisfaction with "always best connected" ubiquitous services and increase the operators' and service providers' revenue. Therefore, JCAC algorithms need to support multiple-calls from any type of multi-

homed device.

2.7.2 Simplicity

To a certain extent, the type of JCAC algorithm used in HWNs determines the radio resource utilization. Therefore, a simple algorithm will have a low computational overhead and therefore may not incur additional delay in the network. However, a simple algorithm may compromise the QoS requirements for multiple-calls from a single-homed multi-mode terminal [4]. On the other hand, a sophisticated JCAC algorithm will not compromise the QoS requirements necessary to support multiple-calls from a single-homed multi-mode terminal in HWNs, especially in a scenario where users are dynamically roaming across different access networks. This implies that there is a tradeoff between the simplicity and the efficiency of JCAC algorithms [4].

2.7.3 High-execution Speed

In HWNs, the JCAC algorithms are expected to execute the network operations in the shortest possible time. Therefore, the execution speed of multiple-calls should be fast and prompt at all times so as to avoid unnecessary delay in HWNs [4]. The high-execution speed of the JCAC algorithm is expected to enhance the QoS and the users' satisfaction for subscribed services in HWNs.

2.7.4 Efficiency

In HWNs, efficiency is a measure of how a particular JCAC algorithm performs with respect to RAT-selection criteria in HWNs. The performance level of each of the JCAC algorithms in HWNs varies from one algorithm to another for RAT-selection. Therefore, operators and service providers must select a suitable JCAC algorithm selected for RAT-selection in order to enhance the QoS, the users' satisfaction and the overall system utilization in HNWs.

2.7.5 Scalability

The need to expand the overall system capacity for high consuming bandwidth services such as video-on-demand and video streaming over a communication channel may require the use of a suitable JCAC algorithm. In HWNs, a JCAC algorithm needs to be flexible and

accommodate increase in capacity of individual RATs [5].

2.7.6 Stability

The robustness of a good network can be measured through its performance (i.e., the overall system utilization, and throughput) based on the type of JCAC algorithm used. These performance metrics may be used to determine the overall stability performance of a network. However, using an inappropriate JCAC scheme may result in unbalanced distribution of the traffic load amongst available RATs in HWNs, and therefore cause a particular RAT being overloaded [4].

2.8 Next Generation Mobile Terminals (Terminal Heterogeneity)

The mobile terminals in NGWNs are heterogeneous, in which different modalities interfaces are embedded to support one, two or more classes of calls in HWNs [31]. In addition, the multi-mode terminals have the capabilities to perform intelligent RAT-selection and dynamically reconfigure without receiving assistance or support from the users. This makes it unique compared to the single interface terminal [5]. In the next subsection the classifications of mobile terminals in NGWNs will be explained in detail.

2.8.1 Classification of Mobile Terminals Capabilities

As aforementioned, mobile terminals' capabilities can be classified into two general modes i.e., single-mode and multi-mode [5], [35]. A single-mode mobile terminal is essentially single-homed while a multi-mode terminal can be single-homed or multi-homed. Both single-mode and multi-mode mobile terminals have some advantages and disadvantages when used in HWNs [35]. A multi-mode mobile terminal is regarded as a single-homed terminal if it can connect to only one RAT at a time, even though it has multiple interfaces to support more than one RAT in an HWN.

Similarly, a mobile terminal is referred to as a multi-homed terminal if it can connect to more than one RAT at the same time. Examples are dual-homed (i.e., can connect to two networks simultaneously), triple-homed (i.e., can connect to three networks simultaneously) or quad-homed (i.e., can connect to four networks simultaneously) in HWNs [5].

2.9 Related Works on RAT-selection in Heterogeneous Wireless Networks

In literature, a number of schemes have been proposed for making RAT-selection decisions in HWNs [6, 7, 11, 12, 29, 36, 37, 39, 40, 41, 42, 43, 44]. These schemes have been primarily designed for making RAT-selection decisions for a single call from a mobile terminal in HWNs. For example, Lahby et al. [6] studied five weighted schemes, namely AHP, the fuzzy analytic hierarchy process (FAHP), analytical network process (ANP), fuzzy analytical network process (FANP) and random weighting (RW) for RAT-selection. These schemes were compared using four traffic classes, namely conversational, background, interactive and streaming. A MATLAB simulation tool was used to analyze the results. The results showed that TOPSIS based ANP outperformed the other chosen schemes in terms of ranking abnormalities for conversational, background, interactive and streaming traffic in an HWN. Moreover, the results obtained also showed that the least performed was the RW technique among the five weighed schemes for making a RAT-selection for a single call in an HWN. However, this framework is not suitable for making a RAT-selection for multiple-calls from a single-homed multi-mode terminal in an HWN, because of its inability to solve the group decision problem of different QoS for multiple-calls in HWNs. Moreover, selection of RATs for multiple-calls using a single-homed multi-mode terminal and consensus-based model was not considered.

Maaloul et al. [7] proposed a modification to an existing RAT-selection scheme called Enhanced-Simple Additive Weighting (E-SAW) for ranking different RATs in HWNs. The scheme was designed to rank six candidate RATs, in order to determine the most suitable RAT that satisfies the minimum required QoS for user applications. The focus of the proposed scheme was to avoid the processing delay caused by unnecessary handover decisions for a single call in HWNs. This is because unnecessary handover decisions affect the network performance and the QoS perceived by end users. However, the authors' framework is not suitable for making RAT-selection decisions for a group of handoff calls from a single-homed multi-mode terminal in HWNs, because of its inability to solve the group decision problem of different QoS for multiple-calls in HWNs.

Ahmed et al. [12] proposed a context-aware handoff decision scheme using multiple-criteria for decision-making in an HWN. The scheme was designed for making RAT-selection for a single call from a mobile terminal. The proposed scheme is not suitable for making RAT-

selection decisions for multiple-calls as well because of its inability to address the group decision problem of different QoS for multiple-calls from a single-homed multi-mode terminal in HWNs.

Martinez-Morales et al. [29] presented the performance of seven vertical handoff schemes for making a RAT-selection decision for a single call in HWNs using the MADM technique such as SAW, MEW, VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR), GRA, weighted Markov chain (WMC), elimination and choice translating priority (ELECTRE) and TOPSIS. The authors' framework provided the basic understanding of the above-mentioned schemes using two user applications. These applications were voice call and multimedia connections. Additionally, the simulation results from authors' framework showed that SAW, VIKOR, ELECTRE, WMC and TOPSIS schemes were suitable for voice call connections compared to other chosen schemes because of low values of jitter and packet delay achieved for voice call in HWNs. Similarly, the simulation results also showed that the GRA and MEW schemes were more suitable for data connection compared to voice call connections. Therefore GRA and MEW would be the most preferred schemes for high bandwidth service. However, the simulation results obtained from the authors' framework are not suitable for making RAT-selection decision for multiple-calls from a single-homed multi-mode terminal because a single-homed multi-mode terminal can only be connected to one RAT at a time and each of the calls requires different provision for QoS connection levels. Therefore RAT-selection for multiple-calls is a group decision problem. In addition, the authors' framework did not consider the use of the consensus-based model for RAT-selection in HWNs.

Stevens-Navarro and Wong [36] proposed a comparative analysis of RAT-selection techniques for a single call using four existing vertical handoff decision schemes for RAT-selection in HWNs. The aim of the comparative analysis was to evaluate the performance of the selected schemes for RAT-selection. These schemes considered were multiplicative exponent weighting (MEW), simple additive weighting (SAW), the technique for order of preference by similarity to ideal solution (TOPSIS) and grey relational analysis (GRA). In addition, authors used the analytic hierarchy process (AHP) method to determine the relative importance of the assigned weights criteria. The results showed the performance of the four schemes for a single call. However, the comparison analysis only focused on RAT-selection for a single call in an HWN. Therefore, the comparison analysis is not suitable for multiple-calls from a single-homed multi-mode terminal because of its inability to solve the group decision problem of different QoS for multiple-calls in HWNs. As stated before, the problem

of RAT-selection for multiple-calls from a single-homed multi-mode terminal is a group decision problem, and therefore requires the use of group decision schemes.

Tran and Boukhatem [37] proposed a scheme named distance to ideal alternative (DIA). The proposed scheme is compared with multi-attribute decision making (MADM) schemes i.e., SAW, weighted product (WP), and TOPSIS in terms of ranking abnormalities of RATs for a single call in HWNs. The proposed scheme focused on the RAT-selection for a single call in HWNs. Moreover, the authors applied the scheme to solve the ranking abnormalities problems of RAT-selection in HWNs. Ranking abnormalities occur in a HWN when a number of RATs are removed from the list of candidate RATs, and this results in an alteration of the ranking preferences of the choice of RATs in HWNs. This means the initial RAT selected as the most suitable RAT is displaced by another RAT in the HWN. This could compromise the suitability of RATs for calls in terms of connection-level QoS in HWNs.

The results obtained show the DIA scheme outperformed other MADM decisions schemes (SAW, WP and TOPSIS) in terms of ranking abnormalities occurrence in HWNs. Moreover, the DIA scheme adopts the Manhattan distance (in the m -dimensional space) based on the positive and negative ideal attribute concepts. The Manhattan distance approach is relatively different from that of Euclidean distance, because it allows a change in distance when a particular RAT is being removed from the candidates list [38]. The positive ideal alternative (PIA) is the minimum distance to the positive ideal attribute. It also determines the appropriate RAT for single calls in HWNs, while the negative ideal alternative (NIA) is used to determine the maximum distance to the negative ideal attribute. However, the authors' framework did not consider the RAT-selection scheme for multiple-calls from a single-homed multi-mode terminal. Also, the use of the consensus-based model was not considered in HWNs as well.

Davalos et al. [39] proposed a new evaluation model based on the vertical handover algorithm (VHA) technique, using multi-criteria evaluations for RAT-selection for a single call. The performance of the proposed technique was measured using three parameters, namely number of handoffs, handoff delay and computational complexity. The analyses of the three parameters were based on a single call. However, the results obtained are not suitable for multiple-calls in HWNs, because of its inability to solve the group decision problem of different QoS for multiple-calls in HWNs. Moreover, the use of the consensus-based model was not considered as well for RAT-selection in HWNs.

Al Sabbagh et al. [40] proposed an intelligent hybrid power efficient RAT selection scheme. The scheme was referred to as a battery power saver. The proposed scheme worked by sorting available RATs based on individual RAT information obtained, using the IEEE P1900.4 protocol, and making RAT-selection decision for the incoming calls. The essence of the authors' framework was to improve users' satisfactions and as well, save the battery power life. In addition, the authors compared the proposed scheme with two existing schemes, namely the centralized and the distributed, to determine the effectiveness of the proposed scheme in terms of users' satisfactions for terminal battery consumption, new call blocking and vertical handover dropping probabilities. The simulation results showed that the proposed scheme outperformed the two existing schemes (i.e., centralized and distributed) in terms of dropping, blocking and users' satisfaction probabilities. Both the proposed and the distributed schemes had similar performance in terms of saving battery power compared to the centralized scheme. Furthermore, both schemes performed better than the centralized scheme. However, the simulation results obtained from the authors' framework are not suitable for selecting the most suitable RAT for multiple-calls handoff from a single-homed multi-mode terminal. This is because a single-homed multi-mode terminal can only be connected to one RAT at a time and each of the calls requires different QoS for connection levels in HWNs. Moreover, the authors' framework did not consider the use of a consensus-based model for RAT-selection for a group of handoff calls from a single-homed multi-mode terminal in HWNs.

Kafle et al. [41] proposed a scheme which uses the prediction of user mobility patterns to select a suitable RAT amongst available RATs in HWNs. These authors, formulated user satisfaction metrics using bandwidth utility and handoff latency in HWNs. The aim of the authors work is to ensure that user's satisfaction on subscribed services is achieved at all times in HWNs. The proposed scheme is used to predict the user's mobility pattern and call holding time in HWNs. In addition the proposed scheme determines all the available RATs that can serve the call request based on the user's current location in HWNs. Moreover, the proposed scheme also ensures that the available RATs are sorted in descending order of their bandwidth capacity. The RAT with highest bandwidth capacity is then selected as the most suitable RAT amongst available RATs for the new call or handoff call from a mobile terminal in HWNs. Therefore, the probability that the user moves from the RAT with highest bandwidth capacity is estimated based on the network layout and user's mobility pattern. Authors make use of probability to estimate the effective user satisfaction in HWNs. The

results obtained were compared with the bandwidth utility function of the next RAT on the candidate list in HWNs. If the user satisfaction from the use of the current RAT under consideration is larger than the utility function of the next RAT, the current RAT is selected as the suitable network. Otherwise, the next RAT on the list is chosen and the above procedure is repeated to find the RAT with optimal user satisfaction at all times in HWNs. However, the proposed scheme is not suitable for multiple-calls from a single-homed multi-mode terminal in HWNs, because of its inability to solve the group decision problem of different QoS for multiple-calls in HWNs. In addition, the authors' framework did not consider the use of the consensus-based model for RAT-selection for a group of handoff calls from a single-homed multi-mode terminal in HWNs.

Ali and Pierre [42] proposed a layer-based predictive JCAC scheme for overlaid HWNs. The proposed scheme accommodates an incoming call or handoff call into a particular layer (i.e., layer k). On the other hand, when the incoming call or handoff call is blocked in layer k due to unavailability of radio resources to accommodate the call, the scheme ensures that the call is admitted into the next lower layer and tries all the available layers in HWNs. However, when none of the available layers has enough resources to accommodate the call, the call will be blocked. In addition, the above authors consider a scenario where the proposed scheme is used to admit an incoming handoff call into a new cell within the current layer (i.e., layer k). On the other hand, if the handoff calls cannot be admitted into the current layer (k), the scheme attempts to admit the call into the next layer ($k-1$). The aim of the scheme is to minimize new call blocking probability while guaranteeing a hard constraint on handoff call dropping probability.

Moreover, the performance of the proposed scheme was evaluated using a trace driven simulation of a 24 hours call and mobility traffic of voice calls from SUMATRA (Stanford 33 University Activity TRAcEs). Also, three-RATs were considered (i.e., GPRS, UMTS, and WLAN) in HWNs. Furthermore, the authors compared the proposed scheme with that of the separate layer predictive CAC scheme (i.e., independent admission control among different RATs) in the same HWNs. The results obtained showed the proposed scheme improved the overall call blocking probability by about 97% when compared to the separate layer predictive CAC scheme. However, the proposed JCAC scheme can lead to highly-unbalanced loads among the three layers (RATs) considered. Also, the proposed scheme is not suitable for multiple-calls from a single-homed multi-mode terminal in HWNs, and the authors' framework did not consider the use of the consensus-based model for RAT-selection for a

group of handoff calls from a single-homed multi-mode terminal in HWNs.

Song et al. [43] proposed a service-based JCAC scheme for integrated WLAN/UMTS in HWNs, considering two types of services (i.e., voice call and data). The authors proposed that in an overlap coverage area, the proposed scheme should accommodate voice calls into the UMTS network; however, when there is no radio resource to accommodate the call in UMTS, the call is admitted into WLAN or else the voice call is blocked in HWNs. The main aims of the proposed scheme are to reduce the frequency of vertical handoff of the voice calls in the HWNs. Furthermore, the effectiveness of the proposed scheme was carried out using a numerical analysis to determine the performance of the proposed scheme when one WLAN access point (AP) is located in each UMTS cell. Also, effectiveness of the proposed scheme was compared with that of a “WLAN-first” JCAC scheme for RAT-selection in HWNs. The following performance metrics were used: (1) average percentage of time served by the UMTS network against user mobility measure and (2) average number of handoffs per voice call against a user mobility measure. The results obtained showed that under high user mobility, the proposed service-based JCAC scheme reduces the average number of handoffs per voice call to about 37% compared to the “WLAN-first” JCAC scheme. In addition, the results show the proposed scheme achieved up to 1.3 times of the “WLAN-first” scheme in terms of the percentage of time served by the UMTS network.

However, the authors proposed scheme is not suitable for RAT-selection of a group of multiple-calls from a single-homed multi-mode terminal in HWNs, because of its inability to solve the group decision problem of different QoS for multiple-calls in HWNs. Even at that, the authors' framework did not consider the use of a consensus-based model for RAT-selection for a group of handoff calls from a single-homed multi-mode terminal in HWNs likewise.

Melhem et al. [44] proposed a new hybrid approach that assists in making RAT selection decisions in HWNs. The proposed scheme is based on the approach that combines the benefit derived from the mobile terminal centric and the network-centric. The mobile terminal centric makes use of the periodically broadcast information from the network for making a RAT-selection decision and considers the user needs and preferences in HWNs. Additionally, it is envisioned in HWNs that the users' choice of preferences will contribute to the RAT-selection decision, making for a suitable RAT that is capable of providing adequate QoS to the subscribed services, while the network-centric is responsible to broadcast the appropriate and current state information status to all mobile terminals using the logical communication

channel (i.e., IEEE standard 1900.4) [45] to exploit the scarce radio resources effectively in HWNs. Furthermore, the authors presented two tuning policies to dynamically adjust the signal to the mobiles' information using the staircase and the slope tuning policies. The main purpose of the policies was to enhance resource utilization, and ensure that users derive maximum satisfaction for their subscribed services. The results showed the tuning policies enhanced network performance in terms of resource utilization, operational revenue and users' satisfaction compared to static scheme approach for RAT-selection in HWNs. However, the authors proposed scheme is not suitable for RAT-selection of a group of multiple-calls from a single-homed multi-mode terminal in HWNs. In addition, the authors' framework did not consider the use of the consensus-based model for RAT-selection for a group of handoff calls from a single-homed multi-mode terminal in HWNs.

Falowo and Chan [11] proposed a scheme for making RAT-selection decisions for multiple-calls in HWNs. The scheme used the modified TOPSIS group decision-making technique to select the most suitable RAT for the group of multiple-calls from a multi-mode terminal in HWNs. The proposed technique dealt with both single call and multiple-calls from a mobile terminal. However, the proposed scheme did not consider criteria sensitivities for a group of multiple-calls and the group decision problem of different QoS for multiple-calls in HWNs was not considered as well. Moreover, the scheme did not consider consensus level among multiple-calls in making RAT-selection decisions in HWNs.

In light of the above related work, there is a need to address the aforementioned gaps in the literature through the comparative analysis of candidate schemes that could be adapted for making RAT-selection decisions for multiple-calls in HWNs. Moreover, it is important to consider consensus level among multiple-calls in making RAT-selection decisions in HWNs. Thus, this dissertation focuses on these two issues.

2.10 Chapter Summary

This chapter has presented the background and literature review of mobile telecommunications technologies which includes the overview of the evolution of NGWNs, and particularly the key concepts on why a single RAT cannot meet the QoS requirements of all services at all times. The relevance of HWNs has been discussed, which includes the motivation and the issues to be addressed in HWNs.

Next, the radio resource management in HWNs has been discussed extensively, includes how to manage the joint pool of radio resources for the purpose of achieving optimal network

performance in the paradigm of "always best connected" of users' service request to the available RATs at all times, in any place. The classification of the radio resource management i.e. independent and joint radio resource managements were discussed as well. Furthermore, the JCAC algorithms prerequisites for selecting the most suitable RAT from a mobile terminal among available RATs in HWNs have been discussed.

The next generation mobile terminals have been discussed including the modalities interfaces, the classification of mobile terminal capabilities and their advantages for resource utilization in HWNs. Finally, related works on RAT-selection in HWNs have been explained in detail.

University of Cape Town

Chapter 3 Comparative Analysis of Multi-Criteria Group Decision-Making Schemes for Multiple-calls.

This chapter focuses on four candidate multi-criteria group decision-making schemes that could be adapted for making RAT selection decisions for multiple-calls in HWNs. It adapts the four schemes for use in HWNs, and then compares their performance.

3.1 Introduction

Existing RAT-selection schemes based on either single-criterion or multi-criteria are not suitable for making RAT-selection decisions for multiple-calls from a single-homed multi-mode terminal in HWNs [11, 12, 39, 40]. This is because each call in a group of multiple-sessions requires different levels of QoS.

To solve the RAT-selection decision problem, some modification needs to be made to the existing schemes. To do so, the use of MCGDM is considered for making RAT-selection decisions for a group of multiple handoff calls from a single-homed multi-mode terminal in HWNs. Thus, the MCGDM schemes differ from multi-criteria decision-making (MCDM) schemes for RAT-selection because they can solve the group decision problem, whereas MCDM schemes cannot [4].

In light of the above, MCGDM schemes require the following steps in making RAT-selection decisions for a group of multiple handoff calls in HWNs.

(1) Definition of RAT-selection Problem in HWNs

In HWNs, it is important to define the RAT-selection problems and give clear descriptions of the entities involved in RAT-selection decisions. The entities include: number of RATs, set of criteria, set of preferences, classes of calls, types of terminals, etc [1].

(2) Adequate Information on Capabilities of Available RATs

Adequate information on the capabilities of available RATs are important. This information is used in selecting the RAT that best offers the QoS requirements of a group of multiple-calls in HWNs.

(3) Assignment of Priority Weight

Assignment of priority weights to different classes of calls allows users to assign preferential

treatment to a particular call type (voice call) in a group of calls such as voice call, file download, and video streaming in HWNs. The essence of priority weights is to show the degree of significance and importance a user associate with a particular call [11].

3.2 RAT-selection Criteria in Heterogeneous Wireless Networks

In comparative analysis of the four candidate RAT-selection schemes adapted for making RAT-selection decisions for multiple-calls, five RAT-selection criteria namely service price, data rate, security, battery power-consumption and network delay are considered. These criteria are explained as follows [4].

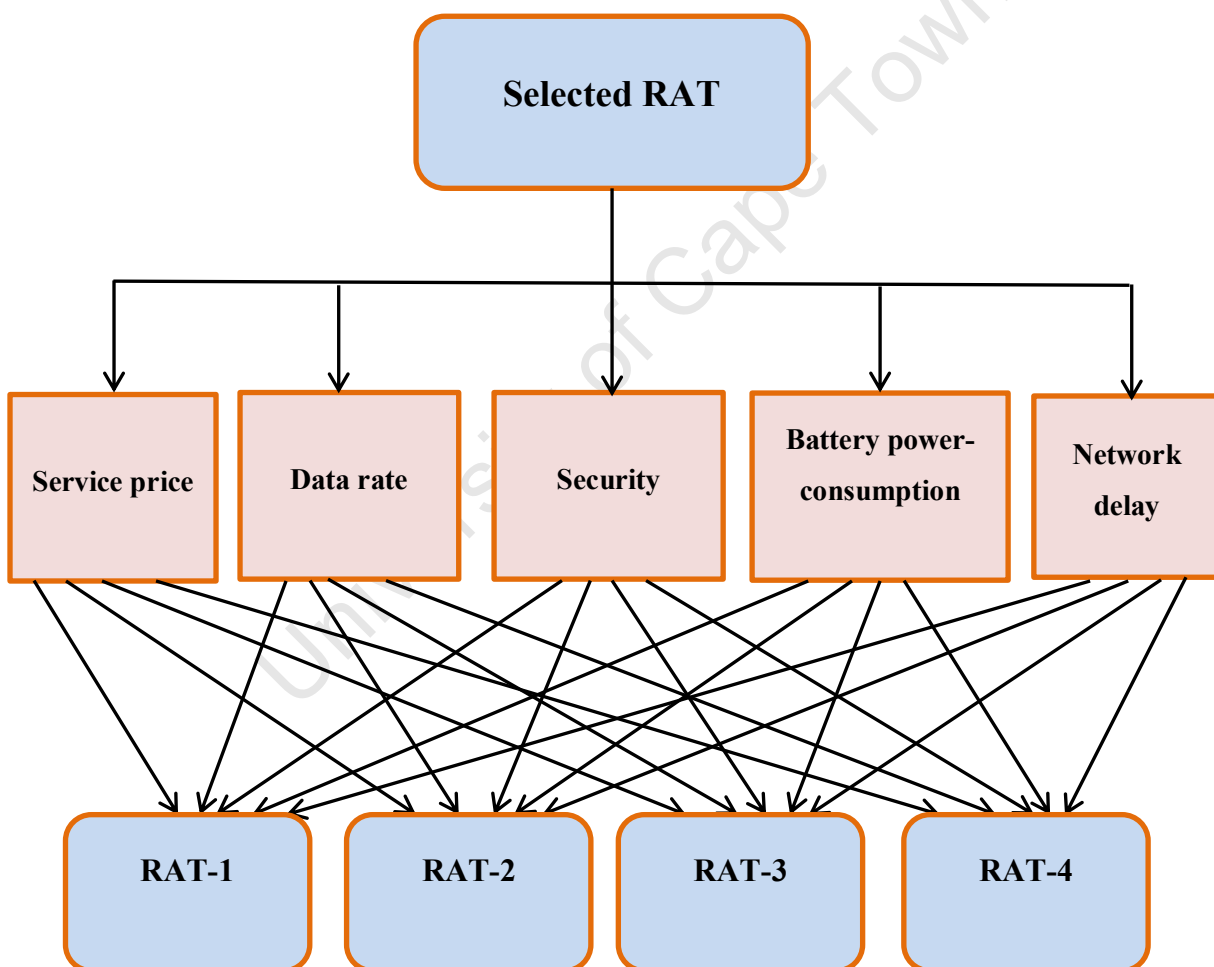


Figure 3.1: RAT-selection Connection of Multi-criteria to four candidate RATs in HWNs.

(1) **Service price:** This indicates the price the operators and the content providers charge on a particular service (call). Most often, if not all, users will prefer to select a RAT that offers the lowest price for their subscribed calls.

- (2) **Data rate:** This indicates the amount of bit rate a particular RAT can offer for a given class of service, such as voice call, video streaming, and file download. The data rate is measured in Kbps, Mbps and Gbps.
- (3) **Security:** This indicates the provisions and policies adopted by network administrators to monitor and prevent unauthorized access, modification, or denial of resources in a network.
- (4) **Battery power-consumption:** Is the energy consumption any terminal uses while accessing network services through a specific network. Furthermore, the energy consumption rate determines the battery life span of a mobile terminal (single-homing terminal or multi-homing terminal).
- (5) **Network delay:** Is the measure of the latency experienced while accessing the network resource for a given class of service, such as multimedia services in HWNs.

Some of the RAT-selection criteria in Figure 3.1 are specified with linguistic terms while others are not. For example, data rate criterion is specified using real numbers, while other criteria such as service price, security, battery power-consumption, and network delay are specified using five linguistic terms such as "very high, high, medium, low and very low". In addition, the linguistic terms denote the relative importance and scaling between criteria levels, and they play important roles in the performance of the mentioned MCGDM schemes in HWNs.

3.3 Multi-Criteria RAT-selection Problem Definition

This section describes the problem of RAT selection for multiple-calls from a single-homed multi-mode terminal in HWNs.

Consider a single-homed multi-mode terminal that needs to select the most suitable RAT among the n available RATs for a group of multiple handoff calls in a HWN based on a set of RAT-selection criteria. The RAT-selection problem can be expressed as follows:

Let R be a set of available RATs in a HWN; where $R = \{r_1, r_2, \dots, r_n\}$, ($n \geq 2$), and n is the maximum number of RATs (1)

Let C be a set of criteria; where C is given as: $C = \{c_1, c_2, \dots, c_h\}$, ($h \geq 2$) (2)

Let E be a set of services; where E is given as: $E = \{e_1, e_2, \dots, e_m\}$ ($m \geq 2$) (3)

Let D represent a decision matrix that performs the rating of the RAT R based on criteria C . Where $D = \{d_{i,j}\}$, for $i = \{1, \dots, n\}$ and $j = \{1, \dots, h\}$ (4)

Let W be a set of users' specified weights; where W represents the relative importance of each criterion c_m for each service and is given as:

$$W = \{W_{x,j}\}, x = \{1, \dots, m\}, j = \{1, \dots, h\} \quad (5)$$

When a single-homed multi-mode terminal, having multiple-calls, wants to make RAT-selection decisions in HWNs. The RAT-selection decisions are based on weight assigned to each of the criteria by the user.

For example, Table 3.1 shows the assignment of weights by a user to five RAT-selection criteria for four multiple-calls. The weights assigned to criteria can be based on the standard scales from (1-9). The weight assignment indicates how important the particular criterion is to user in making RAT-selection decisions for individual call. The scale point (1) represents the least important and scale point (9) represents the highest importance that can be assigned to a particular class of service.

Table 3.1: Example of Users' Specified Weights for Criteria per Service Class.

Criteria Service	Service price (c_1)	Data rate (mbps) (c_2)	Security (c_3)	Battery power-consumption (c_4)	Network delay (c_5)
Voice call	2	3	8	3	1
Video streaming	8	9	4	8	1
File download	4	7	5	4	1
Web browsing	3	8	6	7	1

In addition, the weights allocated to criteria in Table 3.1 are flexible, such that users can make changes to the already assigned weights for RAT-selection. The weight represents the relative importance of each RAT-selection criterion when a user is making a particular call or a group of calls from a single-homed multi-mode terminal. For instance, a user choice for network security may be very important for voice call, whereas the same user may consider network security for web browsing and file download as less important to him/her.

Some of the criteria are expressed in linguistic terms, and therefore need to be converted into crisp values for scaling between criteria levels. The following section describes the procedure

for linguistic terms conversion into crisp values.

3.4 Conversion of Linguistic Terms to Crisp Values

Table 3.2 shows the conversion of five linguistic terms (very low, low, medium, high and very high) to fuzzy values (0.0910, 0.2830, 0.5000, 0.7170 and 0.9090) respectively [46]. The linguistic term "very high" represents the highest performance preference, while "very low" represents the least performance preference for a given service (call) type in HWNs.

Table 3.2: User Service Scales.

Service Type Scale	Fuzzy Converted Number
Very Low (VL)	0.0910
Low (L)	0.2830
Medium (M)	0.5000
High (H)	0.7170
Very High (VH)	0.9090

The linguistic terms are converted to fuzzy numbers using a conversion scale as shown in Table 3.2. The fuzzy numbers are converted to crisp numbers using the relative user service scale [46]. These crisp numbers vary from 0 to 1. A fuzzy scoring scheme is utilized to convert each fuzzy number to a corresponding crisp value.

The next section describes the four adapted MCGDM schemes considered for making RAT-selection decision in HWNs. It also describes the procedures used to select a suitable RAT amongst available RATs in HWNs.

3.5 Adapted Multi-Criteria Group Decision-making and Procedures

This section explains four candidate MCGDM schemes i.e., SAW-GDM, MEW-GDM, TOPSIS-GDM, and DIA-GDM for making RAT-selection decision for a group of multiple handoff calls in HWNs. In literature, a number of schemes have been proposed for making RAT-selection decisions in HWNs. However, they are not suitable for making RAT-selection

decisions for multiple handoffs calls in HWNs because they are primarily designed for making RAT-selection decisions for a single call from a mobile terminal. The problem of RAT-selection for multiple-calls from a single-homed multi-mode terminal is a group decision problem. Therefore, the use of group decision-making schemes is required to solve the problem of making RAT-selection decisions for multiple handoffs calls from a single-homed multi-mode terminal in HWNs.

Even at that, the existing schemes could be adapted to MCGDM schemes for RAT-selection of a group of multiple handoff calls in HWNs. This study considers four schemes from the existing schemes (SAW, MEW, TOPSIS, and DIA) in literature, and adapts them for making RAT-selection decisions for a group of handoff calls from a single-homed multi-mode terminal in HWNs. The next section explains the four adapted MCGDM schemes considered for RAT-selection in HWNs.

3.5.1 Simply Additive Weighting-Group Decision-making

The SAW-GDM is one of the decision schemes used for RAT-selection in HWNs. The following steps are used by SAW-GDM to solve the group decision problem of RAT-selection of a group of handoff calls in HWNs as follows:

Step 1: Specify the user weight W for a set of services E from a single-homed multi-mode terminal for suitable RAT-selection in an HWN.

$$W = \{w_{x,j}\}, x = \{1, \dots, m\}, j = \{1, \dots, h\} \quad (6)$$

Next, the weight ratio (i.e., the normalized weight value) is computed (because criteria have different metrics) as follows:

$$\overline{W}_{x,j} = \frac{w_{x,j}}{\sum_{j=1}^h (w_{x,j})}, x = \{1, \dots, m\}, j = \{1, \dots, h\} \quad (7)$$

The normalized weighting \overline{W} represents equal metric for criteria and is given as:

$$\overline{W} = \{\overline{w}_{x,j}\}, x = \{1, \dots, m\}, j = \{1, \dots, h\} \quad (8)$$

Step 2: Aggregate the normalized weighting $\overline{w}_{x,j}$ for each criterion for different services $\{e_1, e_2, \dots, e_m\}$, ($m \geq 2$) to obtain a group weight per criterion from a single-homed multi-mode terminal.

$$g_t = \frac{1}{m} \sum_{x=1}^m \overline{w}_{x,j}, x = \{1, \dots, m\}, (t, j = 1, \dots, h) \quad (9)$$

Where x is the dimension of number of services and j the dimension of criteria. Then, the collective criterion for the group aggregated (g) is obtained as follows:

$$g = \{g_t\}, t = \{1, \dots, h\} \quad (10)$$

Step 3: Construct a decision matrix D for RAT R and criteria C .

$$D = \begin{matrix} & c_1 & c_2 & \dots & c_n \\ \begin{matrix} r_1 \\ r_2 \\ \vdots \\ r_n \end{matrix} & \begin{bmatrix} d_{11} & d_{12} & \dots & d_{1n} \\ d_{21} & d_{22} & \dots & d_{2n} \\ \vdots & \vdots & \dots & \vdots \\ d_{n1} & d_{n2} & \dots & d_{nn} \end{bmatrix} \end{matrix}$$

Note that the elements obtained from Table 3.2 and the decision matrix contain both linguistic terms and crisp values [11]. Table 3.3 shows the four services (multiple-calls) and their user assigned weights, for each selection criterion for handoff of multiple-calls in HWNs [11].

Table 3.3: RAT-selection Criteria for Handoff Multiple-calls.

Criteria Networks	Service price (c_1)	Data rate (mbps) (c_2)	Security (c_3)	Battery power-consumption (c_4)	Network delay (c_5)
RAT-1	Low	54	Low	Medium	High
RAT-2	High	7.5	Very High	High	Low
RAT-3	Medium	25	Medium	Very High	Very Low
RAT-4	Medium	15	High	High	Low

(b) From Table 3.3, the decision matrix D is obtained as:

$$D = \begin{matrix} & c_1 & c_2 & c_3 & c_4 & c_5 \\ \begin{matrix} r_1 \\ r_2 \\ r_3 \\ r_4 \end{matrix} & \begin{bmatrix} \text{Low} & 54.0000 & \text{Low} & \text{Medium} & \text{High} \\ \text{High} & 7.5000 & \text{Very High} & \text{High} & \text{Low} \\ \text{Medium} & 25.0000 & \text{Medium} & \text{Very High} & \text{Very Low} \\ \text{Medium} & 15.0000 & \text{High} & \text{High} & \text{Low} \end{bmatrix} \end{matrix}$$

The linguistic terms in the decision matrix are converted to crisp values as offered by Table 3.2.

$$D = \begin{matrix} & c_1 & c_2 & c_3 & c_4 & c_5 \\ \begin{matrix} r_1 \\ r_2 \\ r_3 \\ r_4 \end{matrix} & \begin{bmatrix} 0.2830 & 54.0000 & 0.2830 & 0.5000 & 0.7170 \\ 0.7170 & 7.5000 & 0.9090 & 0.7170 & 0.2830 \\ 0.5000 & 25.0000 & 0.5000 & 0.9090 & 0.0910 \\ 0.5000 & 15.0000 & 0.7170 & 0.7170 & 0.2830 \end{bmatrix} \end{matrix}$$

Step 4: Construct the normalized decision matrix \overline{DM} for each element $d_{i,u}$ using the "Maximum" method [29].

- For benefit criteria; $\overline{DM}_{i,j}$ is normalized as follow:

$$\overline{DM}_{i,j} = d_{i,u} / \max\{d_{i,u} \mid i = \{1, \dots, n\}; u, j = \{1, \dots, h\}\} \quad (11)$$

- For cost criteria; $\overline{DM}_{i,u}$ is normalized as follow:

$$\overline{DM}_{i,j} = \min\{d_{i,u} \mid i = \{1, \dots, n\}; u, j = \{1, \dots, h\}\} / d_{i,u} \quad (12)$$

Step 5: Aggregate the normalized decision matrix \overline{DM} and the group-weighting vector g to obtain the weighted normalized decision matrix V , which is given as:

$$v_{i,u} = g_t * \overline{DM}_{i,j} \quad \forall i \in \{1, \dots, n\}; j, t, u \in \{1, \dots, h\} \quad (13)$$

$$V = \begin{matrix} & c_1 & c_2 & \dots & c_h \\ \begin{matrix} r_1 \\ r_2 \\ \vdots \\ r_n \end{matrix} & \begin{bmatrix} v_{11} & v_{12} & \dots & v_{1h} \\ v_{21} & v_{22} & \dots & v_{2h} \\ \vdots & \vdots & \dots & \vdots \\ v_{n1} & v_{n2} & \dots & v_{nh} \end{bmatrix} \end{matrix}$$

Step 6: Compute the score (S_i) of each RAT r_i as follows:

$$S_i = \sum_{u=1}^h v_{i,u}; \text{ for } i \in \{1, \dots, n\}, u \in \{1, \dots, h\} \quad (14)$$

Step 7: The RAT R with the highest score S_i value is then selected as the most suitable RAT for a group of multiple-calls from a single-homed multi-mode terminal in HWNs.

$$SAW - GDM^* = \max_{i=1}^n S_i \quad (15)$$

3.5.2 Multiplicative Exponent Weighting-Group Decision-making

The MEW-GDM is another scheme used to solve the group decision problem for RAT selection in HWNs. To do so, the following steps describe the procedures of the MEW-GDM scheme as follows:

Step 1: Specify the user weight and determine the normalized weight value using equations (6-8).

Step 2: Determine the group aggregate weighting vector g for each criterion using equations (9-10).

Step 3: Construct a decision matrix as offered by Table 3.3.

Step 4: Obtain the normalized decision matrix \overline{DM} using equations (11-12).

Step 5: Construct the weighted normalized matrix V (i.e., the group aggregated weighted vector) for each criterion and exponent the normalized decision matrix \overline{DM} as follows:

$$v_{i,u} = (\overline{DM}_{i,u})^{g_t}, \forall i \in \{1, \dots, n\}; t, u \in \{1, \dots, h\} \quad (16)$$

Step 6: Compute the score (P_i) of each RAT r_i as follows:

$$P_i = \prod_{u=1}^h v_{i,u}, \forall i \in \{1, \dots, n\}, u \in \{1, \dots, h\} \quad (17)$$

Step 7: Select RAT R with the highest score P_i value as the most suitable RAT for a group of multiple-calls from a single-homed multi-mode terminal in HWNs.

$$MEW - GDM^* = \max_{i=1}^n P_i \quad (18)$$

3.5.3 Technique for Order Preference by Similarity to Ideal Solution-Group Decision making

The following steps are used for RAT-selection using TOPSIS-GDM scheme for selecting the most suitable RAT in HWNs as follows:

Step 1: Determine the user weight and the normalized weight value using equations (6-8).

Step 2: Determine the group of handoff calls aggregate weighting vector g for each criterion using equations (9-10).

Step 3: Construct a decision matrix as offered by Table 3.3.

Step 4: Construct the normalized decision matrix as follows:

$$\overline{DM} = \frac{d_{i,u}}{\sqrt{\sum_{i=1}^n (d_{i,u})^2}}, i = \{1, \dots, n\}, u = \{1, \dots, h\} \quad (19)$$

Step 5: Construct the weighed normalized decision matrix using equation (13).

Step 6: Determine the positive ideal solution (A^+) and the negative ideal solution (A^-) for (V_u), where (h') and (h'') represents benefit and cost criteria.

$$A^+ = [v_1^+, v_2^+, \dots, v_h^+] \text{ and } A^- = [v_1^-, v_2^-, \dots, v_h^-] \quad (20)$$

- **For benefit criteria is given as:**

$$V^+ = [v_1^+, v_2^+, \dots, v_h^+] \quad (21)$$

$$V^+ = \left\{ \left(\max_{i \in n} v_{i,u} \mid u \in h' \right), \left(\min_{i \in n} v_{i,u} \mid u \in h'' \right) \right\} \quad (22)$$

- **For cost criteria is given as:**

$$V^- = [v_1^-, v_2^-, \dots, v_h^-]. \quad (23)$$

$$V^- = \left\{ \left(\min_{i \in n} v_{i,u} \mid u \in h' \right), \left(\max_{i \in n} v_{i,u} \mid u \in h'' \right) \right\} \quad (24)$$

Step 7: Calculate the similarity distance S_j^* and S_j^- .

$$S_j^* = \sqrt{\sum_{i=1}^h (v_{i,u} - v_i^+)^2}, i = \{1, \dots, n\}, u = \{1, \dots, h\} \quad (25)$$

and;

$$S_j^- = \sqrt{\sum_{i=1}^h (v_{i,u} - v_i^-)^2}, i = \{1, \dots, n\}, u = \{1, \dots, h\} \quad (26)$$

Step 8: Compute the closeness coefficient $TOPSIS - GDM^*$ of each RAT R as given.

$$TOPSIS - GDM^* = \frac{S_j^-}{(S_j^- + S_j^*)}, \forall j = \{1, \dots, n\} \quad (27)$$

Therefore, RAT R with the highest $TOPSIS - GDM^*$ value is select as the most suitable RAT for a group of multiple-calls from a single-homed multi-mode terminal in HWNs.

3.5.4 Distance to the Ideal Alternative-Group Decision-making

The DIA-GDM scheme is also used to solve the group decision problem for RAT-selection in HWNs and the steps are discussed as follows:

Step 1: Specify the user weight and determine the normalized weight value using equations (6-8).

Step 2: Determine the group aggregate weighting vector g for each criterion using equations (9-10).

Step 3: Construct a decision matrix as offered by Table 3.3.

Step 4: Construct the normalized decision matrix using equation (19).

Step 5: Construct the weighed normalized decision matrix using equation (13).

Step 6: Determine the positive ideal solution A^+ and the negative ideal solution A^- for $v_{i,u}$. Where h' and h'' represent benefit and cost criteria using equations (20-24).

Step 7: Calculate the Manhattan distance to the positive ideal value M_j^* and negative ideal value M_j^- criteria.

$$M_j^* = \sum_{i=1}^n |v_{i,u} - v_i^+|, i = \{1, \dots, n\}, u = \{1, \dots, h\} \quad (28)$$

and

$$M_j^- = \sum_{i=1}^n |v_{i,u} - v_i^-|, i = \{1, \dots, n\}, u = \{1, \dots, h\} \quad (29)$$

Step 8: Determine the DIA minimum value for the positive ideal alternative (M^*) and maximum value for the negative ideal alternative (M^-).

$$\min M^* = \min M_j^* = \min_j \sum_{i=1}^n |v_{i,u} - v_i^+| \quad (30)$$

and;

$$\max M^- = \max M_j^- = \max_j \sum_{i=1}^n |v_{i,u} - v_i^-| \quad (31)$$

Step 9: Calculate the absolute distance of RAT R to the positive ideal alternative.

$$DIA - GDM^* = \sqrt{(M_j^* - \{\min M^*\})^2 + (M_j^- - \{\max M^-\})^2} \quad (32)$$

Note that RAT R with the smallest $DIA - GDM^*$ value has the shortest distance to the

positive ideal alternative and is therefore selected as the most preferred RAT for the group of multiple-calls in HWNs.

3.6 Numerical Simulations and Results

This section discussed the results obtained from the numerical simulation of the four candidate MCGDM schemes, namely SAW-GDM, MEW-GDM, TOPSIS-GDM and DIA-GDM using the MATLAB simulation tool. Different user specified weight levels are considered for individual call criterion. The simulation results of the four adapted MCGDM schemes are analyzed. The analysis shows the sensitivities of individual candidates for the MCGDM scheme, as well as how the range of users' specified weight levels (i.e., 1 to 9) affects the RAT-selection choice for a group of multiple-calls. In addition, the analysis shows how the multiple-calls are distributed amongst RATs in HWNs.

Table 3.4 shows the possible range of weights values (i.e., five user assigned weights) that can be assigned to the RAT-selection criteria for the group of calls in HWN.

Table 3.4: User Assigned Weights.

User specified weights	1	3	5	7	9
-------------------------------	---	---	---	---	---

The HWNs consists of four RATs (RAT-1, RAT-2, RAT-3 and RAT-4) out of which the most suitable RAT is to be selected for each group of handoff calls. In addition, the sensitivity of each of the RAT-selections for the four adapted MCGDM schemes with respect to each criterion is examined and analyzed.

Furthermore, 100 groups of multiple handoff calls are considered in the simulations, and each group consists of four classes of handover calls, namely voice call, video streaming, file download and web browsing. Each of the classes of active call is assigned a weight for each of the five RAT-selection criteria, namely service price, data rate, security, battery power-consumption, and network delay.

For a particular group of calls, the weight assigned to the criterion whose sensitivity is to be analyzed is varied from 1 to 9, whereas the weights assigned to the remaining criteria are kept constant for the group of handoff calls. These weights assigned to remaining criteria are randomly generated for each group of calls.

The aim of the scenario is to investigate how the users' weights specified for a particular

criterion affect RAT selection decisions and load distribution pattern for a group of multiple-calls in HWNs. In NGWNs, users will have the right to dictate what they want from the network; therefore users can specify different weight values for different criteria. The value of a particular criterion weight depends on the importance of the criterion to individual users for different classes of service (call).

The results obtained from the sensitivity analysis of the adapted schemes for each criterion are given in the following subsection 3.6.1.

3.6.1 RAT-selection Sensitivity Analysis

Figures 3.2 to 3.6 show the analysis of the adapted MCGDM schemes sensitivity for the five selected criteria in selecting the most suitable RAT for a group of multiple handoff calls from a single-homed multi-mode terminal in a HWN.

Figure 3.2 presents the results obtained by implementing the schemes on service price (criterion-1). The analysis indicates that TOPSIS-GDM and DIA-GDM schemes give a relatively uniform distribution for the multiple handoff calls across the RATs in HWNs over the assigned weights, while for the other two schemes SAW-GDM and MEW-GDM the distributions are not uniform.

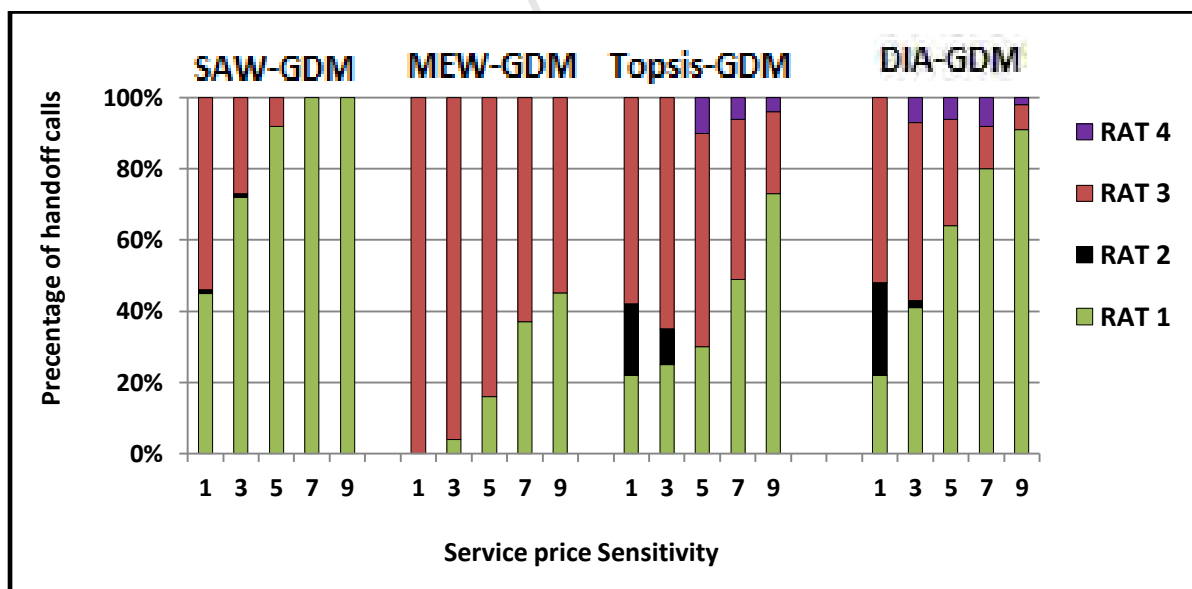


Figure 3.2: Service price Sensitivity on RAT-selection for Multiple-calls in HWNs.

It can be seen from the results in Figure 3.2 that, despite different weights allocated, TOPSIS-GDM and DIA-GDM schemes are less-sensitive to the change in scale of measurement, while SAW-GDM and MEW-GDM schemes are more influenced by the weight scaling. For

example, it can be seen that the MEW-GDM scheme assigns almost 100 percent of handoff calls to RAT-1 at the lowest weight value (1), and at the highest weight value (9); it assigns about 55 percent of handoff calls to RAT-3, whereas the remaining 45 percent of the handoff calls are assigned into RAT-1.

Moreover, Figure 3.2 shows that the distributions of the 100 groups of handoff calls for RAT-selection have similar pattern for TOPSIS-GDM and DIA-GDM schemes, compared to that of the SAW-GDM and MEW-GDM schemes.

Figure 3.3 depicts the sensitivity of the implemented schemes on data rate (criterion-2) for the groups of multiple handoff calls in HWNs. The distribution patterns of the group of calls among the four available RATs are similar for TOPSIS-GDM and DIA-GDM schemes while SAW-GDM and MEW-GDM schemes are not, especially when the weight attached to data rate is very low.

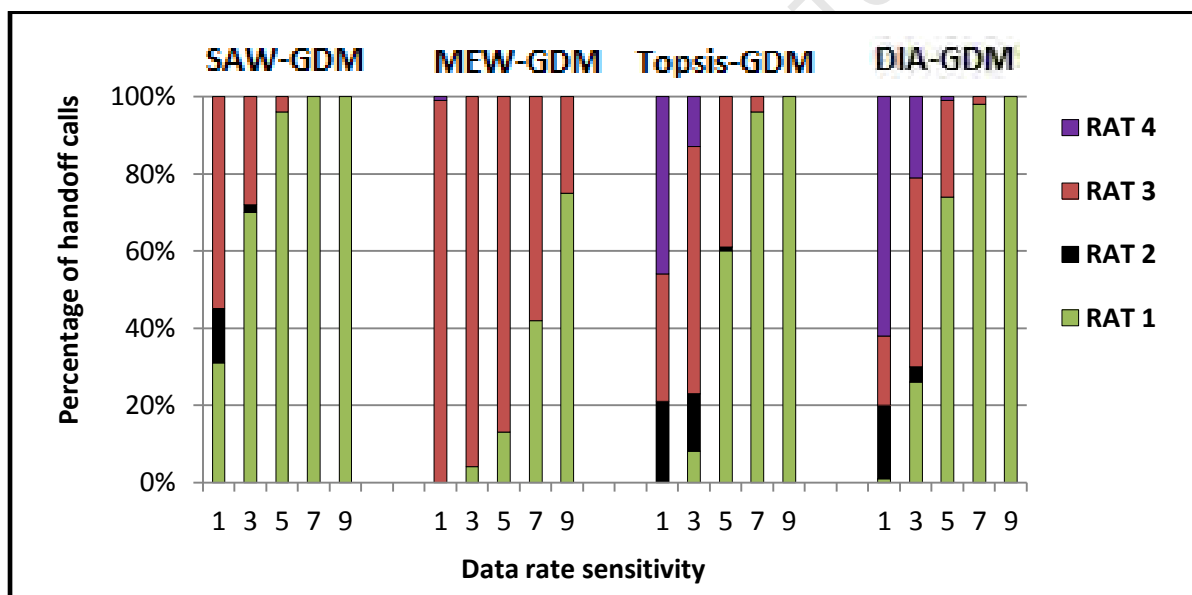


Figure 3.3: Data rate Sensitivity on RAT-selection for Multiple-calls in HWNs.

In Figure 3.4, the results obtained by implementing the adapted schemes on security (criterion-3) also show a fair distribution pattern of multiple handoff calls across the MCGDM schemes when the assigned weight value is seven, except for the MEW-GDM scheme. The MEW-GDM scheme assigned almost 98 per cent of the handoff calls into RAT-3.

Even at that, it can be seen that TOPSIS-GDM and DIA-GDM schemes distribute the 100 handoff calls uniformly across the RATs in an effective manner compared to that of SAW-GDM and MEW-GDM schemes, particularly as the assigned weights increase from very low

to very high (i.e., 1 to 9) in HWNs.

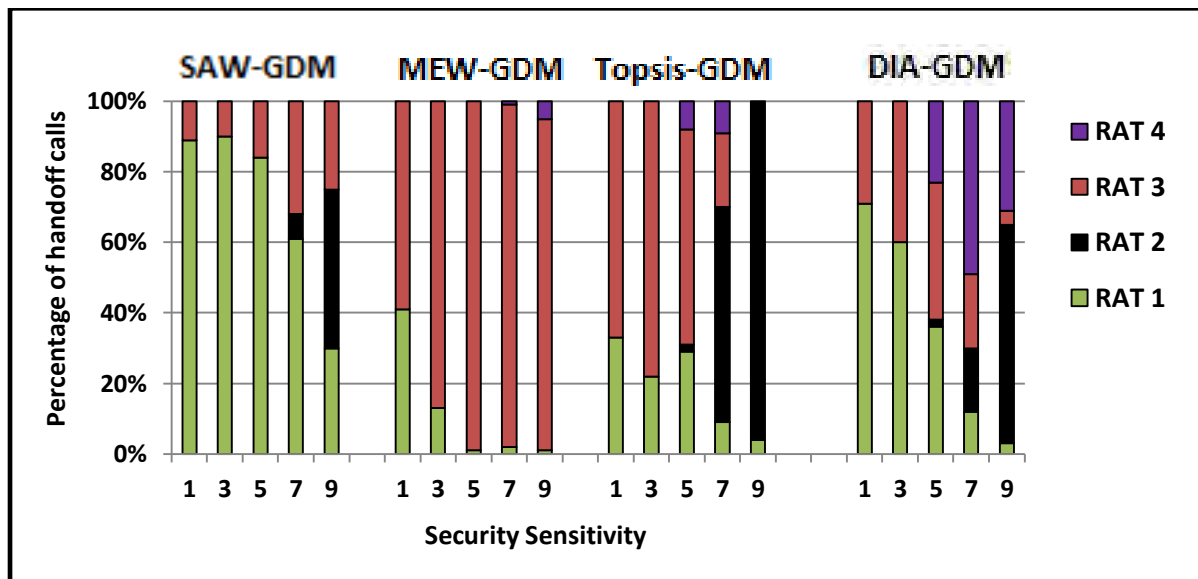


Figure 3.4: Security Sensitivity on RAT-selection for Multiple-calls in HWNs.

Therefore, the SAW-GDM and MEW-GDM schemes may cause a particular RAT in HWNs to be overloaded because almost the entire handoff calls are accommodated into a single RAT, while other RATs are under-utilized in HWNs.

Figure 3.5 depicts the results obtained by implementing the adapted MCGDM schemes on battery power consumption (criterion-4).

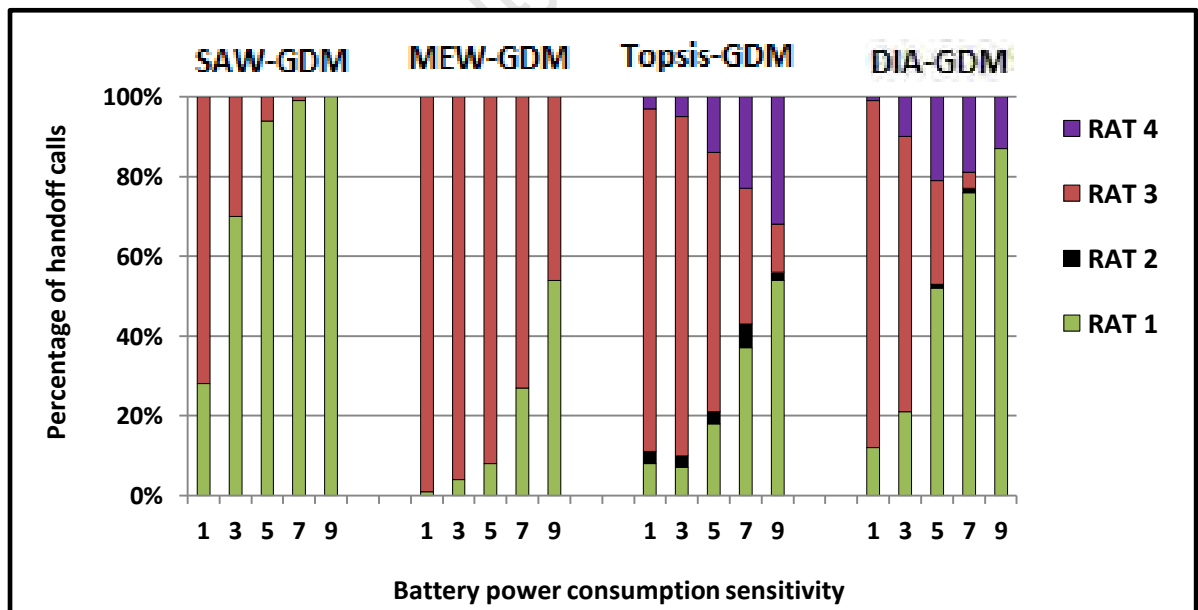


Figure 3.5: Battery Power-consumption Sensitivity on RAT-selection for Multiple-calls in HWNs.

In Figure 3.5, it can be seen that TOPSIS-GDM and DIA-GDM schemes gave a slightly

uniform distribution of the handoff calls as the assigned weight value increases from 1 to 9 across the four RATs, whereas SAW-GDM and MEW-GDM schemes distribute the handoff calls into two RATs in HWNs.

The uniform distribution of the handoff calls into the four RATs prevents a single-RAT to be over-loaded in HWNs. In addition, as the assigned weight levels change, TOPSIS-GDM and DIA-GDM schemes are less-sensitive in accommodating a certain percentage of the handoff calls across the four RATs in HWNs. Also, Figure 3.5 shows that weights attached to battery power consumption, to some extent, determine the RATs selected for the groups of handoff calls in HWNs.

Figure 3.6 illustrates the results obtained by implementing the adapted MCGDM schemes on network delay (criterion-5) for RAT-selection using a single-homed multi-mode terminal for the groups of handoff calls in the HWNs.

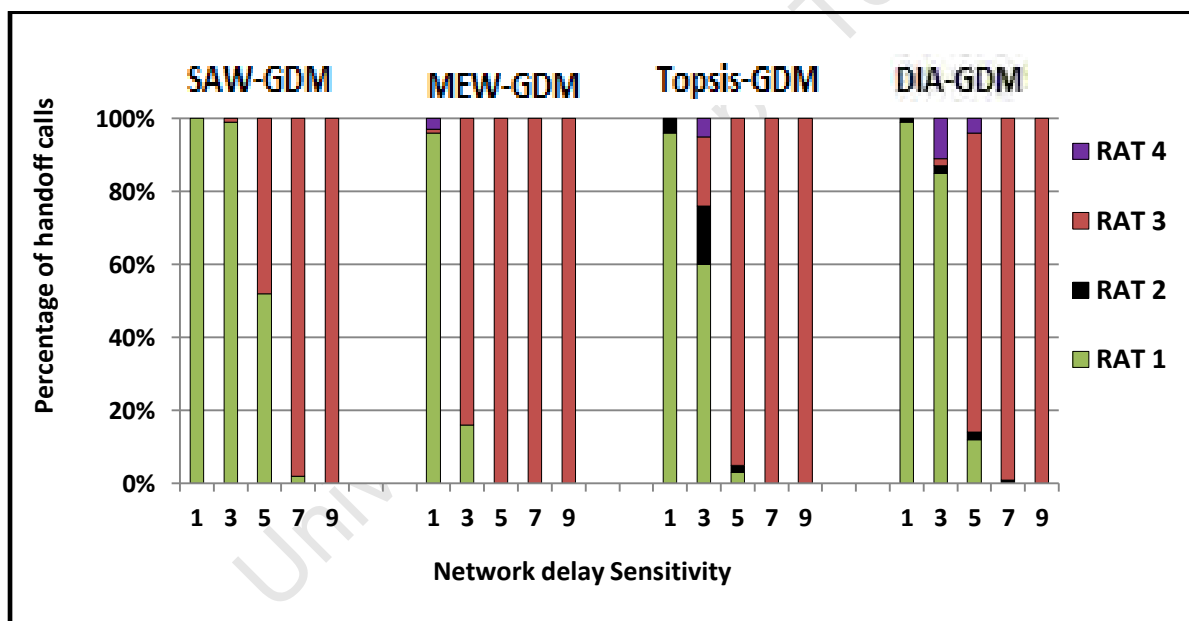


Figure 3.6: Network delay Sensitivity on RAT-selection for Multiple-calls in HWNs.

It can be seen in Figure 3.6 that all the adapted schemes mostly selected RAT-1 as the most suitable RAT, when the assigned weight attached to the delay is very low (i.e., 1). As the weight value increases from (3 to 5), the distribution pattern of multiple handoff calls across the RATs changes for both TOPSIS-GDM and DIA-GDM schemes compared to the SAW-GDM and MEW-GDM schemes. In addition, when the weight attached to criterion-5 is very high, the most preferred RAT is RAT 3 for all the adapted MCGDM schemes.

3.7 Chapter Summary

This chapter has evaluated and compared the performance of four candidate MCGDM schemes for RAT-selection for 100 groups of multiple handoff calls from a single-homed multi-mode terminal in HWN. It first describes the RAT-selection decisions for a group of handoff calls from a single-homed multi-mode terminal and highlighted the five chosen user preference criteria for RAT-selection in HWNs. Four adapted MCGDM schemes (SAW-GDM, MEW-GDM, TOPSIS-GDM and DIA-GDM) are considered for RAT-selection in HWNs.

The numerical simulation results have been discussed to identify the pros and cons of the four adapted candidate MCGDM schemes to solve the group decision problem of multiple-calls. The numerical simulation results show how the users' weights specified for a particular criterion affects RAT selection decisions in HWNs. The results indicate that TOPSIS-GDM and DIA-GDM schemes are more suitable for making multiple handoff calls than the SAW-GDM and MEW-GDM schemes because they give consistent results across all the five chosen sensitivities criteria.

Chapter 4 Consensus RAT-selection Scheme for Making RAT-selection Decisions for Multiple Handoff calls in Heterogeneous Wireless Networks

4.1 Introduction

The previous chapter compares the performance of four adapted MCGDM schemes for making a RAT-selection decision for a group of handoff calls from a single-homed multi-mode terminal in a HWN, based on five chosen criteria.

In this chapter, a new scheme is proposed to solve the group decision problem for multiple-calls from a single-homed multi-mode terminal in HWNs. The proposed scheme, named the consensus RAT-selection scheme, selects the most suitable RAT that offers the QoS requirements for multiple handoff sessions in HWNs, and it handles the issue of disparity of QoS requirements for multiple-calls. It uses a coherent group decision method to combine all requirements into collective QoS, before selecting the RAT that best satisfies the collective agreements (QoS requirements) of multiple-calls from a single-homed multi-mode terminal in HWNs [47].

Furthermore, in RAT-selection decision-making, preference relations are the most common representations format used to represent call criteria in the form of linguistic terms, such as very high, medium and low in HWNs. This is because linguistic terms are related to human perception and as well, aid users to express their opinions and desires, which may be subjective, imprecise and vague when selecting a preference for classes of calls. Users find it easier and natural to use words in ordinary language (linguistic terms) rather than using numerical values to express their opinions [47], [48]. In addition, the new scheme is based on symbolic computation and it works by utilizing the fuzzy preference relation to reach consensus among the group of multiple handoff calls in HWNs [47], [49], [50].

In view of the above, consensus RAT-selection is also proposed for selecting a subset of a group of multiple-calls during handoff, when none of the candidate RATs has enough capacity to accommodate the entire group of handoff calls. Lastly, the performance of the proposed scheme is evaluated using numerical simulations, and results obtained are presented. Results show the effectiveness of the consensus RAT-selection scheme for selecting a RAT for a group of handoff calls from a single-homed multi-mode terminal in

HWNs. The following section explains the concepts used in the consensus RAT-selection scheme in HWNs.

4.2 Consensus RAT-selection Scheme Concepts for RAT-selection in Heterogeneous Wireless Networks

The consensus RAT-selection scheme consists of two distinct aspects namely, the consensus degrees and the proximity measures [49]. In HWNs, the consensus degree is used to determine the RAT that best offers the highest level of QoS requirements for a group of multiple-calls. The proximity measure ensures that criteria use for RAT-selection satisfy the minimum criterion threshold (β), before the consensus decisions for a suitable RAT is agreed upon by the group of handoff calls in HWNs. Therefore, the proximity measures play major roles to ensure/guarantee that the selected RAT is capable of supporting the entire group of multiple-calls. Furthermore, the proximity measures also ensure that the QoS is not compromise in HWNs.

To do so, an agent system (decision module) is required to coordinate the proximity measures. For example, Figure 4.1 shows the flow chart of the consensus RAT-selection scheme decisions, as well as how the decision module in HWNs guides the assignments of the user's preferences.

The decision module ensures that the minimum criterion threshold (β) is achieved at all times before selecting the most suitable RAT amongst available RATs for a group of multiple-calls in HWNs.

However, when the minimum criterion threshold (β) is not met, the decision module is triggered to advice and guides the affected call to change its criterion accordingly. The preference change is performed, using the following two rules as follows:

Rule 1: if $pa_i^h \geq \beta$, then do not change the assigned user linguistic preference.

Rule 2: if $pa_i^h < \beta$, then increase and select the next user linguistic preference.

The reason why the entire criteria for RAT-selection must satisfy the minimum criterion threshold (β) is to guarantee that the selected RAT will provide the QoS requirements for the group of multiple-calls at all time in HWNs.

Apparently, the aforementioned processes (the consensus degrees and the proximity measures) are useful and necessary in addressing the RAT-selection problem using consensus

RAT-selection scheme in HWNs [49], [51].

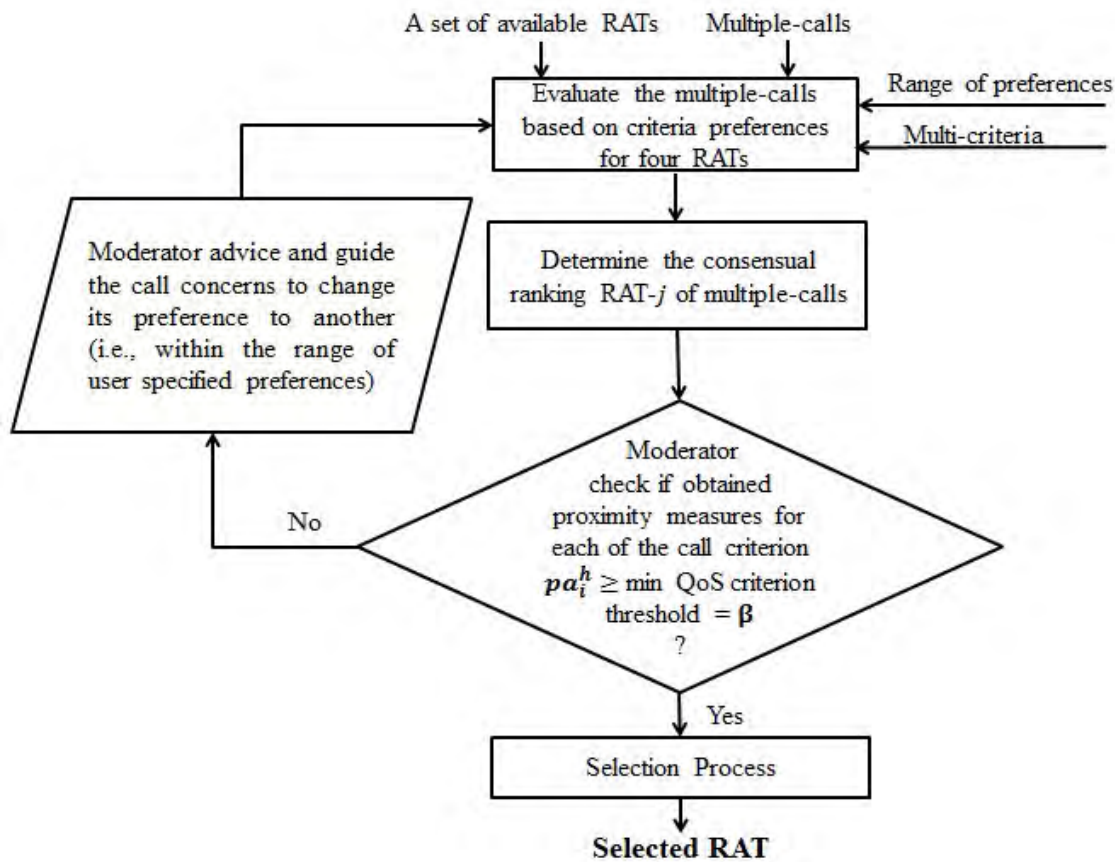


Figure 4.1: A Flow Chart of Consensus RAT-selection Scheme Decisions in HWNs.

The essence of using consensus degrees and proximity measures is to select the best RAT that can support a group of handoff calls, and thereby improve the user's QoS by reducing the dropping probability of handoff calls from a single-homed multi-mode terminal in HWNs.

The objectives of consensus RAT-selection schemes are to:

- ❖ Select the RAT that offers the best QoS requirements for a group of handoff calls in HWNs.
- ❖ Consider a range of user preference values per criterion in making RAT selection decisions for a group of calls in HWNs.
- ❖ Perform selective dropping of a subset of a group of calls when none of the available RATs has enough capacity to accommodate the entire group of handoff calls from a single-homed multi-mode terminal in an HWN.

Moreover, the consensus RAT-selection scheme differs from RAT-selection schemes compared in Chapter 3 (i.e., SAW-GDM, MEW-GDM, TOPSIS-GDM, and DIA-GDM). This is because the consensus RAT-selection scheme can measure the contributions of RAT-

selection criteria towards the final group decision of a suitable RAT in HWNs. The next section explains the fuzzy preference relations for RAT-selection in HWNs.

4.3 Fuzzy Preference Relations for RAT-selection in Heterogeneous Wireless Networks.

In a user-centric network where users are allowed to indicate their preference of choice for various call types, most users, if not all, will base their decisions on what they want from the networks, rather than what the networks could offer. Users in this condition care about their own throughputs or needs without having regard for other users [52], [53]. However, soft coincidence among preferences will be an appropriate way to achieve users' requests using the consensus RAT-selection scheme in HWNs. This is because soft coincidence among preferences measures the closeness of consensus degree by considering different possibilities within the membership function of 0.0000 to 1.0000 [50]. The value 0.0000 denotes the least priority while value 1.0000 denotes the highest priority. Table 4.1, shows the conversion of seven fuzzy linguistic terms to crisp values [46].

Table 4.1: Fuzzy Linguistic Conversion Scales.

S	Service Type Scale	Linguistic terms	Crisp Number
s_0	None	N	0.0000
s_1	Very Low	VL	0.1700
s_2	Low	L	0.3300
s_3	Medium	M	0.5000
s_4	High	H	0.6700
s_5	Very High	VH	0.8400
s_6	Tally	T	1.0000

As shown in Table 4.1, the linguistic labels are transformed into crisp numbers such as N for 0.0000, VL for 0.1700, T for 1.0000. The linguistic terms "T" and "N" represent the highest

and the least preferences a user can allocate/assign to a given call type in a HWN respectively.

Computing with words is appropriate for a similarity of preference coincidence in HWNs. Coincidence is defined as a common connection or relation that exists between two different entities, in terms of criteria [49]. To do so, aggregating operator such as the linguistic ordered weighted averaging (LOWA) can be applied for coincidence of preferences using the consensus RAT-selection scheme for group decisions in HWNs. This is because of the following benefits [54], [55]: (i) it simplifies the processes of computing with words, (ii) it utilizes the concept of fuzzy majority to represent the linguistic quantifiers, and (iii) it aggregates non-weighted and weighted linguistic information.

The LOWA operator denotes the concept of fuzzy majority using fuzzy linguistic quantifiers $Q(r)$ to compute the value of the weighting vector W . Where $W = \{w_k\}$, ($k \geq 1$) represents the OWA operator [50]. The OWA aggregation operator defined by Yager [55] is use to simplify a non-decreasing proportional fuzzy linguistic quantifier $Q(r)$ as follows:

$$\text{The } Q(r) \text{ is given by } w_i = Q\left(\frac{i}{n}\right) - Q\left(\frac{i-1}{n}\right), i = 1, \dots, n \quad (33)$$

being the membership function of $Q(r)$:

$$Q(r) = \begin{cases} 0 & \text{if } r < a \\ \frac{r-a}{b-a} & \text{if } a \leq r \leq b \\ 1 & \text{if } r > b \end{cases} \quad (34)$$

Thus $a, b, r \in [0, 1]$, and the non-decreasing proportional with fuzzy linguistic quantifier "most" [56].

Section 4.4 presents how the consensus RAT-selection scheme is used to solve the group decision problem for a group of handoff calls from a single-homed multi-mode terminal in HWNs.

4.4 Consensus RAT-selection Scheme for Making Group Decision in Heterogeneous Wireless Networks

In literature, three coincidence criteria are widely used to compute soft consensus measures such as: (1) strict coincidence among preferences, (2) soft coincidence among preferences and (3) coincidence among solution. This is because they have the capabilities to generate

recommendations that help the calls to change its criteria preferences to optimum preferences when making group decisions. Even at that, they have their drawbacks in fuzzy group decision-making problems [49], [57].

However, this dissertation consider the soft coincidence among preferences as the most preferred coincidence among the existing coincidence methods to solve the group decision problem for a group of handoff calls in HWNs. This is because the soft coincidence among preferences determines the possible coincidences that exist between two or more calls (voice call, file download, and video streaming) before making a decision for the most suitable RAT in HWNs. The next section describes the RAT-selection problem for making RAT-selection decision in HWNs.

4.4.1 RAT-selection Problem Statement in Heterogeneous Wireless Networks

This section describes the problem of RAT selection for multiple-calls from a single-homed multi-mode terminal in HWNs. Consider a single-homed multi-mode terminal that needs to select the most suitable RAT among n available RATs for a group of multiple handoff calls in a HWN, based on a set of RAT-selection criteria. The RAT-selection problem can be expressed as follows:

Let S be a set of linguistic range of preference terms (N, VL, L, M, H, VH and T), where $S = \{s_0, \dots, s_t\}$. For example, $S = \{N = s_0, VL = s_1, L = s_2, M = s_3, H = s_4, VH = s_5, \text{ and } T = s_6\}$. Usually, the set S has an odd number of elements whose cardinality is given as $\#S = t + 1$

$$(35)$$

Let R be a set of available RATs in a HWN, where $RAT = \{r_1, r_2, \dots, r_n\}$, ($n \geq 2$), and n is the maximum number of RATs

$$(36)$$

Let C be a set of criteria, where $C = \{c_1, c_2, \dots, c_h\}$, ($h \geq 2$), and h is the maximum number of criteria

$$(37)$$

Let E be a set of services, where $E = \{e_1, e_2, \dots, e_m\}$ ($m \geq 2$), and m is the maximum number of services

$$(38)$$

Let F_i^a be a set of user preferences assigned to criterion c_i by service e_a . Where $i \in \{1, \dots, h\}$, and $a \in \{1, \dots, m\}$

$$(39)$$

Let W be a set of weight vector, where $W = [w_1, \dots, w_m]$ represents the relative importance of each service e_i with the pair of (0.3, 0.8) [56]. The corresponding ordered weighted averaging (OWA) is given as $W = [0.06, 0.68, 0.26]$ (40)

Let P^a be a set of preference relations, where $P^a = p_{ij}^a$ assigned to criterion c_i by service e_a , for $i \in \{1, \dots, h\}$, $a \in \{1, \dots, m\}$ and $j \in \{1, \dots, n\}$. (41)

Let P^c be the collective fuzzy preference relation, where $P^c = \emptyset(P^a)$ (42)

The following section describes the numerical example of consensus RAT-selection scheme for selecting a suitable RAT for multiple-calls from a single-homed multi-mode terminal in a HWN.

4.5 Numerical Example of Application of Consensus Scheme for RAT-selection for Multiple-calls in a Heterogeneous Wireless Network

This section illustrates the application of the consensus RAT-selection scheme to solve group decision problems of selecting the most suitable RAT for multiple handoff calls (i.e., voice call, file download and video streaming) from a single-homed multi-mode terminal, using four criteria (Service price, Data rate, Security, Network delay) in HWNs.

For example, consider that a user assigns a range of linguistic preferences from Table 4.1 to multiple-calls (voice call, file download, video streaming) through his/her mobile device (i.e., single-homed multi-mode terminal) using four RAT-selection criteria (i.e., service price, data rate, security, network delay) in HWNs.

That is;

$$F_{Service\ price}^{voice\ call} = \{VL, L\}, F_{Data\ rate}^{voice\ call} = \{H, VH\}, F_{Security}^{voice\ call} = \{VH, T\}, F_{Network\ delay}^{voice\ call} = \{L, M\}.$$

$$F_{Service\ price}^{file\ download} = \{VL, L\}, F_{Data\ rate}^{file\ download} = \{H\}, F_{Security}^{file\ download} = \{M, H\}, F_{Network\ delay}^{file\ download} = \{L, M\}.$$

$$F_{Service\ price}^{video\ streaming} = \{M, H\}, F_{Data\ rate}^{video\ streaming} = \text{Data rate} \in \{H, VH, T\}, F_{Security}^{video\ streaming} = \{VL, L, M\}, F_{Network\ delay}^{video\ streaming} = \{VL, L, M, H\}.$$

Table 4.2: Linguistic Preferences for a Group of Multiple-calls in HWNs.

Criteria Call-types	Service price (c_1)	Data rate (mbps)(c_2)	Security(c_3)	Network delay(c_4)
Voice call	VL	H	VH	L
File download	VL	H	M	L
Video streaming	M	H	VL	VL

Thus, the consensus RAT-selection scheme selects the first element of user specified preferences to determine the most suitable RAT for a group of multiple-calls from a single-homed multi-mode terminal in HWNs as offered by Table 4.2. Therefore, the following steps are used by the consensus RAT-selection scheme to select the RAT that offers the best QoS for a group of handoff calls from a single-homed multi-mode terminal in HWNs as follows:

Step 1: Convert the linguistic preferences in Table 4.2 to its crisp values as offered by Table 4.3.

Table 4.3: Crisp Value for a Group of Multiple-calls Preferences in HWNs.

Criteria Call-types	Service price (c_1)	Data rate (mbps)(c_2)	Security(c_3)	Network delay (c_4)
Voice call	0.1700	0.6700	0.8400	0.3300
File download	0.1700	0.6700	0.5000	0.3300
Video streaming	0.5000	0.6700	0.1700	0.1700

Step 2: Compute the normalized preference $\overline{F}^a = \overline{f}_i^a$. Where \overline{f}_i^a represents the normalized preference for each of the calls in Table 4.3.

$$\overline{f}_i^a = \frac{f_i^a}{\sum_{j=1}^h (f_j^a)}, i \in \{1, \dots, h\}, a \in \{1, \dots, m\} \quad (43)$$

The normalized preferences for multiple-calls (i.e., voice call, file download and video streaming) are given as follows:

$$\overline{F^{voice\ call}} = [0.0846 \quad 0.3333 \quad 0.4179 \quad 0.1642]$$

$$\overline{F^{file\ download}} = [0.1018 \quad 0.4012 \quad 0.2994 \quad 0.1976]$$

$$\overline{F^{video\ streaming}} = [0.3311 \quad 0.4437 \quad 0.1126 \quad 0.1126]$$

Step 3: Construct a decision matrix D for RAT- j and criteria C .

$$D = \begin{matrix} & c_1 & c_2 & \dots & c_h \\ \begin{matrix} r_1 \\ r_2 \\ \vdots \\ r_n \end{matrix} & \begin{bmatrix} d_{11} & d_{12} & \dots & d_{1h} \\ d_{21} & d_{22} & \dots & d_{2h} \\ \vdots & \vdots & \dots & \vdots \\ d_{n1} & d_{n2} & \dots & d_{nh} \end{bmatrix} \end{matrix}$$

Note that the elements in decision matrix are obtained from Table 4.1, and the decision matrix contain both linguistic terms and crisp values as shown in Table 4.4 [11].

Table 4.4: RAT-selection Criteria for Handoff Multiple-calls.

Criteria \ Networks	Service price (c_1)	Data rate (mbps) (c_2)	Security (c_3)	Network delay (c_4)
RAT-1 (WLAN 802.a)	Low	54	Low	High
RAT-2 (3G HSPA)	High	7.5	Very High	Very Low
RAT-3 (WiMAX)	Medium	25	High	Low
RAT-4 (WLAN 802.b)	Very Low	11	Very Low	Medium

From Table 4.4, the decision matrix D is obtained as:

$$D = \begin{matrix} & c_1 & c_2 & c_3 & c_4 \\ \begin{matrix} r_1 \\ r_2 \\ r_3 \\ r_4 \end{matrix} & \begin{bmatrix} \text{Low} & 54.0000 & \text{Low} & \text{High} \\ \text{High} & 7.5000 & \text{Very High} & \text{Very Low} \\ \text{Medium} & 25.0000 & \text{High} & \text{Low} \\ \text{Very Low} & 11.0000 & \text{Very Low} & \text{Medium} \end{bmatrix} \end{matrix}$$

The linguistic terms in the decision matrix are converted to crisp values as offered by Table 4.1.

$$D = \begin{matrix} & c_1 & c_2 & c_3 & c_4 \\ \begin{matrix} r_1 \\ r_2 \\ r_3 \\ r_4 \end{matrix} & \begin{bmatrix} 0.3300 & 54.0000 & 0.3300 & 0.6700 \\ 0.6700 & 7.5000 & 0.8400 & 0.1700 \\ 0.5000 & 25.0000 & 0.6700 & 0.3300 \\ 0.1700 & 11.0000 & 0.1700 & 0.5000 \end{bmatrix} \end{matrix}$$

Step 4: Construct the normalized decision matrix \overline{DM} for each element $d_{i,u}$ using the "Maximum" method [29].

- For benefit criteria; $\overline{dm}_{i,j}$ is normalized as follow:

$$\overline{dm}_{i,j} = d_{i,u} / \max\{d_{i,u} \mid i = \{1, \dots, n\}; u, j = \{1, \dots, h\}\} \quad (44)$$

- For cost criteria; $\overline{dm}_{i,u}$ is normalized as follow:

$$\overline{dm}_{i,j} = \min\{d_{i,u} \mid i = \{1, \dots, n\}; u, j = \{1, \dots, h\}\} / d_{i,u} \quad (45)$$

$$\overline{DM} = \begin{matrix} & c_1 & c_2 & c_3 & c_4 \\ \begin{matrix} r_1 \\ r_2 \\ r_3 \\ r_4 \end{matrix} & \begin{bmatrix} 0.5152 & 1.0000 & 0.3929 & 0.2537 \\ 0.2537 & 0.1389 & 1.0000 & 1.0000 \\ 0.3400 & 0.4630 & 0.7976 & 0.5152 \\ 1.0000 & 0.2037 & 0.2024 & 0.3400 \end{bmatrix} \end{matrix}$$

Step 5: Multiply the normalized decision matrix \overline{DM} by the normalized preference for each of the call (voice call, file download and video streaming) respectively as follows:

- (a) Multiply \overline{DM} in step 4 by the normalized preference of voice call in step 2, and is

represented as $S_1 = \overline{DM}_{voice}$.

$$\overline{DM}_{voice} = \begin{matrix} & c_1 & c_2 & c_3 & c_4 \\ \begin{matrix} r_1 \\ r_2 \\ r_3 \\ r_4 \end{matrix} & \begin{bmatrix} 0.5152 & 1.0000 & 0.3929 & 0.2537 \\ 0.2537 & 0.1389 & 1.0000 & 1.0000 \\ 0.3400 & 0.4630 & 0.7976 & 0.5152 \\ 1.0000 & 0.2037 & 0.2024 & 0.3400 \end{bmatrix} \end{matrix} \times \begin{bmatrix} 0.0846 \\ 0.3333 \\ 0.4179 \\ 0.1642 \end{bmatrix}$$

The results obtained are presented in Table 4.5.

- (b) Multiply \overline{DM} in step 4 by the normalized preference of file download in step 2, and is

represented as $S_2 = \overline{DM}_{file\ download}$.

$$\overline{DM_file\ download} = \begin{matrix} r_1 \\ r_2 \\ r_3 \\ r_4 \end{matrix} \begin{bmatrix} c_1 & c_2 & c_3 & c_4 \\ 0.5152 & 1.0000 & 0.3929 & 0.2537 \\ 0.2537 & 0.1389 & 1.0000 & 1.0000 \\ 0.3400 & 0.4630 & 0.7976 & 0.5152 \\ 1.0000 & 0.2037 & 0.2024 & 0.3400 \end{bmatrix} \times \begin{bmatrix} 0.1018 \\ 0.4012 \\ 0.2994 \\ 0.1976 \end{bmatrix}$$

The results obtained are presented in Table 4.5.

(c) Multiply \overline{DM} in step 4 by the normalized preference of video streaming in step 2, and is represented as $S_3 = \overline{DM_video\ streaming}$.

$$\overline{DM_video\ streaming} = \begin{matrix} r_1 \\ r_2 \\ r_3 \\ r_4 \end{matrix} \begin{bmatrix} c_1 & c_2 & c_3 & c_4 \\ 0.5152 & 1.0000 & 0.3929 & 0.2537 \\ 0.2537 & 0.1389 & 1.0000 & 1.0000 \\ 0.3400 & 0.4630 & 0.7976 & 0.5152 \\ 1.0000 & 0.2037 & 0.2024 & 0.3400 \end{bmatrix} \times \begin{bmatrix} 0.3311 \\ 0.4437 \\ 0.1126 \\ 0.1126 \end{bmatrix}$$

The results obtained are presented in Table 4.5.

Step 6: Compute the overall performance score (S_i) of multiple-calls (voice call, file download and video streaming) as offered by Table 4.5.

Table 4.5: Overall Performance Scores of Multiple Handoff Calls in HWNs.

Overall Performance value	Voice call weight	File download weight	Video streaming weight
RAT -1	0.5827	0.6214	0.6871
RAT-2	0.6498	0.5786	0.3708
RAT -3	0.6010	0.5610	0.4658
RAT- 4	0.2929	0.3113	0.4826

Step 7: Compute the pairwise comparison for each of the calls in Table 4.5 for four available RATs. The pairwise comparison is used to determine the preference for each of the calls (i.e., voice call, file download and video streaming) respectively, using the concepts of analytic hierarchy process (AHP) [58]. The obtained pairwise comparisons are presented in Tables 4.6-4.8.

Table 4.6: Analytic Hierarchy Process Pairwise Comparison of four RATs for Voice call.

Voice call	RAT 1	RAT 2	RAT 3	RAT 4
RAT-1	1.0000	0.8967	0.9696	1.9897
RAT-2	1.1152	1.0000	1.0813	2.2188
RAT-3	1.0313	0.9248	1.0000	2.0520
RAT-4	0.5026	0.4507	0.4873	1.0000

Table 4.7: Analytic Hierarchy Process Pairwise Comparison of four RATs for File download.

File download	RAT 1	RAT 2	RAT 3	RAT 4
RAT-1	1.0000	1.0740	1.1078	1.9961
RAT-2	0.9311	1.0000	1.0314	1.8585
RAT-3	0.9027	0.9696	1.0000	1.8020
RAT-4	0.5010	0.5381	0.5549	1.0000

Table 4.8: Analytic Hierarchy Process Pairwise Comparison of four RATs for Video streaming.

Video streaming	RAT 1	RAT 2	RAT 3	RAT 4
RAT-1	1.0000	1.8529	1.4751	1.4238
RAT-2	0.5397	1.0000	0.7961	0.7684
RAT-3	0.6779	1.2562	1.0000	0.9652
RAT-4	0.7024	1.3014	1.0360	1.0000

Step 8: Convert the obtained results as offered by Tables (4.6-4.8) respectively into fuzzy preference relations $P^i = p_{ij}^a$. Where p_{ij}^a is given as $1/2(1 + \log_9 p_{ij}^a)$ [56]. Where a, i and j represent service types, row and column elements respectively. The fuzzy preference relations P^i are given as follows:

$$p^{voice\ call}(P^1) = \begin{bmatrix} 0.5000 & 0.4752 & 0.4930 & 0.6566 \\ 0.5248 & 0.5000 & 0.5178 & 0.6814 \\ 0.5070 & 0.4822 & 0.5000 & 0.6636 \\ 0.3434 & 0.3186 & 0.3364 & 0.5000 \end{bmatrix}$$

$$p^{file\ download}(P^2) = \begin{bmatrix} 0.5000 & 0.5163 & 0.5233 & 0.6573 \\ 0.4837 & 0.5000 & 0.5070 & 0.6410 \\ 0.4767 & 0.4930 & 0.5000 & 0.6340 \\ 0.3427 & 0.3590 & 0.3660 & 0.5000 \end{bmatrix}$$

$$p^{video\ streaming}(P^3) = \begin{bmatrix} 0.5000 & 0.6404 & 0.5885 & 0.5804 \\ 0.3596 & 0.5000 & 0.4481 & 0.4401 \\ 0.4115 & 0.5519 & 0.5000 & 0.4919 \\ 0.4196 & 0.5599 & 0.5081 & 0.5000 \end{bmatrix}$$

Step 9: Compute the similarity function between preferences (i.e., $p^{voice\ call}(P^1)$, $p^{file\ download}(P^2)$ and $p^{video\ streaming}(P^3)$) in HWNs, called SM^{bl} [49].

$$\text{Thus: } SM^{bl} = 1 - |p_{ij}^b - p_{ij}^l| \quad (46)$$

$$SM^{12} = \begin{bmatrix} 1.0000 & 0.9589 & 0.9697 & 0.9993 \\ 0.9589 & 1.0000 & 0.9892 & 0.9597 \\ 0.9697 & 0.9892 & 1.0000 & 0.9704 \\ 0.9993 & 0.9597 & 0.9704 & 1.0000 \end{bmatrix}$$

$$SM^{13} = \begin{bmatrix} 1.0000 & 0.8348 & 0.9045 & 0.9238 \\ 0.8348 & 1.0000 & 0.9303 & 0.7587 \\ 0.9045 & 0.9303 & 1.0000 & 0.8284 \\ 0.9238 & 0.7587 & 0.8284 & 1.0000 \end{bmatrix}$$

$$SM^{23} = \begin{bmatrix} 1.0000 & 0.8759 & 0.9348 & 0.9231 \\ 0.8759 & 1.0000 & 0.9411 & 0.7990 \\ 0.9348 & 0.9411 & 1.0000 & 0.8579 \\ 0.9231 & 0.7990 & 0.8579 & 1.0000 \end{bmatrix}$$

Note that SM^{12} , SM^{13} and SM^{23} in step 9 represent the similarity matrix, which expresses the similarity preferences between two calls. The similarity preferences for $p^{voice\ call}(P^1)$, $p^{file\ download}(P^2)$ and $p^{video\ streaming}(P^3)$ measures the soft coincidence

that exist between two services (i.e., voice call and video streaming), (voice call and file download) and (video streaming and file download) respectively.

Step 10: Compute a collective similarity matrix SM . Where $SM = \{sm_{ij}\}$, and is obtained by aggregating the entire similarity matrix SM^{bl} in step 9, using the arithmetic mean.

$$SM = \begin{bmatrix} 1.0000 & 0.8899 & 0.9394 & 0.9487 \\ 0.8899 & 1.0000 & 0.9535 & 0.8391 \\ 0.9394 & 0.9535 & 1.0000 & 0.88564 \\ 0.9487 & 0.8391 & 0.8856 & 1.0000 \end{bmatrix}$$

Step 11: Compute the consensus RAT-selection ranking $RAT - j$ as follows:

$$RAT - j = \prod_{i=1}^h sm_{ij}, \forall, i \in \{1, \dots, h\}, j \in \{1, \dots, n\} \quad (47)$$

$$RAT-1 = 0.7905$$

$$RAT-2 = 0.7120$$

$$RAT-3 = 0.7907$$

$$RAT-4 = 0.7050$$

Step 12: Select $RAT - j^*$ with the highest consensus degree for the group of multiple handoff calls (voice call, file download and video streaming). The selected $RAT - j^*$ is preferred as the most suitable RAT for a group of multiple handoff calls from a single-homed multi-mode terminal in HWNs.

$$RAT - j^* = \max_{j=1}^n RAT - j \quad (48)$$

Thus: **RAT-3** > RAT-1 > RAT-2 > RAT-4

The results obtained in equation (48) show that RAT-3 and RAT-4 have the highest and least consensus RAT-selection decisions respectively for the entire group of multiple handoff calls from a single-homed multi-mode terminal.

However, in order to select **RAT-3** as the most preferred RAT amongst four RATs available for the group of multiple handoff calls, the proximity measures for all the criteria for the RAT-selection decision must be greater than or equal to the minimum criterion threshold of $\beta = 0.90$ before the obtained decision in equation (48) is valid, else another consensus decision is required. Consequently, the proximity measures for the first consensus decisions

are determined using steps (13-15) as follows:

Step 13: Determine the collective preference relation P^c . Where $P^c = \{p_{ij}^c\}$ is obtained by means of aggregation of all individual fuzzy preference relations ($P^{voice\ call}(P^1)$, $P^{file\ download}(P^2)$ and $P^{video\ streaming}(P^3)$). The aggregation operation is carried out by means of ordered weight aggregate (OWA) operator ϕ_Q [55]. The fuzzy quantifier "most" with the pair of (0.3, 0.8) is used [56]. Therefore the corresponding OWA operator ϕ_Q is represented as the weighting vector $W = [0.06, 0.68, 0.26]$.

Thus,

$$p_{ij}^c = \phi(p_{ij}^1, \dots, p_{ij}^m) = \sum_{k=1}^n (w_a \cdot p_{ij}^a) \text{ for } a \in \{1, \dots, m\}, i = 1, \dots, h; j = 1, \dots, n \quad (49)$$

$$P^c = \begin{bmatrix} 0.5000 & 0.5130 & 0.5193 & 0.6368 \\ 0.4539 & 0.5000 & 0.4924 & 0.5912 \\ 0.4616 & 0.4937 & 0.5000 & 0.5988 \\ 0.3478 & 0.3605 & 0.3668 & 0.5000 \end{bmatrix}$$

Step 14: Determine the proximity measures PM^a on pairs of calls e_a . That is,

$$PM^a = 1 - |p_{ij}^a - p_{ji}^a| \quad \text{for } a \in \{1, \dots, m\}, i = 1, \dots, h; j = 1, \dots, n \quad (50)$$

$$PM^{voice\ call} = \begin{bmatrix} 1.0000 & 0.9622 & 0.9737 & 0.9802 \\ 0.9291 & 1.0000 & 0.9746 & 0.9098 \\ 0.9546 & 0.9885 & 1.0000 & 0.9353 \\ 0.9956 & 0.9581 & 0.9696 & 1.0000 \end{bmatrix}$$

$$PM^{file\ download} = \begin{bmatrix} 1.0000 & 0.9968 & 0.9960 & 0.9795 \\ 0.9702 & 1.0000 & 0.9853 & 0.9502 \\ 0.9849 & 0.9993 & 1.0000 & 0.9648 \\ 0.9949 & 0.9984 & 0.9992 & 1.0000 \end{bmatrix}$$

$$PM^{video\ streaming} = \begin{bmatrix} 1.0000 & 0.8727 & 0.9309 & 0.9436 \\ 0.9057 & 1.0000 & 0.9557 & 0.8489 \\ 0.9500 & 0.9418 & 1.0000 & 0.8931 \\ 0.9282 & 0.8006 & 0.8588 & 1.0000 \end{bmatrix}$$

Where $PM^{voice\ call}(PM^1)$, $PM^{file\ download}(PM^2)$ and $PM^{video\ streaming}(PM^3)$ represent proximity measures for voice call, file download and video streaming respectively for RAT-selection from a single-homed multi-mode terminal.

Step 15: Determine the individual proximity pa_j^a toward the RAT-selection decisions in equation (48) for each of the calls as offered by step 14 [49]. Where pa_j^a is given as:

$$pa_j^a = \frac{\sum_{i=1, j \neq i}^h (pm_{ij}^a + pm_{ji}^a)}{2n - 2} \text{ for } a \in \{1, \dots, m\}, i = 1, \dots, h; j = 1, \dots, n \quad (51)$$

Thus:

$$pa_1^{voice\ call}, pa_2^{voice\ call}, pa_3^{voice\ call}, pa_4^{voice\ call} = \{0.9659, 0.9537, 0.9660, 0.9581\}$$

$$pa_1^{file\ download}, pa_2^{file\ download}, pa_3^{file\ download}, pa_4^{file\ download} = \{0.9870, 0.9834, 0.9882, 0.9812\}$$

$$pa_1^{video\ streaming}, pa_2^{video\ streaming}, pa_3^{video\ streaming}, pa_4^{video\ streaming} = \{0.9218, \mathbf{0.8876}, 0.9217, \mathbf{0.8789}\}$$

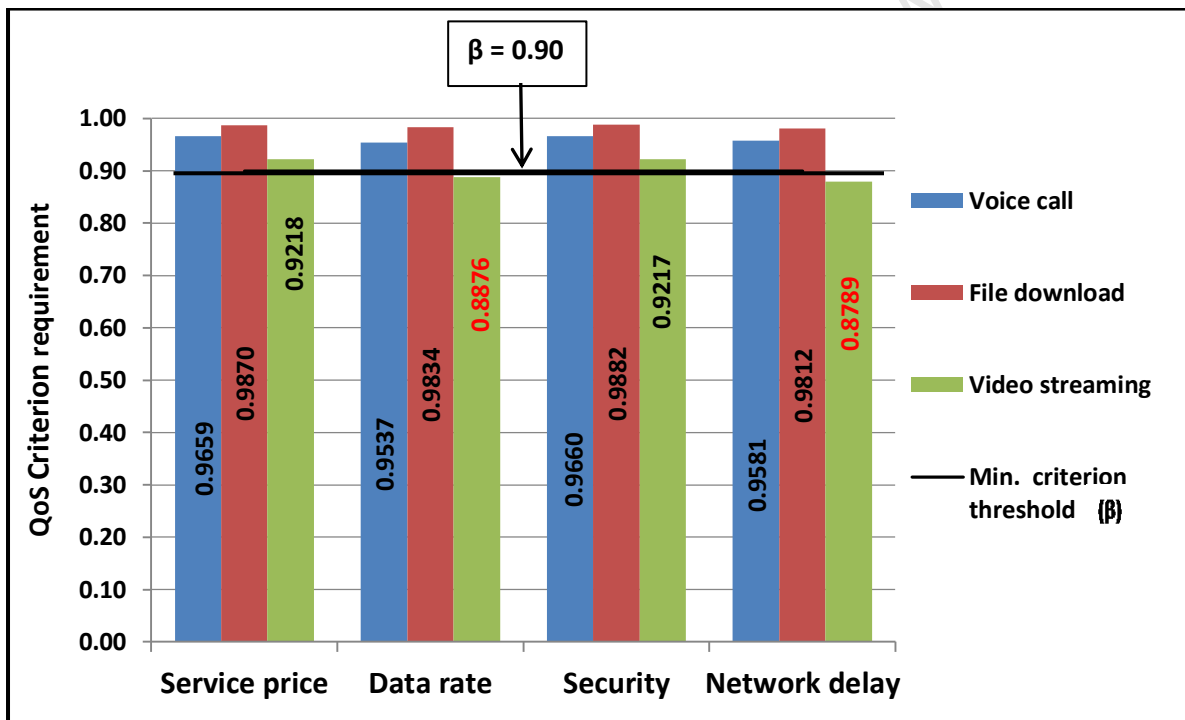


Figure 4.2: Criteria threshold for a Group of Multiple Handoff Calls in HWNs (First-Proximity Decision).

Figure 4.2, shows that two of the criteria (i.e., data rate and network delay) for video streaming do not satisfy the minimum criterion threshold $\beta = 0.90$. However, all the criteria for voice call and file download satisfied the minimum criterion threshold for the group of multiple handoff calls in HWNs.

Meanwhile, the QoS requirement of video streaming has been compromised because two of the RAT-selection criteria (i.e., data rate and network delay) do not satisfy the minimum

criterion threshold for individual calls. Therefore, the collective consensus decision of a suitable RAT in equation (48) is not valid for the group of multiple-calls. This is because the requirements of the group of multiple-calls have not been satisfied based on the minimum criterion threshold across the entire RAT-selection criteria for multiple handoff calls from a single-homed multi-mode terminal.

To resolve the above problem, the consensus RAT-selection scheme utilizes a recommendation system known as decision module that advises and guides the video streaming call to change the affected preferences for multiple-calls in HWNs. To do so, the following two rules set by the decision module are used to inflict change to both the data rate and the network delay for video streaming criteria as stated in subsection 4.5.1.

4.5.1 Rules and Directions Governing Change of Preference to RAT-selection Criteria in Heterogeneous Wireless Networks

The decision module makes changes to the two criteria (data rate and network delay) for video streaming by selecting the next user preference from the range of specified preferences (i.e., from High (H) to Very High (VH) and Very Low (VL) to Low (L)) for multiple-calls in HWNs. The changes made to the two criteria are based on Rule 2 below.

Rule 1: if $pa_i^h \geq 0.90$, then do not change the assigned user linguistic preference.

Rule 2: if $pa_i^h < 0.90$, then increase and select the next user linguistic preference.

Furthermore, it is necessary to determine the consensus degree for the newly assigned preferences by making another consensus decision for the group of multiple handoff calls from a single-homed multi-mode in HWNs.

4.5.2 Second-iteration for Consensus RAT-selection Decisions

This section presents the second-iteration of the consensus RAT-selection scheme for the new set of preferences for multiple-calls in HWNs. In addition, Table 4.9 offers the newly selected criteria preferences (i.e., the data rate (VH) and the network delay (L)) for video streaming. While both the voice call and the file download criteria remain the same for RAT-selection decision in HWNs.

Table 4.9: Linguistic Preferences for a Group of Multiple-calls in HWNs.

Criteria Call-types	Service price (c_1)	Data rate (mbps)(c_2)	Security (c_3)	Network delay (c_4)
Voice call	VL	H	VH	L
File download	VL	H	M	L
Video streaming	M	VH	VL	L

From Table 4.9, the linguistic preferences are converted to its crisp values as offered by Table 4.10.

Table 4.10: Crisp Value for a Group of Multiple-calls Preferences in HWNs.

Criteria Call-types	Service price (c_1)	Data rate (mbps)(c_2)	Security(c_3)	Network delay (c_4)
Voice call	0.1700	0.6700	0.8400	0.3300
File download	0.1700	0.6700	0.5000	0.3300
Video streaming	0.5000	0.8400	0.1700	0.3300

Step 16: Compute the normalized preference for each of the call in Table 4.10, using equation (43).

$$\overline{F^{voice\ call}} = [0.0846, 0.3333, 0.4179, 0.1642]$$

$$\overline{F^{file\ download}} = [0.1018, 0.4012, 0.2994, 0.1976]$$

$$\overline{F^{video\ streaming}} = [0.2717, 0.4565, 0.0924, 0.1793]$$

Step 17: Determine the normalized decision preference for voice call, file download and video streaming respectively.

(a) Multiply \overline{DM} in step 4 by the normalized preference of voice call in step 16, and is

represented as $S_1 = \overline{DM_2_voice}$.

$$\overline{DM_2_voice} = \begin{matrix} & c_1 & c_2 & c_3 & c_4 \\ \begin{matrix} r_1 \\ r_2 \\ r_3 \\ r_4 \end{matrix} & \begin{bmatrix} 1.0000 & 1.0000 & 0.3976 & 0.2537 \\ 0.4925 & 0.1389 & 1.0000 & 0.5152 \\ 0.6600 & 0.4630 & 0.6024 & 1.0000 \\ 0.6600 & 0.2778 & 0.8072 & 0.5152 \end{bmatrix} \end{matrix} \times \begin{bmatrix} 0.0846 \\ 0.3333 \\ 0.4179 \\ 0.1642 \end{bmatrix}$$

The results obtained are presented in Table 4.11.

(b) Multiply \overline{DM} in step 4 by the normalized preference of voice call in step 16, and is represented as $S_2 = \overline{DM_2_file\ download}$.

$$\overline{DM_2_file\ download} = \begin{matrix} & c_1 & c_2 & c_3 & c_4 \\ \begin{matrix} r_1 \\ r_2 \\ r_3 \\ r_4 \end{matrix} & \begin{bmatrix} 0.5152 & 1.0000 & 0.3929 & 0.2537 \\ 0.2537 & 0.1389 & 1.0000 & 1.0000 \\ 0.3400 & 0.4630 & 0.7976 & 0.5152 \\ 1.0000 & 0.2037 & 0.2024 & 0.3400 \end{bmatrix} \end{matrix} \times \begin{bmatrix} 0.1018 \\ 0.4012 \\ 0.2994 \\ 0.1976 \end{bmatrix}$$

The results obtained are presented in Table 4.11.

(c) Multiply \overline{DM} in step 4 by the normalized preference of voice call in step 16, and is represented as $S_3 = \overline{DM_2_video\ streaming}$.

$$\overline{DM_2_video\ streaming} = \begin{matrix} & c_1 & c_2 & c_3 & c_4 \\ \begin{matrix} r_1 \\ r_2 \\ r_3 \\ r_4 \end{matrix} & \begin{bmatrix} 0.5152 & 1.0000 & 0.3929 & 0.2537 \\ 0.2537 & 0.1389 & 1.0000 & 1.0000 \\ 0.3400 & 0.4630 & 0.7976 & 0.5152 \\ 1.0000 & 0.2037 & 0.2024 & 0.3400 \end{bmatrix} \end{matrix} \times \begin{bmatrix} 0.2717 \\ 0.4565 \\ 0.0924 \\ 0.1793 \end{bmatrix}$$

The results obtained are presented in Table 4.11.

Step 18: Compute the overall performance score (S_i) of multiple-calls (voice call, file download and video streaming) as offered by Table 4.11.

Table 4.11: Overall Performance Scores of Multiple Handoff Calls in HWNs.

Overall Performance value	Voice call weight	File download weight	Video streaming weight
RAT 1	0.5827	0.6214	0.6783
RAT 2	0.6498	0.5786	0.4041
RAT 3	0.6010	0.5610	0.4698
RAT 4	0.2929	0.3113	0.4444

Step 19: Compute the pairwise comparison for each of the calls in Table 4.11 for the four available RATs. The pairwise comparison is used to determine the preference for each of the

calls (i.e., voice call, file download and video streaming) respectively, using the concepts of AHP [58]. The obtained pairwise comparisons are presented in Tables 4.12-4.14.

Table 4.12: Analytic Hierarchy Process Pairwise Comparison of four RATs for Voice call.

Voice call	RAT 1	RAT 2	RAT 3	RAT 4
RAT 1	1.0000	0.8967	0.9696	1.9897
RAT 2	1.1152	1.0000	1.0813	2.2188
RAT 3	1.0313	0.9248	1.0000	2.0520
RAT 4	0.5026	0.4507	0.4873	1.0000

Table 4.13: Analytic Hierarchy Process Pairwise Comparison of four RATs for File download.

File download	RAT 1	RAT 2	RAT 3	RAT 4
RAT 1	1.0000	1.0740	1.1078	1.9961
RAT 2	0.9311	1.0000	1.0314	1.8585
RAT 3	0.9027	0.9696	1.0000	1.8020
RAT 4	0.5010	0.5381	0.5549	1.0000

Table 4.14: Analytic Hierarchy Process Pairwise Comparison of four RATs for Video streaming.

Video streaming	RAT 1	RAT 2	RAT 3	RAT 4
RAT 1	1.0000	1.6786	1.4437	1.5263
RAT 2	0.5957	1.0000	0.8601	0.9093
RAT 3	0.6926	1.1627	1.0000	1.0572
RAT 4	0.6552	1.0998	1.9459	1.0000

Step 20: Convert the obtained results as offered by Tables (4.12-4.14) respectively into fuzzy preference relations $P^i = p_{ij}^a$. Where p_{ij}^a is given as $1/2(1 + \log_9 p_{ij}^a)$ [56]. Where a, i and j represent service types, row and column elements respectively. The fuzzy preference relations P^i are given as follows:

$$p^{voice\ call}(P^1) = \begin{bmatrix} 0.5000 & 0.4752 & 0.4930 & 0.6566 \\ 0.5248 & 0.5000 & 0.5178 & 0.6814 \\ 0.5070 & 0.4822 & 0.5000 & 0.6636 \\ 0.3434 & 0.3186 & 0.3364 & 0.5000 \end{bmatrix}$$

$$p^{file\ download}(P^2) = \begin{bmatrix} 0.5000 & 0.5163 & 0.5233 & 0.6573 \\ 0.4837 & 0.5000 & 0.5070 & 0.6410 \\ 0.4767 & 0.4930 & 0.5000 & 0.6340 \\ 0.3427 & 0.3590 & 0.3660 & 0.5000 \end{bmatrix}$$

$$p^{video\ streaming}(P^3) = \begin{bmatrix} 0.5000 & 0.6179 & 0.5836 & 0.5962 \\ 0.3821 & 0.5000 & 0.4657 & 0.4784 \\ 0.4164 & 0.5343 & 0.5000 & 0.5127 \\ 0.4038 & 0.5216 & 0.4873 & 0.5000 \end{bmatrix}$$

Step 21: Compute the similarity function between preferences (i.e., $P^{voice\ call}(P^1)$, $P^{file\ download}(P^2)$ and $P^{video\ streaming}(P^3)$) in HWNs, using $SM^{bl} = 1 - |p_{ij}^b - p_{ij}^l|$ [49].

$$SM^{12} = \begin{bmatrix} 1.0000 & 0.9589 & 0.9697 & 0.9993 \\ 0.9589 & 1.0000 & 0.9892 & 0.9597 \\ 0.9697 & 0.9892 & 1.0000 & 0.9704 \\ 0.9993 & 0.9597 & 0.9704 & 1.0000 \end{bmatrix}$$

$$SM^{13} = \begin{bmatrix} 1.0000 & 0.8573 & 0.9094 & 0.9397 \\ 0.8573 & 1.0000 & 0.9479 & 0.7970 \\ 0.9094 & 0.9479 & 1.0000 & 0.8491 \\ 0.9397 & 0.7970 & 0.8491 & 1.0000 \end{bmatrix}$$

$$SM^{23} = \begin{bmatrix} 1.0000 & 0.8984 & 0.9397 & 0.9389 \\ 0.8984 & 1.0000 & 0.9587 & 0.8373 \\ 0.9397 & 0.9587 & 1.0000 & 0.8787 \\ 0.9389 & 0.8373 & 0.8787 & 1.0000 \end{bmatrix}$$

Note that SM^{12} , SM^{13} and SM^{23} in step 21 represent the similarity matrix, which expresses the similarity preferences between two calls. The similarity preferences for $P^{voice\ call}(P^1)$, $P^{file\ download}(P^2)$ and $P^{video\ streaming}(P^3)$ measures the soft coincidence that exist between two services (i.e., voice call and video streaming), (voice call and file

download) and (video streaming and file download) respectively.

Step 22: Compute a collective similarity matrix SM . Where $SM = \{sm_{ij}\}$, and is obtained by aggregating the entire similarity matrix SM^{bl} in step 21, using the arithmetic mean.

$$SM = \begin{bmatrix} 1.0000 & 0.9049 & 0.9396 & 0.9593 \\ 0.9049 & 1.0000 & 0.9653 & 0.8647 \\ 0.9396 & 0.9653 & 1.0000 & 0.8994 \\ 0.9593 & 0.8647 & 0.8994 & 1.0000 \end{bmatrix}$$

Step 23: Determine the consensus RAT-selection ranking $RAT - j$ as follows:

$$RAT - j = \prod_{i=1}^h sm_{ij}, \forall, i \in \{1, \dots, h\}, j \in \{1, \dots, n\} \quad (52)$$

$$RAT-1 = 0.8156$$

$$RAT-2 = 0.7553$$

$$RAT-3 = 0.8157$$

$$RAT-4 = 0.7460$$

Step 24: Select $RAT - j^*$ with the highest consensus degree for the group of multiple handoff calls (voice call, file download and video streaming). The selected $RAT - j^*$ is preferred as the most suitable RAT for a group of multiple handoff calls from a single-homed multi-mode terminal in HWNs.

$$RAT - j^* = \max_{j=1}^n RAT - j \quad (53)$$

Thus: **RAT-3** > RAT-1 > RAT-2 > RAT-4

Moreover, the results obtained in equation (53) give similar results as obtained in the first iteration for consensus RAT-selection decisions. The results show that **RAT-3** is the most preferred RAT, while RAT-4 is the least preferred RAT amongst the four available RATs from a single-homed multi-mode terminal.

However, in order to select RAT-3 as the most preferred RAT for a group of multiple handoff calls, the proximity measures for all the criteria for the RAT-selection decision must be greater than or equal to the minimum criterion threshold of $\beta = 0.90$ before the obtained decision in equation (53) is valid, else another consensus decision is required. Consequently, the proximity measures for the second consensus decisions are determined using steps (25-

27) as follows:

Step 25: Determine the collective preference relation P^{c-1} . Where $P^{c-1} = \{p_{ij}^c\}$ is obtained by means of aggregation of all individual fuzzy preference relations ($P^{voice\ call}(P^1)$, $P^{file\ download}(P^2)$ and $P^{video\ streaming}(P^3)$). The aggregation operation is carried out by means of ordered weight aggregate (OWA) operator \emptyset_Q [55]. The fuzzy quantifier "most" with the pair of (0.3, 0.8) is used [56]. Therefore the corresponding OWA operator \emptyset_Q is represented as the weighting vector $W = [0.06, 0.68, 0.26]$.

Thus,

$$p_{ij}^c = \emptyset(p_{ij}^1, \dots, p_{ij}^m) = \sum_{k=1}^n (w_a \cdot p_{ij}^a) \text{ for } a \in \{1, \dots, m\}, i = 1, \dots, h; j = 1, \dots, n \quad (54)$$

$$P^{c-1} = \begin{bmatrix} 0.5000 & 0.5117 & 0.5190 & 0.6409 \\ 0.4598 & 0.5000 & 0.4969 & 0.6012 \\ 0.4629 & 0.4927 & 0.5000 & 0.6042 \\ 0.3469 & 0.3582 & 0.3656 & 0.5000 \end{bmatrix}$$

Step 26: Determine the proximity measures $PM^a = \{pm_{ij}^a\}$ on pairs of calls e_a as follows:

$$\text{That is, } pm_{ij}^a = 1 - |p_{ij}^a - p_{ij}^c| \quad \text{for } a \in \{1, \dots, m\}, i = 1, \dots, h; j = 1, \dots, n \quad (55)$$

$$PM^{voice\ call} = \begin{bmatrix} 1.0000 & 0.9635 & 0.9740 & 0.9844 \\ 0.9350 & 1.0000 & 0.9791 & 0.9198 \\ 0.9558 & 0.9896 & 1.0000 & 0.9407 \\ 0.9966 & 0.9604 & 0.9708 & 1.0000 \end{bmatrix}$$

$$PM^{file\ download} = \begin{bmatrix} 1.0000 & 0.9954 & 0.9957 & 0.9836 \\ 0.9760 & 1.0000 & 0.9899 & 0.9601 \\ 0.9861 & 0.9997 & 1.0000 & 0.9702 \\ 0.9958 & 0.9993 & 0.9996 & 1.0000 \end{bmatrix}$$

$$PM^{video\ streaming} = \begin{bmatrix} 1.0000 & 0.8938 & 0.9355 & 0.9553 \\ 0.9223 & 1.0000 & 0.9688 & 0.8772 \\ 0.9536 & 0.9584 & 1.0000 & 0.9084 \\ 0.9431 & 0.8366 & 0.8782 & 1.0000 \end{bmatrix}$$

Where $PM^{voice\ call}(PM^1)$, $PM^{file\ download}(PM^2)$ and $PM^{video\ streaming}(PM^3)$ represent proximity measures for voice call, file download and video streaming respectively for RAT-selection from a single-homed multi-mode terminal.

Step 27: Determine the individual proximity pa_j^a toward the RAT-selection decisions in equation (53) for each of the calls as offered by step 26 [49]. Where pa_j^a is given as:

$$pa_j^a = \frac{\sum_{i=1, j \neq i}^h (pm_{ij}^a + pm_{ji}^a)}{2n - 2} \text{ for } a \in \{1, \dots, m\}, i = 1, \dots, h; j = 1, \dots, n \quad (56)$$

Hence:

$$pa_1^{voice\ call}, pa_2^{voice\ call}, pa_3^{voice\ call}, pa_4^{voice\ call} = \{0.9682, 0.9579, 0.9683, 0.9621\}$$

$$pa_1^{file\ download}, pa_2^{file\ download}, pa_3^{file\ download}, pa_4^{file\ download} = \{0.9888, 0.9867, 0.9902, 0.9848\}$$

$$pa_1^{video\ streaming}, pa_2^{video\ streaming}, pa_3^{video\ streaming}, pa_4^{video\ streaming} = \{0.9339, 0.9095, 0.9338, \mathbf{0.8998}\}$$

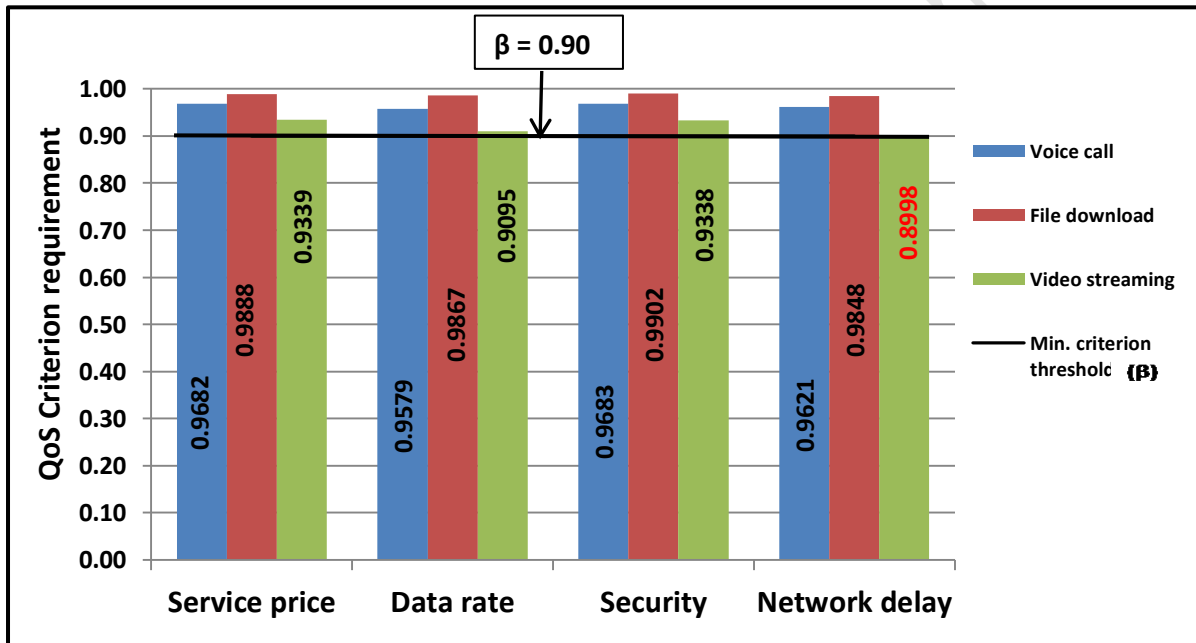


Figure 4.3: Criteria threshold for Group of Multiple Handoff Calls in HWNs (Second-Proximity Decisions).

Figure 4.3, shows that one of the criteria (i.e., network delay has a value of **0.8998**) for video streaming does not satisfy the minimum criterion threshold $\beta = 0.90$, while all the criteria for voice call and file download have satisfied the minimum criterion threshold for individual calls.

Furthermore, the collective consensus RAT-selection decision shows that RAT-3 has the highest consensual value. Even at that, the collective consensus decision for RAT-3 in equation (53) is not valid for the group of multiple-calls. This is because the requirements of the group of multiple-calls have not been satisfied based on the minimum criterion threshold

across the entire RAT-selection criteria for multiple handoff calls from a single-homed multi-mode terminal.

Thus, it is necessary to resolve the above consensus decision problem (i.e., the second consensus decisions) for a group of multiple-calls from a single-homed multi-mode terminal. To do so, the recommendation system advice (decision module) needs to guide the video streaming to change the preference for network delay from Low (L) to Medium (M) using the rules in subsection 4.5.1.

Therefore, third consensus decision is required for a group of multiple-calls from a single-homed multi-mode terminal in HWNs. The next section presents the third consensus RAT-selection decision and the proximity measures for the group of multiple handoff calls from a single-homed multi-mode terminal in HWNs.

4.5.3 Third Consensus RAT-selection Decisions for a group of Multiple-calls in HWNs

This section presents the third-iteration of the consensus RAT-selection scheme for multiple-calls in HWNs. In addition, Table 4.15 offered the newly selected criteria preferences (i.e., network delay (M)) for video streaming; whereas both the voice call and the file download criteria remained the same for RAT-selection decision in HWNs.

Table 4.15: Linguistic Preferences for a Group of Multiple-calls in HWNs.

Criteria Call-types	Service price (c₁)	Data rate (mbps)(c₂)	Security(c₃)	Network delay(c₄)
Voice call	VL	H	VH	L
File download	VL	H	M	L
Video streaming	M	VH	VL	M

From Table 4.15, the linguistic preferences are converted to its crisp values as offered by Table 4.16.

Table 4.16: Crisp Value for a Group of Multiple-calls Preferences in HWNs.

Call-types \ Criteria	Service price (c_1)	Data rate (mbps)(c_2)	Security(c_3)	Network delay (c_4)
Voice call	0.1700	0.6700	0.8400	0.3300
File download	0.1700	0.6700	0.5000	0.3300
Video streaming	0.5000	0.8400	0.1700	0.5000

Step 28: Compute the normalized preference for each of the call in Table 4.16, using equation (43).

$$\overline{F^{voice\ call}} = [0.0846 \quad 0.3333 \quad 0.4179 \quad 0.1642]$$

$$\overline{F^{file\ download}} = [0.1018 \quad 0.4012 \quad 0.2994 \quad 0.1976]$$

$$\overline{F^{video\ streaming}} = [0.2488 \quad 0.4179 \quad 0.0846 \quad 0.2488]$$

Step 29: Determine the normalized decision preference for voice call, file download and video streaming respectively.

(a) Multiply \overline{DM} in step 4 by the normalized preference of voice call in step 28, and is represented as $\overline{DM_3_voice}$.

$$\overline{DM_3_voice} = \begin{matrix} & c_1 & c_2 & c_3 & c_4 \\ \begin{matrix} r_1 \\ r_2 \\ r_3 \\ r_4 \end{matrix} & \begin{bmatrix} 1.0000 & 1.0000 & 0.3976 & 0.2537 \\ 0.4925 & 0.1389 & 1.0000 & 0.5152 \\ 0.6600 & 0.4630 & 0.6024 & 1.0000 \\ 0.6600 & 0.2778 & 0.8072 & 0.5152 \end{bmatrix} & \times & \begin{bmatrix} 0.0846 \\ 0.3333 \\ 0.4179 \\ 0.1642 \end{bmatrix} \end{matrix}$$

The results obtained are presented in Table 4.17.

(b) Multiply \overline{DM} in step 4 by the normalized preference of file download in step 28, and is represented by $\overline{DM_3_file\ download}$.

$$\overline{DM_3_file\ download} = \begin{matrix} r_1 \\ r_2 \\ r_3 \\ r_4 \end{matrix} \begin{bmatrix} c_1 & c_2 & c_3 & c_4 \\ 0.5152 & 1.0000 & 0.3929 & 0.2537 \\ 0.2537 & 0.1389 & 1.0000 & 1.0000 \\ 0.3400 & 0.4630 & 0.7976 & 0.5152 \\ 1.0000 & 0.2037 & 0.2024 & 0.3400 \end{bmatrix} \times \begin{bmatrix} 0.1018 \\ 0.4012 \\ 0.2994 \\ 0.1976 \end{bmatrix}$$

The results obtained are presented in Table 4.17.

(c) Multiply \overline{DM} in step 4 by the normalized preference of video streaming in step 28, and is represented as $S_3 = \overline{DM_3_video\ streaming}$.

$$\overline{DM_3_video\ streaming} = \begin{matrix} r_1 \\ r_2 \\ r_3 \\ r_4 \end{matrix} \begin{bmatrix} c_1 & c_2 & c_3 & c_4 \\ 0.5152 & 1.0000 & 0.3929 & 0.2537 \\ 0.2537 & 0.1389 & 1.0000 & 1.0000 \\ 0.3400 & 0.4630 & 0.7976 & 0.5152 \\ 1.0000 & 0.2037 & 0.2024 & 0.3400 \end{bmatrix} \times \begin{bmatrix} 0.2488 \\ 0.4179 \\ 0.0846 \\ 0.2488 \end{bmatrix}$$

The results obtained are presented in Table 4.17.

Step 30: Compute the overall performance score (S_i) of multiple-calls (voice call, file download and video streaming) as offered by Table 4.17.

Table 4.17: Overall Performance Score of Multiple Handoff Calls in HWNs.

Overall Performance value	Voice call weight	File download weight	Video streaming weight
RAT 1	0.5827	0.6214	0.6424
RAT 2	0.6498	0.5786	0.4545
RAT 3	0.6010	0.5610	0.4737
RAT 4	0.2929	0.3113	0.4356

Step 31: Compute the pairwise comparison for each of the calls in Table 4.17 for the four available RATs. The pairwise comparison is used to determine the preference for each of the calls (i.e., voice call, file download and video streaming) respectively, using the concepts of AHP [58]. The obtained pairwise comparisons are presented in Tables 4.18-4.20.

Table 4.18: Analytic Hierarchy Process Pairwise Comparison of four RATs for Voice call.

Voice call	RAT 1	RAT 2	RAT 3	RAT 4
RAT 1	1.0000	0.8967	0.9696	1.9897
RAT 2	1.1152	1.0000	1.0813	2.2188
RAT 3	1.0313	0.9248	1.0000	2.0520
RAT 4	0.5026	0.4507	0.4873	1.0000

Table 4.19: Analytic Hierarchy Process Pairwise Comparison of four RATs for File download.

File download	RAT 1	RAT 2	RAT 3	RAT 4
RAT 1	1.0000	1.0740	1.1078	1.9961
RAT 2	0.9311	1.0000	1.0314	1.8585
RAT 3	0.9027	0.9696	1.0000	1.8020
RAT 4	0.5010	0.5381	0.5549	1.0000

Table 4.20: Analytic Hierarchy Process Pairwise Comparison of four RATs for Video streaming.

Video streaming	RAT 1	RAT 2	RAT 3	RAT 4
RAT 1	1.0000	1.4134	1.3562	1.4748
RAT 2	0.7075	1.0000	0.9595	1.0434
RAT 3	0.7373	1.0422	1.0000	1.0874
RAT 4	0.6780	0.9584	0.9196	1.0000

Step 32: Convert the obtained results as offered by Tables (4.18-4.20) respectively into fuzzy preference relations $P^i = p_{ij}^a$. Where p_{ij}^a is given as $\frac{1}{2}(1 + \log_9 p_{ij}^a)$ [56]. Where a, i and j represent service types, row and column elements respectively. The fuzzy preference relations P^i are given as follows:

$$p^{voice\ call}(P^1) = \begin{bmatrix} 0.5000 & 0.4752 & 0.4930 & 0.6566 \\ 0.5248 & 0.5000 & 0.5178 & 0.6814 \\ 0.5070 & 0.4822 & 0.5000 & 0.6636 \\ 0.3434 & 0.3186 & 0.3364 & 0.5000 \end{bmatrix}$$

$$p^{file\ download}(P^2) = \begin{bmatrix} 0.5000 & 0.5163 & 0.5233 & 0.6573 \\ 0.4837 & 0.5000 & 0.5070 & 0.6410 \\ 0.4767 & 0.4930 & 0.5000 & 0.6340 \\ 0.3427 & 0.3590 & 0.3660 & 0.5000 \end{bmatrix}$$

$$p^{video\ streaming}(P^3) = \begin{bmatrix} 0.5000 & 0.5787 & 0.5693 & 0.5884 \\ 0.4213 & 0.5000 & 0.4906 & 0.5097 \\ 0.4307 & 0.5094 & 0.5000 & 0.5191 \\ 0.4116 & 0.4903 & 0.4809 & 0.5000 \end{bmatrix}$$

Step 33: Compute the similarity function between preferences (i.e., $p^{voice\ call}(P^1)$, $p^{file\ download}(P^2)$ and $p^{video\ streaming}(P^3)$) in HWNs, using $SM^{bl} = 1 - |p_{ij}^b - p_{ij}^l|$ [49].

$$SM^{12} = \begin{bmatrix} 1.0000 & 0.9589 & 0.9697 & 0.9993 \\ 0.9589 & 1.0000 & 0.9892 & 0.9597 \\ 0.9697 & 0.9892 & 1.0000 & 0.9704 \\ 0.9993 & 0.9597 & 0.9704 & 1.0000 \end{bmatrix}$$

$$SM^{13} = \begin{bmatrix} 1.0000 & 0.8965 & 0.9236 & 0.9319 \\ 0.8965 & 1.0000 & 0.9728 & 0.8283 \\ 0.9236 & 0.9728 & 1.0000 & 0.8555 \\ 0.9319 & 0.8283 & 0.8555 & 1.0000 \end{bmatrix}$$

$$SM^{23} = \begin{bmatrix} 1.0000 & 0.9375 & 0.9539 & 0.9311 \\ 0.9375 & 1.0000 & 0.9836 & 0.8686 \\ 0.9539 & 0.9836 & 1.0000 & 0.8851 \\ 0.9311 & 0.8686 & 0.8851 & 1.0000 \end{bmatrix}$$

Note that SM^{12} , SM^{13} and SM^{23} in step 33 represent the similarity matrix, which expresses the similarity preferences between two calls. The similarity preferences for $p^{voice\ call}(P^1)$, $p^{file\ download}(P^2)$ and $p^{video\ streaming}(P^3)$ measures the soft coincidence that exist between two services (i.e., voice call and video streaming), (voice call and file download) and (video streaming and file download) respectively.

Step 34: Compute a collective similarity matrix SM . Where $SM = \{sm_{ij}\}$, and is obtained by aggregating the entire similarity matrix SM^{bl} in step 33, using the arithmetic mean.

$$SM = \begin{bmatrix} 1.0000 & 0.9310 & 0.9491 & 0.9541 \\ 0.9310 & 1.0000 & 0.9819 & 0.8855 \\ 0.9491 & 0.9819 & 1.0000 & 0.9037 \\ 0.9541 & 0.8855 & 0.9037 & 1.0000 \end{bmatrix}$$

Step 35: Determine the consensus RAT-selection ranking $RAT - j$ as follows:

$$RAT - j = \prod_{i=1}^h sm_{ij}, \forall, i \in \{1, \dots, h\}, j \in \{1, \dots, n\} \quad (57)$$

$$RAT-1 = 0.8430$$

$$RAT-2 = 0.8095$$

$$RAT-3 = 0.8421$$

$$RAT-4 = 0.7635$$

Step 36: Select $RAT - j^*$ with the highest score value as the most suitable RAT for a group of multiple-calls from a single-homed multi-mode terminal in HWNs.

$$RAT - j^* = \max_{j=1}^n RAT - j \quad (58)$$

Hence: $RAT-1 > RAT-3 > RAT-2 > RAT-4$

On the other hand, the obtained results for the third consensus RAT-selection decisions differed from that obtained in the first and second consensus RAT-selection decisions. In the previous RAT-selection decisions (first and second consensus decisions), **RAT-3** has been selected as the most suitable that best offer the QoS requirements for the entire group of multiple handoff calls, while the third consensus RAT-selection decisions show that **RAT-1** is best preferred compared to the other three available RATs (RAT-2, RAT-3 and RAT-4) from a single-homed multi-mode terminal in HWNs.

However, in order to select RAT-1 as the most preferred RAT for a group of multiple handoff calls from a single-homed multi-mode terminal, the proximity measures for all the criteria used for RAT-selection decisions must be greater than or equal to the minimum criterion threshold of $\beta = 0.90$ before the obtained decision in equation (58) is valid, else another consensus decision is required. Therefore, the proximity measures for the third consensus

decisions are determined using steps (37-39) as follows:

Step 37: Determine the collective preference relation $P^{c_new_1}$. Where $P^{c_new_1} = \{p_{ij}^c\}$ is obtained by means of aggregation of all individual fuzzy preference relations ($p^{voice\ call}(P^1)$, $p^{file\ download}(P^2)$, $p^{video\ streaming}(P^3)$). The aggregation operation is carried out by means of ordered weight aggregate (OWA) operator ϕ_Q [55]. The fuzzy quantifier "most" with the pair of (0.3, 0.8) is used [56]. Therefore the corresponding OWA operator ϕ_Q is represented as the weighting vector $W = [0.06, 0.68, 0.26]$.

Thus,

$$p_{ij}^c = \phi(p_{ij}^1, \dots, p_{ij}^m) = \sum_{k=1}^n (w_a \cdot p_{ij}^a) \text{ for } a \in \{1, \dots, m\}, i = 1, \dots, h; j = 1, \dots, n \quad (59)$$

$$P^{c_new_1} = \begin{bmatrix} 0.5000 & 0.5093 & 0.5182 & 0.6389 \\ 0.4700 & 0.5000 & 0.5034 & 0.6093 \\ 0.4666 & 0.4912 & 0.5000 & 0.6059 \\ 0.3473 & 0.3564 & 0.3652 & 0.5000 \end{bmatrix}$$

Step 38: Determine the proximity measures $PM^a = \{pm_{ij}^a\}$ on pairs of calls e_a as follows:

$$\text{That is, } pm_{ij}^a = 1 - |p_{ij}^a - p_{ij}^c| \quad \text{for } a \in \{1, \dots, m\}, i = 1, \dots, h; j = 1, \dots, n \quad (60)$$

$$PM^{voice\ call} = \begin{bmatrix} 1.0000 & 0.9659 & 0.9748 & 0.9823 \\ 0.9452 & 1.0000 & 0.9856 & 0.9279 \\ 0.9595 & 0.9911 & 1.0000 & 0.9423 \\ 0.9961 & 0.9623 & 0.9712 & 1.0000 \end{bmatrix}$$

$$PM^{file\ download} = \begin{bmatrix} 1.0000 & 0.9931 & 0.9949 & 0.9816 \\ 0.9862 & 1.0000 & 0.9964 & 0.9683 \\ 0.9898 & 0.9982 & 1.0000 & 0.9719 \\ 0.9954 & 0.9974 & 0.9992 & 1.0000 \end{bmatrix}$$

$$PM^{video\ streaming} = \begin{bmatrix} 1.0000 & 0.9306 & 0.9488 & 0.9495 \\ 0.9513 & 1.0000 & 0.9872 & 0.9004 \\ 0.9641 & 0.9818 & 1.0000 & 0.9132 \\ 0.9358 & 0.8660 & 0.8843 & 1.0000 \end{bmatrix}$$

Where $PM^{voice\ call}(PM^1)$, $PM^{file\ download}(PM^2)$ and $PM^{video\ streaming}(PM^3)$ represent proximity measures for voice call, file download and video streaming respectively for the RAT-selection decisions from a single-homed multi-mode terminal in HWNs.

Step 39: Determine the individual proximity pa_j^a toward the RAT-selection decisions in equation (58) for each of the calls as offered by step 38 [49]. Where pa_j^a is given as:

$$pa_j^a = \frac{\sum_{i=1; j \neq i}^h (pm_{ij}^a + pm_{ji}^a)}{2n - 2} \text{ for } a \in \{1, \dots, m\}, i = 1, \dots, h; j = 1, \dots, n \quad (61)$$

Hence:

$$pa_1^{voice\ call}, pa_2^{voice\ call}, pa_3^{voice\ call}, pa_4^{voice\ call} = \{0.9706, 0.9630, 0.9708, 0.9637\}$$

$$pa_1^{file\ download}, pa_2^{file\ download}, pa_3^{file\ download}, pa_4^{file\ download} = \{0.9902, 0.9899, 0.9917, 0.9856\}$$

$$pa_1^{video\ streaming}, pa_2^{video\ streaming}, pa_3^{video\ streaming}, pa_4^{video\ streaming} = \{0.9467, 0.9362, 0.9466, 0.9082\}$$

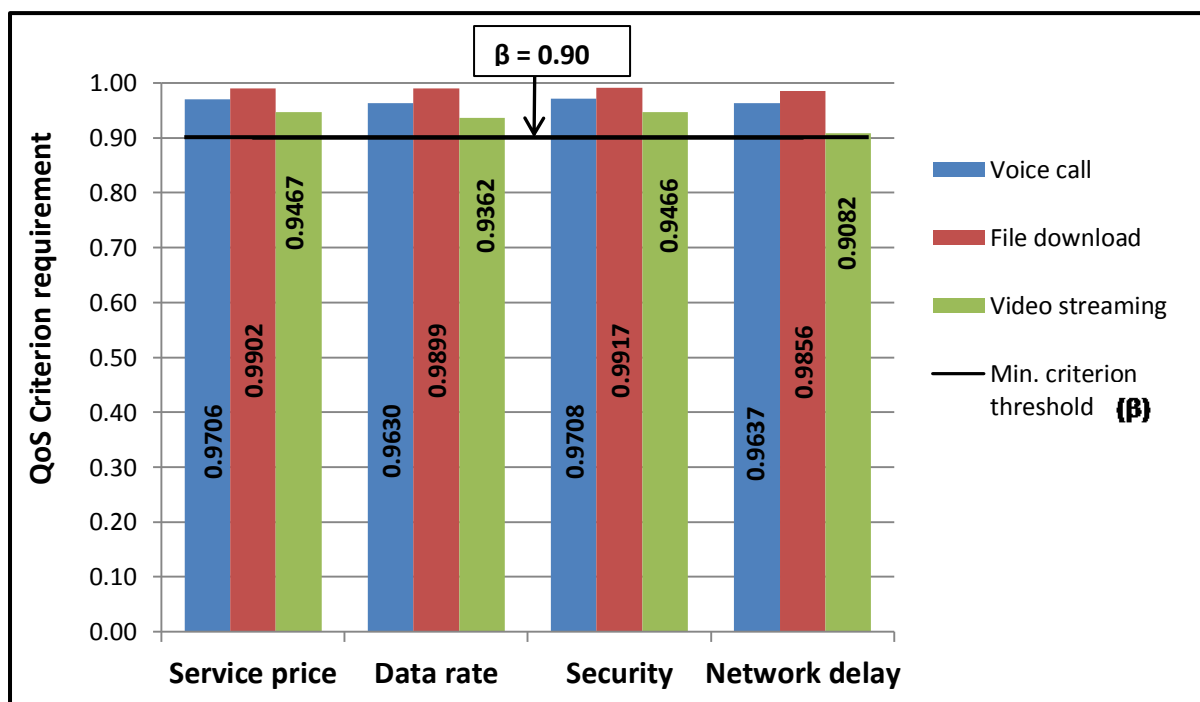


Figure 4.4: Criteria threshold for Group of Multiple Handoff Calls in HWNs (Third-Proximity Decision).

Figure 4.4, shows that all criteria satisfied the minimum criterion threshold ($\beta = 0.90$) for the group of multiple handoff calls from a single-homed multi-mode terminal. Furthermore, the results show that the criteria for the security and the network delay have the highest and least values of **0.9917** and **0.9082** respectively among the criteria for a group of multiple-calls.

Therefore, the consensus RAT-selection decisions in equation (58) remain valid (i.e., RAT-1 = 0.8430, RAT-2 = 0.8095, RAT-3 = 0.8421 and RAT-4 = 0.7635) for the group of multiple handoff calls from a single-homed multi-mode terminal in HWNs. Hence, RAT-1 is then selected as most preferred RAT that best offers the QoS requirements for a group of multiple

handoff calls from a single-homed multi-mode terminal in HWNs.

In addition, Table 4.21 presents the ranking order of the RAT-selection decisions (i.e., from the first to the third selection decisions) for a group of multiple handoff calls from a single-homed multi-mode terminal in HWNs.

Table 4.21: Ranking Order of RAT-selection in HWNs.

Networks	First Consensus RAT-selection Decisions	Second Consensus RAT-selection Decisions	Third Consensus RAT-selection Decisions
RAT-1	0.7905 Rank # 2	0.8156 Rank # 2	0.8430 Rank # 1
RAT-2	0.7120 Rank # 3	0.7553 Rank # 3	0.8095 Rank # 3
RAT-3	0.7907 Rank # 1	0.8157 Rank # 1	0.8421 Rank # 2
RAT-4	0.7050 Rank # 4	0.7460 Rank # 4	0.7635 Rank # 4

In Table 4.21, the first and the second consensus RAT-selection decisions show the same ranking order (RAT-3 > RAT-1 > RAT-2 > RAT-4) and also selected **RAT-3** as the most preferred RAT that best offers the QoS requirements for a group of multiple-calls from a single-homed multi-mode terminal in HWNs. However, the consensus RAT-selection decisions for selecting RAT-3 in the first and the second consensus process remained invalid because the minimum criterion threshold for QoS requirements was compromised.

The ranking order for the third consensus RAT-selection decisions are RAT-1 > RAT-3 > RAT-2 > RAT-4. Therefore **RAT-1** is selected as the most preferred RAT that best offers the QoS requirements for a group of multiple-calls from a single-homed multi-mode terminal in HWNs. The ranking order for the third consensus RAT-selection decisions differ from that of the first and the second consensus RAT-selection decisions. In addition, all the criteria for the third consensus RAT-selection decisions satisfy the minimum criterion threshold for QoS requirements for multiple handoff calls from a single-homed multi-mode terminal in HWNs.

In Figure 4.5 the consensus RAT-selection process for a single user (user-1) is presented. The results obtained in Figure 4.5 shows the consensus degrees that were reached among the group of multiple handoff calls from a single-homed multi-mode terminal when selecting the

most suitable RAT that best offer the QoS requirements amongst the four available RATs in HWNs.

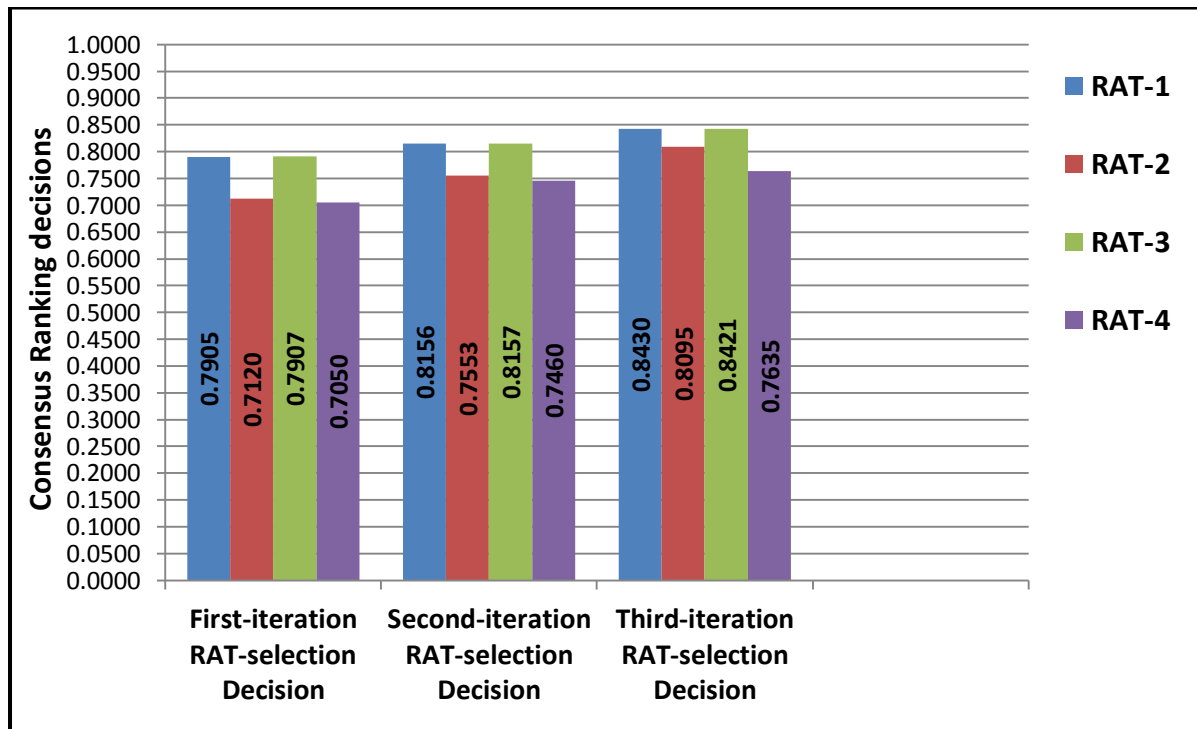


Figure 4.5: Consensus RAT-selection Decisions for a Group of Multiple-calls in HWNs (User-1).

Furthermore, the results in Figure 4.5 also show that the highest and the least consensus ranking decisions for a group of multiple handoff calls are 0.8430 (i.e., RAT-1) and 0.7050 (i.e., RAT-4) respectively in HWNs, which occur during the first and the third consensus RAT-selection decisions.

The results shown in Figures 4.6 to 4.8 has been performed for 19 more users with different random range of preferences for selecting the most suitable RAT from a single-homed multi-mode terminal for multiple-call in HWNs.

Figure 4.6 shows the consensus ranking decision for a group of multiple-calls, considering multiple-users (20-users) in HWNs. The obtained results show that the selected RATs vary from one user to another. This is based on the random range of preferences assigned by users for multiple-calls (voice call, file download, video streaming) criteria.

Furthermore, the results in Figure 4.6 also show that the user's assigned preference of choice contributes to the consensus RAT-selection decision that determine the most preferred RAT for a group of multiple handoff calls from a single-homed multi-mode terminal in HWNs.

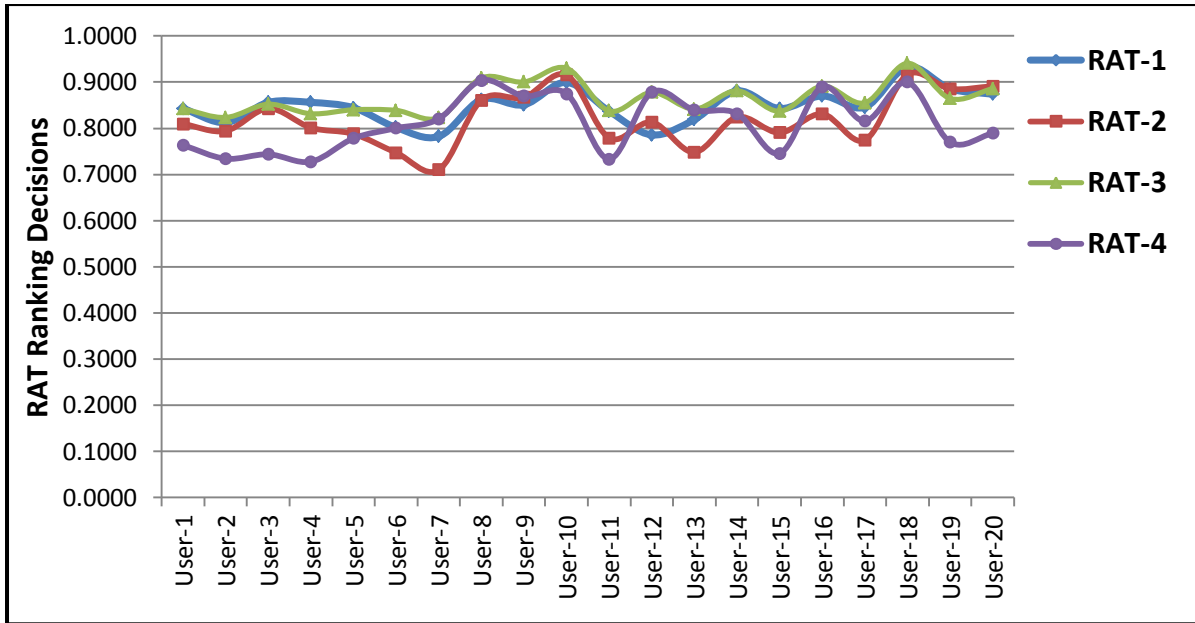


Figure 4.6: Consensus Ranking Decisions for a Group of Multiple-calls in HWNs.

Figure 4.7 depicts the number of consensus phase required for a group of multiple handoff calls (voice call, file download and video streaming) before a consensus for the most suitable RAT that best offer the QoS requirements from a single-homed multi-mode terminal is selected in HWNs. For example, the results from Figure 4.6 show that user-19 takes four consensus RAT-selection decisions before the minimum QoS requirements for a group of multiple handoff calls are met.

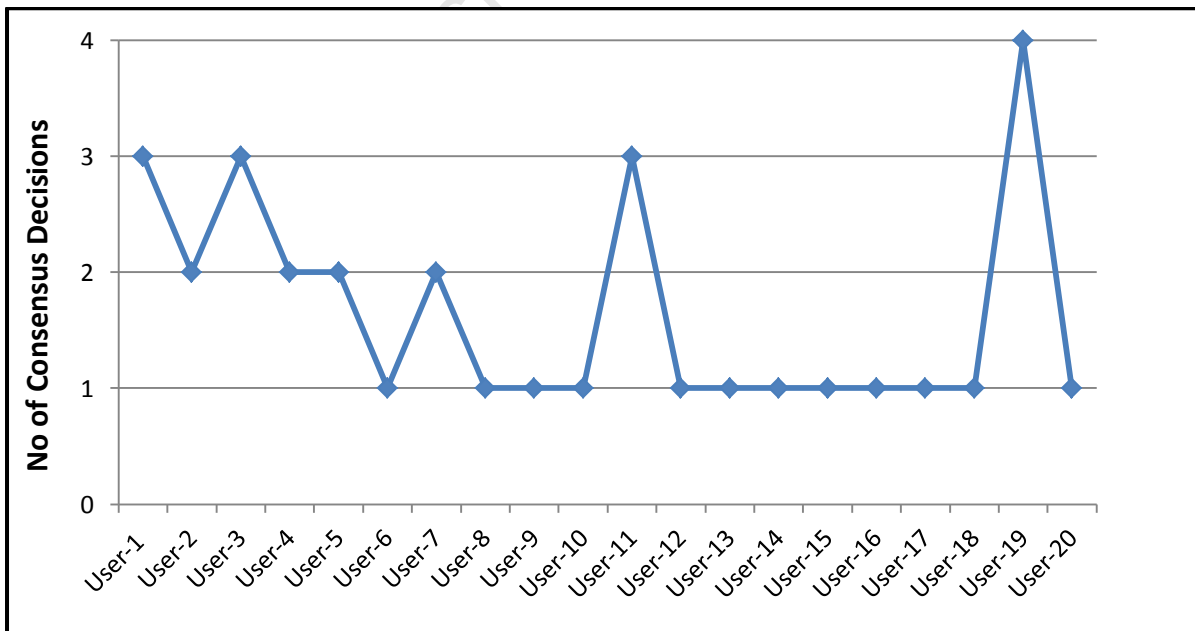


Figure 4.7: Number of Consensus Decisions for a Group of Multiple Handoff Calls in HWNs.

While user-1, user-3 and user-11 require three consensus decisions, whereas user-2, user-(4 to 5) and user-7 require two consensus decisions among the group of multiple handoff calls. User-6, users-(8 to 19) and user-20 only require one consensus RAT-selection decision for a group of multiple-calls from a single-homed multi-mode terminal in HWNs.

Figure 4.8 presents the consensual RAT selected for multiple-users (20-users), using a single-homed multi-mode terminal to select the most preferred RAT amongst four available RATs that best provide the QoS-requirements for a group of multiple-calls (voice call, file download and video streaming) in a HWN. In this case, it is observed that thirteen out of twenty users selected RAT-3 as the most preferred RAT, and while five users selected RAT-1.

In addition, the results obtained in Figure 4.8 also show that one user selected RAT-2 and RAT-4 respectively as the most preferred network for a group of multiple handoff calls in a HWN.

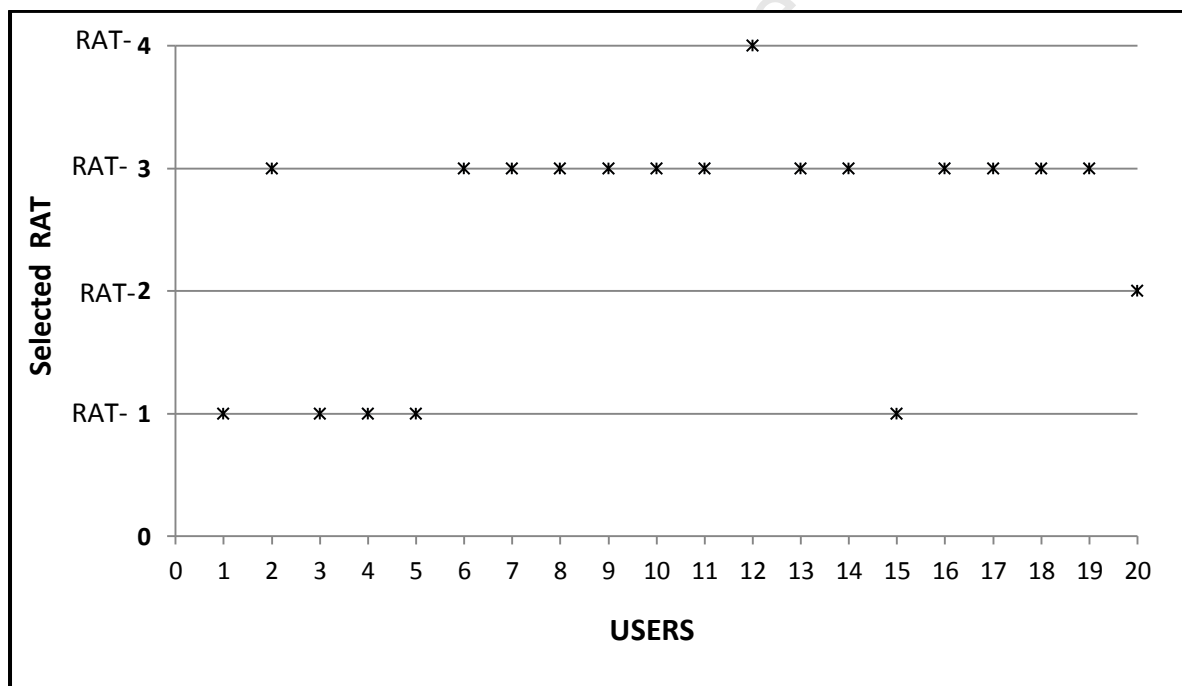


Figure 4.8: Consensual RAT-selection Decisions in HWNs.

Furthermore, Figure 4.8 shows that the consensus RAT-selection decision varies from a range of preference to another in HWNs. Therefore, the user's ranges of preferences for multiple-calls contribute to the consensus RAT-selection decision for determining a suitable RAT in HWNs.

4.5.4 Analysis of Proximity measures for Selective Subset of a Group of Handoff-calls in a Heterogeneous Wireless Network

As mentioned earlier, the use of proximity measures are utilized when none of the candidate RATs has enough capacity to accommodate the entire group of calls from a single-homed multi-mode terminal in an HWN. Therefore, a selective subset is performed for a segment of groups of calls to avoid the entire group of calls being dropped from the HWNs.

For example, the results in equation (58) show that **RAT-1** will be selected as the most preferred RAT because it has the highest consensus decision among the available RATs. Users are free to move from one geographical area to another, it is possible that RAT-1 has less coverage than other RATs, and the movement of a user from the coverage area of RAT-1 will necessitate RAT-1 to handoff the entire group of calls to one of the other three RATs (i.e., RAT-2, RAT-3 and RAT-4) in a HWN as shown in Figure 4.9.

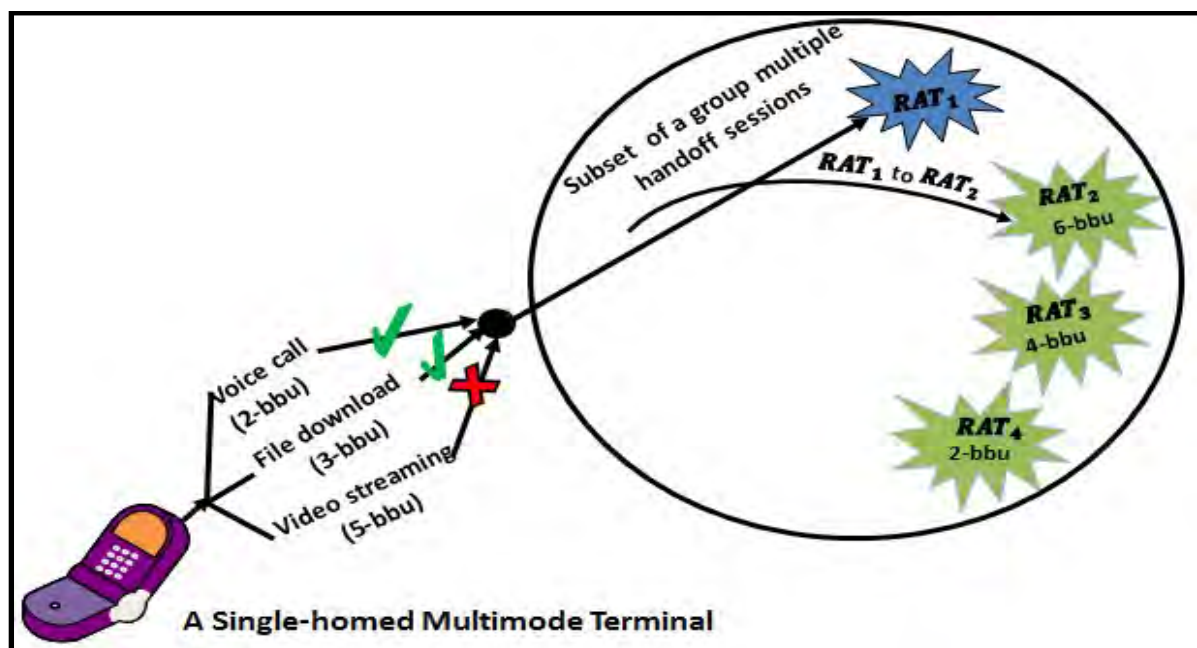


Figure 4.9: A Subset Selection of a Group of Handoff-calls from a Single-homed Multimode Terminal in an HWN.

Assume that the basic bandwidth unit (bbu) required for the multiple-calls are given as: voice call = 2-bbu, file download = 3-bbu, and video streaming = 5-bbu. Therefore, it is expected that the available candidate RATs (RAT-2, RAT-3 and RAT-4) have a minimum bandwidth of 10-bbu, before the entire group of calls can be handed over to it.

In a situation where none of the candidate RATs (i.e., RAT-2, RAT-3 and RAT-4) has

enough bbu to accommodate the calls, a subset of the multiple-calls has to be selected for handoff. The question then is: how do we determine the calls to be accepted for handoff and the ones to be dropped?

The proposed consensus scheme performs the function of selecting a subset of the entire group of handoff calls from a single-homed multi-mode terminal in HWNs, using proximity measures in equations (61). The call that has the least cumulative proximity measures is dropped from the group of calls in the network. The results in equations (61) show that video streaming has the least proximity value, while file download has the highest value. Therefore, the proposed scheme will select voice call and file download, and then handoff the calls into RAT-2, as shown in Figure 4.9. Therefore RAT-2 is selected because it has enough capacity (6-bbu) to support the two calls.

If after dropping the call with the least cumulative proximity measures (video streaming in the case) and there is still not enough bbu to accommodate the remaining calls in any of the available RATs, the next call with the lowest proximity measures (voice call) is dropped, and so on.

4.6 Chapter Summary

This chapter has presented a new RAT-selection scheme, named consensus RAT-selection scheme, for selecting the RAT that best meets the QoS requirements for a group of handoff calls in HWNs. It has further explained the concepts of consensus RAT-selection to solve group decision problem for a group of multiple-calls in HWNs. This includes the models of computation with words (fuzzy preference relation). Furthermore, the assignment of a range of preferences from a single-homed multi-mode terminal has been explained in HWNs. The rules that are used to guide the change of preference from one choice to another in HWNs have been explained as well.

Lastly, the proposed scheme has been applied to select a subset of a group of handoff calls from multiple-calls when none of the available RATs has enough bbu to accommodate all the incoming calls.

Chapter 5 Conclusion and Future Work

5.1 Summary of Contributions

This section summarises the contributions of the dissertation.

In chapter 2, the literature reviewed shows the limitations of the existing RAT-selection schemes for making RAT-selection decisions for a group of multiple-calls from a single-homed multi-mode terminal in HWNs. Thus, most of the existing RAT-selection schemes in the literature are not suitable for selecting RATs for multiple-calls. Therefore, the use of group decision-making schemes are required to solve the problem of making RAT-selection decisions for multiple handoff calls from a single-homed multi-mode terminal in HWNs. The main contributions of the dissertation are summarized in two folds as follows:

In chapter 3, the study has compared the performance of four multi-criteria group decision-making (MCGDM) schemes. These are SAW-GDM, MEW-GDM, TOPSIS-GDM and DIA-GDM. The criteria sensitivities of the schemes have been evaluated using five criteria namely service price, data rate, security level, battery power consumption and network delay for selecting the most suitable RAT among available RATs (i.e., RAT-1, RAT-2, RAT-3 and RAT-4) for multiple handoff calls.

The effects of having multiple users (100 mobile users) using various selection criteria for RAT-selection preference based on different MCGDM schemes have been discussed. The simulation results obtained reveal the sensitivities of five selection criteria through the comparative analysis of four adapted MCGDM schemes for making multiple-calls. This study was analysed using the MATLAB tool, which shows the effectiveness and the performance for each of the adapted MCGDM schemes used for RAT-selection for a group of multiple-calls in HWNs.

The comparative analyses reveal that TOPSIS-GDM and DIA-GDM schemes are more consistent across the five criteria mentioned above when compared to the SAW-GDM and MEW-GDM schemes in an HWN. In addition, TOPSIS-GDM and DIA-GDM schemes distribute the group of multiple handoff calls more evenly across the four available RATs compared to SAW-GDM and MEW-GDM schemes, using the five chosen criteria in an HWN. Therefore, TOPSIS-GDM and DIA-GDM schemes are more suitable for making RAT-selection decisions for a group of multiple handoff calls from a single-homed multi-mode terminal in a HWN.

In chapter 4, the consensus RAT-selection scheme has been presented based on soft coincidence among preferences to select the most suitable RAT for a group of multiple handoff calls from a single-homed multi-mode terminal in a HWN. The proposed scheme is composed of two distinct processes, namely the consensus degrees and the proximity measures. Both processes are used to solve the group decision problems among the multiple-calls for suitable RAT-selection in HWNs.

Furthermore, chapter 4 presents one of the scenarios evaluated and its steps, using the consensus RAT-selection scheme for making RAT-selection decision for a group of multiple handoff calls from a single-homed multi-mode terminal in HWNs. The results show that RAT-1 is selected as the most suitable RAT amongst the four available RATs (RAT-1, RAT-2, RAT-3 and RAT-4) for the group of multiple-calls in HWNs. The results also show the collective degree of consensus levels that best represent the collective group decision for the multiple handoff calls from a single-homed multi-mode terminal in HWNs.

Moreover, the consensus RAT-selection scheme makes use of proximity measures to select a subset of a group of multiple handoff calls based on the least proximity measured for each of the calls. The call with the least proximity measured is dropped when none of the candidate RATs has enough capacity to accommodate the entire group of handoff calls (voice call, file download and video streaming). This concept reduces the dropping probability of handoff for a group of calls in HWNs.

The results obtained show the effectiveness of the consensus RAT-selection scheme. Therefore, the consensus RAT-selection scheme is a promising scheme for RAT-selection in HWNs. The consensus RAT-selection scheme should be adopted for RAT-selection and for enabling a single-homed multi-mode terminal in HWNs to select a subset of calls from a group of handoff calls when the available candidate RATs did not have enough resources to accommodate the entire group of calls. This provides a valuable solution to the operators and service providers because of its economic advantage. It also improves user quality of experience.

5.2 Recommendations and Future Work

Based on the findings from this study, the following recommendations and direction for future research are stated:

- 1 Further studies should be conducted to estimate the amount of revenue a network operator

could generate when a subset of calls is dropped rather than dropping an entire group of calls because of radio resource constraints among available RATs in an HWN.

- 2 Further studies should be conducted to determine the computational overhead that the proposed RAT-selection scheme could incur when used in HWNs.
- 3 Finally, studies should be conducted on the extension of the MCGDM scheme to cover abnormal ranking of RAT-selection when the least preferred RAT is removed from the list of candidate RATs for a group of multiple-calls in HWNs, keeping in view the user range of preferences and call priorities.

University of Cape Town

References

- [1] Q. Nguyen-Vuong, N. Agoulmine, E. H. Cherkaoui and L. Toni, "Multicriteria optimization of access selection to improve the quality of experience in heterogeneous wireless access networks," *IEEE Transactions on Vehicular Technology*, vol. 62, issue 4, pp. 1785-1800, May 2013.
- [2] E. Gustafsson and A. Jonsson, "Always best connected," *IEEE Transactions on Wireless Communications*, , vol. 10, issue 1, pp. 49-55, February 2003.
- [3] H. Kaaranen, A. Ahtiainen, L. Laitinen, S. Naghian and V. Niemi, UMTS networks, architecture, mobility and services, *Second Edition*, John Wiley and Sons, 2005.
- [4] O. E. Falowo and H. A. Chan, "Joint call admission control algorithms: Requirements, approaches, and design considerations," *International Journal of Computer communication*, vol. 31, issue 6, pp. 1200-1217, April 2008.
- [5] O. E. Falowo, "Terminal-modality-based joint call admission control algorithm for fair radio resource allocation in heterogeneous cellular networks," *International Journal of Communications, Network and System Sciences*, vol. 5, no. 7, pp. 392-404, July 2012.
- [6] M. Lahby, C. Leghris and A. Adib, "An enhanced evaluation model for vertical handover algorithm in heterogeneous networks," *International Journal of Computer Science (IJCSI)*, vol. 9, issue 3, no. 2, pp. 254-259, May 2012.
- [7] S. Maaloul, M. Afif and S. Tabbane, "Vertical handover decision policy based on the end user's perceived quality of service," *Proceedings of 27th International Conference on Advanced Information Networking and Applications Workshops (WAINA)*, pp. 493-498, Barcelona, Spain, March 2013.
- [8] R. Agusti, O. Salient, J. Perez-Romero and L. Giupponi, "A fuzzy-neural based approach for joint radio resource management in a beyond 3G framework," *Proceedings of 1st International Conference on Quality of Service in Heterogeneous Wired/Wireless Networks, ICTS IEEE (QSHINE)*, pp. 216-224, Dallas, Texas, USA, October 2004.
- [9] A. Klein, C. Lottermann, C. Mannweiler, J. Schneider and H. D. Schotten, "A novel approach for combined joint call admission control and dynamic bandwidth adaptation in heterogeneous wireless networks," *Proceedings of 7th EURO-NF Conference on Next Generation Internet (NGI)*, Kaiserslautern, Germany, pp. 1-8,

June 2011.

- [10] L. Giupponi, R. Agusti, J. Perez-Romero and O. Sallent, "Joint radio resource management algorithm for multi-RAT networks," *IEEE Global Telecommunications Conference, GLOBECOM'05*, vol. 6, pp.5-pp.,3855, USA, 2-2 December 2005.
- [11] O. E. Falowo and H. A. Chan, "RAT selection for multiple-calls in heterogeneous wireless networks using modified TOPSIS group decision making technique," *Proceedings of the 22nd IEEE Symposium on Personal, Indoor, Mobile and Radio Communications (PIMRC 2011)*, pp. 1371-1375, Toronto, Canada, 11-14 September 2011.
- [12] T. Ahmed, K. Kyamakya and M. Ludwig, "A context-aware vertical handover decision algorithm for multi-mode mobile terminals and its performance," *Proceedings of the IEEE/ACM Euro American Conference on Telematics and Information Systems (EATIS 2006)*, pp. 19-28, Santa Marta, Colombia, 7-10 February 2006.
- [13] S. T. Yang and A. Ephremides, "Resolving the CDMA cell breathing effect and near-far unfair access problem by bandwidth-space partitioning," *Proceedings of the 53rd, IEEE Conference on Vehicular Technology*, spring, vol.2, pp. 1037-1041, May 2001.
- [14] J. Perez-Romero, O. Salient, R. Agusti, N. Garcia, L. Wang and H. Aghvami, "Network-controlled cell-breathing for capacity improvement in heterogeneous CDMA/TDMA scenarios," *Proceedings of the IEEE on Wireless Communications and Networking Conference (WCNC 2006)*, vol.1, pp. 36-41, 3-6 April 2006.
- [15] G. Ning, G. Zhu, L. Peng and X. Lu, "Load balancing based on traffic selection in heterogeneous overlapping cellular networks," *Proceedings of the Internet, the First IEEE and IFIP International Conference in Central Asia*, pp. 5 pp., 26-29 September 2005.
- [16] L. Yi, K. Miao and A. Liu, "A comparative study of WiMAX and LTE as the next generation mobile enterprise network," *Proceedings of the 13th International Conference on Advanced Communication Technology (ICACT 2011)*, pp. 654-658, 13-16 February 2011.
- [17] T. Salam, S. Mushtaq, T. Khalid, M. Ali and M. Amin, "Efficient vertical handover approaches for increased user satisfaction in next generation networks," *Proceedings of the International Conference on Computer Networks and Information Technology (ICCNIT)*, pp. 233-239, 11-13 July 2011.
- [18] A. Singhrova and N. Prakash, "Vertical handoff decision algorithm for improved

- quality of service in heterogeneous wireless networks," *IET Communications*, vol. 6, no. 2, pp. 211-223, 2012.
- [19] J. Z. Tristan, "Analysis of next generation mobile terminals in heterogeneous wireless networks," *BSc. Thesis {Unpublished}*, 2012.
- [20] M. Fiterau, O. Ormond and G. Muntean, "Performance of handover for multiple users in heterogeneous wireless networks," *Proceedings of the 34th IEEE on Local Computer Networks (LCN) Conference*, pp. 257-260, Zürich, Switzerland, 20-23 October 2009.
- [21] J. Sachs, H. Wiemann, J. Lundsjo and P. Magnusson, "Integration of multi-radio access in a beyond 3G network," *Proceedings of the 15th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC)*, vol.2, pp. 757-762, 5-8 September 2004.
- [22] N. Ekiz, T. Salih, S. Küçüköner, and K. Fidanboyulu, "An Overview of handoff techniques in cellular networks," *International Journal of Information Technology*, vol. 2, no. 2, pp. 132-136, 2005.
- [23] T. Ali-Yahiya, K. Sethom and G. Pujolle, "Seamless continuity of service across WLAN and WMAN networks: Challenges and performance evaluation," *Proceedings of the 2nd IEEE/IFIP International Workshop on Broadband Convergence Networks (BCN)*, pp. 1-12, 21-21 May 2007.
- [24] B. Ma, X. Liao and X. Xie, "Risk-aware vertical handoff algorithm for security access support in heterogeneous wireless networks," *Proceedings of the 5th International Conference on Biomedical Engineering and Informatics (BMEI 2012)*, pp. 1515-1519, 16-18 October 2012.
- [25] A. Tolli, P. Hakalin and H. Holma, "Performance evaluation of common radio resource management (CRRM)," *Proceedings of the IEEE International Conference on Communications (ICC)*, vol.5. pp. 3429-3433, 2002.
- [26] Y. Choi, H. Kim, S. Han and Y. Han, "Joint resource allocation for parallel multi-radio access in heterogeneous wireless networks," *Proceedings of the IEEE Transactions on Wireless Communications*, vol. 9, no. 11, pp. 3324-3329, November 2010.
- [27] C. E. C. Bastidas, G. Vanhoy, H. I. Volos and T. Bose, "An initial approach towards quality of service based spectrum trading," *Proceedings of the IEEE on Aerospace Conference*, pp. 1-8, USA, 2-9 March 2013.
- [28] Y. Zheng, S. Jie and T. Liang-rui, "A novel call admission control scheme based on

- triangle module operator for heterogeneous wireless networks," *Proceedings of the 9th International Conference on Fuzzy Systems and Knowledge Discovery (FSKD)*, pp. 2078-2082, 29-31 May 2012.
- [29] J. D. Martínez-Morales, U. Pineda-Rico and E. Stevens-Navarro, "Performance comparison between MADM algorithms for vertical handoff in 4G networks," *Proceedings of the 7th International Conference on Electrical Engineering Computing Science and Automatic Control (CCE)*, pp. 309-314, 8-10 September 2010.
- [30] O. E. Falowo and H. A. Chan, "Joint call admission control algorithm for fair radio resource allocation in heterogeneous wireless networks supporting heterogeneous mobile terminals," *Proceedings of the 7th IEEE on Consumer Communications and Networking Conference (CCNC)*, pp. 1-5, Las Vegas, USA, 9-12 January 2010.
- [31] G. Ning, G. Zhu, L. Peng and X. Lu, "Load balancing based on traffic selection in heterogeneous overlapping cellular networks," *Proceedings of the First IEEE and IFIP International Conference on Internet in Central Asia*, pp. 5 pp., 26-29 September 2005.
- [32] S. Jin, W. Xuanli and S. Xuejun, "Load balancing algorithm with multi-service in heterogeneous wireless networks," *Proceedings of the 6th International ICST Conference on Communications and Networking in China (CHINACOM)*, pp. 703-707, Harbin, China, 17-19 August 2011.
- [33] H. Jin, Y. You, X. Ji, Y. Li and W. Wang, "Network selection in integrated heterogeneous wireless network: A novel MADM based approach," *International Journal on China Communications*, vol. 8, issue 8, pp. 34-43, 2011.
- [34] L. Mohamed, C. Leghris and A. Abdellah, "A survey and comparison study on weighting algorithms for access network selection," *Proceedings of the 9th Annual Conference on Wireless on-Demand Network Systems and Services (WONS)*, pp. 35-38, 9-11 January 2012.
- [35] O. E. Falowo, N. Ventura and H. A. Chan, "Effect of mobile terminal heterogeneity on connection-level QOS in next generation wireless networks," *Proceedings of the Canadian Conference on Electrical and Computer Engineering (CCECE)*, pp. 931-935, 3-6 May 2009.
- [36] E. Stevens-Navarro and V. W. S. Wong, "Comparison between vertical handoff decision algorithms for heterogeneous wireless networks," *Proceedings of the 63th IEEE on Vehicular Technology Conference (VTC)*, Spring, pp. 947-951, 7-10 May

2006.

- [37] P. N. Tran and N. Boukhatem, "The distance to the ideal alternative (DIA) algorithm for interface selection in heterogeneous wireless networks," *Proceedings of the 6th ACM International Symposium on Mobility Management and Wireless Access (MobiWac)*, pp. 61-68, Vancouver, British Columbia, Canada, 27-31 October 2008.
- [38] P. N. Tran and N. Boukhatem, "Comparison of MADM decision algorithms for interface selection in heterogeneous wireless networks," *Proceedings of the 16th International Conference on Software, Telecommunications and Computer Networks (SoftCOM)*, pp. 119-124, Split, Croatia, 25-27 September 2008.
- [39] A. G. Davalos, L. Escobar, A. Navarro, A. Arteaga, F. Guerrero and C. Salazar, "Vertical handoff algorithms: A new approach for performance evaluation," *Proceedings of the IEEE GLOBECOM Workshops (GlobeCom Workshops)*, pp. 1724-1728, Miami, USA, 6-10 December 2010.
- [40] A. Al-Sabbagh, R. Braun and M. Abolhasan, "A power efficient RAT selection algorithm for heterogeneous wireless networks," *Proceedings of the International Symposium on Communications and Information Technologies (ISCIT)*, pp. 997-1002, 2-5 October 2012.
- [41] V.P. Kafle, E. Kamioka, and S. Yamada, "Maximizing user satisfaction based on mobility in heterogeneous mobile communication networks," *Proceedings of the IEICE Transactions on Communications E88-B*, vol. 7, pp. 2709–2717, 2005.
- [42] R. B. Ali and S. Pierre, "An efficient predictive admission control policy for heterogeneous wireless bandwidth allocation in next generation mobile networks," *Proceedings of the International Conference on Communications and Mobile Computing (IWCMC'06)*, pp. 635-640, Vancouver, Canada, July 3-6, 2006.
- [43] W. Song, H. Jiang, W. Zhuang, and X. Shen, "Resource management for QoS support in WLAN/Cellular interworking," *Proceedings of the IEEE on Network*, vol. 9, no. 5, pp. 12–18, 2005.
- [44] M. E. Helou, S. Lahoud, M. Ibrahim, and K. Khawam, "A hybrid approach for radio access technology selection in heterogeneous wireless networks," *Proceedings of the 19th European on Wireless Conference*, pp.1-6, Guildford, United Kingdom, 16-18 April 2013.
- [45] "IEEE standard for architectural building blocks enabling network device distributed decision making for optimized radio resource usage in heterogeneous wireless access networks," *IEEE Standard*, 1900.4, pp. C1-119, 2009.

- [46] S. Chen, C. Hwang and F. P. Hwang, *Fuzzy multiple attribute decision making*. Berlin: Springer, 1992.
- [47] F. Herrera, E. Herrera-Viedma and J. L. Verdegay, "Linguistic measures based on fuzzy coincidence for reaching consensus in group decision making," *International Journal of Approximate Reasoning*, vol. 16, issues 3-4, pp. 309-334, 1997.
- [48] E. Herrera-Viedma, L. Martinez, F. Mata and F. Chiclana, "A consensus support system model for group decision-making problems with multi-granular linguistic preference relations," *IEEE Transactions on Fuzzy Systems*, vol. 13, no.5, pp. 644-658, October 2005.
- [49] F. J. Cabrerizo, J. M. Moreno, I. J. Pérez and E. Herrera-Viedma, "Analyzing consensus approaches in fuzzy group decision making: advantages and drawbacks," *Soft Computing* vol. 14, issue 5, pp. 451-463, March 2010.
- [50] L. A. Zadeh, "A computational approach to fuzzy quantifiers in natural languages" *Computers and Mathematics with Applications*, vol. 9, issue1, pp. 149-184, 1983.
- [51] J. Kacprzyk, S. Zadrozny and Z. W. Ras, "Action rules in consensus reaching process support," *Proceedings of the 9th International Conference on Intelligent Systems Design and Applications (ISDA)*, pp. 827-832, Pisa, Italy, 30 November – 2 December 2009.
- [52] J. Kacprzyk, S. Zadrozny, M. Fedrizzi and H. Nurmi, "On group decision making, consensus reaching, voting and voting paradoxes under fuzzy preferences and a fuzzy majority: A Survey and some Perspectives," *Fuzzy Sets and Their Extensions: Representation, Aggregation and Models Studies on Fuzziness and Soft Computing*, vol. 220, pp. 263-295, 16 July 2008.
- [53] A. Hasib and A. O. Fapojuwo, "Analysis of common radio resource management scheme for end-to-end QoS support in multiservice heterogeneous wireless networks," *Proceedings of the IEEE Transactions on Vehicular Technology*, vol. 57, no.4, pp. 2426-2439, July 2008.
- [54] F. Herrera, E. Herrera-Viedma and J. L. Verdegay, "Direct approach processes in group decision making using linguistic OWA operators" *Fuzzy Sets and Systems*, vol. 79, issue 2, pp. 175-190, 1996.
- [55] R. R. Yager, "On ordered weighted averaging aggregation operators in multi-criteria decision-making," *IEEE Transactions on Systems, Man and Cybernetics*, vol. 18, no. 1, pp. 183-190, 1988.

- [56] E. Herrera-Viedma, F. Herrera and F. Chiclana, "A consensus model for multiperson decision making with different preference structures," *IEEE Transactions on Systems, Man and Cybernetics, Part A: Systems and Humans*, vol. 32, no. 3, pp. 394-402, May 2002.
- [57] R. Heradio, F. J. Cabrerizo, D. Fernandez-Amoros, M. Herrera and E. Herrera-Viedma, "A fuzzy linguistic model to evaluate the quality of Library 2.0 functionalities," *International Journal of Information Management*, vol. 33, issue 4, pp. 642-654, August 2013.
- [58] D. Dalalah, F. Al-oqla and M. Hayajneh, "Application of the analytic hierarchy process (AHP) in multi-criteria analysis of the selection of cranes," *Jordan Journal of Mechanical and Industrial Engineering*, vol. 4, no. 5, pp. 567-578, November 2010.

University of Cape Town