Access Network Selection Schemes for Multiple Calls in Next Generation Wireless Networks

BY

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A thesis submitted for the degree of
Doctor of Philosophy
in the Department of Electrical Engineering,
Faculty of Engineering and the Built Environment, University of Cape Town
June 2017

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

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Sign:

Date: 12 March 2017

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.

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JOSEPH FOLORUNSHO ORIMOLADE	MARCH 12, 2017
NAME	DATE

Dedication

This thesis is dedicated to the Almighty God; who is the source of my inspiration and strength, my help in ages past, and my hope of years to come.

Acknowledgements

First and foremost, my appreciation goes to the Almighty God who sustained me and my family throughout the period of this program.

I also want to acknowledge the contributions of my supervisor, Mr Neco Ventura, for your comments, corrections, suggestions and other form of support I have received towards the completion of this research work. Many thanks to my co-supervisor, Associate Professor O.E. Falowo, for his valuable suggestions throughout the course of this study.

My sincere appreciation is extended to colleagues who have been of a great encouragement through their technical skills and suggestions while going through this path. To Dr. Enoruwa Obayiuwana, Dr. Ramoni Adeogun, Engr. Lateef Akinyemei, Gbenga Taiwo, Dr Petro Pesha, Henry Ohazie, Joyce Mwangama, Bessie Malilla, thank you all.

I am immensely thankful to my employer, the Federal University of Agriculture, Abeokuta (FUNNAB), Nigeria for granting me the opportunity and support during my study at University of Cape Town. Special thanks to the Dean of Engineering, Prof J.K Adewumi, My Head of Department, and colleagues who served as my Guarantors; Prof Wheed, Prof J. K Adewumi, Dr. O.A Akinola and Dr. Sobowale.

My appreciations goes to friends who made the "foreign land a home away from home through their support and continuous encouragement. Thank you to the Maseko family, Euginia, and Ashley. To Sisanda, Dr. and Mrs A. Ajibesin, Mr and Mrs Chukwuma, Pastor Sam, Evelyn, Josuah Adeleke, Micheal Tararafa, Elizabeth, Uyoata, Didacianne, and Mary.

I appreciate the Orimolade family; Mr and Mrs J.A Orimolade, Mr and Mrs M.D Orimolade, Mr and Mrs M.Aiyeni, Engr. and Mrs S. O Orimolade, for your prayers and support.

Finally, my special appreciation goes to my wife, Mrs S.T Orimolade, for holding forth throughout this period.Thank you for being there always.

I appreciate my lovely daughters; Tinuoluwa, Ibukunoluwa and Marvelous for taking good care of Mummy during my absence from home, and especially for your brilliant performances now and always.

Thank you all.

Contents

Abstract

There is an increasing demand for Internet services by mobile subscribers over the wireless access networks, with limited radio resources and capacity constraints. A viable solution to this capacity crunch is the deployment of heterogeneous networks. However, in this wireless environment, the choice of the most appropriate Radio Access Technology (RAT) that can sustain or meet the quality of service (QoS) requirements of users applications require careful planning and cost efficient radio resource management methods.

Previous research works on access network selection have focused on selecting a suitable RAT for a users single call request. With the present request for multiple calls over wireless access networks, where each call has different QoS requirements and the available networks exhibit dynamic channel conditions, the choice of a suitable RAT capable of providing the Always Best Connected (ABC) experience for the user becomes a challenge.

In this thesis, the problem of selecting the suitable RAT that is capable of meeting the QoS requirements for multiple call requests by mobile users in access networks is investigated. In addressing this problem, we proposed the use of Complex PRoprtional ASsesment (COPRAS) and Consensus-based Multi-Attribute Group Decision Making (MAGDM) techniques as novel and viable RAT selection methods for a grouped-multiple call.

The performance of the proposed COPRAS multi-attribute decision making approach to RAT selection for a grouped-call has been evaluated through simulations in different network scenarios. The results show that the COPRAS method, which is simple and flexible, is more efficient in the selection of appropriate RAT for group multiple calls. The COPRAS method reduces handoff frequency and is computationally inexpensive when compared with other methods such as the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Simple Additive Weighting (SAW) and Multiplicative Exponent Weighting (MEW).

The application of the proposed consensus-based algorithm in the selection of a suitable RAT for group-multiple calls, comprising of voice, video-streaming, and file-downloading has been intensively investigated. This algorithm aggregates the QoS requirement of the individual application into a collective QoS for the group calls. This new and novel approach to RAT selection for a grouped-call measures and compares the consensus degree of the collective solution and individual solution against a predefined threshold value.

Using the methods of coincidence among preferences and coincidence among solutions with a predefined consensus threshold of 0.9, we evaluated the performance of the consensus-based RAT selection scheme through simulations under different network scenarios. The obtained results show that both methods of coincidences have the capability to select the most suitable RAT for a group of multiple calls. However, the method of coincidence among solutions achieves better results in terms of accuracy, it is less complex and the number of iteration before achieving the predefined consensus threshold is reduced.

A utility-based RAT selection method for parallel traffic-streaming in an overlapped heterogeneous wireless network has also been developed. The RAT selection method was modeled with constraints on terminal battery power, service cost and network congestion to select a specified number of RATs that optimizes the terminal interface utility. The results obtained show an optimum RAT selection strategy that maximizes the terminal utility and

selects the best RAT combinations for users parallel-streaming for voice, video and file-download.

List of Abbreviations

AAA	Authentication Authorization and Accounting
ABC	Always Best Connected
AC	Always Connected
ANGW	Access Network Gateway
AHP	Analytic Hierarchy Process
AMPS	Advanced Mobile Phone Service
ANDSF	Access Network Discovery and Selection Function
AP	Access Point
AT&T	American Telephone and Telegraph
BER	Bit Error Rate
BS	Base Station
BSSID	Basic Service Set Identifier
CAPEX	Capital Expenditure
CAC	Call Admission Control
CDMA	Code Division Multiple Access
CN	Core Network
COPRAS	Complex PRoprtional ASsesment
CR	Consistency Ratio
CPU	Central Processing
DIA	Distance to Ideal Solution
ePDG	Evolved Packet Gateway
EDGE	Enhanced Data Rate for GSM Evolution
EH	Extremely High
EPC	Evolved Packet Core
EPS	Evolved Packet System
ETSI	European Telecommunication Standard Institute
E-UTRAN	Evolve Universal Terrestrial Radio Access Networks
FAPs	Femto Access Points
FAX	Telfacsimile
FDMA	Frequency Division Multiple Access
FM	Frequency Modulation
GPRS	General Packet Radio Service
GRA	Grey Relational Analysis

GSM	Global System for Mobile communication
H	High
HetNets	Heterogeneous Networks
HSDPA	High-Speed Data Packet Access
HSS	Home Subscriber Server
HWNs	Heterogeneous Wireless Networks
IEEE	Institute of Electrical Electronics Engineers
IMSI	International Mobile Subscriber Identity
IoT	Internet of Things
IP	Internet Protocol
IFOM	IP flow Mobility
ISMP	Inter System Mobility Policy
ISRP	Inter System Routing Policy
ITU	International Telecommunication Union
KPI	Key Performance Index
L	Low
LOWA	Linguistic OWA
LTE	The Long Term Evolution
LTE-A	Long Term Evolution Advanced
M	Medium
MAC	Medium Access Control
MADM	Multi-Attribute Decision Making
MAGDM	Multi-Attribute Group Decision Making
MAPCON	Multiple-Access PDN connectivity
MCDM	Multi-Criteria Decision Making
MCGDM	Multi–Criteria Group–Decision
MEW	Multiplicative Exponent Weighting
MH	Medium High
MH	Mobile Hotspot
MIH	Media Independent Handover
MIMO	Multiple Input Multiple Output
ML	Medium Low
MME	Mobility Management Entity
MN	Mobile Node
MTS	Mobile Telephone Service
M2M	Machine-to-Machine
N	None
NMT	Nordic Mobile Telephone
NGWNs	Next Generation Wireless Networks
NFV	Network Function Virtualization
OPEX	Operational Expenditure
OWA	Ordered Weighted Aggregator
PoA	Point of Attachment
PCs	Personal Computers

PCC	Policy and Charging Control
PCRF	Policy Control and Charging Rules Function
PDN-GW	Packet Data Network Gateway
PDC	Personal Digital Cellular
QoE	Quality of Experience
QoS	Quality of Service
RATs	Radio Access Technologies
RSSI	Received Signal Strength Indicator
RRM	Radio Resource Management
SPR	Subscription Profile Repository
SLAs	Service Level Agreements
SAW	Simple Additive Weighting
SDN	Software Defined Network
S-GW	Serving Gate Way
SMS	Short Message Service
SNR	Signal-to-Noise Ratio
SINR	Signal-to-Interference-plus-Noise Ratio
SSID	Service Set Identifier
T	Tally
TACs	Total Access Communication Systems
TDMA	Time Division Multiple Access
TFN	Triangle Fuzzy Numbers
TFT	Traffic Flow Template
TOPSIS	Technique for Order Preference by Similarity to Ideal Solutions
UE	User Equipment
UMTS	Universal Mobile Telecommunications System
VH	Very High
VHO	Vertical Handover
VL	Very Low
VNI	Visual Networking Index
VoIP	Voice over Internet Protocol
WCDMA	Wideband Code Division Multiple Access
MCS	Mobile Control Station
WiFi	Wireless Fidelity
WiMAX	Worldwide Interoperability for Microwave Access
WLANs	Wireless Local Area Networks
WWAN	Wireless Wide Area Network
WP	Weighting Product
WPAN	Wireless Personal Area Network
3GPP	Third Generation Partnership Project
1G	First Generation
2G	Second Generation
3G	Third Generation
4G	Fouth Generation
5G	Fifth Generation

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Chapter 1

General Introduction

1.1 Background

The emergence of wireless networks over the years has been targeted at improving application quality of service (QoS) and overall user quality of experience (QoE). To achieve this, different key performance indicators (KPI) such as data rate, end-to-end delay, bit error rate, jitter, level of network coverage, mobility support, etc., are usually defined and used as a benchmark for comparing the performance of current and previous generation of wireless networks. The introduction of a new generation wireless network also implies additional modifications or enhancements in the available user equipment, application requirements, radio access technology (RAT) and access schemes, and the introduction of new Internet services by content providers [1, 2].

The introduction of First Generation (1G) wireless network witnessed the provision of voice services, while the Second Generation (2G) network such as the Global System for

Mobile Communication (GSM), provides voice and limited data services. Third Generation (3G) Universal Mobile Telecommunication System (UMTS) and other variants of 3G such as High Service Packet Access (HSPA) and (HSPA+) provide both voice and high-speed data services with improved user Quality of Experience (QoE) [3, 4]. The current 4th Generation Evolved Packet System (EPS), has the long-term evolution (LTE) as the access network. The development of the 4G wireless access network introduced LTE-Advanced (LTE-A) for outdoor coverage (macro cell) while Femtocell with Femto Access Points (FAPs) defined the indoor coverage (microcell). To take advantage of the high capacity 4G wireless broadband networks, Internet services such as voice over IP (VoIP), interactive gaming, online shopping and video streaming, which are bandwidth intensive applications have increased in recent times, and been offered as free, or at affordable prices [5]. Similarly, user equipment (UE) and mobile devices have become more advanced with multi-homed and multimode capability. The description of the heterogeneous wireless network with users in different radio coverage,

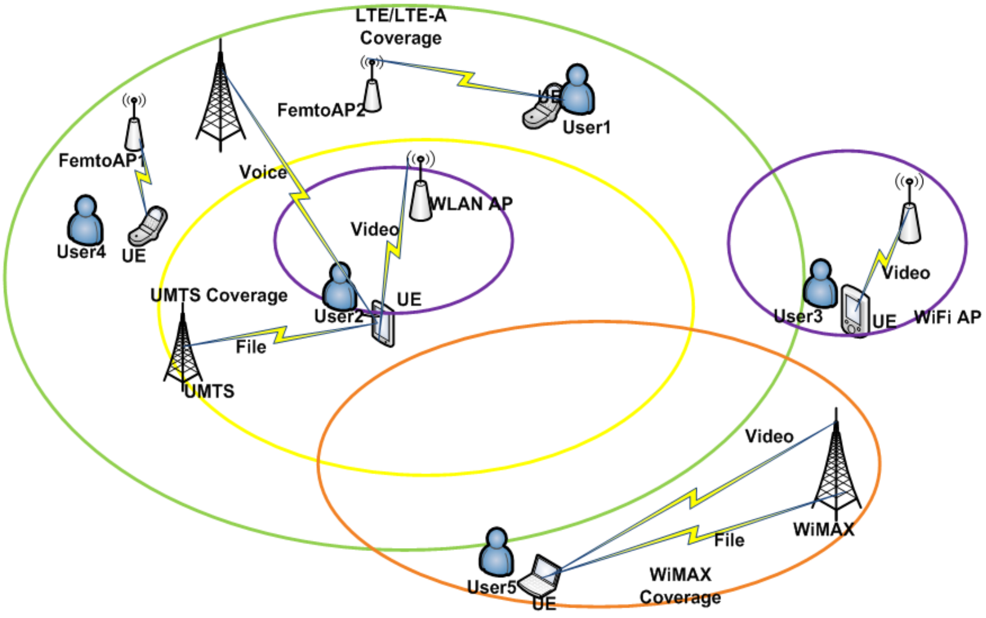

Figure 1.1: Heterogeneous wireless networks with overlapping coverage.

intelligent mobile terminal and user application subscription, is shown in Figure 1.1. These evolutions in Internet services and devices have resulted in an increase in the number of mobile subscribers, and subsequently, an exponential growth in data traffic on the cellular networks. According to Cisco Visual Networking Index (VNI) for global mobile data traffic forecasts, the number of connected devices, such as smartphones, tablets, PCs, etc., mobile subscribers and data traffic is expected to increase several folds between the periods of 2015-2020 [6]. To accommodate the present and future explosion in data traffic over the cellular networks, the next generation of mobile broadband wireless networks, known as the Fifth Generation (5G), is being proposed for standardization and expected to be deployed in the year 2020. The Next Generation wireless networks, which is 5G, is currently the major focus of academia, researchers, industry and the business sectors; and is expected to usher in a new evolution in mobile broadband wireless communication [7].

When fully deployed, the 5G network architecture will enhance user experience, where the context of users will cover a larger scope, to include humans, machines, and devices. The expected 5G techniques, therefore, promise to provide an improved or enhanced mobile broadband experience over the existing technology in the aspects of flexible spectrum usage, higher data rate, very low latency, network reliability, multi-antenna deployment and advanced backhaul technology such as millimeter wave. The 5G mobile broadband network will also provide an enabling environment for the implementation of newer technologies such as Internet of Things (IoT), Machine-to-Machine (M2M) communication, Device-to-Device (D2D) communication, Network Function Virtualization (NFV), Software Defined Networking (SDN), cloud computing, etc [8–10].

The design and deployment of previous generations of wireless networks were aimed at providing the current and future service demands of mobile subscribers. However, with the current growth in Internet traffic, service requirements, and mobile users, existing wireless network can not sufficiently meet the expected QoE or level of satisfaction of the numerous users in the wireless network environment. Therefore, the 5G wireless network will consist of a dense deployment of multiple RATs to form a heterogeneous wireless network (HetNets) [11]. The HetNets will increase the wireless coverage, bring the base stations and access points closer to the users, and provide alternative RAT for the different service requests. In this scenario, each application is characterized with different QoS requirements and made available to the subscribers based on individual service level agreements (SLAs).

1.2 Motivation

The heterogeneous wireless network was introduced as part of the 3GPP solution to address the capacity crunch currently experienced in cellular networks. HetNets consists of the existing wireless technologies; the wireless wide area network (WWAN) such as GSM, UMTS, HSPA, and beyond 3G wireless technologies such as the LTE. The HetNets also includes wireless local area networks (WLANs) standards such as IEEE 802.11a, IEEE 802.11b, IEEE 802.11c/g/n, wireless metropolitan area networks (WMAN) such as WiMax, and wireless personal area networks (WPAN) such as Bluetooth and ZigBee technology. In the 5G architecture, a closer coverage for human and devices is envisaged; therefore, the Femto Access Points (FAPs) are introduced and defined in LTE-A technology [12]. The motivation of the heterogeneous wireless networks is to provide ubiquitous coverage, load balancing and high QoS across the networks, thereby improving the perceived user broadband experiences.

In a related manner, HetNets provide the user with the choice of alternative access networks since no single access network can satisfy all user application requests, as some RATs are best suited for certain applications due to the modulation schemes and inherent access methods. Similarly, smart mobile terminals (cell phones, laptops, etc.) are usually installed with multiple network interfaces supporting LTE, HSPA, WLAN, etc., and used to request desired services from the available networks. In this scenario, a subscriber service request is carried out by associating the appropriate interfaces to the corresponding RATs for an uplink or downlink service flow. The performance of such mobile devices depend largely on the efficiency of its battery power, which cumulatively, reflects the power consumption of each selected interface during uplink, downlink or idle state. User preference for a single call, or multiple calls, therefore, requires a well-coordinated flow/interface and access network association that can guarantee the best user experience [13].

The available or requested applications such as voice over IP (VoIP), file-download, video-streaming, etc., require some basic QoS parameters in order to meet specific performance thresholds. To achieve these requirements, the concept of bearers, which is a logical link/channel with assigned or designated QoS parameters for the particular application request, was introduced in 3GPP standard specifications. Through the use of network resource management, the operator assigns a default bearer for basic call setup operations, and dedicated bearers for guaranteed or non-guaranteed bit rates depending on the subscriber's profile or operator service level agreements [14].

Given the aforementioned issues on application requirements, terminal capability, user preferences and dynamic characteristics of the wireless network environment, the selection of the best RAT that ensures the Always Best Connected (ABC) experience for mobile users requesting for multiple calls in HetNets is a major challenge. This is because the selected RAT or subset of RATs must satisfy the requested applications QoS requirements, optimize mobile terminal battery power, and meet user preference for cost, mobility support, and other required criteria [15, 16]. The motivation for this work is to address the problems of the decision process involved in the selection of the appropriate RAT for users' multiple calls request in HetNets. Network selection involves a complex decision process and requires solutions that incorporate comprehensive application attributes, terminal capability, user preferences, and network criteria, where some of these criteria are dynamic and fuzzy in nature.

1.3 HetNets RAT selection description

In the heterogeneous wireless environment, the choice of the optimum RAT for a user's application is carried out during the initial selection of access networks, reselection for vertical handovers or data offloading from a cellular network to adjacent WLAN or FAP. These procedures involve the use of RAT selection decision algorithms modules, which can be terminal controlled, network controlled or a hybrid of both.

Figure 3.1 shows a description of RAT selection scenarios in HetNets environment for mobile users(user1, user2, user3, user4, etc.), equipped with multi-mode/multi-homed devices. Based on individual subscription profile, each user can subscribe for a single call

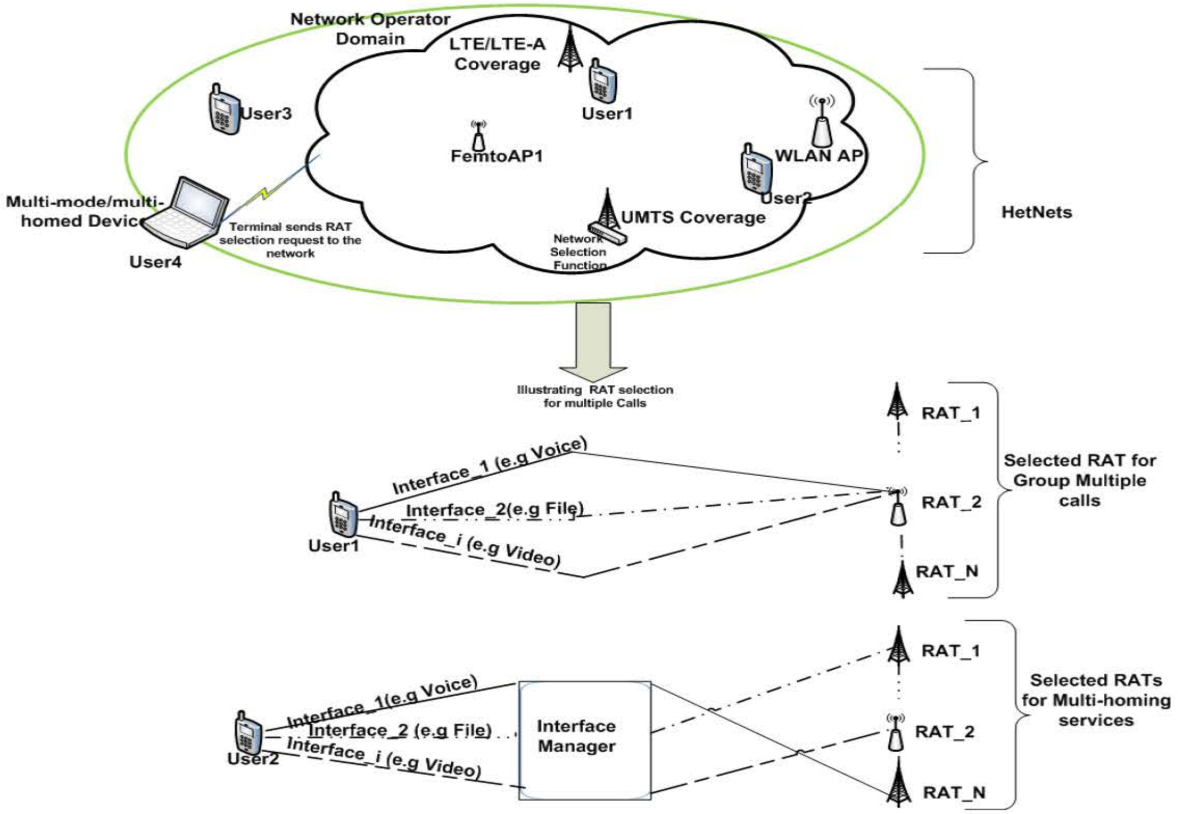

Figure 1.2: RAT selection problem description in heterogeneous wireless networks.

or multiple calls. Multiple calls refer to users requesting for two or more classes of calls simultaneously, using a multimode terminal. Multiple calls service request can be in the form of a grouped-multiple calls or parallel streaming of user applications as indicated in Figure 3.1. Requesting for a group-call implies that a user with a single-homed, multimode terminal can access multiple services such as voice, video streaming, and file-download simultaneously through a single RAT that can offer the QoS requirements of the grouped calls. Multiple calls involving parallel streaming of users' applications requires a multi-homed capable terminal that supports different network interfaces.

To request for any class of call in terminal initiated, network-controlled RAT selection scheme, the user, with a preconfigured preference information sends request to the network for the available RATs. This request is aimed at selecting the best RAT that meets the user requirements for initial access or handoff call. The network selection module, which resides in the network as part of the radio resource management entity, uses the user preference information and available network information to rank and select the best RAT for the user. Information on the selected RAT is sent to the user (mobile terminal) to associate with the target RAT. In terminal-controlled RAT selection scheme, the evaluation and ranking of the available RATs is carried out by the mobile terminal. Information on the available RATs is obtained through a logical initial network association request and channel probing by the terminal.

Research contributions in the area of network selection have been the major focus of the industry and academic community in recent times since the selection of the appropriate RAT can help the operator achieve network load balancing and user satisfaction. Most of the schemes provided consider multiple attributes which are associated with the applications, available access networks, and the mobile terminal. These criteria are used as inputs to existing complex decision algorithms which are employed to provide the needed solutions. It is, therefore, necessary to have a more simple and reliable RAT selection scheme than the existing solutions [17].

In HetNets, some RAT selection criteria, are QoS related (bandwidth, data rate, jitter, delay/latency, bit error rate, packet loss, etc.), while others include power consumption, mobility, price, security, network congestion or load. These criteria are usually considered as static parameters when used as decision metrics in the choice of RAT selection techniques. In such a scenario, the dynamic nature of the wireless environment cannot be adequately represented. It is expected that in the upcoming 5G heterogeneous wireless networks, RAT selection will be context-aware in order to reflect the dynamic state of the wireless environment [11],[18]. The proposed 3GPP solution to assist the mobile terminal to discover and select a suitable RAT within its vicinity is expected to enhance the mobile equipment RAT selection capability [19].

In consideration of access network load or congestion state, selecting a suitable RAT requires proper planning as the best RAT may be on the verge of reaching a maximum congestion threshold. Selecting a congested access network for data offloading can further increase the congestion state of the selected RAT and hence, degrade the QoS experienced by the offloaded traffic. A multi-attribute RAT selection scheme, which incorporates the dynamic nature of RAT selection criteria, especially network congestion state, which changes over time, will help to improve RAT selection efficiency in a changing network environment.

1.4 Problem Description

In a group-call, the call setup and handoff signaling overhead as well as the battery power consumption incurred is highly reduced due to the use of single interface of the mobile device. However, a high handoff frequency can be experienced when the selected RAT cannot meet the application QoS requirements of the individual call, leading to complexity in the selection and reselection of a suitable RAT and degradation of user perceived QoE. This is because, different call services have different QoS requirements. For instance, an inelastic application such as voice service has a more stringent QoS requirement when compared with a moderately inelastic video streaming service, while an elastic application like data traffic is more tolerant to QoS variations. In addition to QoS attributes, the user perceived QoE for each requested application is highly dependent on the user preferences and network capability. The selection of a suitable RAT for handoff of grouped-multiple calls in a heterogeneous wireless environment will, therefore, be highly dependent on the capability of the selected RAT to sustain the QoS requirements of the group of calls [20]. In addition, a selection process or algorithm which is simple, reliable and able to reduce handoff frequency is required for a group multiple calls.

Most research works on RAT selection have focused primarily on selecting the best RAT for a single call [21, 22]. In the literature where RAT selection for multiple calls is discussed, the selection criteria used for multiple calls have been applied without considering the issues of disparity in the QoS requirements for the individual calls [23, 24]. Similarly, the methods of aggregating these requirements into a collective QoS for the grouped-calls are not well defined. The existing solutions used the traditional multi-attribute decision making (MADM) algorithms for the ranking and selection of the best RAT. However, the selection of appropriate RAT for handoff a group multiple call requires a group decision making process, hence modifications to the exiting MADM algorithms are needed. Given the advantages derived by the mobile subscribers and network providers through group multiple call services, an efficient RAT selection algorithm which aggregates the individual QoS and other application criteria into a collective requirement for the group-calls in order to provide the best user experience is, therefore, required.

In the heterogeneous wireless environment, where mobile subscribers terminals are equipped with multiple interfaces, the multi-homing capability of such devices allows the users to simultaneously connect to more than one RAT through different interfaces of the mobile terminal. Multi-homing ensures the user is always connected and provides the ABC experience by reducing connection failures, increasing access reliability, and providing an alternative data path for network users. Parallel streaming of users application such as voice, video and file-download services and session splitting of scalable video traffic through different radio access technology (LTE, UMTS, WLAN, etc.) can be achieved using multi-homing capable terminals. To sustain the advantages of parallel streaming of user traffic, the problem of association of the respective interfaces of the terminal to the appropriate RAT must be addressed. Similarly, the issue of excessive battery consumption, which impacts negatively on the performance of the multi-homed terminals, needs to be investigated and a viable solution provided.

1.5 Research Aim and Objectives

The aim of this research study is to develop efficient RAT selection methods for identifying best access network that meets the requirements for multiple calls in HetNet environment. This aim is achieved through the following objectives:

1. To carry out a comprehensive literature survey and related works on RAT selection methods in HetNets environment in order to examine the strength and weaknesses of the existing RAT selection schemes.

2. To propose novel access network selection methods for group multiple calls and parallel streaming service requests in HetNets.

3. To develop novel MADM and consensus-based algorithms for group multiple calls; and utility-based algorithms for parallel streaming service request.

4. To evaluate the performance of the proposed algorithms and compare them with existing algorithms.

1.6 Research Scope

The main focus of this research is to develop RAT selection schemes, which select the access network that is most suitable for the users class of service request in a heterogeneous wireless network with multiple RATs. The classes of service considered here are, grouped-multiple calls and multi-homing services. The choice of the appropriate RAT for each class of service is determined using existing theories and techniques in multi-attribute group decision making, consensus theory, and utility optimization. The evaluations of the proposed schemes are carried out in MATLAB simulation software. While this work can be carried out in known simulation environments such as NS3, Opnet, OMNeT++, or a testbed setup, such evaluation is considered as future work.

1.7 Contribution

The selection of the appropriate RAT that will achieve the ABC paradigm for different service classes of users in heterogeneous networks is the goal of this research. In achieving this, several challenges relating to efficient RAT selection schemes for multiple calls have been raised in Section 1.4. In order to address these issues, we have considered the need to achieve a simple and flexible RAT selection method, the need to address the issue of disparity in QoS and other related criteria such as cost among group multiple calls, and the assignment of the appropriate interfaces of the mobile terminal to the best subset of RATs for multi-homing services. The solutions to these challenges, which are provided in Chapter 3 - Chapter 5, are the major contributions of this thesis, and are outlined as follows:

- **Comprehensive Literature survey of RAT selection in heterogeneous wireless networks.**

  A comprehensive survey of existing RAT selection methods and algorithms for heterogeneous wireless networks has been carried out. The literature survey, which covers different approaches and algorithms, has been used to classify and compare the performance of these techniques. The inherent advantages and disadvantages of these methods have been considered in order to come up with different design approaches and solutions reported in this thesis.

- **A COPRAS-based MADM method for RAT selection in heterogeneous wireless networks is presented.** Detailed performance comparison of the proposed COPRAS-based MADM method and other existing methods has been carried out using performance indicators such as ranking index, ranking reversal and ranking consistency. The results show that the COPRAS method outperforms the existing methods with respect to these key performance indicators. Similarly, the performance evaluation of both COPRAS and TOPSIS method and their suitability for RAT selection has been carried out for both single call and group multiple calls. The results show show that the

COPRAS method presents a promising algorithm in the selection of appropriate RAT for group multiple calls. The COPRAS method outperforms the TOPSIS method due to its simplicity and reduced handoff frequency in group multiple calls. The method also shows a better performance in terms of time complexity.

- **A consensus-based group decision-making method for the selection of appropriate RAT for a group of multiple calls.** Using the consensus group decision making process approach to RAT selection, a consensus threshold which defines a unified level of agreement, or aggregation of QoS and other criteria requirements among group of multiple calls was achieved. Two consensus methods: The methods of coincidence among alternatives and coincidence among solutions have been investigated and their performance in the ranking and selection of suitable RAT for group multiple calls evaluated. The results obtained show that the method of coincidence among solutions attained the consensus threshold and acceptable proximity measure in the first round of the consensus process when compared with the methods of coincidence among alternatives. The method of coincidence among solutions also demonstrated improved time complexity, and the selection of the most appropriate RAT for the group calls. This method has therefore addressed the problem aggregating the QoS requirements for the individual calls into a collective QoS for the grouped-calls, and the selection of the appropriate RAT for the group of multiple calls.

- **A utility-based access network selection in heterogeneous wireless networks which minimizes terminal interface power consumption and maximizes user satisfaction.**

  A utility-based, terminal-controlled RAT selection scheme which uses exhaustive search method to search and select a subset of RATs in the vicinity of the user has been developed. The algorithm developed can select appropriate RATs with minimal level of congestion, and also minimizes terminal battery consumption and monetary cost. The algorithm dynamically generates the possible RAT combinations to reflect the changing nature of the wireless environment and the combinations which satisfy user's defined constraints on the terminal device, and available networks are selected. An additive utility function was defined, and used to associate the respective interfaces of the multi-homed capable terminal to the best RATs for parallel streaming of user's applications. This method, therefore, has achieved the selection of the best subset of RATs for individual applications of the user multi-homing services, optimizes the terminal battery power and monetary cost and thereby, improved the user perceived QoE.

  Some of these contributions are outlined in the author's paper publications and peer-reviewed presentations below:

Peer-Reviewed Journal Publication

Joseph Orimolade, Neco Ventura, Olabisi Falowo, "COPRAS-based Access Network Selection Schemes for multiple Calls in Heterogeneous Wireless Networks", *Submitted to the Springer Journal of wireless networks(WINE),2017.*

Peer-Reviewed Conference Publications

1. Joseph Orimolade, Neco Ventura, Olabisi Falowo, ”Utility-Based Access Network Selection for Next Generation Heterogeneous Networks”, Proceedings of Southern Africa Telecommunication Networks and Applications Conference (SATNAC) 2016, Fancourt in George, Western Cape, South Africa, 4-7 September 2016, pp 379 - 384, ISBN: 978-0-620-67151-4.

2. Joseph Orimolade, Neco Ventura, Olabisi Falowo, ”ANDSF-based WLAN Offloading in the Evolved Packet System (EPS)”, 18th Mediterranean Electrotechnical Conference (MELECON), IEEE MELECON 2016, pp 1-6. DOI: 10.1109/MELCON.2016.7495385.

3. Joseph Orimolade, Neco Ventura. ”Intelligent Access Network Selection for Data Offloading in Heterogeneous Networks”, Proceedings of the 12th IEEE AFRICON International Conference, Addis Ababa, Ethiopia, 14-17 September, 2015, pp 218-222, ISBN: 978-1-4799-7497-9.

4. Joseph Orimolade, Neco Ventur, ”COPRAS-based Access Network Selection in Heterogeneous Wireless Networks”, Proceedings of Southern Africa Telecommunication Networks and Applications Conference (SATNAC) 2015, Arabella, Hermanus, Western Cape, South Africa, 6 - 9 September 2015, pp 379 - 384, ISBN: 978-0-620-67151-4.

5. Joseph Orimolade, Neco Ventura; ”Policy-Based IP Flow Mobility Support in the Evolved Packet Core (EPC)” , Proceedings of Southern Africa Telecommunication Networks and Applications Conference (SATNAC) 2013, Stellenbosch, Western Cape , South Africa, 1-4 September 2013, pp 67-72, ISBN: 978-0-620-57883-7.

1.8 Thesis Outline

The rest of the thesis is organized as follows:

Chapter 2 gives the detailed background, description, and future directions in wireless networks. Issues relating to current trends and emerging techniques in radio access technology selection, smart mobile terminal capability, and new Internet services in a heterogeneous wireless network are also discussed.

Chapter 3 provides an overview for the proposed COPRAS-based access network selection scheme. The conceptual RAT selection procedures are discussed, and the performance of known MADM-based techniques are compared with the proposed COPRAS method. Comparative performance evaluations are carried out through intensive simulation. Available information and standard specifications of the mobile terminal, application, network attributes and traffic load or network congestion are used as input for the simulation of different network scenarios. The simulation outputs are used to assess the efficiency of the proposed scheme.

Chapter 4 proposes the consensus-based radio access selection for a group of multiple calls in heterogeneous networks. Coincidence among preferences and coincidence among solutions are the two schemes used and evaluated through simulations. A feedback system which allows for the adjustment of individual call QoS parameters is introduced in both cases. The number of iterations performed to reach the consensus level for RAT selection and the contribution of the feedback system in the determination of appropriate RAT in both techniques is used as a measure of effectiveness for the two techniques.

Chapter 5 presents a proposed RAT selection scheme for multi-homing application services in heterogeneous wireless networks using a utility-based optimization technique to minimize the cost criteria and maximize the benefit criteria relating to terminal power consumption cost, network congestion, and application QoS attributes. The scheme which dynamically searches for possible RAT combinations is evaluated through simulation. The simulation results are used to discuss the performance and efficiency of the scheme.

Chapter 6 gives the summary of this thesis, the contributions, open issues, and suggestions for future works.

Chapter 2

Background and Overview

This chapter presents the background materials and related work in this thesis. A literature survey on the evolution, trends and research direction of wireless networks, and RAT selection techniques,is also presented.

2.1 Evolution of Wireless Networks

The evolution of wireless and cellular mobile network has experienced successive changes over the years, resulting in different generations of wireless networks. The emergence of each generation introduces new wireless technology and services. The progression in wireless technology provide improvement over the previous generation in terms of data rates, radio access, switching techniques, level of mobility support and other technology related criteria [20, 25]. The participation and contributions of the key players such as researchers, academic community, network operators and service providers are targeted at providing enhancements in design, implementation and deployment. Such contributions are also capable of minimizing both capital expenditure (CAPEX) and operational expenditure (OPEX), increase revenue and improve the quality of experience of the mobile users who subscribe and pay for such services.

In the late 1970s, the First Generation (1G) wireless network emerged and was deployed during early 1980s. The 1G wireless network was developed as narrowband analog networks. It employs the frequency division multiple access (FDMA) as a multiple access scheme, while circuit switching technique was used to provide voice only service with a speed of 2.4kbps. The USA Advanced Mobile Phone Services (AMPS), which was invented in Bell Labs and launched in 1982, the Total Access Communication Systems (TACs), in England, and Mobile Control Station (MCS-L1), in Japan, are examples of 1G wireless technology. The Nordic Mobile Telephone (NMT) found in Denmark, Finland, Sweden and some part of Europe was the first mobile network with international roaming capability [26].

Due to its limited capacity, coverage, and other key performance indicators, the second generation (2G) wireless networks was developed as an improvement over 1G. The 2G, Global System for Mobile Communication (GSM) is a narrow band digital network. Compared to 1G, the 2G wireless networks use the Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA). These are digital access scheme for spectrum sharing, as well as circuit switching technique to provide higher spectrum efficiency and data rate of approximately 9.6kbps. The 2G network provides traditional voice service and limited data services such as short message service (SMS), telefacsimile (FAX) and Internet browsing at limited rates to subscribers. In 1990, the European standard for 2G, which is the TDMA Global System for Mobile Communications (GSM) was deployed. Other 2G standards include the Personal Digital Cellular (PDC) in Japan and the United States Digital Cellular Standard (IS-95) which is based on CDMA technology and designed to be compatible with the AMPS [27].

The 2G cellular network evolved to 2.5G with the introduction of General Packet Radio Service (GPRS) technology which enables packet switching on top of the existing GSM networks. The GPRS system provides an IP-based technology with a data rate of about 14.4kbps and facilitated Internet services such as email, web browsing and file transfer, in addition to voice services. It also provides a relatively better connectivity to the network. The need for a higher data rate motivated the emergence of the Enhanced Data Rate for GSM (EDGE) technology which provides Multimedia Message Service (MMS), in addition to existing Internet services to the cellular networks. The EDGE technology, which is sometimes referred to as the 2.75G, can provide a data rate of about 156kbps while the CDMAone (IS-95B) has a data rate of 115kbps, and provides a roadmap to the emergence of the 3G wireless networks [28]. In order to provide air-interface connection efficiency, higher throughput, global standards and services that are technology independent, the Third Generation (3G) of wireless network was developed. The International Telecommunication Union (ITU) defined the requirements for 3G networks in the IMT-2000 standard, while the Third Generation Partnership Project (3GPP) provides the mobile network complacence specifications for the 3G. The 3G standard is backward compatible with the GSM and EDGE technologies and includes the America CDMA2000, the Universal Terrestrial Mobile System (UMTS) found in Europe, with its presence in Africa (Mauritius) in 2006. The 3G technology offers mobile subscribers variety of application services, ranging from simultaneous voice and data transmission, international roaming, advanced web services at a data rate of about 2Mbps when stationary, 384kbps when moving and 144kbps for driving [29].

In order to enhance the throughput of 3G networks, the 3GPP Release 6 introduced the High-Speed Packet Access (HSPA) standard to improve the uplink and downlink data rate of UMTS. The HSPA forms the family of 3.5G wireless network and has the High-Speed Down Stream Packet (HSDPA) which support downlink speed of 1.8, 3.6, 7.2 and 14Mbps. The Evolved HSDPA (HSPA+) has been defined in 3GPP release 9, and support a data rate of 42Mbps and 84Mbps for downlink and uplink, respectively [30]. As the wireless cellular network is gaining high momentum with increasing data rates and attractive mobile services, the Wireless Local Area Network (WLAN) standard is becoming popular due to its high data rate, ease of installation, low installation cost, and provisioning of broadband experience to the users. The IEEE 802.11 a/b/g/n standards are currently being deployed in hotspots such as airports, offices, homes, stadium, etc., with a data rate in the range of 11-54Mbps, depending on the implemented standard. The 3GPP has also standardized interoperability between the legacy cellular networks and WLAN for data offloading in order to achieve load balancing and improve user experience [31, 32].

The 4G wireless networks comprise mainly of the 3GPP Long Term Evolution (LTE) and the more advanced (LTE-A). The LTE-A is expected to pave the way for 5G networks. The LTE standard is an all-IP packet switch network that supports seamless mobility, very low delay, and high data peak rate of 1Gbps. The WiMAX network is the IEEE 802.16 standard which is designed to provide a line of sight solution within a larger network coverage. WiMAX has evolved over the years, resulting in different standards, e.g., (IEEE 802.16a and IEEE

802.16e), WiMAX is expected to provide both fixed and mobile wireless solution. Figure 2.1 shows the transitional stage of the various evolutions of wireless networks.

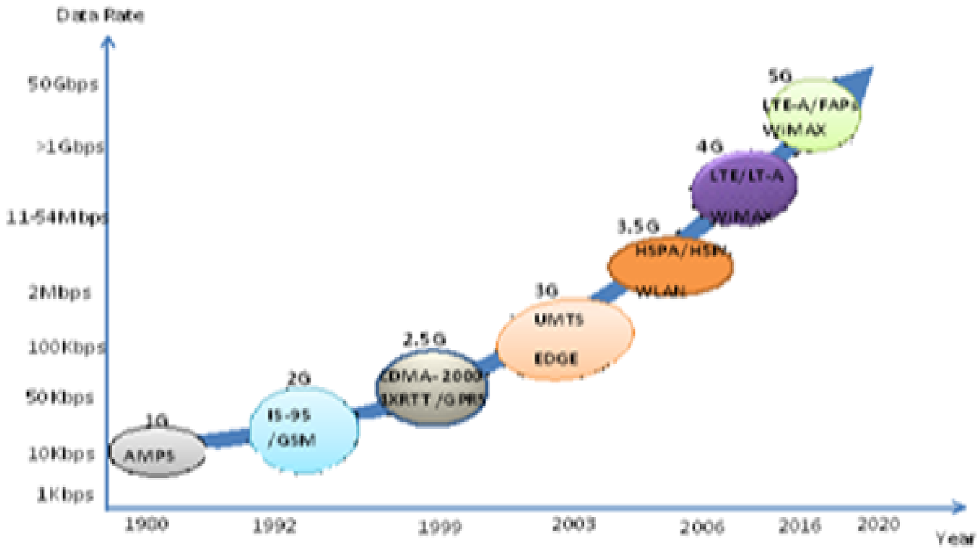

Figure 2.1: Evolution of wireless communication networks.

The evolution of 4G to 5G networks is envisaged to further improve systems performance in terms of peak data rate, spectrum efficiency, the level of mobility support, end-to-end delay, and coverage [1, 10, 33]. The 5G networks will feature new technologies such as Machine-to-Machine communication, Device-to-Device communications, Network Function Virtualization (NFV), Software Defined Networks (SDN), Internet of Things (IoT). The era of 5G will provide new applications, high-performance mobile devices, and the ABC user experience.

2.2 Next Generation Heterogeneous Wireless Networks

The radio access technology which emerges from each generation of the wireless network has specific design features and unique characteristics which make such RAT most suitable for a particular user service demands. It is, therefore, necessary to aggregate the performance of each generation of the wireless access network in order to provide seamless communication and adaptive QoS that guarantees users QoE.

2.2.1 3GPP Evolved Packet System (EPS) for next generation heterogeneous wireless networks

One of the motivations for the introduction of the System Architecture Evolution (SAE) by the 3GPP is to provide support for multiple radio accesses in order to improve overall system capacity. The SAE defines both the radio access network (RAN) and the mobile core network. These specifications, called Evolved Packet System (EPS) are included in 3GPP Release 8 [32, 34]. The EPS provides a framework for the Next Generation Wireless Networks (NGWNs) where different RATs coexist in an overlapping coverage area.

The EPS has the Long Term Evolution (LTE) as the access network and the evolved packet core (EPC) being the core network. The EPC provides connectivity across the legacy 3GPP accesses such as GSM, UMTS, LTE, and non-3GPP accesses such as WLAN and WiMAX for efficient radio resource management. The underlying architecture of the evolved packet system comprising of the network entities and interfaces are shown in Figure 2.2. The core network of the EPS, the EPC consists of a set of access gateways for each radio access

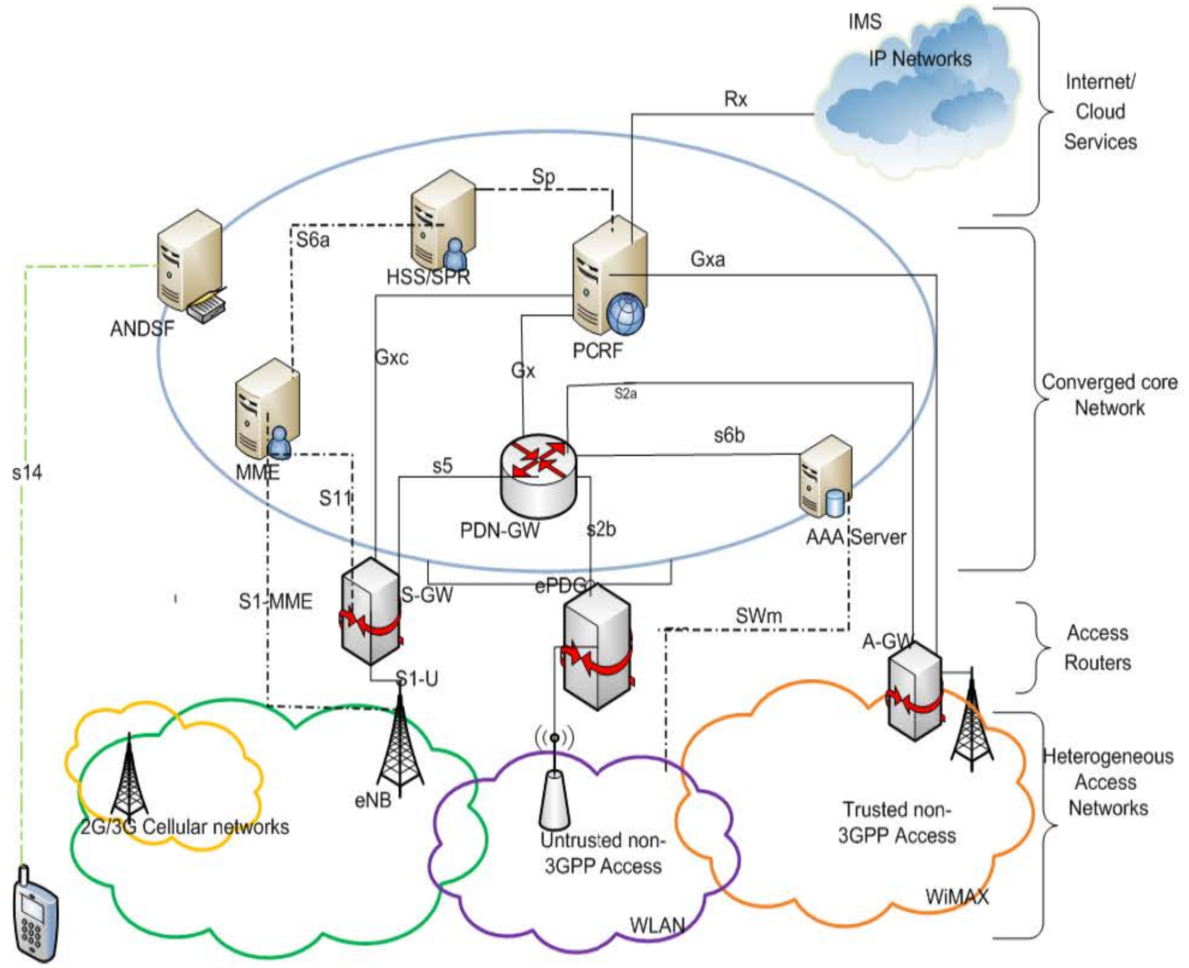

Figure 2.2: Network architecture of the Evolved Packet Systems. [32]

network. The serving gateway (S-GW) is used for 3GPP radio access technology, the Evolved Packet Gateway (ePDG) is used to access the untrusted non-3GPP access network such as WLAN. The Generic Access Network Gateway (ANGW) for trusted non-3GPP access such as WiMAX. The Packet Data Network Gateway (PDN GW) is the mobility anchor point and the gateway for all data traffic to and from the external networks such as the Internet. It also serves as the central anchor point for both the control and data plane in the EPC [21, 34].

The EPC also contain subscription data entities, such as the Home Subscriber Server (HSS), Subscription Profile Repository (SPR), Authentication Authorization and Accounting (AAA) server. These entities store the users profiles and perform authentication and authorization procedures that allow the user to gain access to the network. The Policy Control and Charging Rules Function (PCRF) is the control entity of the Policy and Charging Control(PCC) architecture in the EPC. It uses the user profile and operators policies for enforcing QoS control and service charging at the relevant gateways.

For the discovery and selection or reselection of the appropriate target access networks, the EPC architecture incorporates a network discovery and selection function (ANDSF), which is interfaced to the UE [19]. Information on the available networks in the vicinity of the UE preferred operators network for handover, and other information is provided by the ANDSF to the UE over the s14 logical interface via a PULL or PUSH mechanism.

The EPS, therefore, presents an all-IP heterogeneous wireless network environment which serves as the enabler for joint radio resource management in next generation wireless networks. Some of the advantages of heterogeneous wireless networks include seamless mobility, network reliability, common billing platform, and flexibility in the selection of appropriate RAT for user service demand.

2.2.2 Mobile terminal capabilities in next generation wireless networks

The evolution of wireless networks comes with value added services and increasingly rich and attractive features, which are made available to the mobile subscribers. Starting from voice, the only service provided to users by the first generation networks, voice and limited data services provided by the second generation network, the Internet services component have progressively evolved to more advanced applications such as high-speed web browsing, video conferencing, TV-streaming, interactive gaming and other multimedia services.

The evolution of advanced wireless technology and services have also resulted in the availability of more advanced mobile terminals. Some of the mobile terminals (user equipment) have different interfaces which support different classes of calls simultaneously and also the capability to simultaneously connect to multiple RATs with the different interfaces. These features allow the mobile terminal to intelligently and adaptively perform RAT selection and handoff within the wireless environment. Most traditional phones are single-mode capable; that is, they can connect to one RAT (e.g., GSM, UMTS HSPA) and subscribe to one service (e.g., voice, video-streaming, or file-download). The multimode capable terminals can simultaneously subscribe to multiple services on an access network. Mobile terminals with multimode and multi-homing capabilities are able to subscribe to multiple services from different RATs. These smart mobile devices are enablers for service continuity and provide the ABC experience for mobile subscribers.

2.3 Access Network Selection in Heterogeneous Wireless Networks

In the heterogeneous wireless environment, each mobile user has varying application request, diverse QoS requirements and preferences for the available RATs. Similarly, different mobile wireless networks are best suited for some specific services or applications, and also operate at different QoS, mobility, coverage range and security levels. In a heterogeneous wireless network environment, therefore, the choice of the appropriate access network for users application, which is a major component of radio resource management, presents a major challenge that requires optimum solution [35, 36]. This has triggered the interest of the industry, research and academic community in recent times to develop reliable and robust access network selection solutions for users need. Since there is no single access network that can provide all the service requirements of the users, selecting the best RAT or combination of RATs for the user will depend on network state, users preference, application type and QoS requirements, as well as the mobile terminal capability. Choosing the appropriate RAT for the user service request will require a systematic approach as illustrated in Figure 2.3.

In most literature, access network selection is generally viewed as a seamless handover of the user traffic from its current point of attachment (RAT) to the next available RAT with less emphasis on initial access selection. While the two scenarios are different, they both involve a similar process, with the common aim of selecting the most appropriate RAT for the user traffic. Initial access selection is a process carried out after a successful authentication and authorization (initial access) procedures for admitting the user to the network has been achieved. Access reselection or handoff can be executed after the user has been admitted to the network and there is a need to seek for an alternative access network. Access reselection or handoff can be initiated or executed due to the following reasons:

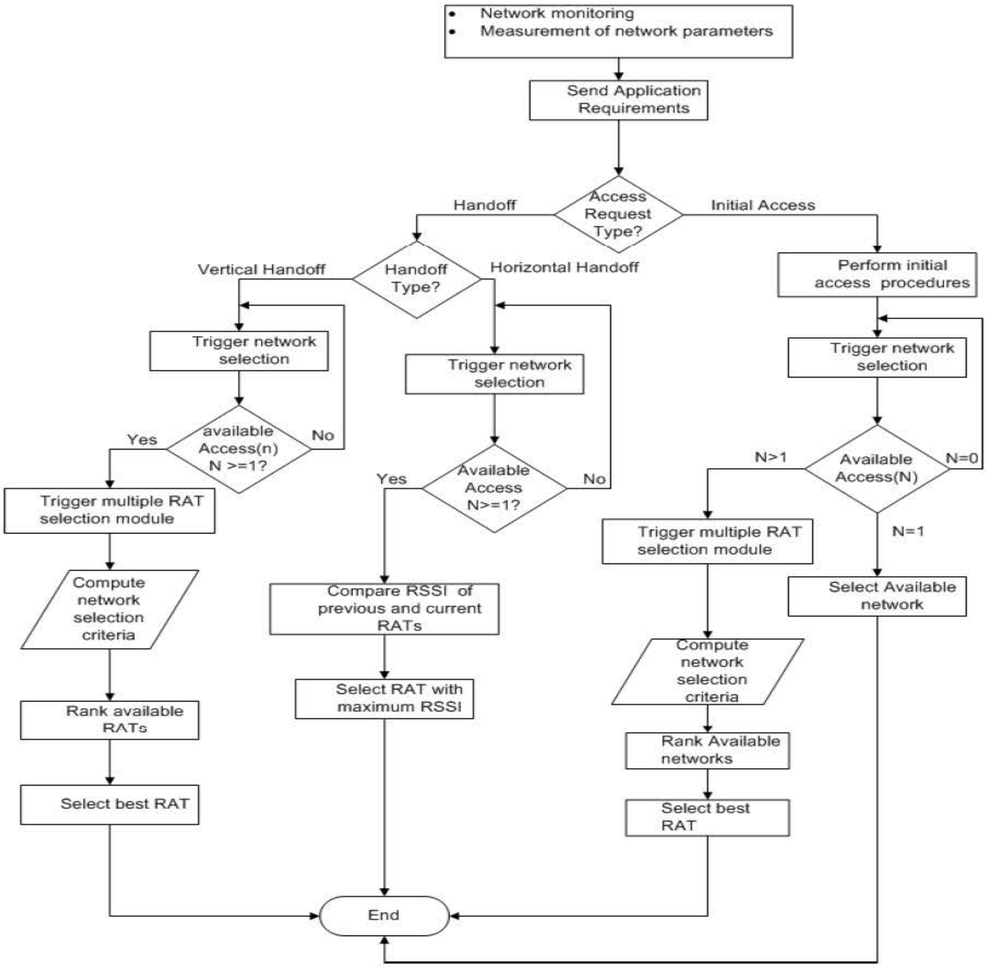

Figure 2.3: Access networks selection procedures in heterogenous wireless network

- Degradation in the radio quality (RSSI) of current access network which may be due to user's current location, atmospheric conditions or current access network low performance.

- User preference for cost or availability of alternative access network such as WiFi at home, offices, hotspots, as an alternative to a cellular network such as UMTS for video-streaming.

- Operator controlled handoff process for load balancing, ensuring improved network performance.
- User terminal controlled handoff due to the failure of current RAN interface on a mobile equipment with multimode and multi-homing capability.

In general, handoff process can be classified as horizontal handoff or vertical handoff. In the later, access selection is carried out in an overlapped region containing the same radio access technology, e.g., between LTE, UMTS or WLAN, while the former involves handoff between two different access technologies. Access selection process can be terminal controlled, network controlled or a hybrid of both depending on where the controlled algorithm is implemented [37, 38]. The process of access network selection in heterogeneous networks involves three phases, which are: information gathering phase, decision phase, and execution phase.

2.3.1 Information gathering phase

In this phase, network monitoring and measurements of relevant parameters such QoS related information(data rate, jitter, delay/latency, bit error rate, packet loss, etc) are carried out. The details or amount of information provided depends on the operator configuration, and terminal capability to sense the wireless environment, capture relevant information and store such for further processing. While some network data are provided dynamically, others are hardcoded on the Subscriber Identity Memory (SIM)card of the user by the network operator. Relevant information on network attributes, a user profile describing service level agreements between the subscriber and operator, terminal capability and preferences are made available dynamically or statically as decision criteria for the next stage of the selection phase. The

ANDSF server of the 3GPP, Hotspot2.0 of the WiFi Alliance and MIH of the IEEE 16.2 standard specifications are core network entities which can provide specific information about the available access networks to the mobile terminal [39, 40].

2.3.2 Decision process phase

The decision process provides methods of assessing the performance and suitability of individual access networks to meet the current service demands of the user. During the decision phase, decision algorithms are executed using the parameters provided in the information gathering phase to rate, rank and select the most suitable RAT or combinations of RATs for the user. The decision process depends on the access request type, e.g., initial selection and handoff (horizontal handoff or vertical handoff). Due to the time sensitivity of the user request for network service and the selection of the corresponding radio access network, a simple and reliable decision algorithm is required for this phase.

2.3.3 Access selection execution phase

Once the decision phase is triggered, and the ranking and determination of the appropriate access are determined, the process of selection or reselection of the target access network is executed according to a given rule. In the case of initial access network selection, the user terminal is associated with the target network through authentication and authorization procedures before initiating uplink or downlink services. For handoff process, seamless transfer of users traffic is carried out from the current RAT to the new RAT. The flow chart in Figure 2.3 describes the three phases discussed above.

2.4 Access Network Selection Criteria

Network selection criteria are variables or parameters used as input into the decision module of the RAT selection process. These parameters are scaled, normalized and used as decision metrics for the ranking of the available access networks. Access network criteria are classified as network criteria, terminal criteria, application criteria and user preference criteria.

2.4.1 Network criteria

The network criteria are attributes used to evaluate the performance of the available access networks for the purpose of comparison among pairs and to select the most suitable for a specific application based on user demands. Network criteria such as received signal strength indicator (RSSI) and signal-to-interference noise ratio (SINR) are signal strength performance indicators which give the measure of network availability. Other network criteria include power consumption, coverage area, monetary cost, the level and type of security supported. The coverage area gives the level of mobility support while the monetary cost of using any network is a criterion which depends on the technology involved in the setup and operational maintainability of such network. A major criterion relating to network selection is the level of QoS support available for the user application in the respective access networks within the vicinity of the users. Attributes such as throughput, available bandwidth, jitter, and latency are often considered as network criteria.

2.4.2 Terminal criteria

Terminal criteria put into consideration the attributes required to optimize the performance of the mobile terminal. The major attribute relating to the user device is the energy consumed during the uplink, downlink and idle state of the terminal. User speed and the capability of the mobile terminal may also be considered.

2.4.3 User preference criteria

The user-related criteria include a user preference for a particular access technology, application type, price or usage cost, level of security and performance considerations that can affect the perceived quality of experience.

2.4.4 Application criteria

Application criteria basically describe the level of QoS support for such application. Voice service is an inelastic application which requires stringent QoS support while streaming video, which is partially elastic and file-download which is an elastic application can support some degree of QoS. Application flow type and flow identification contained in the traffic flow template (TFT) can also be used as attributes for flow classification and selection during access selection for flow mobility.

2.5 Methods of Access Selection

There exist different access network selection methods that have been developed in recent times for the purpose of making a decision on the best available access network. These different methods implement a specific algorithm which uses specific access selection criteria as inputs to evaluate, rank and recommend the most suitable access network for selection. Some of the commonly used methods include the Multiple Attribute Decision Making (MADM), Fuzzy logic, Utility optimization, Game theory, Artificial Intelligence and combinatorial optimization. Some of these techniques are explained in the following section.

2.5.1 Multiple attribute decision making (MADM)

The MADM method is a decision making process which presents the means and method of providing the best alternative among multiple alternatives in the presence of decision criteria. The techniques of MADM have been applied in the field of construction, medicine, economics, RAT selection, etc. Some of the MADM methods include Simple Additive Weighting (SAW), Distance to Ideal Alternative (DIA), Technique for Order preference by Similarity to Ideal Solution (TOPSIS), Analytical Hierarchal Process (AHP), Grey Rational Analysis (GRA), etc. The general approach to MADM method follows four basic steps of the specification, normalization, ranking and selection [17, 41, 42].

2.5.1.1 Specification stage

The attributes or criteria relating to the various alternatives are specified, and the level of importance of each criterion to the decision-making process is also given as weight values. The respective criteria value and the corresponding weight for each alternative are represented in a matrix form, and known as the decision matrix. The general form for the MADM problem can be modeled as $D(N \times V)$ problem. A mathematical description for D is given in Equation 2.1.

$$D = \begin{array}{cc} \begin{array}{cccccc} C_1 & C_2 & \cdots & C_j & \cdots & C_V \end{array} & \\ \begin{bmatrix} x_{1,1} & x_{1,2} & \cdots & x_{1,j} & \cdots & x_{1,N} \\ x_{2,1} & x_{2,2} & \cdots & x_{2,j} & \cdots & x_{2,N} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{i,1} & x_{i,2} & \cdots & x_{i,j} & \cdots & x_{i,N} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{N,1} & x_{N,2} & \cdots & x_{N,j} & \cdots & x_{N,V} \end{bmatrix} & \begin{array}{c} X_1 \\ X_2 \\ \vdots \\ X_i \\ \vdots \\ X_N \end{array} \end{array}, \tag{2.1}$$

where $\{X_1, X_2, X_3, \cdots, X_i, \cdots, X_N\}$ represents the set of N available alternatives for selection, and $\{C_1, C_2, C_3, \cdots, C_j, \cdots, C_V\}$ denotes the set of V criteria which are used to evaluate and score the performance of each alternative. The value of $x_{i,j}$ is used to indicates the performance rating of the i^{th} alternative, with respect to the j^{th} criterion of the decision matrix. The set of weight values, W, which represents the level of importance attributed to each criterion value can be represented as:

$$W = \{w_1, w_2, w_3, \cdots, w_j, \cdots, w_V\}. \tag{2.2}$$

In access network selection, the alternatives represent the possible access networks in the vicinity of the user. The performance or suitability of each alternative access network is evaluated using the given criteria, and the corresponding weights. The final ranking and selection process is carried out base on the implemented algorithm.

The decision matrix formulation for a typical RAT selection in heterogeneous network scenario with specified attributes and weight can be described as follows:

The set of the available RATs is given as R, where where $R = \{r_1, r_2, \ldots, r_n\}$; $(r \geq 2)$ and n is the maximum number of RATs. Similarly, let the set of criteria be defined as C, where $C = \{c_1, c_2, \ldots, c_v\}$, $(v \geq 2)$ and the user assigned preference weight to each decision criteria be given as $W = \{w_1, w_2, \ldots, w_v\}$, $(v \geq 2)$; and v is the maximum number of criteria. The decision matrix, $D = \{r_{i,j}\}$; for $i = \{1, \ldots, n\}$, and $j = \{1, \ldots, v\}$ for the above RAT selection scenario is described in the following equation;

$$D = \begin{array}{cc} \begin{matrix} C_1 & C_2 & \cdots & C_j & \cdots & C_V \end{matrix} & \\ \begin{bmatrix} r_{1,1} & r_{1,2} & \cdots & r_{1,j} & \cdots & r_{1,n} \\ r_{2,1} & r_{2,2} & \cdots & r_{2,j} & \cdots & r_{2,n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ r_{i,1} & r_{i,2} & \cdots & r_{i,j} & \cdots & r_{i,n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ r_{n,1} & r_{n,2} & \cdots & r_{n,j} & \cdots & r_{n,v} \end{bmatrix} & \begin{matrix} r_1 \\ r_2 \\ \vdots \\ r_i \\ \vdots \\ r_n \end{matrix} \end{array}, \tag{2.3}$$

The weight specification is as defined in Equation 2.2. Using similar definition, The value of $r_{i,j}$ is used to indicates the performance rating of the i^{th} RAT, with respect to the j^{th} criterion of the decision matrix, D.

2.5.1.2 Normalization stage

The decision matrix entries obtained as a performance score of an access network under a given criteria is used in the normalization stage. These entries obtained from different criteria having different dimensions/units, are normalized for the purpose of comparison. Different normalization methods are employed based on the MADM method considered. Some of the MADM normalization techniques include [43]:

- Vector normalization

  The vector normalization process, also known as Euclidian normalization method, converts the elements of the network decision matrix into dimensionless units by dividing the performance rating of each alternative by its norm according to the given expression.

  $$d_{ij} = \frac{r_{ij}}{\sqrt{\sum_{i=1}^{n} r_{ij}^{2}}} \tag{2.4}$$

  This method can achieve an inter-attribute comparison of the network decision metrics. However, it encounters difficulty in straightforward comparison due to non-equal scale length

- Max Method

In this approach, the performance rating of each attribute (r_{ij}) is divided by the maximum performance rating (r_j^{max}) of that attribute to obtain the normalized value. For benefit criteria, the normalized value is obtained as:

$$\widehat{d}_{ij} = \frac{r_{ij}}{r_j^{max}} \tag{2.5}$$

For cost criteria, the normalized value can be obtained as:

$$\widehat{d}_{ij} = 1 - \frac{r_{ij}}{r_j^{max}} \tag{2.6}$$

The method has the advantage of presenting the outcome of normalized rating in a linear way.

- Max-Min Method

This method considers the effect of the maximum (r_j^{max}) and minimum (r_j^{min}) performance ratings among the pairs of alternatives. For benefit criteria, the normalized value is obtained as:

$$\widehat{d}_{ij} = \frac{r_{ij} - r_j^{max}}{r_j^{max} - r_j^{min}} \tag{2.7}$$

For cost criteria, the normalized value is obtained as:

$$\widehat{d}_{ij} = \frac{r_j^{max} - r_{ij}}{r_j^{max} - r_j^{min}} \tag{2.8}$$

- Sum Method

  The sum method calculates the ratio of the attribute values of each alternative with respect to the sum of the attribute values of the alternatives using the given expression.

$$d_{ij} = \frac{r_{ij}}{\sum_{i=1}^{n} r_{ij}} \tag{2.9}$$

2.5.2 MADM techniques for access network selection

In this section, an overview of some commonly used MADM techniques and algorithm for access network selection will be discussed selection [37, 44, 45].

2.5.2.1 Simple Additive Weighting (SAW) Method

The SAW method is one of the most popular decision methods used for multiple attribute decision making techniques and is computed based on the weighted sum of all attribute values. The method of SAW evaluates and ranks the entire access network by taking the weighted sum of all the network criteria, obtain the normalized contributions of each criterion and multiply it by the weight assigned to each criterion. The network with the highest score is selected as the preferred network. The network specifications in Section 2.5.1.1, a set of services S, where $S = \{s_1, s_2, \ldots, s_m\}$ and user-assigned weight, $W = \{w_{s,j}\}$, are used to describe the step-by-step approach to the SAW method, as illustrated below: In this method, $w_{s,j}$ is the weight assigned to s^{th} service with respect to the j^{th} criterion, and m is the maximum number of services.

Step 1: Specify the assigned weight, W, for a set of service request by the mobile terminal user from available RATs in heterogeneous network according to the expression

$$W = \{w_{s,j}\}, s = \{1, \ldots, m\}, j = \{1, \ldots, v\} \tag{2.10}$$

Step 2: Obtain the normalized weight, assigned to each criterion with respect to benefit and cost criteria

$$\widehat{W}_{s,j} = \frac{w_{s,j}}{\sum_{j=1}^{v} w_{s,j}}, s = \{1, \ldots, m\}, j = \{1, \ldots, v\} \tag{2.11}$$

Step 3: Obtain the normalized decision matrix $\widehat{d_{i,j}}$. The normalized decision matrix consists of each element describing the network attributes. The benefit criteria ($\widehat{d}^{b}_{i,j}$) and cost criteria ($\widehat{d}^{c}_{i,j}$) are given by the following expressions.

$$\widehat{d}^{b}_{i,j} = \frac{d_{i,j}}{max\{d_{i,j}\}, i = 1, 2, \cdots, n} \tag{2.12}$$

$$\widehat{d}^{c}_{i,j} = \frac{min\{d_{i,j} | i = \{1, \ldots, n\}; \{j = 1, \ldots, k\}}{d_{i,j}} \tag{2.13}$$

Step 4: Obtain the weighted normalized decision matrix ($\widehat{d}^{wt}_{i,j}$) by aggregating the product of ($\widehat{d}_{i,j}$) and ($\widehat{W}_{s,j}$) according to the following expression.

$$\widehat{d}^{wt}_{i,j} = \widehat{d}_{i,j} * \widehat{W}_{s,j} = \begin{array}{cc} \begin{array}{cccccc} C_1 & C_2 & \cdots & C_j & \cdots & C_V \end{array} & \\ \begin{bmatrix} d_{1,1} & d_{1,2} & \cdots & d_{1,j} & \cdots & r_{1,n} \\ d_{2,1} & d_{2,2} & \cdots & d_{2,j} & \cdots & r_{2,n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ d_{i,1} & d_{i,2} & \cdots & d_{i,j} & \cdots & r_{i,n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ d_{n,1} & d_{n,2} & \cdots & d_{n,j} & \cdots & r_{n,v} \end{bmatrix} & \begin{array}{c} r_1 \\ r_2 \\ \vdots \\ r_i \\ \vdots \\ r_n \end{array} \end{array}, \tag{2.14}$$

Step 5: The score of each access network is determined using values obtained from the normalized decision matrix as an input to the following expression.

$$SAW - Ranking(R_j) = max\sum_{j=1}^{v}\widehat{d}^{wt}_{i,j} \tag{2.15}$$

The RAT with the highest score(R_i) is then selected as the appropriate RAT for the requested service by the mobile user.

2.5.2.2 Multiplicative Exponent Weighting (MEW) Method

This approach is often referred to as the Weighting Product (WP) method and shares some similarities with the SAW method except that the final ranking is obtained as the weighted product of the normalized criteria. The MEW method is described below:

Step 1: The specification step for user defined weights, normalization step for network attributes and user weight, and the weighted normalized decision matrix are obtained as contained in steps 1 to step 5 of Section 2.5.2.1

Step 2: The ranking of each access network is determined using values obtained from the normalized decision matrix. The best RAT is determined using the following expression.

$$MEW - Ranking(R_j) = max\prod_{j=1}^{v}\widehat{d}_{i,j}^{wt} \tag{2.16}$$

2.5.2.3 Techniques for Order Preference by Similarity to Ideal Solution (TOPSIS)

The TOPSIS method is popularly used for RAT selection and contains two solution sets namely which are the ideal solution and worst case solution. The best ranked access network is considered as the one closest to the ideal solution and farthest from the worst case solution. The steps required for TOPSIS method is described below.

Step 1: The weight specifications and normalization follow the procedures described in Equation 2.10.

Step 2: The normalized decision matrix is determined as follows:

$$d_{ij} = \frac{r_{ij}}{\sqrt{\sum_{i=1}^{n} r_{ij}^2}}, i = \{1, \ldots, m\}, j = \{1, \ldots, v\} \tag{2.17}$$

Step 3: The weighted normalized decision matrix is obtained according to Equation 2.14

Step 4: Determine the positive ideal solution (P^+) and negative ideal solution (P^-), respectively according to these expressions:

$$(P^+) = min(u_{i,j}) = \{u_1^+, u_2^+, \ldots, u_i^+, \ldots, u_v^+\} \tag{2.18}$$

$$(P^-) = max(u_{i,j}) = \{u_1^-, u_2^-, \ldots, u_i^-, \ldots, u_v^-\} \tag{2.19}$$

Step 5: the similarity measures as the distance between each alternative and the ideal solutions. For positive ideal solution, the similarity measure (T_j^+) is obtained as follows:

$$T_j^+ = \sqrt{\sum_{i=1}^{v}(u_{i,j} - u_i^+)^2} \tag{2.20}$$

For negative ideal solution, the similarity measure (T_j^-)) is obtained as follows:

$$T_j^- = \sqrt{\sum_{i=1}^{v}(u_{i,j} - u_i^-)^2} \tag{2.21}$$

Step 6: Calculate the closeness coefficient for each available access network as follows:

$$TOPSIS - Ranking(R_j) = \frac{T_j^-}{T_j^- + T_j^+} \tag{2.22}$$

The computed closeness coefficient contains values in the range of [0, 1], higher values indicate the best score among the available alternatives.

2.5.3 Analytical hierarchy process (AHP)

The AHP method is a multi-criteria decision making method used to solve complex decision problem. The method allows the decision makers to decompose the decision problem into a hierarchy of sub-problems, which define the problem goals, criteria, sub-criteria, and alternatives. AHP determines the relative importance of the decision variables with respect to the goals using the Saatys scale, and the outcome is used for the construction of comparison matrix (P)[44]. The comparison matrix is used to perform a pairwise comparison of the given criteria in order to obtain the relative weights of importance for the decision criteria. It also provides the performance measure of the given alternatives with respect to the individual decision criterion.

In a multi-attribute decision-making problem such as access network selection, the problem goal is to select the best RAT for the user service request. The selection attributes such as throughput, delay, cost, power consumption, and network load is formulated as the network criteria, and the Saatys scale is used to compute the criteria weight from the comparison matrix (P). For a given $\lceil m_{i,j} \rceil_{mxn}$, where n is the number of criteria or comparing factor, AHP ranks each row in $i = \{1, 2, \ldots, n\}$ with respect to the criteria in the column $j = \{1, 2, \ldots, m\}$, on a scale of 1-9. If $m_{i,j} = 1$, then, i and j, have equal importance, however, $m_{i,j} = 3, 5, 7, 9$, signify that i have moderate importance, strong importance, very strong importance and extreme importance more than j, respectively [9].

The comparison matrix (P) is then normalized, and the eigenvector (v) corresponding to the largest eigenvalue (λ_{max}) is used to determine the relative weight. A consistency ratio $(CR < 0.1)$ is determined such that $CR = CI/RI$; where CI and RI represent the consistency index and random index, respectively. The values of RI are obtained from Saaty scale in Table 2.1 and CI is calculated from the following expression:

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{2.23}$$

Table 2.1: Saatys scale for Random Index (RI)

n	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48

2.5.4 Fuzzy logic methods

In many multi-criteria decision making problems, certain decision parameters contain some degree of uncertainty, imprecision, and vagueness. These can affect the experts judgment on the selection of the best alternatives. In order to address this drawback, Zadeh and Bellman [46], proposed the fuzzy set theory as a way of expressing imprecise criteria data in linguistic variables. The linguistic variables are then mapped into a fuzzy membership function, which defines the degree of membership of the criteria between 0 and 1. It is then processed by a fuzzy rule-based system, and the outcome is converted into crisp value for scoring or ranking of the alternatives. Commonly used membership function includes triangular membership function, trapezoidal membership function, and sigmoidal membership function.

In the fuzzy logic approach to RAT selection, the selection criteria are mapped as input into the appropriate fuzzy membership function for conversion into their respective crisp values. The fuzzifier then maps the crisp values into fuzzy sets which serve as input to the fuzzy inference engine. Fuzzy rules which guide the selection of the best alternative are defined independently for each criterion or jointly for all criteria. The inference engine combines the fuzzy rules for the decision process, and the defuzzifier converts the result into crisp values for scoring and ranking of the alternative access networks. RAT selection using fuzzy logic is sometimes implemented as a hybrid solution, such as Fuzzy TOPSIS, Fuzzy SAW or Fuzzy AHP [40, 47].

In fuzzy set theory, given a universe of discourse X, a fuzzy set $\widehat{u}$ is described by a membership function $\mu_{\widehat{u}}(x)$. The membership function represents the degree of membership of x,in $\widehat{u}$ and performs a mapping of each element x in X to the corresponding crisp value in the range of interval described above. The Triangular fuzzy number (TFN) and corresponding membership function is illustrated in Figure 2.4. Given that,$\widehat{u} = u_1, u_2, u_3$, the corresponding membership function can be obtained using Equation 2.24

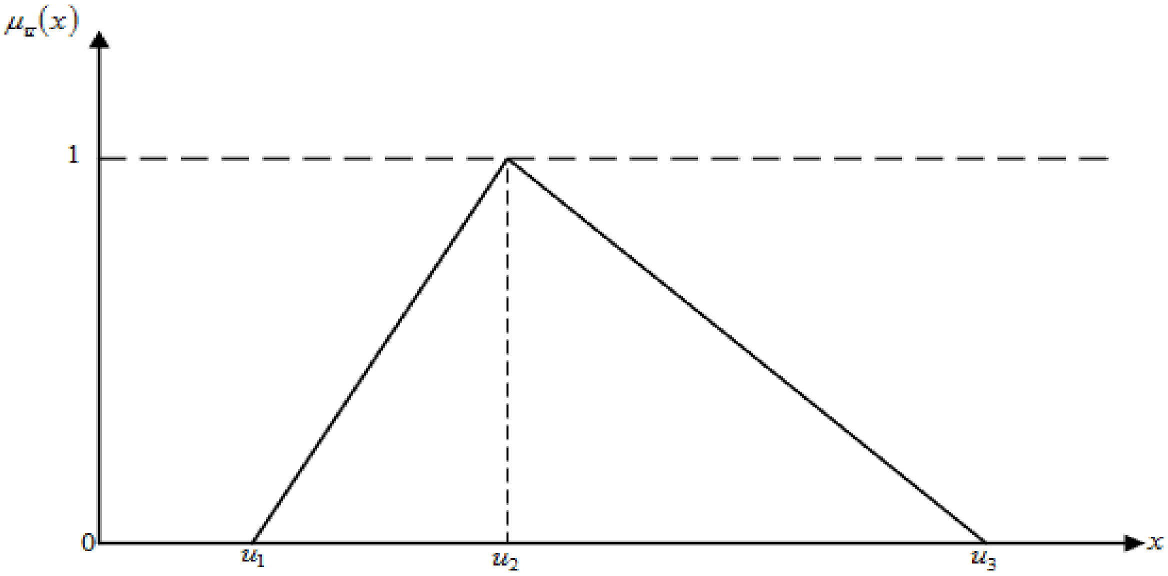

Figure 2.4: Triangular fuzzy number.

$$\mu_{\widehat{u}}(x) = \begin{cases} 0, & x < u_1 \\ \frac{x-u_1}{u_2-u_1}, & u_1 \leq x \leq u_2 \\ \frac{u_3-x}{u_3-u_2}, & u_2 \leq x \leq u_3 \\ 1, & x > u_3 \end{cases} \tag{2.24}$$

In the defuzzyfication process, several techniques such as centroid of area, Best known fuzzy performance, α-cut, etc. are used to obtain the crisp values. The linguistic terms and fuzzy numbers are shown in Figure 2.5. For the purpose of this work, six linguistic terms, which are: none, very low, low, medium, high and extremely high, on a scale of 0, 1,3,5,7 and 9 are used, respectively to show the relative importance between preferences. Applying the Triangular Fuzzy Number (TFN) conversion scale on the fuzzy label sets, the corresponding crisp values (μ_m) can be obtained using Equation 2.25 [12].

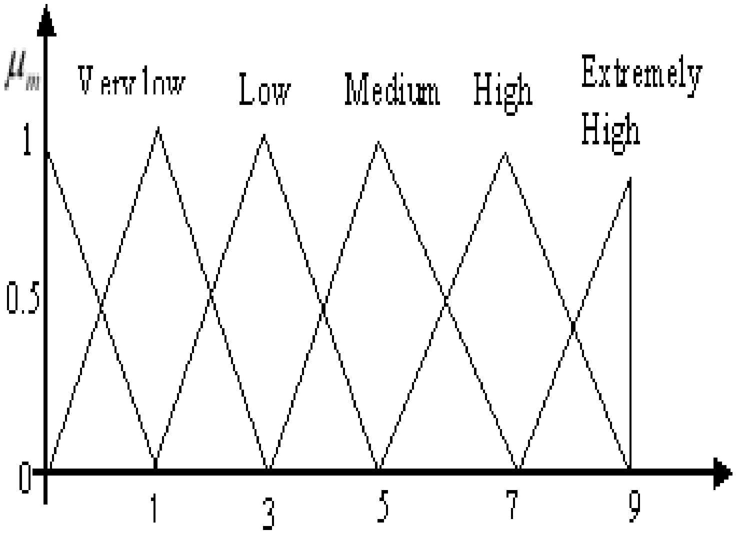

Figure 2.5: Linguistic terms and fuzzy number of TFN.

$$\mu_x = \frac{1}{6}\left(x_l + 4x_n + x_u\right) \tag{2.25}$$

Where x_l and x_n represents the lower and upper bound of the fuzzy numbers , respectively and x_u is the intermediate fuzzy number. Table 2.2 shows the crisp values obtained from Figure 2.5 and Equation 2.25

Table 2.2: Lingustic Preference Relation

Linguistic labels	**Linguistic terms**	**Symbols**	**TFN**	**Crips values**
None	N	s_0	0,0,0	0.000
Very Low	VL	s_1	0,1,3	0.0333
Low	L	s_2	1,3,5	0.3333
Medium	M	s_3	3,5,7	0.5500
High	H	s_4	5,7,9	0.7550
Extremely High	EH	s_5	7,9,9	0.9617
Tally	T	s_6	9,9,9	1.000

2.5.5 Utility optimization method

Utility is the measure of satisfaction derived by individuals from consumed goods and services. It is a subjective measure since different users can express different preferences for the same product. In decision making process, utility functions are mathematical expressions used to measure the degree or level of satisfaction derived from available alternatives using the variables or characteristics describing such alternatives.

Generally, a single criterion utility function is formulated to evaluate each alternative subject to predefined goals. The alternative with the highest utility value is then selected as the preferred alternative. For multi-attribute utility function optimization, selection criteria are classified as maximizing or minimizing criteria and the total utility is given as additive or multiplicative utility function.

In access network selection, the selection criteria describing the access network, terminal capability, application requirements and user preferences are mapped as input to the given utility function or set of utility functions [48]. The output, which is a measure of user satisfaction, is used to rank the available networks. Given that the utility function of a single criterion is $u(x) = f(x_1, \ldots, x_v)$, for $(v \geqslant 1)$, where x are the decision criteria, the additive and multiplicative aggregate utility function for a multi-criteria decision problem can be expressed as in Equation 2.26 and Equation 2.27 , respectively:

$$U(x) = \sum_{i=1}^{v} w_i u_i(x_i), where \sum_{i=1}^{v} w_i = 1 \tag{2.26}$$

$$U(x) = \prod_{i=1}^{v} [u_i(x_i)]^{w_i} \tag{2.27}$$

2.5.6 Policy-based RAT selection

Policy-based RAT selection schemes are implemented through well-defined policy statements containing a set of rules guided by specified conditions. Once these conditions are satisfied, the required action is triggered, in this case, the selection of the available RAT. Policy-based RAT selection method, therefore, differs from the analytical methods used for ranking and selection of access networks. The 3GPP ANDSF-based access selection method discussed in Section 2.2.1 is a typical policy-based, network-controlled access selection scheme. In this method, the ANDSF server in the operators domain provides network discovery information, Inter system Mobility Policy (ISMP) and Inter System Routing Policy (ISRP) information to the user equipment for the selection of the appropriate access network.

The ANDSF is interfaced to the UE via the s14 interface for the exchange of access network discovery and selection information using either in a PULL or PUSH mode [21, 49]. The identities of the available access networks within the vicinity of the UE are contained in the network discovery information. Information such as Service Set Identity (SSID) and Basic Service Set identity (BSSID) for WiFi, Network Service Provider Identity (NSP-id) and Network Access Point Identity (NAP-id) for WiMax, Cell-Id for cellular networks, etc is provided to the UE. The inter-system mobility policy (ISMP) contains rules for inter-system handover. These rules may include allowed or restricted access networks, validity conditions such as location and time of day. Inter-system routing policies (ISRP) controls the routing of IP flows through simultaneous interfaces, and contain the allowed or restricted interface for a particular IP traffic during IP flow mobility (IFOM) or multiple-access PDN connectivity (MAPCON).

Chapter 3

COPRAS-Based RAT Selection Scheme for Multiple Handoff Calls in Heterogeneous Networks

3.1 Introduction

HetNets RAT selection problem description has been outlined in Section 1.3 and Section 1.4 of this thesis. Several solutions have been proposed for RAT selection in HetNets. These solutions have considered single criterion or multiple criteria for selecting the best RAT for user application request [50–52]. However, the existing solutions are not suitable for the selection of the best RAT for the handoff of a grouped-multiple calls. This is because, the issue of QoS disparity among each call in a group of multiple sessions are not addressed. Since each call has preference for different RATs, which can lead to increase in handoff frequency. Similarly, handoff of group multiple calls can introduce additional complexities in terms of processing time, leading to excessive delay and degradation in application QoS. It is therefore necessary to have an efficient RAT selection scheme for handoff of group multiple calls. Such schemes will address the issues of QoS disparity among multiple calls, reduce handoff frequency and time complexity or processing time. This chapter therefore, is aimed at providing a novel solution that will address the above stated. In this section, we present an architectural overview of our proposed solution for RAT selection for multiple be calls in HetNets environment. The proposed RAT selection method, which is terminal-initiated and network-controlled, consists of the interface manager (IM) in the mobile terminal and network selection function (NSF) in the access network selection module (ANSM). These entities are shown in Figure 3.1.

The NSF implements the RAT selection algorithm, using the user subscription information and network discovery information to evaluate, rank and select the appropriate RAT for the user's multiple calls subscription. The user subscription information which consists of user preferences on application and network specific criteria is obtained from the mobile terminal. Network discovery information can be obtained from the dynamic access network criteria module (DANCM). The DANCM obtained real time access network information and provide the same to the network discovery information based on operator specifications. Information flows are made possible through the use of logical connections such as described in [21]. The interface manager in the terminal controls the ON/OFF state of the mobile terminal based on the RAT selection information received from the NSF. It enables a single interface on the terminal to associate with corresponding target RAT for group multiple calls or multiple interfaces which correspond to the selected subset of RATs for multi-homing services. The proposed RAT selection algorithms in this thesis are based on the architecture presented in Figure 3.1.

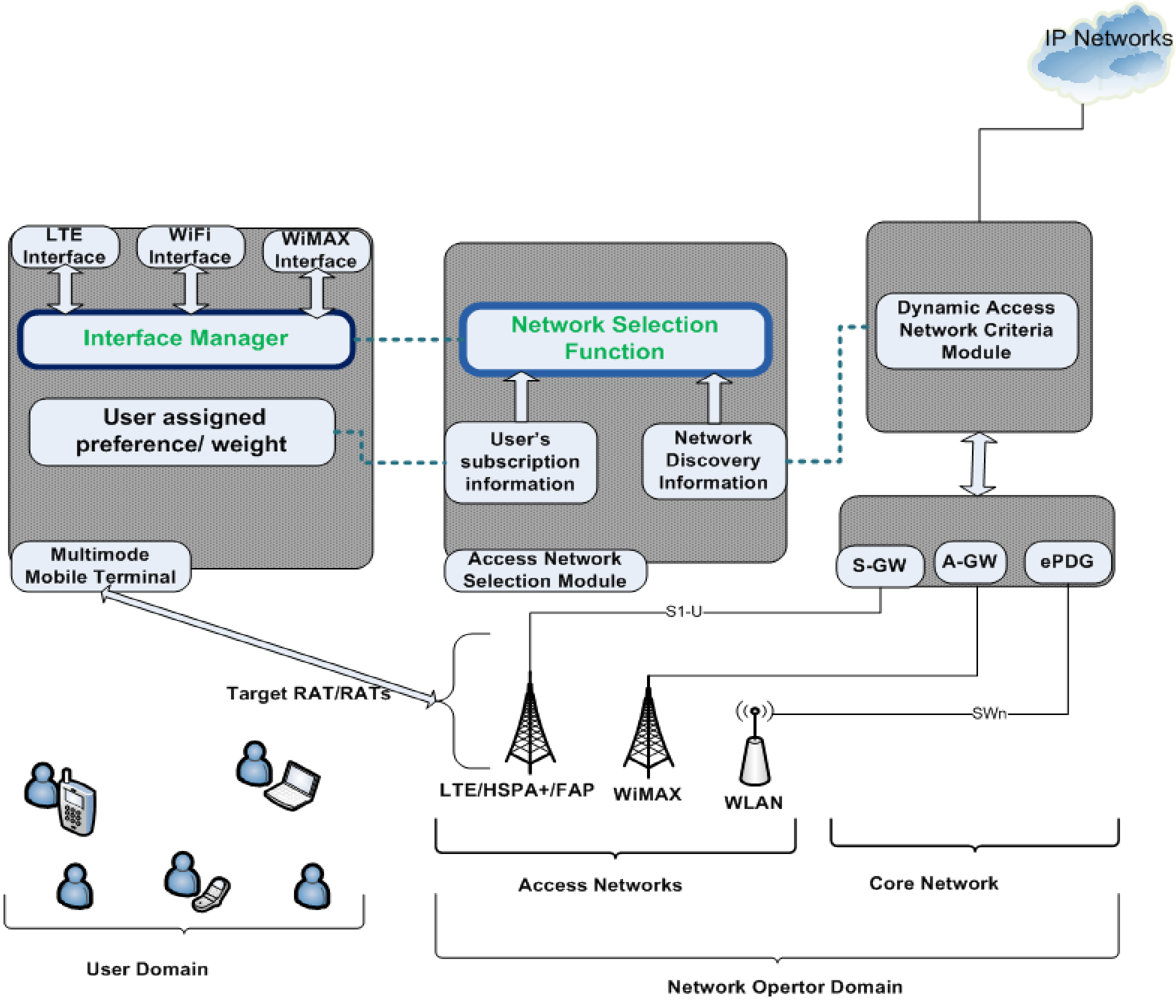

Figure 3.1: Proposed solution architecture for multiple calls in HetNets.

In this chapter, the MADM approach to access network selection is presented. The MADM method is a suitable technique for handling complex decision problems involving multiple criteria. As mentioned earlier, the techniques have been applied in the area of medicine, economics, government, and in the selection and reselection of Radio Access Technology (RAT). Furthermore, a new and novel MADM method, the Complex PRoprtional

ASsesment (COPRAS) method is proposed for radio access selection. The COPRAS method is known for its simplicity and reliability in the selection of best alternative among available alternatives with multiple criteria. To the best of our knowledge, this is the first time the COPRAS method is being considered as a candidate MADM algorithm for access network selection. A comprehensive performance evaluation of the COPRAS method and some known MADM methods used for access network selection is also carried out. The existing MADM methods considered in this chapter include Simple Additive Weighting (SAW), Multiplicative Exponent Weighting (MEW), and the Technique for Order of preference by Similarity to Ideal Solution (TOPSIS) [10].

The remainder of this chapter is outlined as follows: Section 3.2 contains the related works on MADM method for access network selection. Section 3.3 explains the COPRAS algorithm while Section 3.4 gives the comparative analysis of the existing MADM methods and the COPRAS method. Section 3.5 presents the radio access selection approach for voice, file-download and video-streaming applications using both the COPRAS and TOPSIS method. Section 3.6 explains the MADM approach to access Selection for Group multiple calls. Section 3.7 discuses the effect of preference margin on grouped multiple calls and Section 3.9 concludes the chapter.

3.2 Related Works on MADM Methods

Some existing works on MADM RAT-selection techniques are explained below.

Different MADM methods [53–55] have been presented in the literature for ranking and selection of the best access network capable of supporting the user application request. In

[53], a multi-criteria decision-making algorithm for access network selection in overlapped WiMAX-WLAN heterogeneous networks is proposed. The WiMAX network is deployed to provide the backhaul functionality while several WiFi access points are deployed to serve as an alternative source of routing user traffic, especially during heavy congestion. The authors considered five classes of applications with bandwidth, delay, jitter and other QoS parameters as attributes. In the same scenario, three service level agreements (SLA) have been considered, with each SLA evaluated against WiFi network attributes such as bandwidth, delay, jitter, price and service type. AHP method is used to determine application criteria weight through a pairwise comparison for the different SLAs and the method of TOPSIS is applied for the ranking and selection of appropriate access network. The results show the effectiveness of these two MADM methods in ranking and selection of access network. The authors in [54], proposed two vertical handover decision schemes using the method of SAW and TOPSIS.

In both schemes, a user connected to a WiFi access is to select the best network among two WiFi and four WiMax access networks using delay, bandwidth, cost and jitter as vertical handoff criteria. In the distributed vertical handover decision scheme, a mobile terminal sends a handoff request to all available networks. Each network uses its criteria to compute and compare the required and offered network quality values, and sends the same to the mobile terminal. The mobile terminal selects the network with the highest quality value. Similarly, the trusted distributed decision scheme introduces the concept of level of trust, which allows a potential target network to be evaluated for service availability. The performance of the schemes is evaluated using processing delay, throughput, end-to-end delay, handover event and packet delivery ratio. The schemes show that TOPSIS method is a better decision maker than SAW.

In [55], a seamless mobile video offloading in heterogeneous wireless networks comprising of 3G UMTS and WLAN based on Media Independent Handover (IEEE 802.21) Standard is proposed. The scheme uses the method of TOPSIS with decision parameters such as mean opinion score, peak signal-to-noise ratio, channel quality indicator, security, client SNR, and user preference. The MIH module which interfaces between layer 2 and layer 3 handover uses the channel quality indicator values obtained from the mobile terminal as well as the QoE agreements between the user and operator to effect the handover process. The proposed solution was implemented in NS2 simulator and selected the best target access network for a given user video application.

Due to the changing nature of the wireless environment, imprecision may occur in characterizing various network attributes. As mentioned in the previous chapter, the fuzzy logic system is used to account for these variations. In [56, 57], a fuzzy-based MADM method has been applied to RAT selection. In [56], the authors have proposed RAT selection schemes which combine MADM and Mahalanobis methods. In this scheme, intra-class and inter-class weighting system based on fuzzy AHP have been defined and used to construct the decision matrix. The selection of the optimal network is obtained using the Mahalanobis distance methods. This method measures the distance between each alternative and the weighted normalized decision matrix, and the smallest distance gives the best alternative. Several simulations were carried out using six candidate networks (2 UMTS, 2WLAN, and 2 WiMAX) and six network criteria. The results obtained for the proposed solution are compared with existing MADM methods such as TOPSIS, GRA and DIA. The results show that the proposed scheme is able to reduce ranking abnormality and the number of handoff as compared to other known methods. The authors in [23, 58] proposed a RAT-selection schemes for handoff of a group of multiple calls in heterogeneous wireless networks. In the proposed scheme, the TOPSIS MADM techniques has been modified to aggregate the different user preferences on the individual application. The scheme also assigned priority to each call. The new multi-criteria Group decision making technique (TOPSIS) has been evaluated under different network scenario and network preference margins have been set to evaluate RAT selection handover frequency. While different simulations have been carried out to validate these schemes, the simulation results have not been compared with other known methods. Similarly, the effect of time complexity which can impact negatively on the application QoS was not investigated.

3.3 COPRAS-Based MADM Schemes for RAT Selection in Heterogeneous Networks

The Complex PRoprtional ASsesment (COPRAS) method is a MADM method developed by Zavadskas et al. (1994) [59]. It introduces a cost efficient multi-attribute decision-making technique, which allows for the qualitative and quantitative assessment of criteria, and provides the means for evaluating the impact of both positive (maximizing) and negative (minimizing) criteria on the set of alternatives. It is simple, flexible and computationally inexpensive to implement when compared with other known MADM methods. The COPRAS

MADM method is a step-wise evaluation procedure used to rank and select the most suitable alternatives, based on their level of significance. The method is used to measure and compare the degree of utility of one alternative to another. There are two variants of COPRAS MADM methods namely; COPRAS-F and COPRAS-G methods. The COPRAS-F is used as a hybrid of COPRAS and Fuzzy MADM algorithm, other applications of COPRAS method also considered a hybrid of AHP with COPRAS [60, 61].

In some cases, the associated attributes and corresponding weights of alternatives contain some degree of uncertainty and this has motivated Zavadskas et al., (2008)[62] to introduce the COPRAS-G method. COPRAS-G, therefore, is the application of COPRAS to include the selection of alternatives with grey or imprecise data. A hybrid of fuzzy MADM and COPRAS-G can also be applied for ranking and selection of alternatives. COPRAS MADM has been applied in the field of employee selection [63], website selection [64], engineering material selection [65], robot selection [66], degree of project utility [67], etc. While the COPRAS method has been applied in these areas, there is no known application of COPRAS in the ranking and selection of radio access technology. However, our preliminary evaluation on the use of COPRAS method for RAT selection can be found in [4].

3.3.1 COPRAS-F ranking and selection procedures

The procedures for RAT selection using COPRAS-F method is outlined below:

Step 1: Given a set of alternatives (X), where X is associated with a given set of criteria (C) and weight values (W) as described in Section 2.5.1.1. The assigned weights on each alternative can be defined as:

$$W = \{w_{c,j}\}, j = \{1, \cdots, v\} \tag{3.1}$$

The criteria weight is normalized in order to obtain comparable scale of criteria values since the assigned criteria weights have a different dimension.The normalization procedure can be carried out as follows:

$$\widehat{w}_j = \frac{w_j}{\sum_{j=1}^{v} w_j}, j = \{1, \ldots, v\} \;\; and \;\; \sum_{j=1}^{v} \widehat{w_j} = 1 \tag{3.2}$$

Step 2: In this step, a decision matrix, $D = \{d_{i,j}\}$; for $i = \{1, \ldots, n\}$, and $j = \{1, \ldots, v\}$ for the above RAT selection scenario is described in the following equation

$$D_M = \begin{array}{cccccc|c} C_1 & C_2 & \cdots & C_j & \cdots & C_V & \\ d_{1,1} & d_{1,2} & \cdots & d_{1,j} & \cdots & d_{1,n} & X_1 \\ d_{2,1} & d_{2,2} & \cdots & d_{2,j} & \cdots & d_{2,n} & X_2 \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \vdots \\ d_{i,1} & d_{i,2} & \cdots & d_{i,j} & \cdots & d_{i,n} & X_i \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \vdots \\ d_{n,1} & d_{n,2} & \cdots & d_{n,j} & \cdots & d_{n,v} & X_n \end{array}, \tag{3.3}$$

Step 3: Calculate the normalized decision matrix for each element in Equation 3.3

$$\widehat{d_{i,j}} = \frac{d_{i,j}}{\sqrt{\sum_{i=1}^{n}(d_{i,j})^2}} \tag{3.4}$$

Step 4: Calculate the weighted normalized decision matrix, $A = \{a_{i,j}\}$, by taking the product of the normalized decision matrix with the corresponding weights of each alternative using the expression;

$$a_{i,j} = \widehat{w_j}\widehat{d_{i,j}}; i = \{1, 2 \cdots, n\}, j = \{1, 2 \cdots, v\} \tag{3.5}$$

Step 5: Classify the alternatives as positive (maximizing) and negative (minimizing) with respect to the criteria. The sum of the maximizing and minimizing criteria is determined, respectively as:

$$S_{i+}^{+} = \sum_{j=1}^{v} A_{i,j} | j \in j^{max} \tag{3.6}$$

$$S_{i}^{-} = \sum_{j=1}^{v} A_{i,j} | j \in j^{min} \tag{3.7}$$

Step 6: Determine the relative importance (prioritization) ranking of the alternatives Q_j as follows:

$$Q_i = S_i^{+} + \frac{minS_i^{-}\sum_{j=1}^{v} S_i^{-}}{S_i^{-}\sum_{j=1}^{v}\frac{minS_i^{-}}{S_i^{-}}} \tag{3.8}$$

Step 7: Determine the utility (N_i) values for each alternative:

$$N_i = \frac{Q_i}{Q_{max}} \tag{3.9}$$

The alternatives are ranked in descending order based on the values of Q_i.

The continuous variations in the characteristics of the wireless networks can be attributed to the dynamics of the wireless environment. The performance evaluation of these changing network attributes therefore, requires a method which incorporates the fuzzy nature of the wireless environment. The COPRAS-F method, which is a hybrid of COPRAS and Fuzzy MADM algorithm is more suitable with respect to the COPRAS-G method in this regard and is, therefore, used for the evaluation, ranking and selection of the most suitable access network in this chapter.

3.4 Comparative Analysis for SAW, MEW, TOPSIS and COPRAS Schemes

In this section, a comprehensive performance comparison of the four MADM schemes (SAW, MEW, TOPSIS and COPRAS) and their suitability for access network selection are evaluated through simulation in MATLAB environment. Similar comparison study involving MADM methods has been reported in [4, 68]. In the first work, performance indicators such as ranking order, ranking abnormality and difference in ranking were used to compare the effectiveness of SAW, MEW and TOPSIS methods. Similarly, call distribution among the available RATs, using the method of TOPSIS and COPRAS, has been used as a major performance indicator in the second work. However, the performance comparison carried out in this chapter, has introduced additional performance indicators such as ranking consistency, processing time, and handoff margin.

The problem formulation for the comparison analysis considers a set of alternative access networks (LTE, HSPA, WLAN1, WLAN2, and WiMAX) and a set of criteria, as described in Section 2.5.1.1. The evaluation of the alternative access networks is carried out using six criteria (throughput, delay, network load, power, service price, and mobility support). The selected criteria are suitable attributes that best describe the capability of the available RATs to support the request applications, and hence user satisfaction or QoE. These criteria are described below:

- Throughput: This is the maximum data rate in Mbps (or Kbps) offered by any RAT. It is a measure of the difference between the total network capacity and occupied bandwidth of the network. Network throughput can be used to measure the network availability or capability to satisfy users application request. Network throughput may vary over time as a result of the changing state of the wireless environment or network congestion.

- Delay: Network delay measures the amount of time it takes the smallest unit of information to be transmitted from source to destination. Network delay is a stringent QoS parameter which can degrade network performance. Allowable end-to-end delay or jitter has therefore been specified for different network and applications in order to achieve the required quality of service.

- Network Load: The network load can be used to determine the level of network congestion. Over loaded network can introduce some network impairments such as increased end-to-end delay, call blocking and dropping probability, reduced throughput and eventually, network inefficiency. Network load is an important criterion in the selection of access network; this is because selecting already congested network can result in severe service disruption or degradation.

- Power consumption: The multi-homed terminal can support multiple network interfaces and parallel application subscription. This makes battery power consumption a major criteria to be considered in the selection of a suitable RAT in heterogeneous wireless networks. Selecting an access network which minimizes the terminal interface power consumption is a path towards achieving energy efficiency in next generation networks.

- Service Price: Cost is the amount paid by users per unit of information or services subscribed for, either in an uplink or downlink request, which form part of operator revenue. Users sensitivity to cost is measured by user willingness to pay. A pricing scheme which is beneficial to both operator and network subscriber has been an active area of research and remains a major criterion for network selection.

- The level of Mobility support: One major advantage of the wireless network is the support for user mobility. In a static and mobile network environment, where the nomadic user seeks to achieve the Always Connected (AC) and Always Best Connected

(ABC) scenario, the level of mobility support becomes an important criterion for network selection.

3.4.1 Ranking performance of SAW, MEW, TOPSIS and COPRAS schemes

The network criteria specifications in this work are given as real numbers, a range of values, or fuzzy linguistic terms. The values are obtained from standard specifications [69, 70]. The fuzzy linguistic terms are converted to their respective crisp values as reported in Subsection 2.5.4.

Table 3.1: RAT criteria configuration.

Criteria RATs	**Data rate (Mbps)**	**Delay (ms)**	**load**	**Power (Watts)**	**Service price(unit/Mb)**	**Mobility support**
LTE (RAT1)	$1-22$	25	5	5	50	VH
HSPA (RAT2)	$1-5$	30	60	4	40	H
WLAN1 (RAT3)	$1-11$	100	40	1	10	M
WLAN2 (RAT4)	$1-54$	100	80	2	20	L
WiMAX (RAT5)	$1-25$	60	35	3	15	H

The network configurations, which are used as simulation parameters for each MADM method, are shown in Table 3.1. The weights, i.e., level of importance assigned to the criteria are given as: w = 0.2100, 0.1600, 0.1600, 0.110, 0.2100, 0.1600. These values can be determined or assigned by the user or network operator. The ranking index and corresponding ranking order for each access network are determined using the methods of SAW, MEW, TOPSIS and COPRAS, and the results shown in Table 3.2. The ranking order and ranking index values are specific to each algorithm.

The results show that the four methods selected RAT1 as the best alternative and RAT4 as the worst alternative. Similarly, the ranking position of RAT3 is consistent for all the

Table 3.2: MADM ranking index for RATs selection

RATs MADM Methods		**LTE (RAT1)**	**HSPA (RAT2)**	**WLAN1 (RAT3)**	**WLAN2 (RAT4)**	**WiMAX (RAT5)**
SAW	Index	1	2	4	5	3
	Parameter	0.9380	0.8659	0.6913	0.4508	0.8214
MEW	Index	1	2	4	5	3
	Parameter	0.5914	0.5811	0.3768	0.2615	0.5495
TOPSIS	Index	1	2	4	5	3
	Parameter	0.6654	0.6410	0.4388	0.2937	0.6317
COPRAS	Index	1	3	4	5	2
	Parameter	0.6033	0.5651	0.4459	0.3170	0.5884

schemes. The ranking order for SAW, MEW and TOPSIS is RAT1, RAT2, RAT5, RAT3 and RAT4, respectively while COPRAS has a ranking order of RAT1, RAT5, RAT2, RAT3 and RAT4. The ranking results, therefore is a good indicator, which show that the method of COPRAS is an ideal candidate for RAT selection.

COPRAS method provides additional features called the N-values. The N-values provides information on the degree of utility of each alternative RAT as described in Equation 3.9. The results for the N-values are given in Table 3.3.

Table 3.3: Utility values for alternative RATs

RATs	**LTE(RAT1)**	**HSPA(RAT2)**	**WLAN1(RAT3)**	**WLAN2(RAT4)**	**WiMAX(RAT5)**
N	1.00	0.94	0.73	0.53	0.97

The utility values of each RAT indicate the degree of availability or a measure of efficiency of the respective RAT. The N-values can also be used to rank and select the best RAT among the available RATs in the vicinity of the user.

3.4.2 Ranking consistency of SAW, MEW, TOPSIS and COPRAS schemes

To validate these results and test the robustness of each MADM method, a simulator has been developed which allows for ranking the RATs under dynamic criteria. The dynamically generated weights account for the changing nature of the wireless environment. Each selection algorithm is allowed to run for a total of 30 trial instances and for each trial, the best alternative is observed. The ranking order for one trial instance is shown in Figure 3.2

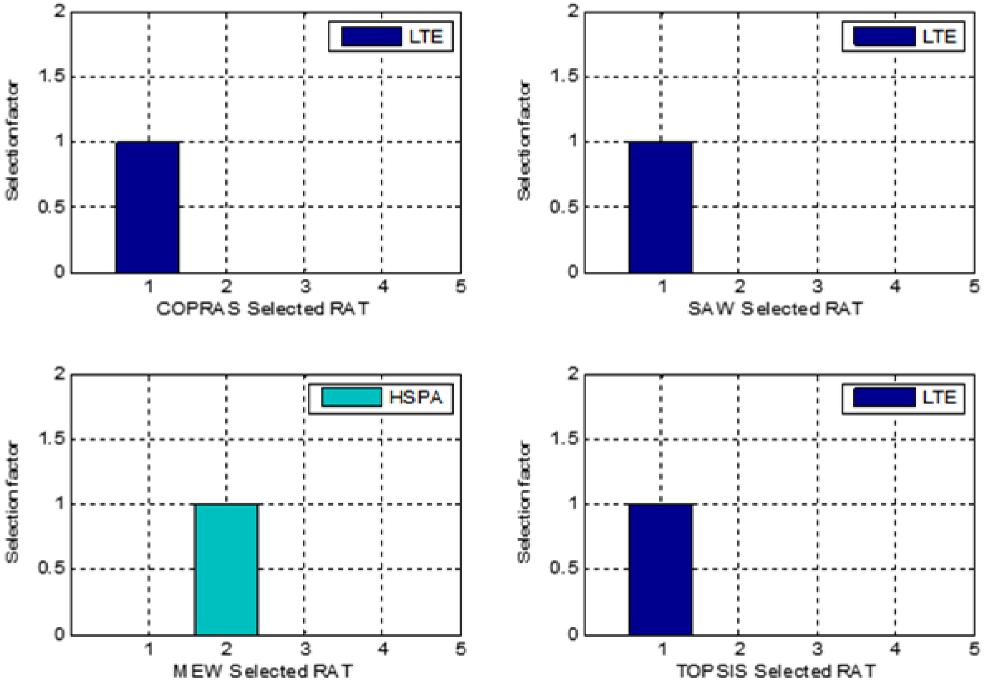

Figure 3.2: Ranking order for each MADM method.

This approach uses a selection factor in the range of [0, 1], where 1 is assigned to a selected RAT and 0 if the RAT is not selected. Figure 3.2 shows that the methods of SAW, TOPSIS and COPRAS selected RAT1 as the best alternative, while RAT2 is selected as the best alternative by MEW in the trial. A consistency ratio (CR) has been defined, which indicates how each method maintains consistency with respect to the selection of the best alternative. The value of CR is obtained as the ratio of the number of times each MADM method maintains the ranking order of the best alternative over the total number of trials. The values of CR expressed in percentage for each method is shown in Table 3.4

Table 3.4: Consistency ratio for MADM Methods

RATs / MADM Methods	**LTE (RAT1)**	**HSPA (RAT2)**	**WLAN1 (RAT3)**	**WLAN2 (RAT4)**	**WiMAX (RAT5)**
SAW	95%	5%	-	-	-
MEW	55%	35%	10%	-	10%
TOPSIS	55%	25%	10%	-	10%
COPRAS	85%	5%	-	-	10%

The results in Table 3.4 show that 85% out of the total trial, COPRAS maintains the selection of LTE (RAT1) as the best alternative, while RAT2 and RAT5 have been selected as the best alternative in 5% and 10% of the total trials, respectively. Similar results for SAW, MEW and TOPSIS show that SAW has the highest CR, follow by COPRAS, TOPSIS and MEW.

3.4.3 Ranking abnormality of SAW MEW TOPSIS and COPRAS schemes

The work also determines the ranking abnormality associated with each method. Ranking abnormality/reversal measures the effect that the ranking methods have over the best alternative when one alternative is eliminated from the lists of available alternatives. To evaluate the effect of ranking reversal, CR is calculated in two separate instances: The first case is the removal of RAT2 and the second scenario is the removal of the worst performing

RAT (RAT4). For the two scenarios, the results are shown in Table 3.5 and Table 3.6, respectively.

Table 3.5: Effect of ranking reversal without RAT2

RATs MADM Methods	**LTE (RAT1)**	**HSPA (RAT2)**	**WLAN1 (RAT3)**	**WLAN2 (RAT4)**	**WiMAX (RAT5)**
SAW	95%	-	30%	-	5%
MEW	25%	-	40%	-	10%
TOPSIS	30%	-	60%	-	10%
COPRAS	60%	-	30%	-	10%

Table 3.6: Consistency ratio for RAT selection

RATs MADM Methods	**LTE (RAT1)**	**HSPA (RAT2)**	**WLAN1 (RAT3)**	**WLAN2 (RAT4)**	**WiMAX (RAT5)**
SAW	95%	-	-%	-	5%
MEW	75%	-	-%	-	25%
TOPSIS	60%	-	-%	-	40%
COPRAS	80%	-	-%	-	20%

Table 3.5 shows that when RAT2 is removed, SAW, COPRAS, TOPSIS and MEW maintains the selection of RAT1 as the best RAT with ranking consistency of 95% 60% 30% and 25%, respectively. when the best performing RAT is Removed. Similarly, by removing the worst performing RAT (RAT4); Table 3.6 shows that SAW, COPRAS, TOPSIS and MEW maintains the selection of RAT1 as the best access network with 95%, 80%, 60% and 75% ranking consistency, respectively. These show that the ranking order of SAW and COPRAS are more stable than MEW, while TOPSIS shows less stability.

3.5 Performance Evaluation of TOPSIS and COPRAS MADM Schemes for Access Network Selection.

In this section, the performance of each MADM RAT selection algorithm is evaluated for different user service request and a comparative analysis carried out to ascertain the strength and weakness of each method. The results obtained from Section 3.4 and some related works [68] show that TOPSIS suffers from ranking reversal, however, it the most popularly used MCDM method and particularly, in access network selection [71, 72]. In situations where network availability is not a major factor, ranking abnormality due to unavailability of one or more networks becomes less important factor than network selection accuracy. The method of TOPSIS has been shown to present greater accuracy in network selection than SAW and MEW [68]. Therefore, further evaluations will consider the performance of COPRAS and TOPSIS method.

In the determination of ranking order and ranking abnormality the worst performing network WLAN2 (RAT4) remains unchanged. Similarly, HSPA (RAT2) was not selected as the best performing network. Therefore, further evaluations will consider the ranking order of LTE, WLAN1 and WiMAX networks.

3.5.1 Access selection for single calls

The evaluation of RAT selection techniques presented by each MADM method is considered as a decision process involving a set of alternatives, a set of criteria and a set of decision makers. The alternatives and criteria values are obtained using the network configuration and criteria specifications given in Table 3.1. The set of decision makers in this context are mapped to the user service flow request, denoted as (S), where $S = \{s_1, s_2, \cdots, s_m\}$, $(m \geq 1)$. Three network services considered are voice service, file-download, and video-streaming.

The specific preference weight assigned to each criterion by users is given in fuzzy linguistic term which is a more convenient way for users to express their preference values.

For computational purpose, the linguistic terms are converted to fuzzy numbers and the fuzzy numbers are converted to their respective crisp values as described in Section 2.5.4. The user assigned random criteria weighting for each application or network services are given in Table 3.6.

Table 3.7: Fuzzy-base user preference weighting

Criteria RATs	**Data rate (Mbps)**	**Delay (ms)**	**load (%)**	**Power (Watts)**	**Service price(unit/Mb)**	**Mobility support**
Voice	L	H	L	L	VL	H
File-download	H	M	H	M	L	M
Video-streaming	H	L	VH	M	M	M

The network and application attributes are classified as maximizing (benefit) and minimizing (cost) criteria. The benefit criteria are maximum data rate and mobility support while the minimizing criteria are the network delay, load, power consumption and service cost. The problem solution seeks to determine the choice of the most appropriate access network that meets the mobile user's application requirements among the available alternatives.

In order to perform access network selection, the mobile user in the operators network domain performs authentication and authorization procedures in order to be admitted into the network. The authentication and authorization procedures are carried out between the mobile terminal and relevant entities in the operators network. The dynamic state (QoS parameters) of the alternative access networks can be obtained through probing signals or router advertisement messages received by the mobile terminal from the access networks, or through the management entity in the operators core network. These entities include the IIS in the Media Information Independent Handover (MIIH) entity of the IEEE standard [7, 29], or the Access Network Discovery and Selection Function (ANDSF) entity of the 3GPP core network. Upon successful completion of the initial access procedures, the user decides to select an appropriate access network for each of voice, file-download and video-streaming services in an overlapped region of LTE, WLAN1 and WiMAX access networks.

The network selection procedure is initiated by the mobile terminal, and applicable to initial access selection, vertical handoff or network reselection for data offloading which can be terminal controlled, network-controlled or a hybrid of both.

The proposed COPRAS MADM access network selection module can reside in the radio resource management (RRM) entity of the network or part of the ANDSF entity. The users preference weight and priority settings can be manually assigned through a graphical user interface (GUI) in the mobile terminal. For proof of concept, the performance of the MADM methods used for access selection for single calls is illustrated with numerical examples and the results shown in Figure 3.3 and Figure 3.4

In the first scenario, most of the voice, data and video-streaming calls are admitted into LTE, WLAN and WiMAX networks, respectively, using the COPRAS method. The TOPSIS method shows a similar trend; with most of the voice and data calls admitted into LTE and WLAN1 networks, respectively, with a variation in the distribution of the video-streaming traffic, where most of the calls are admitted into LTE for COPRAS and WiMAX for TOPSIS, respectively. The variation in the video-streaming calls distribution may be due to users preference, or network conditions; however, this difference is not significant, as about 37 % of the streaming traffic is also admitted into WiMAX for the COPRAS method.

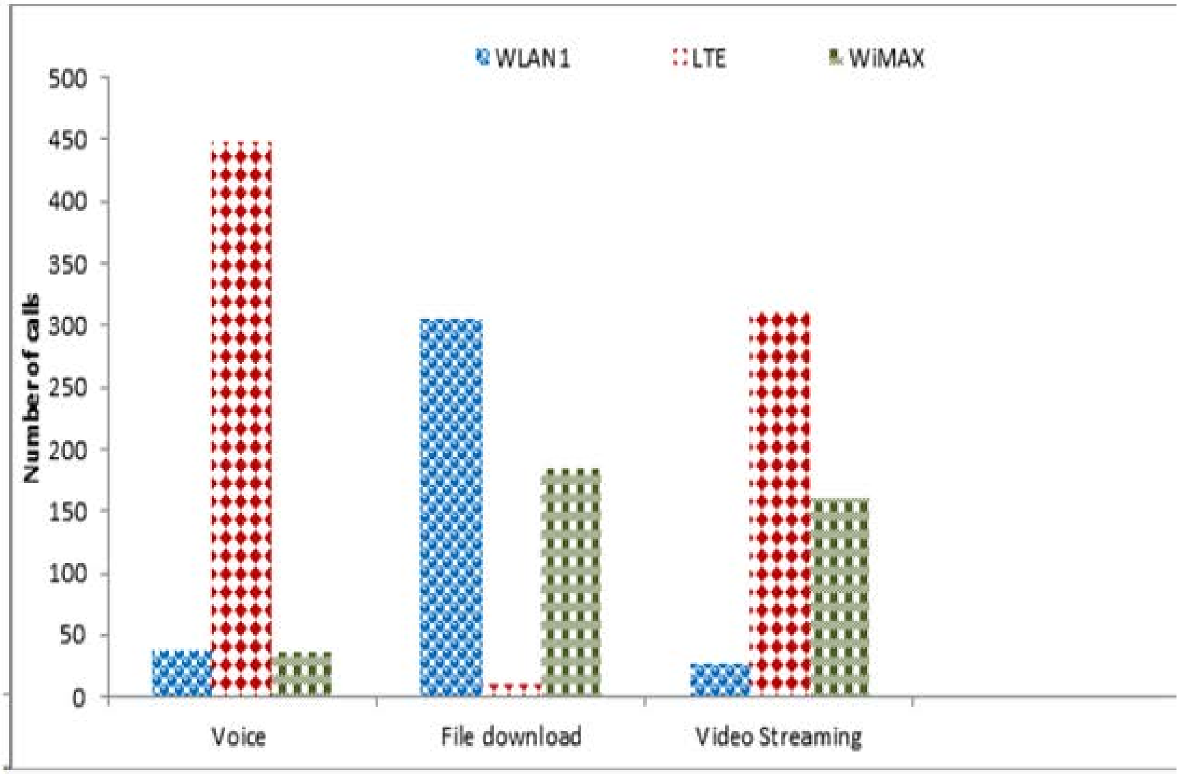

Figure 3.3: Single call distribution with COPRAS method

3.5.2 Access selection for WLAN offloading with dynamic criteria

The scenario considered in this section describes the selection of appropriate target access network for offloading of users traffic within an overlapping heterogeneous access networks consisting LTE, HSPA+, WLAN1, WLAN2, and WiMAX access points. The COPRAS method is used to evaluate the performance of this scenario. The access networks are managed by one operator. Offloading of user traffic can be based on users preference for cost, location or improved QoS during the peak period when congestion is been experienced on the network. It can also be network controlled for the purpose of load balancing. Network selection for WLAN data offloading in this scenario is considered for offloading from 3GPP-cellular networks comprising LTE and HSPA+, to adjacent and available non-3GPP networks consisting of WLAN and WiMAX.

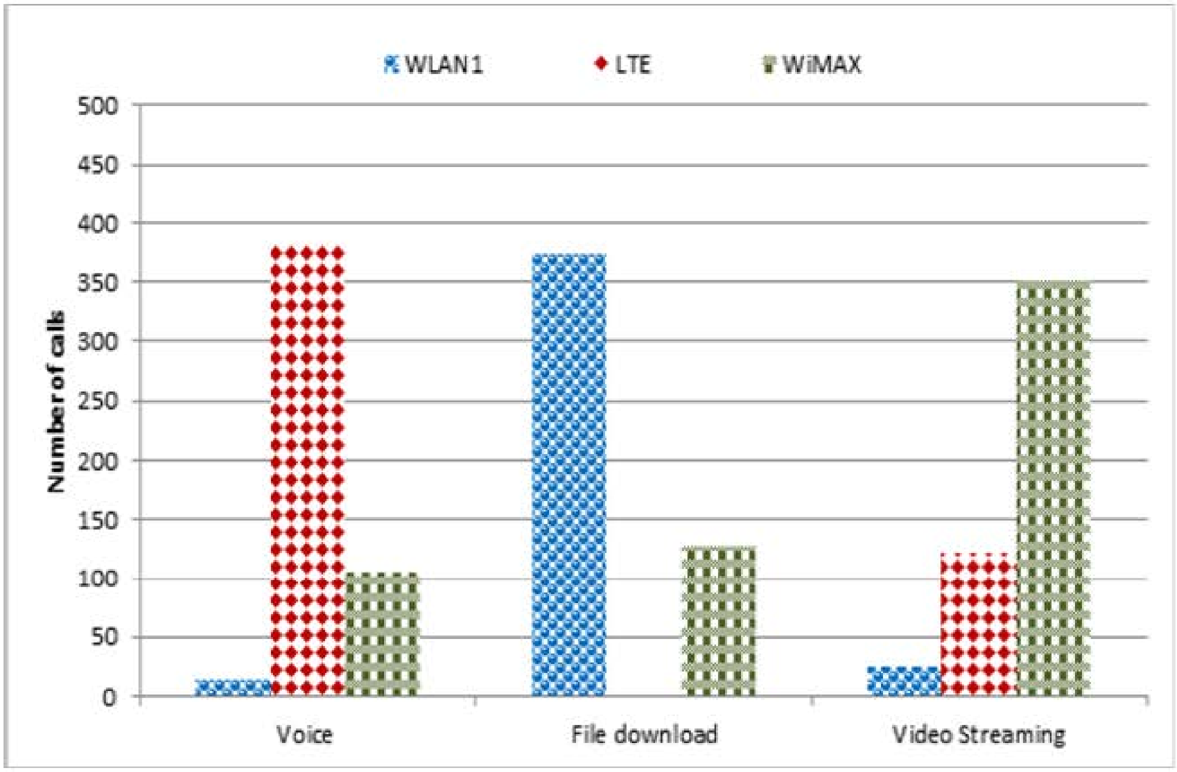

Figure 3.4: Single call distribution with TOPSIS method

For simplicity, it is assumed that the user performs the initial association procedures and is connected to the LTE network. The user subscribes for voice, video and file traffic based on certain service level agreement with the operator. In the heterogeneous networks described in this section, the user can initiates an offloading request to the network via the ANDSF, to offload one or multiple traffic flows from LTE to the available non-3GPP accesses within the vicinity of the user. The choice of the most appropriate access network for offloading depends on the congestion state of the alternative access networks. The work of [73] on 1EEE 802.11b standard classified WiFi congestion into uncongested for channels with less than 30% utilization level, moderately congested for channel utilization of 30%-84% and highly congested, for channel utilization greater than 84%. In this scenario, five congestion levels of 30%, 40%, 50%, 70% and 80% are described with fuzzy linguistic values of Very

Low (VL), Low (L), Medium (M), High (H) and Very High (VH), respectively. As part of the Operator's network management policy, any access network with congestion level greater than or equal to 80% is considered as restricted access for offloading. The five congestion states are assigned to the three WLANs and WIMAX access networks.

The congestion state of an access network can be described as the level of occupied bandwidth or capacity of the network. It shows the degree of total channel utilized or the load condition of the network. For each access network, the available bandwidth or capacity is the difference between its total capacity and the current congestion state. The initial congestion state of the four access networks are configured such that WLAN1 has a very High ($\geq 80\%$) congestion level, WLAN2 has a very low (30%) congestion, WLAN3 has low (40%) congestion and WiMAX has medium (50%) congestion. WLAN2 is configured as 802.11b technology with maximum data rate of 11Mbps, while the 802.11a WLAN networks (WLAN1 and WLAN3) have a maximum data rate of 54Mbps but experiences different congestion levels, hence different available capacity. For each network, the available maximum data rate is the difference between maximum capacity and the occupied network capacity. In order to understand the dynamics of the access networks due to changes in congestion level or network load variations, an exponential is used to describe the congestion states of the access networks as follows:

$$H_n^i = H_n^o + H_n^o \alpha^\rho \tag{3.10}$$

Where, H_n^i = The congestion state of the network k at time instance i, and $n = \{s_1, s_2, \cdots, s_k\}$ represents the available access networks for offloading.

H_n^o = The initial congestion state of network k.

In Equation 3.10, α and ρ represents the network utilization factor and load variations, respectively. The values of α ranges between 0.5 and 1, while ρ is varied between 0 and 100.

The decision matrix and user preference weights are shown in Tables 3.7 and 3.8, respectively.

Table 3.8: Fuzzy-base criteria specifications

Criteria RATs	**Avail BW (Mbps)**	**Delay (ms)**	**congestion (%)**	**Power (Watts)**	**Service price(unit/Mb)**	**Mobility support**
Voice	L	VH	L	L	H	M
File-download	H	M	H	M	L	L
Video-streaming	H	H	VH	M	M	VH

Table 3.9: Fuzzy RAT decision matrix.

Criteria RATs	**Avail BW (Mbps)**	**Delay (ms)**	**congestion (%)**	**Power (Watts)**	**Service price(unit/Mb)**	**Mobility support**
WLAN1	10.8	H	H_1^o	1	M	H
WLAN2	7.70	L	H_2^o	2	M	M
WLAN3	32.80	M	H_3^o	1	L	M
WiMAX	12.50	L	H_4^o	3	H	VH

The corresponding decision matrix using Table 3.9 can be obtained as follows:

$$P^c = \begin{bmatrix} 10.8 & .5000 & H_1^o & .7550 & .5000 \\ .7.7 & .3300 & H_2^o & .5000 & .5000 \\ .32.8 & .5000 & H_3^o & .5000 & .3300 \\ .12.5 & .3300 & H_4^o & .9670 & .7500 \end{bmatrix}.$$

The decision matrix is evaluated using 500 calls in MATLAB and results shown in Figure 3.5. Figure 3.5 shows the results of offloading voice traffic for 500 calls. At the initial congestion state, about 62% of calls are offloaded to WLAN2, 29% to WiMAX and 9% to WLAN3. This shows that WLAN2 is the preferred access network for offloading voice traffic. The choice of WLAN2 is due to the fact that the network exhibits the lowest delay with least

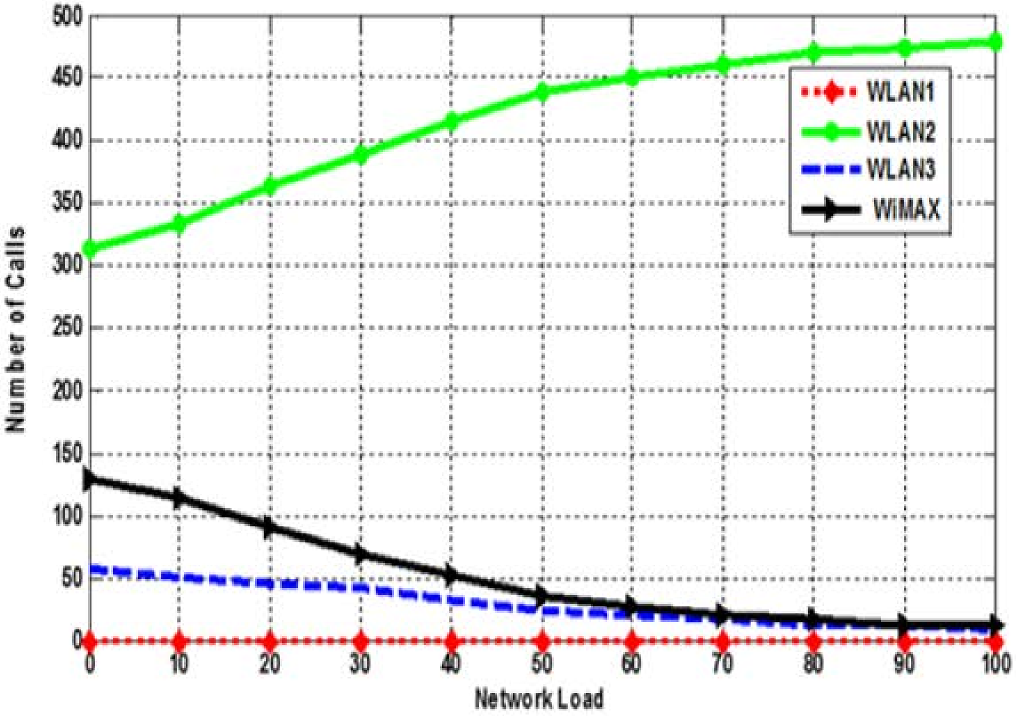

Figure 3.5: COPRAS RAT selection for offloading voice calls

congestion state, which characterizes the QoS profile of voice traffic. As the network load increases, it is seen that network utilization decreases for WLAN3 and WiMAX accesses in proportion to the congestion level; however, there is an increase in utilization for the WLAN2 due to the extremely low congestion. WLAN1 has not been selected due to the very high congestion level of 80% being experienced by the network.

Figure 3.6 shows the call distribution for offloading video traffic. At the initial congestion state, about 68% of the calls are offloaded to WiMAX, 22% to WLAN2 and 10% to WLAN3. This shows that the preferred access network for offloading video-streaming calls is WiMAX network, which exhibits a good available bandwidth, low delay and high RSS. The unavailability of WLAN1 is also observed due to its congestion state, which exceeds the threshold value of 80%.

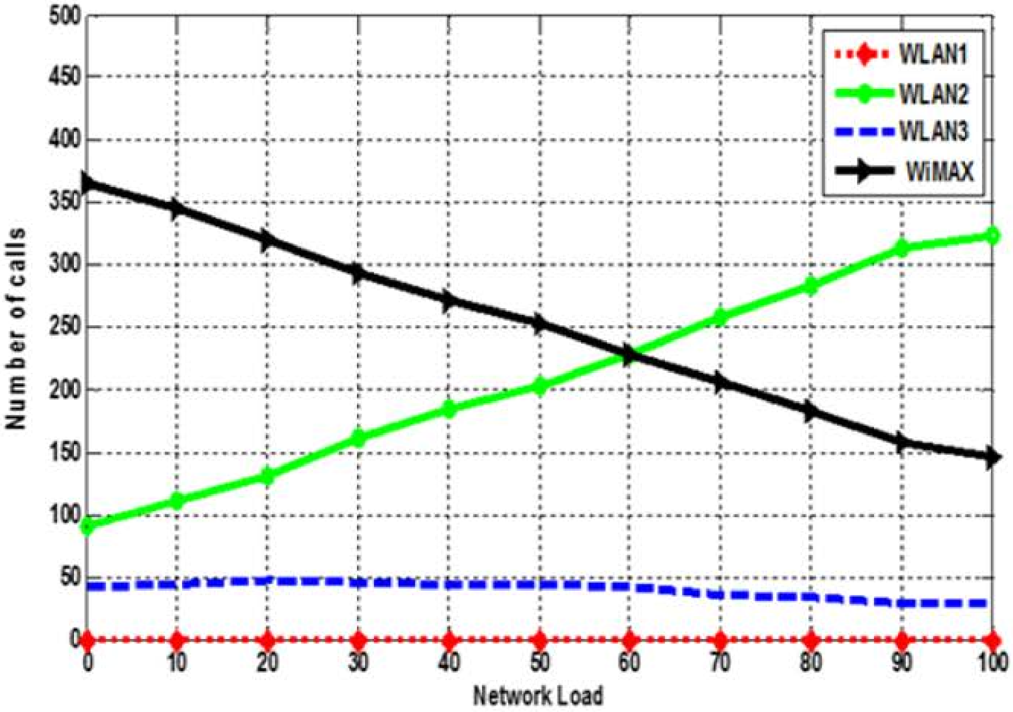

Figure 3.6: COPRAS RAT selection offloading video calls

3.6 MADM Method for Group Multiple Calls

The multi-attribute group decision making (MAGDM) process uses the individual preference values on alternatives to provide an aggregated collective opinion of the decision makers. The overall objective of MAGDM is to provide a harmonized score on each alternative by the group of experts. The application of MAGDM in RAT selection provides the user equipped multi-mode terminal with the opportunity to subscribe for multiple calls from a single RAT. Research works on RAT selection has focused more on the selection of access network for a single call, with little emphases on RAT selection for a group of calls. The selection of a single RAT for multiple calls provides the user/terminal with a reduced handoff signaling and consumed power.

The application of the MADM techniques in grouped-multiple calls requires some modifications to the existing MADM algorithms. For instance, the normalized criteria weight is computed as:

$$\widehat{W}_{s,j} = \frac{w_{s,j}}{\sum_{j=1}^{v} w_{s,j}}, s = \{1, \cdots, m\}, j = \{1, \cdots, v\} \tag{3.11}$$

Where $w_{s,j}$ is the weight assigned by the j^{th} criterion on the s^{th} service. When considering RAT selection for grouped-multiple calls, the different weights computed in Equation 3.11 must be aggregated per criterion as shown below:

$$\widehat{W}_{aggr} = \frac{1}{M} \sum_{j=1}^{M} \widehat{W}_{s,j} \tag{3.12}$$

where M is the maximum number of decision makers; representing the number of service calls. In a group decision-making scenario, the users/operator can assign priority to each call based on certain service level agreements. In other words, a level of priority can be assigned to one application over the other, e.g, voice, assigned a higher priority over file-download or video-streaming. For a priority level P_L^i assigned to different applications, where $i = 1, 2, \cdots, M$, the normalized priority level assigned to each call can be obtained as:

$$\widehat{P}_L = \frac{P_L^i}{\sum_{i=1}^{M} \widehat{P}_L^i}, i = 1, 2, \cdots, M \tag{3.13}$$

The cumulative aggregated weight for each criterion with respect to the call priority is given as:

$$\overline{W}_{aggr} = \frac{1}{M}\sum_{i=1}^{M} W_{s,j} * \widehat{P}_L \tag{3.14}$$

This expression is used for the determination of the weighted normalized decision matrix. Some related works in MCGDM with application to RAT selection can be found in [56–58].

In [58], the selection of target access network for multiple calls in the HetNets has been proposed. The proposed scheme implements a group decision-making technique for multiple calls comprising of voice, video, and file-download applications. In the proposed solution, a fuzzy scoring method was implemented for the specifications of network criteria. Three access networks namely; WLAN1, LTE, and Mobile WiMAX have been considered. The authors assigned priority to calls, use the aggregated weight and network decision matrix to implement the RAT selection procedures. The TOPSIS method has been applied for the ranking and selection of a suitable network. Different scenarios have been used to evaluate the performance of the scheme. The results show that call priority affects the choice of RAT for each group of calls. Similarly, the frequency of handoff decreases with increasing RAT preference margin.

The authors in [57], considered a multi-criteria group decision-making techniques for multiple session handover decision in heterogeneous wireless networks. The authors implement a fuzzy scoring method to formulate the decision matrix, while the user assigned preference values were used to aggregate the weight vector. Four applications (voice, video-streaming, file-download and web-browsing) and four access networks have been considered. Sensitivity analysis for the different criteria has been carried out using the methods of SAW, MEW, TOPSIS and DIA. The results show that TOPSIS and DIA outperform the methods of SAW and MEW.

In this section, we investigate the performance of the proposed COPRAS method for the selection of suitable RAT for a group of multiple calls. In this scenario, the performance of the COPRAS method is then compared with the TOPSIS method. RAT selection for grouped-multiple calls, considers the most suitable RAT that can provided the required QoS for the multiple calls comprising of voice, file-download and video calls.

3.6.1 Access selection for group multiple calls

In the group multiple calls considered in this scenario, each call is assigned a level of priority. Priority assignment to calls shows the level of importance of such calls to the user, the attracted charges and user willingness to pay based on service level agreement between the subscriber and the network operator.

The performance of COPRAS method for the selection of appropriate RATs comprising of LTE, WLAN1 and WiMAX has been considered and evaluated. When the group calls are assigned equal priority, COPRAS method selects WLAN1 as the best RAT, while the TOPSIS method selects LTE as the best RAT. When voice is assigned the highest priority, most of the group calls are admitted into LTE for both COPRAS and TOPSIS method. When video-streaming is assigned the highest priority, most of the group calls are admitted into WLAN1 network for both methods. Similarly, when file-download is assigned the highest priority, WLAN1 becomes the preferred Network for both methods. The results of this scenario are shown in Figure 3.7 and Figure 3.8, respectively. The RAT selection results for

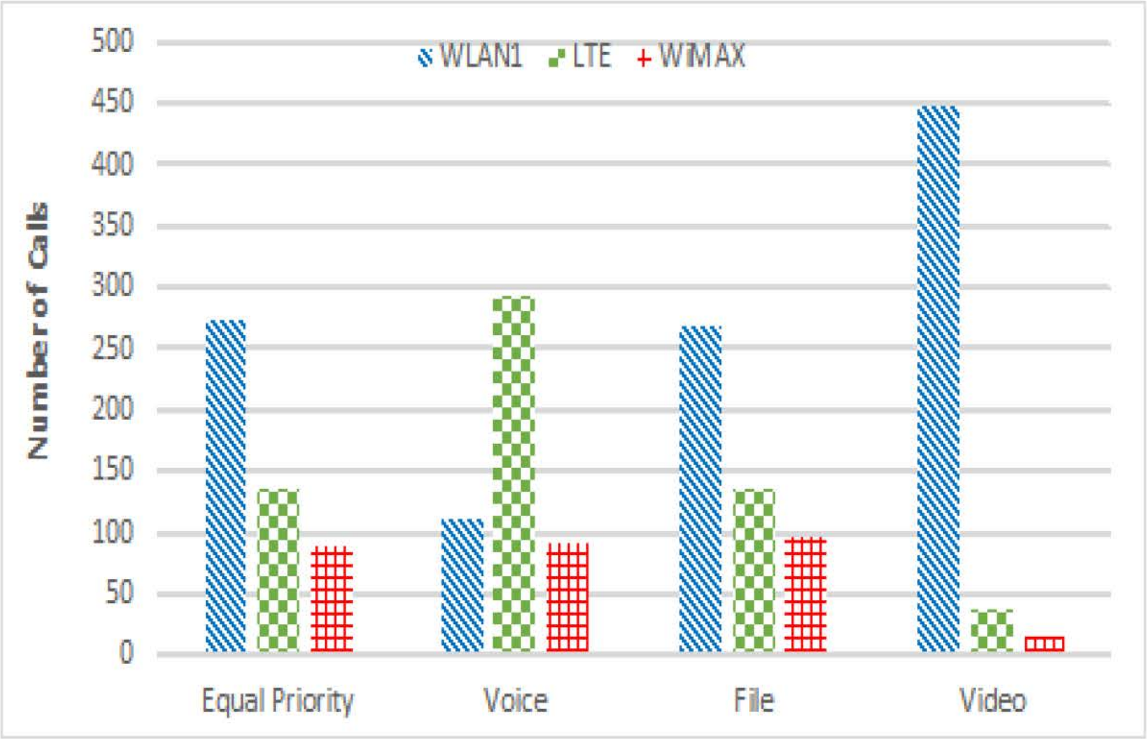

Figure 3.7: Group call distribution with COPRAS method

group multiple calls show that COPRAS method is a an ideal technique for the selection of suitable RAT for group of multiple calls.

3.7 Effect of Preference Margin on Group Handoff Calls

The mobile user equipped with multimode terminal in heterogeneous wireless networks is able to initiate a new call or drop existing call dynamically due to the availability of different RATs supporting different classes of user call requests. For instance, a new call may be initiated in addition to the existing ongoing group multiple calls or a subset of existing group multiple calls may be dropped due to the capability of the available RATs. This

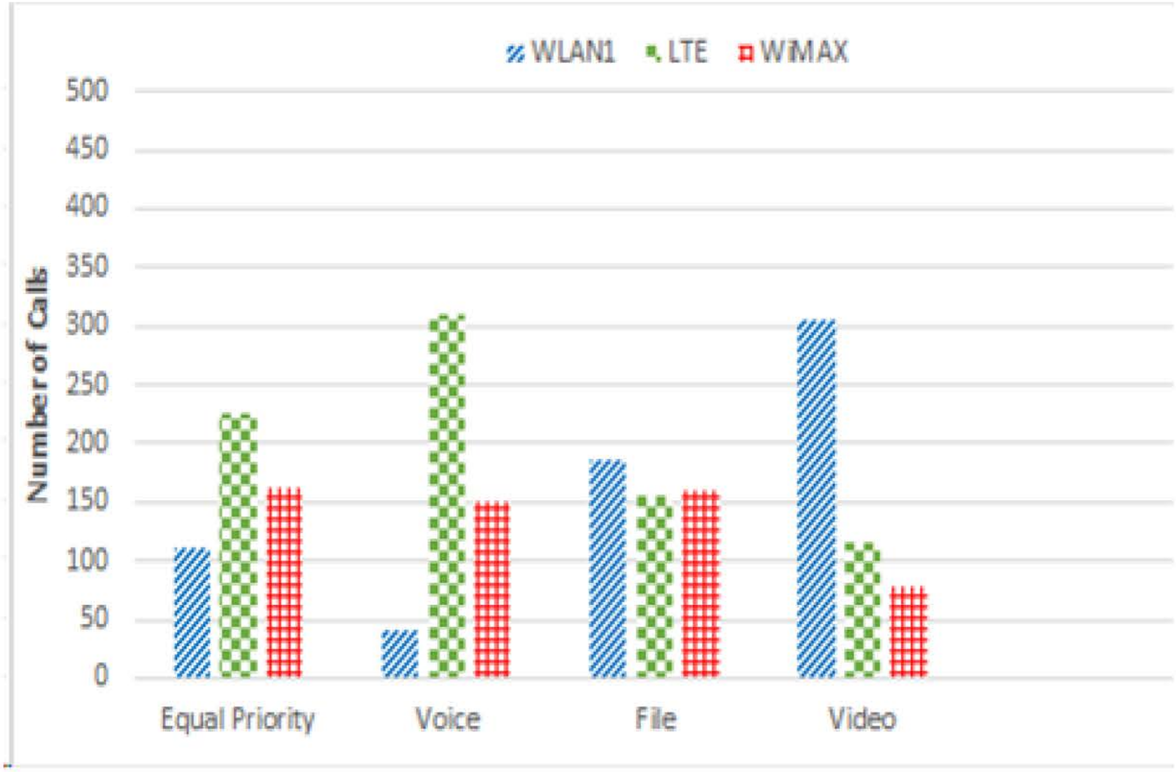

Figure 3.8: Group call distribution with TOPSIS method

inherent dynamics in call setups will result in frequent RAT reselection, thereby increasing handoff frequency. Since high handoff frequency can result in QoS degradation, an efficient RAT selection scheme, which is capable of reducing handoff frequency, is therefore required for group multiple calls.

In this section, the effectiveness of COPRAS and TOPSIS method in reducing group call handoffs frequency is evaluated and compared. The performance comparison is carried out by defining a preference threshold (preference margin) between the current RAT serving the user group multiple calls and a newly preferred RAT for handoff. The preference threshold margin defines the amount by which the current RAT is preferred to the new RAT, and therefore used to determine whether a handoff is allowed or denied. The difference between the ranking indexes for the two RATs can be used as a measure of preference margin, and in such scenario, a preference margin in the range of 0 and 1 is used for evaluation purposes. The performance evaluation considers a scenario where a multi-mode mobile terminal has an ongoing group multiple calls from a currently attached RAT. New call can be initiated or a subset of existing call can be dropped, resulting in RAT reselection or vertical handoff.

For the purpose of clarity, three cases are considered as outlined below:

- Case 1: The multi-mode mobile terminal with ongoing voice and file-download group multiple calls changed the existing subscription to voice and video-streaming group multiple calls.
- Case 2: The multi-mode mobile terminal with ongoing voice and file-download group multiple calls changed the existing subscription to file-download and video-streaming group multiple calls.
- Case 3: The multi-mode mobile terminal with ongoing voice and file-download group multiple calls changed the existing subscription to voice, file-download and video-streaming group multiple calls. Each call is given equal priority in case 1 and case2, while the video call has been assigned a higher priority in case 3.

For each of the three cases described above, RAT selection algorithm using COPRAS and TOPSIS method has been carried out in order to access the effectiveness of each method in reducing handoff frequency. A plot of handoff probability against variations in preference margin is obtained and the results are shown in Figure 3.9 and Figure 3.10, respectively.

In case 1, handoff probability reduces with increasing handoff margin for both COPRAS and TOPSIS method as shown in Figure 3.9. This is because as the preference for the

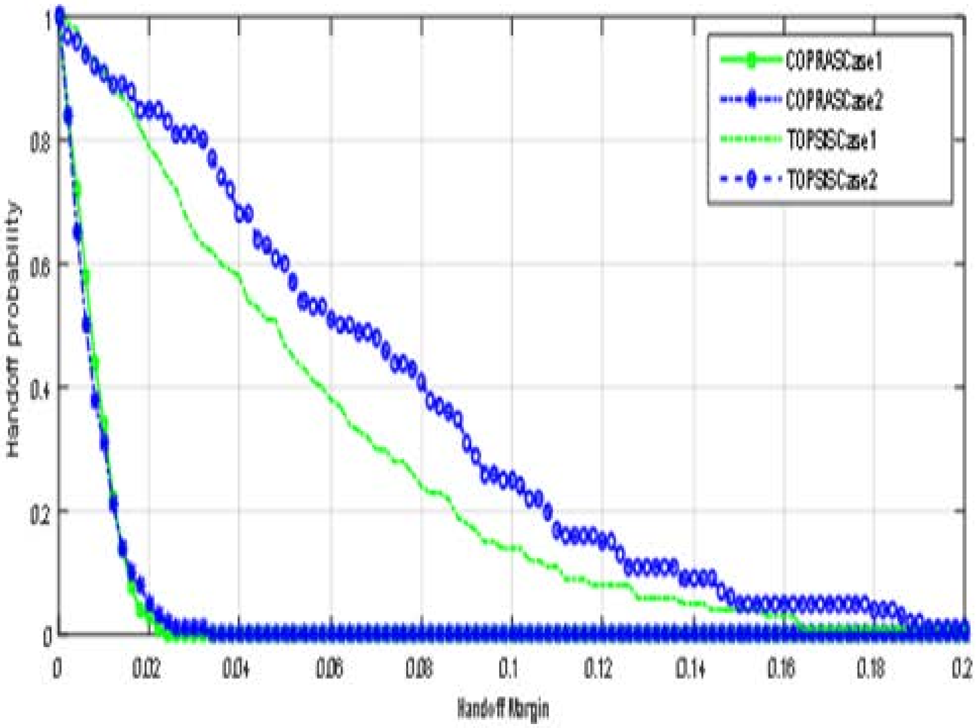

Figure 3.9: Effect of preference margin on handoff probability with equal priority

current RAT increases with respect to the new RAT, the choice for handoff to the new RAT reduces. Similarly, Figure 3.9 shows that TOPSIS method achieved zero handoff probability with a higher value of 0.19 than the COPRAS method which has zero handoff probability at a value of 0.02, which makes the proposed COPRAS method to be about 85% better than TOPSIS in reducing call handoffs. A handoff probability of zero implies that the group calls are maintained on the existing RAT. The results for the second case follow the same trend as discussed in case 1. In both cases, the proposed COPRAS method is more efficient in reducing handoff frequency.

The results of case 3 are shown in Figure 3.10, where TOPSIS method shows a reduction in handoff probability as the handoff margin increases and also achieved zero handoff at a handoff margin of 0.14. The COPRAS method, however, shows a different trend due to

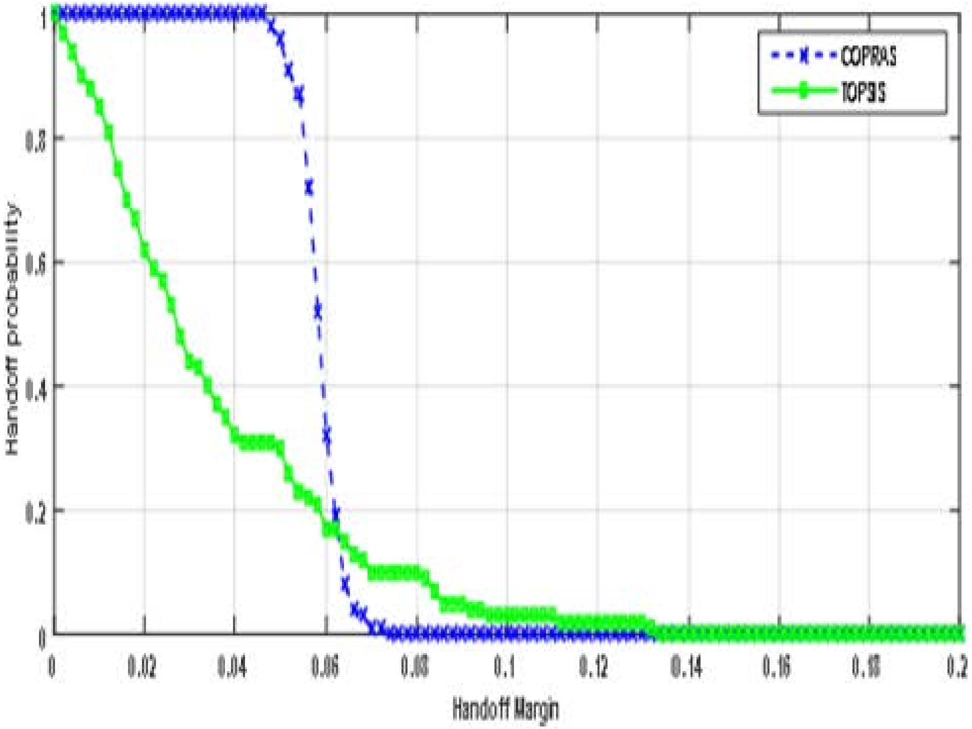

Figure 3.10: Effect of preference margin on handoff probability for video prioritized

the addition of the video call which has been assigned a higher priority than the existing voice and file-download calls. For a lower handoff margin of less than 0.05, the prioritized call dominates the group multiple calls, however, the handoff probability decreases with increasing handoff margin and a zero handoff is achieved at a lower handoff margin than the TOPSIS method. Similarly, the effect of call priority is not significant in the TOPSIS method.

3.8 Complexity Analysis for Group Handoff Calls

In this section, the complexity of the proposed COPRAS method and TOPSIS method is evaluated in MATLAB using the execution time for varying numbers of trials. This analysis is performed in order to determine the execution time for the selection of appropriate RAT for a grouped-multiple calls comprising of voice, file-download and video-streaming.

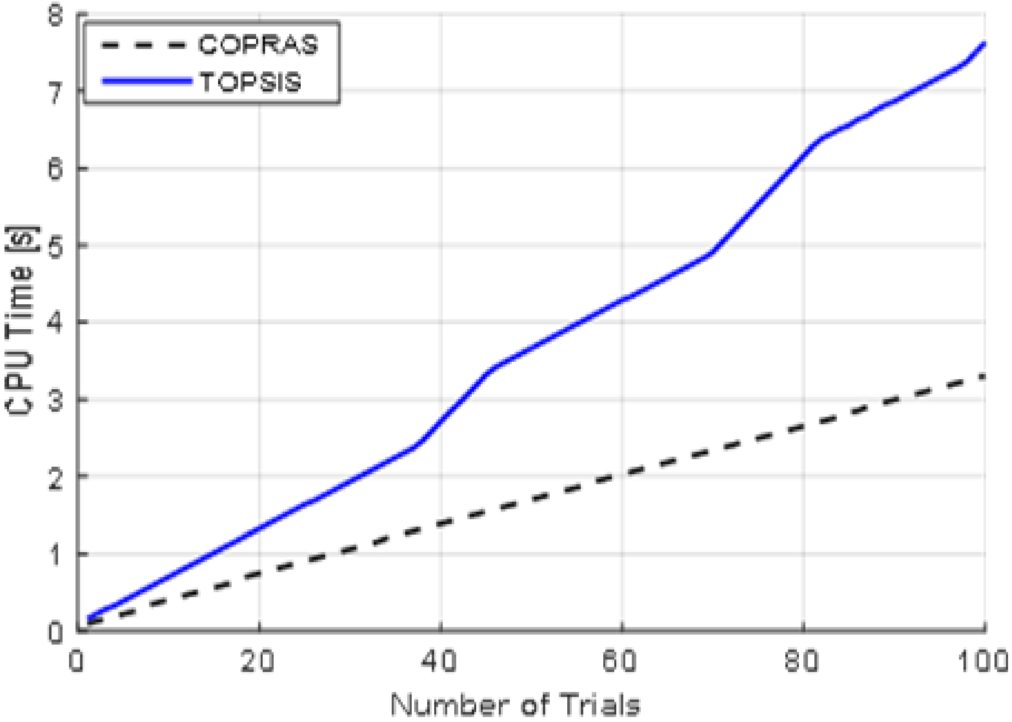

Figure 3.11: Time complexity for COPRAS and TOPSIS method

The analysis is carried out on HP Pavilion Laptop with the following specifications: Intel(R) Core(TM) 2 Duo CPU 2.00GHz, 4.00GB on 64-bits Windows 7 Enterprise.

The processing time for different trials is shown in Figure 4.5. The result shows that for the different trial times, the proposed COPRAS method requires less execution time than the TOPSIS method.

3.9 Conclusion

This chapter discusses MADM approach to RAT selection with emphasis on the methods of SAW, MEW and TOPSIS. A new MADM method, the COPRAS method, which is designed to handle grey numbers with additional features, has also been investigated to test its suitability for RAT selection. The analysis carried out in this chapter show that TOPSIS method suffers from ranking reversal but can be considered a suitable algorithm with greater ranking accuracy than SAW and MEW. COPRAS method has a better performance in terms of ranking abnormality than TOPSIS. It can be used to analyze grey numbers and presents a measure of access network utility.

The effectiveness of COPRAS and TOPSIS method has been evaluated using different access network and application configurations. Results for access selection for using static criteria for both single call and group calls show that COPRAS method provides a better alternative for RAT selection in heterogeneous networks due to its accuracy and simplicity. In another scenario, the performance of COPRAS MADM method has been tested for WLAN offloading in response to network congestion. This scheme is able to select the appropriate access network according to the congestion control mechanism imposed by the network operator. In terms of the processing time, the proposed COPRAS method outperforms the TOPSIS method

Chapter 4

Consensus-Based RAT Selection Scheme in Heterogenous Wireless Networks

4.1 Introduction

The motivation for carrying out a comprehensive study on access selection for multiple calls in the previous chapters is based on the fact that existing RAT-selection algorithms for single call consider single attribute such as RSSI for making RAT-selection decision. These single-criterion selection algorithms are not suitable for a user equipped with a multimode mobile terminal having multiple classes of simultaneous calls. Therefore, the need for simple and efficient RAT-selection decision algorithms for multiple calls was established, and several

MADM RAT-selection schemes were evaluated to assess their suitability for access network selection in HetNets.

The MADM RAT-selection algorithms discussed in **Chapter** 3 provide the optimum QoS requirements for individual application or service, while for group-multiple calls, the aggregate (average) QoS values are determined in order to select the appropriate access network for the class of calls [57, 58]. This approach may seem appropriate for single calls, however, in group-multiple calls; the determination of average QoS may not be suitable for some applications e.g, inelastic or moderately elastic applications. This chapter, introduces the concept of consensus model in MADM process, where MADM problem is approached as a group decision process that allows the decision makers to reach a level of agreement (consensus degree) on the available alternatives before selecting the best alternative. The application of consensus-based MAGDM process to access network selection for multiple calls in heterogeneous wireless networks is investigated.

4.2 Consensus-Based Multi-Attribute Group Decision Making (MAGDM) Process

In the multi-criteria group decision making (MAGDM) process, the decision makers preference values assigned to the decision criteria of the set of alternatives are aggregated and used to rank and select the optimum or preferred alternative. The consensus-based MAGDM process defines a level of agreement or consensus threshold among decision makers in order to select the best alternative among the finite set of alternatives [74–76]. The consensus-based MAGDM algorithm, therefore, requires two processes: consensus process and selection process. The consensus process seeks to achieve a maximum level of agreements among decision makers while the selection process evaluates the decision makers preference values assigned to the decision criteria to arrive at the preferred alternative [77]. The selection process involves two phases: aggregation and exploitation. The aggregation phase provides a collective or global opinion on the solution sets of alternatives, based on the preference values provided by the experts. The exploitation phase provides a global ranking based on the collective information on the alternatives.

A classical consensus process is illustrated in Figure 4.1. The problem space identifies the objective of the group decision process, which is the selection of the best alternative among the solution sets of alternatives. The group of experts, $E = \{e_1, e_2, \cdots, e_n\}$ express their respective opinions or scores about a given set of alternatives, $X = \{X_1, X_2, \cdots, X_n\}$ based on known decision criteria, $C = \{c_1, c_2, \cdots, c_n\}$. The criteria are the known attributes of the alternatives. The experts opinions about the alternatives are given as a set of preference relations, $P = \{p^d_{i,j}\}$, where $d = \{1, 2, \cdots, m\}$ is a measure of the degree of preference of one alternative over the other, expressed by the experts opinions [78]. The preference degree can be expressed in the form of preference ordering, utility function, fuzzy preference relation or multiplicative preference relation [75], and the preference values can be given as an interval-value, numerical and linguistic values, or in a hybrid form [79]

In order to reach an acceptable level of agreement among the experts, a step-wise, systematic, and iterative process is required. The outcome of each consensus process is

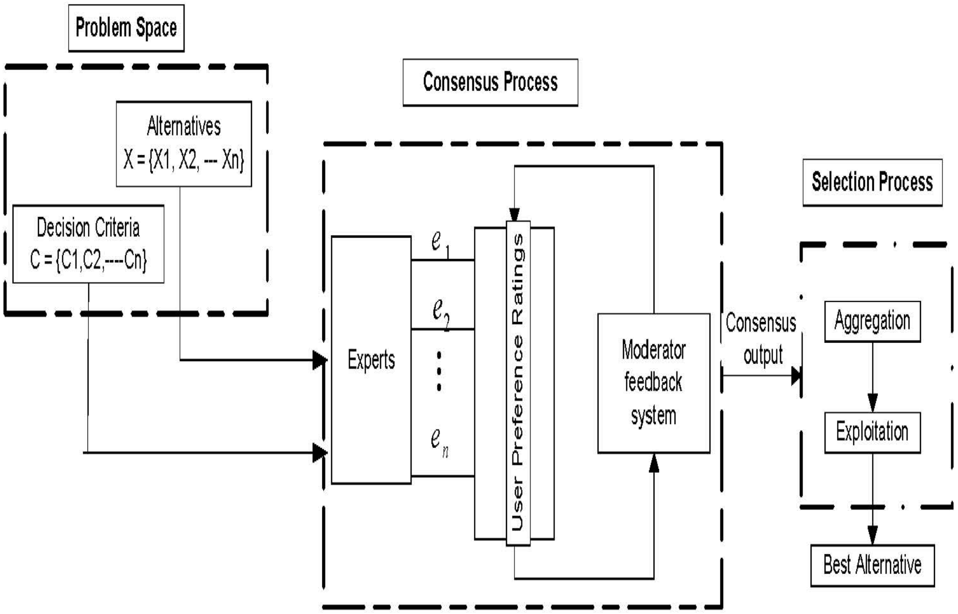

Figure 4.1: Consensus-based MAGDM process

compared with a default threshold value by the moderator feedback system. Once the consensus degree is greater than or equal to the threshold value, the selection process is evaluated; otherwise, the moderator or recommender system instructs the experts to change their opinion or scores about the alternatives, leading to another round of the consensus process. The acceptable level of consensus degree can be reached using a hard consensus process or soft consensus process [80].

The former defines two threshold values with a lower and upper bound [0, 1], where the lower bound represents no consensus and the upper bound represents an acceptable level of consensus. This method does not allow flexibility in the determination of expert's consensus degree and therefore unsuitable for most real life applications. The latter (soft consensus process) is generally employed in real life scenarios as it offers a wide range of values between 0 and 1 from which experts can select an acceptable consensus degree.

4.3 Related Works

In [79], the authors proposed a consensus-based MAGDM model for multiperson decision making with different preference structures. The proposed scheme considers two consensus processes involving consensus measures and proximity measures in order to rank the causes of disruptive behavior in different comprehensive schools. The experts express their opinions through preference ordering, utility values, fuzzy preference relations and multiplicative preference relations. The method of soft coincidence among solutions has been employed and found to efficiently identify and rank causes of disruptive behavior.

The authors of [80] carried out a comprehensive analysis of consensus approaches to fuzzy decision making based on MAGDM processes. The work compares the performance of three coincidence techniques; strict coincidence among preferences, soft coincidence among preferences and coincidence among solutions. Numerical examples were given to compare the advantages and disadvantages of each solution method. The method of coincidence among solution is able to achieve the consensus degree by comparing the position of the alternatives in each solution rather than the opinion of the experts. While the above works show the effective application of consensus-based MAGDM process, they have not been applied to the selection of appropriate RAT for grouped- multiple calls in heterogeneous wireless networks.

The authors of [81] proposed an algorithm for the ranking and selection of access network for group multiple calls using consensus-based MAGDM technique. In this work, when the consensus level among the multiple calls reaches the maximum threshold, the calls are jointly admitted to the selected RAT. However, the individual calls are assigned to appropriate RATs when the consensus degrees among the multiple calls are less than the specified value. However, the effect of proximity measures in determining the requirements for collective QoS of the grouped calls was not addressed. Similarly, the methods of aggregating the individual QoS into a collective QoS for the grouped calls have not been investigated.

4.4 Consensus-Based RAT-Selection Scheme for Group-Multiple Calls.

In the consensus-based RAT selection scheme for group-multiple calls in this chapter, the solution set of alternatives are represented by the available RATs, the experts are represented by the service flows, and the decision criteria are represented by QoS parameters (data rate and delay), service price, power consumption and network load. The dynamic nature of the wireless radio environment is characterized by uncertainty and therefore user preferences are best expressed as fuzzy preference relation and used to achieve a desirable consensus threshold among the group of multiple calls for the selection of the best access network in a heterogeneous wireless environment.

The consensus-based RAT-selection algorithm uses the consensus level among the multiple calls to determine the optimum level of QoS requirements for the group of calls and selects the most suitable access network for the multiple calls based on available network resources. In another scenario, where the consensus degree falls below the threshold value, and none of the available RATs can admit the multiple calls, a subset of the calls is admitted into a suitable RAT that guarantee the QoS requirement of the individual calls.

The consensus-based RAT selection scheme considered in this work is designed to: (1) performs an aggregation of the QoS requirements of the multiple calls so as to satisfy the QoS requirement of the individual call, (2) ensures that the minimum defined threshold values for each decision criteria for the RAT selection scheme are met, and (3) ensures that the selected RAT has enough resources to meet the expected quality of experience (QoE) of the subscriber. The choice of the appropriate RAT for Consensus RAT-selection in the heterogeneous wireless network consists of two aspects: the consensus degree and the proximity measure. The consensus degree is used to determine the RAT with the highest level of QoS or capacity availability and ensures that the selected RAT meets the QoS requirements of a group of multiple calls. To ensure that each decision criterion satisfies the minimum criterion requirement during the determination of the consensus degree, the proximity measure is used to determine the closeness of each decision criterion to the minimum acceptable threshold [80, 82].

4.5 Consensus-Based RAT-Selection Scheme Problem Description.

We considered a heterogeneous wireless network environment with R number of RATs, where $R = \{r_1, r_2, \cdots, r_n\}$; $(r \geq 2)$ and n is the maximum number of RATs. In the same scenario, let S be set of services or application offered by the network provider, where

$S = \{s_1, s_2, \cdots, s_m\}$; $(m \geq 2)$ and m is the maximum number of services requested by the users, and C represents the decision criteria, where $C = \{c_1, c_2, \cdots, c_v\}$, $(v \geq 2)$. The user preference values on each service/application criteria is represented as w_j^a. In MAGDM process, preference relation expressed in linguistic form is the most preferred way experts express their opinion on the decision criteria used to score the available alternatives. This is because the linguistic terms are related to human expression, and best describe such opinions than numerical values [74, 83]. Therefore, each user with multimode or multi-homed mobile equipment requests for multiple calls and expresses their preferences for a group call in fuzzy linguistic terms. The preference values indicate the degree of importance of each RAT selection criterion for each user making a multiple calls. For the purpose of simplicity, the linguistic terms are converted to fuzzy numbers and the fuzzy numbers are converted to their respective crisp values as discussed in Section 2.5.4

4.5.1 Methods for the consensus-based RAT-selection in heterogeneous networks.

The consensus-based MAGDM RAT selection procedure follows the basic steps of specifications, normalization, and selection. In the specification stage, users specify their preference for various call types in fuzzy linguistic terms. This is achieved by assigning to each decision criterion, a degree of importance for each call. The normalization stage allows for the decision matrix formed from different criteria, with different dimensions to be converted to dimensionless quantities for the purpose of comparison. It also provides uniformity of the individual preference relations.

4.5.1.1 Specification and normalization procedures for MAGDM RAT-selection

The specifications and normalization procedures are outlined in seven steps below:

Step 1: In the specification stage, the required number of service/application calls and user preference weighting on each application criteria, as described in Section 4.5 can be specified through the multimode mobile terminal.

Step 2: Using the information on the number of available RATs and RAT selection criteria, define a decision matrix (D_M) which shows the relative importance of the alternatives with respect to the various criteria.

$$D_M = \begin{array}{cc} \begin{array}{cccccc} C_1 & C_2 & \cdots & C_j & \cdots & C_V \end{array} & \\ \begin{bmatrix} d_{1,1} & d_{1,2} & \cdots & d_{1,j} & \cdots & d_{1,n} \\ d_{2,1} & d_{2,2} & \cdots & d_{2,j} & \cdots & d_{2,n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ d_{i,1} & d_{i,2} & \cdots & d_{i,j} & \cdots & d_{i,n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ d_{n,1} & d_{n,2} & \cdots & d_{n,j} & \cdots & d_{n,v} \end{bmatrix} & \begin{array}{c} r_1 \\ r_2 \\ \vdots \\ r_i \\ \vdots \\ r_n \end{array} \end{array}, \tag{4.1}$$

The values of $d_{i,j}$ is used to indicate the performance ratings of the i^{th} alternatives with respect to the j^{th} criterion as defined in Section 2.5.1.1

Step 3: Obtain the normalized preference values ($\widehat{w_i^a}$) from the assigned user preference values (w_j^a) on criteria c_j by service s:

$$\widehat{w_j^a} = \frac{w_i^a}{\sum_{j=1}^{v} w_j^a} \tag{4.2}$$

Step 4: Normalize the decision matrix ($\widehat{d_{i,j}}$) with respect to maximizing (benefit) criteria($\widehat{d_{i,j}^b}$) and minimizing (cost) criteria($\widehat{d_{i,j}^c}$).

$$\widehat{d_{i,j}^b} = \frac{d_{i,j}}{max\{d_{i,j}|i = \{1, \ldots, n\}; \{j = 1, \ldots, k\}} \tag{4.3}$$

$$\widehat{d_{i,j}^c} = \frac{min\{d_{i,j}|i = \{1, \ldots, n\}; \{j = 1, \cdots, k\}}{d_{i,j}} \tag{4.4}$$

In this step, the criterion to be maximized is the data rate, while cost, power, network delay and network congestion are criteria for minimization.

Step 5: Multiply the normalized decision matrix ($\widehat{d_{i,j}}$) and the normalized user preference values ($\widehat{w_j^a}$) to obtain the individual call decision matrix, ($\Gamma_{i,j}$) for each service call (s).

Step 6: Compute the pair-wise comparison of the individual call matrix to obtain a multiplicative preference relation $P_{i,j}^m$.

Step 7: Convert the result of step 6 into fuzzy preference relation for the individual call matrix using Equation 4.5 [84].

$$P_f^i = \frac{1}{2}(1 + log_9 P_{ij}^m) \tag{4.5}$$

Where p_f^1 = voice call, p_f^2 = video-streaming, p_f^3 = file-download.

4.5.1.2 Selection procedures for MAGDM RAT-selection

The selection stage is the core of the MCGDM process and includes the aggregation and exploitation procedures carried out to evaluate and rank the alternatives. In the aggregation stage, the individual preference relations are aggregated to obtain a collective preference relation. In order to obtain the coincidence among preferences or solutions, aggregation operators such as the Ordered Weighted Aggregator or (OWA) aggregation operator defined by Yager [84, 85], Linguistic-OWA (LOWA) aggregation defined in [84], etc are used. The LOWA operator uses the fuzzy majority to represent linguistic quantifier and also aggregates weighted and non-weighted linguistic information.

For the OWA aggregation operator used in this chapter, Let P_{ij}^s be the set of individual preference relations defined for each criterion c_j by each service class s, over the given pair of alternatives i, j; for all $i \in \{1, \cdots, u\}$, $j \in \{1, \cdots, n\}$, and $s \in \{1, \cdots, m\}$, A collective preference relation P_c , which is obtained by the aggregation of the individual fuzzy preference relations, is obtained using the OWA operator (ψ_Q) according to the expression defined below:

$$P_{ij}^c = \psi_Q(P_{ij}^{s_1}, P_{ij}^{s_2}, \ldots, P_{ij}^{s_m}) \tag{4.6}$$

The parameter $P_{ij}^{s_m}$ defines the fuzzy preference relation of service call (s_m) over a pair of alternatives i, j. The parameter Q is the linguistic qualifier used to calculate the weighting vector w_k of the OWA aggregation operator, where $\sum_{n=1}^{n} w_k = 1$ and $w_k \in [0, 1]$.

The values of w_k, can be obtained using the expression:

$$W_k = Q(\frac{k}{n}) - Q(\frac{k-1}{n}), for\ k = 1, \ldots, n \tag{4.7}$$

Linguistic qualifiers are defined over a lower and upper bound. Some linguistic qualifier and their corresponding range of values are: most (0.3, 0.8), at least half (0, 0.5), as many as possible (0.5, 1), and can be computed using the expression:

$$Q(r) = \begin{cases} 0, & r < \widehat{a} \\ \frac{r-\widehat{a}}{\widehat{b}-r}, & \widehat{a} \leq r \leq \widehat{b} \\ 1, & r > \widehat{b} \end{cases} \tag{4.8}$$

4.6 Methods of Coincidence

The soft consensus process is a measure of the coincidence of the similarity among experts decision criteria and can be evaluated using three methods namely; strict coincidence among preferences, soft coincidence among preferences and coincidence among solutions. The strict coincidence among preferences defines a strict similarity matrix with two values, [0, 1] while the soft coincidence among preferences defines a similarity matrix with values between 0 and 1. The method of coincidence among solutions uses the similarity criteria among the solutions obtained by the experts to compute the coincidence values. The method of soft coincidence among preferences and coincidence among solutions described in [78–80] are adopted for the consensus-based MAGDM RAT-selection in this Thesis. To validate the method of soft coincidence in the selection of suitable RAT for group-multiple calls, numerical results for various network scenarios are given for the soft coincidence among preferences in Section 4.8 and soft coincidence among solutions in Section 4.10.

4.7 Consensus Process based on Soft Coincidence among Preferences

The method of soft coincidence among preferences has been extensively discussed in literature [79, 80]. In this approach, each pair of experts; (e_d, e_l) is considered and a similarity matrix is defined as $sm_{i,j}^{d,l}$, where

$$sm_{i,j}^{d,l} = (1 - |P_{ij}^d - P_{ij}^l|) \tag{4.9}$$

All the similarity matrices are aggregated using an aggregation function to obtain a collective similarity (consensus) matrix; $SM = (sm_{i,j})$, where

$$sm_{i,j} = \phi(sm_{i,j}^{d,l}, d = \{1, \cdots, m\}, l = d + 1, \cdots, m) \tag{4.10}$$

The values of consensus matrix are used to compute the consensus degree on a pair of alternatives, consensus degree on alternatives and consensus degree on the relation.

The consensus degree (cp) on pair of alternatives (x_i, x_j)**:** This gives the measure of the consensus degree of experts on the pair of alternatives and is expressed as:

$$cp_{ij} = sm_{ij} \tag{4.11}$$

As $cp_{ij} \rightarrow 1$, the agreement on the pairs of alternatives (x_i, x_j) increases, while lower values of cp_{ij} indicates lower consensus degree among the pair of alternatives.

The consensus degree on alternative (x_i): This gives the measure of the consensus degree among all the experts on that alternative, and can be express as:

$$cp_i = \frac{\sum_{j=1;j\neq i}^{n}(cp_{ij} + cp_{ji})}{2(n-1)} \tag{4.12}$$

The values of cp_i are used to identify alternatives whose consensus degree is lower than the threshold and hence, a modification of the experts preferences on those alternatives can be made.

The consensus degree on relation: This measures the global consensus degree among all the experts and is computed by taking the average of all the consensus degrees on the alternatives. While the values of the consensus measures can be used to ascertain the collective level of agreements of the experts on the feasible set of solutions, the agreement between the individual experts opinion and a feasible solution is obtained by computing the proximity measures on pairs of alternatives, proximity measures on alternatives and proximity measure on the relation.

In order to compute the proximity measure for each expert, the collective preference relation (P_c), of all the experts is calculated by aggregating the set of individual preference relation of each expert. This is the OWA or LOWA aggregation operation described in Section 4.5.1.2 which is expressed as:

$$P_{ij}^{c} = \phi(P_{ij}^{1}, P_{ij}^{2}, \cdots, P_{ij}^{m}) \tag{4.13}$$

For each expert, the proximity measure on a pair of alternatives is obtained as $PM^d = pm_{ij}^d$.

Proximity measure on pair of alternatives: The proximity measures of an expert (e_d) on pair of alternative (x_i, x_j) can be obtained as:

$$pp^d = pm_{ij}^d \tag{4.14}$$

Proximity measure on alternatives: The proximity measures of an expert (e_d) on an alternative (x_i) can be obtained as:

$$Pa_i^d = \frac{\sum_{j=1;j\neq i}^{n}(pp_{ij}^d + pp_{ij}^d)}{2(n-1)} \tag{4.15}$$

Proximity measure on the relation: This is obtained by taking the average of all the proximity measures on all the alternatives.

4.8 Scenarios and Numerical Results for Soft Coincidence among Preferences

This section presents scenarios and numerical examples to illustrate and validate the concepts discussed above. For the purpose of clarity, we consider a mobile subscriber with a multimode/multi-homed capable mobile terminal in an overlapped coverage of five RATs. The mobile terminal is equipped with interfaces supporting LTE (R1), HSPA+ (R2), WLAN1 (R3), WLAN2 (R4) and WiMAX (R5). WLAN1 and WLAN2 are the IEEE 802.11a and 802.11b standard, respectively. This work is aimed at selecting the best access network for a grouped-multiple handoff calls consisting of three calls and based on consensus degree of 0.9000 among the three calls. The consensus degree indicates the level of satisfaction of the QoS (criteria) requirements among the three calls; namely voice, video-streaming, and file-download. The procedures described in Section 4.5.1.1 have been applied as follows:

Step 1: The alternative access network specifications are given in fuzzy linguistic terms and numerical values as shown in Table 4.1.

Table 4.1: RAT criteria configuration.

Criteria RATs	**Data rate (Mbps)**	**Delay (ms)**	**load**	**Power (Watts)**	**Service price(Unit/Mb)**
LTE(R1)	$1-22$	VL	L	5	EH
HSPA(R2)	$1-8$	L	H	4	H
WLAN1(R3)	$1-54$	H	H	2	L
WLAN2(R4)	$1-11$	L	M	1	VL
WiMAX(R5)	$1-25$	M	L	3	M

Step 2: Table 4.1 is used to construct the decision matrix (D_M), which is given as;

$$D_M = \left[\begin{array}{ccccc|c} 22 & 0.0333 & 0.3300 & 5 & 0.9600 & R_1 \\ 7.5 & 0.3300 & 0.7500 & 4 & 0.7500 & R_2 \\ 54 & 0.7500 & 0.7500 & 2 & 0.3300 & R_3 \\ 11 & 0.3300 & 0.5500 & 1 & 0.0300 & R_4 \\ 25 & 0.5500 & 0.3300 & 3 & 0.5500 & R_5 \end{array}\right]$$

Step 3: The user assigned preference weights on each criterion are specified in fuzzy linguistic terms as shown in Table 4.2. In order to assist the users achieve a flexible preference specifications, the preference weightings assigned to each application are given as interval value fuzzy linguistic terms, e.g for voice service, s_a: $S_{voice}^{Datarate} = (H, EH)$, $S_{voice}^{Delay} = (VL, V, M,)$, $S_{voice}^{congestion} = (L, M, H)$, $S_{voice}^{Power} = (VL, L, M)$, $S_{voice}^{cost} = (V, L, H)$.

Table 4.2: Fuzzy-base user preference weighting

Criteria RATs	**Data rate (Mbps)**	**Delay (ms)**	**load (%)**	**Power (Watts)**	**Service price(Unit/Mb)**
Voice	H	M	M	VL	L
File-download	H	H	L	M	M
Video-streaming	H	EH	VL	H	VL

The network and application specifications will be normalized and used for the selection of appropriate target RAT for the group of multiple calls (voice, file-download and video-streaming) in heterogeneous wireless networks using the two methods of soft coincidence described in Section 4.8 and 4.9.

Step 4: Normalization of User Preference Weights is obtained Using Equation 4.2 and Table 4.2. The normalized preference values $(\widehat{w_i^a})$ for each user services is given in Table Table 4.3

Table 4.3: Normalized user preference weight on applications

Criteria RATs	**Data rate (Mbps)**	**Delay (ms)**	**load (%)**	**Power (Watts)**	**Service price(unit/Mb)**
Voice	0.3350	0.1659	0.1659	0.2500	0.0850
File-download	0.2359	0.1761	0.1761	0.2359	0.1761
Video-streaming	0.2659	0.0675	0.0675	0.3300	0.2659

Step 5: This involves the normalization of Decision Matrix. Using the values of D_M, in Equation 4.2, and Equation 4.4 the normalized Decision matrix $(\widehat{D_M})$ can be obtained as:

$$\widehat{D_M} = \left[\begin{array}{ccccc} 0.4074 & 0.0344 & 0.2000 & 1.000 & 1.000 \\ 0.1389 & 0.0404 & 0.2500 & 0.0909 & 0.4400 \\ 1.0000 & 1.0000 & 0.5000 & 0.0400 & 0.4400 \\ 0.2037 & 1.0000 & 1.0000 & 0.0545 & 0.6000 \\ 0.4630 & 0.0604 & 0.3333 & 0.0909 & 1.0000 \end{array}\right] \begin{array}{c} R_1 \\ R_2 \\ R_3 \\ R_4 \\ R_5 \end{array}$$

Step 6: This step is used to determine the Weighted Normalized Decision Matrix. The weighted normalized decision matrix for each service call (voice, file-download and video-streaming) can be obtained by taking the product of the normalized preference values, $\widehat{w_i^a}$ for each application and the normalized decision matrix,($\widehat{D_M}$). These values specify the overall score of each application of the group multiple calls on the available RATs. This is shown in Table 4.4

Table 4.4: Weighted performance score for group multiple calls.

Services / RATs	**Voice**	**File-download**	**Video-streaming**
LTE(R1)	0.5194	0.5015	0.3209
HSPA(R2)	0.2004	0.1930	0.1678
WLAN1(R3)	0.5477	0.4560	0.4915
WLAN2(R4)	0.5112	0.5753	0.6975
WiMAX(R5)	0.4235	0.3905	0.3237

Step 7: Determination of Individual Fuzzy Preference Relation: The results in Table 4.4 are used in AHP process to evaluate the performance of the available access networks for each application or service through a pairwise comparison.

The results of the AHP process are converted into fuzzy preference relation for each service call, according to step 7, and Equation 4.5. The outcome of this step gives the fuzzy preference relation on the available RATs for voice, file-download and video-streaming calls; represented by p_f^1 = voice call, p_f^2 = file-download, p_f^3 = video-streaming, respectively. These are obtained as:

$$p_f^1 = \begin{bmatrix} 0.5000 & 0.7168 & 0.4879 & 0.5036 & 0.5464 \\ 0.2832 & 0.5000 & 0.2712 & 0.2868 & 0.3297 \\ 0.5121 & 0.7288 & 0.5000 & 0.5157 & 0.5585 \\ 0.4969 & 0.7132 & 0.4843 & 0.5000 & 0.5428 \\ 0.4536 & 0.6703 & 0.4416 & 0.4572 & 0.5000 \end{bmatrix}$$

$$p_f^2 = \begin{bmatrix} 0.5000 & 0.7173 & 0.5216 & 0.4688 & 0.5569 \\ 0.2827 & 0.5000 & 0.3043 & 0.2514 & 0.3396 \\ 0.4784 & 0.6957 & 0.5000 & 0.4471 & 0.5353 \\ 0.5312 & 0.7486 & 0.5529 & 0.5000 & 0.5882 \\ 0.4431 & 0.6604 & 0.4647 & 0.4198 & 0.5000 \end{bmatrix}$$

$$p_f^3 = \begin{bmatrix} 0.5000 & 0.6463 & 0.4017 & 0.3220 & 0.4967 \\ 0.3537 & 0.5000 & 0.2554 & 0.1757 & 0.3504 \\ 0.5983 & 0.7446 & 0.5000 & 4203 & 0.5950 \\ 0.0.6780 & 0.8243 & 0.5797 & 0.5000 & 0.6747 \\ 0.0.5033 & 0.6496 & 0.4050 & 0.3253 & 0.5000 \end{bmatrix}$$

4.9 Consensus Process and Similarity Measure

4.9.1 Determination of similarity matrix

Using the individual preference relations (p_f^1, p_f^2, p_f^3) and similarity function in Equation 4.10, the similarity matrix is computed for pairs of calls, (voice and file-download, voice and video-streaming, file-download and video-streaming) with the results given as:

$$SM^{Voice,File-download} = \begin{bmatrix} 1.0000 & 0.7819 & 0.6888 & 0.7942 & 9346 \\ 0.7819 & 1.0000 & 0.9069 & 0.9877 & 0.9466 \\ 0.6888 & 0.9069 & 1.0000 & 0.8946 & 0.9600 \\ 0.7942 & 0.9877 & 0.8946 & 1.0000 & 0.9346 \\ 0.7288 & 0.9468 & 0.9600 & 0.9346 & 1.0000 \end{bmatrix}$$

$$SM^{Voice,video-streaming} = \begin{bmatrix} 1.0000 & 0.0.8300 & 0.7196 & 0.8126 & 0.7699 \\ 0.8300 & 1.0000 & 0.8896 & 0.9827 & 0.9399 \\ 0.7196 & 0.8896 & 1.0000 & 0.9068 & 0.9497 \\ 0.8128 & 0.9827 & 0.9068 & 1.0000 & 0.9579 \\ 0.7699 & 0.9399 & 0.9490 & 0.9571 & 1.0000 \end{bmatrix}$$

$$SM^{File-download,Video-streaming} = \begin{bmatrix} 1.0000 & 0.9519 & 0.9692 & 0.9814 & 0.9589 \\ 0.9519 & 1.0000 & 0.9827 & 0.9705 & 0.9930 \\ 0.9692 & 0.9827 & 1.0000 & 0.9878 & 0.9897 \\ 0.9814 & 0.9705 & 0.9878 & 1.0000 & 0.9775 \\ 0.0.7589 & 0.9930 & 0.9897 & 0.9775 & 1.0000 \end{bmatrix}$$

4.9.2 Determination of collective similarity matrix

These values indicate the similarity preference between a pair of calls as well as the soft coincidences between the indicated services. The aggregation of the similarity matrices gives the collective similarity matrix (SM). This shows the similarity in preferences of the three calls over the given alternatives. The collective similarity matrix is given below:

$$SM = \begin{bmatrix} 1.0000 & 0.8546 & 0.7925 & 0.8628 & 0.8192 \\ 0.8546 & 1.0000 & 0.9264 & 0.9803 & 0.9599 \\ 0.7925 & 0.9264 & 1.0000 & 0.9297 & 0.9665 \\ 0.8628 & 0.9803 & 0.9297 & 1.0000 & 0.9565 \\ 0.8192 & 0.9599 & 0.9665 & 0.9564 & 1.0000 \end{bmatrix}$$

4.9.3 Determination of collective similarity matrix

As discussed earlier, when these values tend to 1, agreement on the pairs of alternatives (x_i, x_j) increases, while lower values indicate lower consensus degree among the pair of alternatives. The consensus degree among the calls (voice, file-download and video) helps to identify which call has a consensus degree less than the minimum threshold, while the consensus degree of relation gives the global consensus degree among all the calls. The global consensus degree computed for the five alternatives RATs from the values of SM is given, respectively as:

$SM^{global} =$ 0.9279, 0.9580, 0.9460, 0.9134, 0.9546. This shows that all the calls achieved a minimum consensus threshold of 0.9000. Based on the achievable consensus values, the consensus ranking of the available RATs is carried out using the values of SM and the weighted product form in Equation 4.16. The ranking output is shown in Table 4.5.

$$RAT_j = \prod_{i=1}^{h} sm_{i,j}, \forall_i \in \{1, 2, \cdots, h\}, j \in \{1, 2, \cdots, n\} \tag{4.16}$$

Table 4.5: Consensus RAT ranking output

RATs	**LTE(RAT1)**	**HSPA(RAT2)**	**WLAN1(RAT3)**	**WLAN2(RAT4)**	**WiMAX(RAT5)**
Ranking	0.4748	0.7450	0.6597	0.7521	0.7268

The consensus RAT-selection output shows that RAT_4 has the highest ranking, and is, therefore, the most appropriate RAT for the group of multiple calls. However, this decision is based on the consensus degree among the group of calls, which is insufficient for a selection process. In order to select RAT_4 as the most appropriate RAT, considerations must be given to the proximity measure for all the criteria considered in the RAT-selection decision process. This requires a feedback system, which ensures that the selected RAT satisfies the minimum criterion threshold.

4.9.4 Feedback moderator system

The moderator feedback mechanism introduced in Section 4.2, Figure 4.1 acts as an agent system which uses the proximity measure to coordinate and ensure that minimum criteria threshold are maintained within the specified range in consensus-based MAGDM process prior to the selection of the best alternative. The moderator feedback mechanism, therefore, applies a rule-based system for the experts to modify their preference values whenever the minimum criterion threshold (π) is violated. To provide the QoS requirements for the group multiple calls in heterogeneous wireless networks, three basic rules are generated by the agent system and applied by the experts (service calls) based on the individual proximity measure towards the RAT selection process. Using the computed values of pa_i^d in Equation 4.15 and the minimum criterion threshold ($\pi = 0.9000$), the following rules are applied towards the final selection of RAT_j:

Rule 1: If $pa_i^d > \pi$, decrease the user preference value associated with criterion C_h on RAT_j.

Rule 2: If $pa_i^d = \pi$, do not change the user preference associated with criterion C_h on RAT_j.

Rule 3: If $pa_i^d < \pi$, increase the user preference value associated with criterion C_h on RAT_j.

For the purpose of this work, rule 1 shall be applied in a similar manner to rule 2. The value of 0.9 has been selected in order to achieve a high consensus threshold of about 90% among the individual calls. In practice, a consensus threshold of 0.7-0.8 is just sufficient to achieve the required level of agreement among experts. The calculation of the individual proximity measures requires the determination of the collective preference relation, P^c, which is computed using the aggregation of the individual fuzzy preference relations (p_f^1, p_f^2, p_f^3) according to Equation 4.7, Equation 4.8 and Equation 4.10. Therefore;

$$P^c = \begin{bmatrix} 0.5000 & 0.6579 & 0.4416 & 0.4088 & 0.4817 \\ 0.3041 & 0.5000 & 0.2909 & 0.2479 & 0.3267 \\ 0.5031 & 0.6883 & 0.5000 & 0.4449 & 0.0.5284 \\ 0.5582 & 0.7462 & 0.5328 & 0.5000 & 0.5729 \\ 0.4682 & 0.6598 & 0.4642 & 0.4100 & 0.5000 \end{bmatrix}$$

The computed values of P_{ij}^c and (p_f^1, p_f^2, p_f^3) are used to determine the proximity measure (PM^s) on pairs of call according to the following expression:

$$PM^s = (1 - |P_{ij}^s - P_{ij}^c|) \tag{4.17}$$

For each service call, the computed values of individual proximity measures are given as:

$$PM^{Voice} = \begin{bmatrix} 1.0000 & 0.8542 & 0.7609 & 0.8574 & 0.7927 \\ 0.8922 & 1.0000 & 0.9139 & 0.9998 & 0.9414 \\ 0.8162 & 0.9343 & 1.0000 & 0.9258 & 0.9799 \\ 0.8905 & 0.9938 & 0.9035 & 1.0000 & 0.9352 \\ 0.8427 & 0.9549 & 0.9726 & 0.9523 & 1.0000 \end{bmatrix}$$

$$PM^{File-download} = \begin{bmatrix} 1.0000 & 0.9559 & 0.9624 & 0.9774 & 0.9570 \\ 0.9179 & 1.0000 & 0.9993 & 0.9755 & 0.9982 \\ 0.9071 & 0.9785 & 1.0000 & 0.9625 & 0.9938 \\ 0.9444 & 0.9814 & 0.9850 & 1.0000 & 0.9796 \\ 0.9069 & 0.9847 & 0.9989 & 0.9625 & 1.0000 \end{bmatrix}$$

$$PM^{Video-streaming} = \begin{bmatrix} 1.0000 & 0.9960 & 0.9933 & 0.9960 & 0.9981 \\ 0.9660 & 1.0000 & 0.9820 & 0.9950 & 0.9912 \\ 0.9379 & 0.9612 & 1.0000 & 0.9749 & 0.9834 \\ 0.9630 & 0.9891 & 0.9972 & 1.0000 & 0.9979 \\ 0.9481 & 0.9777 & 0.9908 & 0.9851 & 1.0000 \end{bmatrix}$$

The computed values of individual proximity measures(Pa) are determined using the values of $(PM^{Voice}, PM^{File-download} and PM^{Video-streaming})$ in Equation 4.7 and the results shown in Table 4.6:

Table 4.6: Computed proximity measures for Voice, File-download and Video-streaming

Criteria PM	**Data rate (Mbps)**	**Delay (ms)**	**load (%)**	**Power (Watts)**	**service price(Mb)**
Pa^{voice}	**0.8122**	0.9300	**0.8908**	0.9292	0.9199
$Pa^{file-download}$	0.9362	0.9749	0.9717	0.9726	0.9726
$Pa^{video-streaming}$	0.9703	0.9795	0.9757	0.9843	0.9834

The results for the individual proximity measures show that all the criteria for File-download and Video-streaming met the minimum criterion threshold $\pi = 0.9000$ required to satisfy the QoS requirements of the three handoff calls in heterogeneous wireless networks. However, two criteria (**data rate**) and (**power**) for the voice call did not satisfy the minimum criterion threshold. At this point, the two calls which satisfied the QoS requirements can be jointly assigned to the selected RAT, while the voice call is assigned to the next appropriate RAT within the heterogenous networks environment.

In order to jointly handoff the three calls as grouped-multiple calls, the rules specified in the feedback mechanism will be applied. According to this rule, the criteria threshold values for data rate and power $(\mathbf{0.8122}, \mathbf{0.8908})$ are less than the 0.9000 minimum values. The recommender system will, therefore, guide the voice call to increase its preference values on the two criteria. To implement the rules, preference values for data rate will be increased from Very low (**VL**) to High (**H**) and power will be increased from Low (**L**) to Medium (**M**). The iteration process is repeated until convergence point is reached, that is, for the three calls, all the criteria have satisfied the requirements for the minimum criteria threshold . In each consensus process, different RATs may be selected for handoff, this is because the criteria. specifications are dynamically updated according to the rules or advice of the recommender system. In this work, three consensus processes have been implemented in order to reach the minimum criterion threshold, and in each consensus process, different RATs have been selected for the handoff of the grouped-multiple calls. The results are shown in Figure 4.2 - Figure 4.4.

In Figure 4.2, the achievable proximity measures for the first consensus process is presented where the criteria threshold for data rate and battery power are below the minimum criterion for voice traffic as explained earlier, leading to the second consensus process. The first consensus process presents WLAN2 (RAT4) with selection index of (**0.7521**) as the best RAT for the group of handoff calls. After the feedback rules have been applied, the new preference values for data rate and power for voice call are used in the second consensus process. The results of the second consensus process in Figure 4.3 show that all the criteria for file-download and video-streaming met the minimum criterion threshold $\pi = 0.9000$, however, the criterion value for data rate in the voice call has a value of (**0.8700**) which is an improvement over the first consensus process but less than the minimum required threshold value of 0.9000.

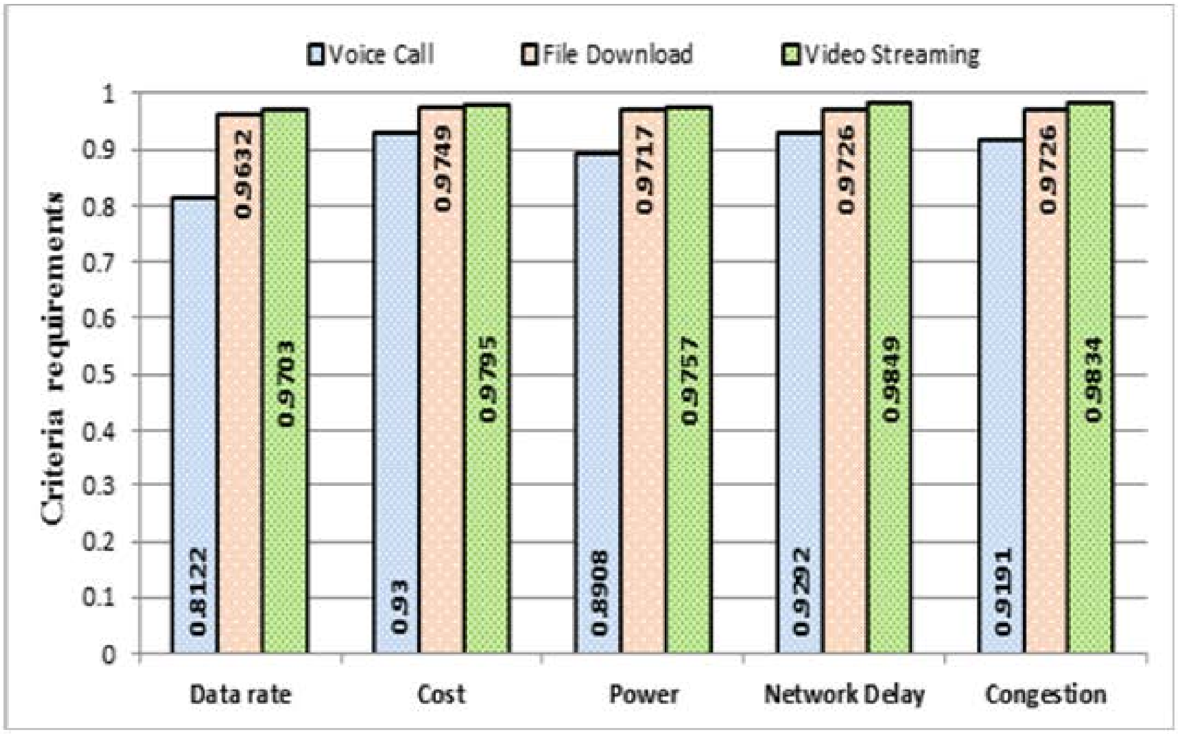

Figure 4.2: Achievable proximity measures for the first consensus process

In the second consensus process, WiMAX (RAT5) has been selected as the best RAT for handoff of the group multiple calls. To achieve the minimum criterion threshold for the three calls, the preference value assigned to data rate must be increased from Medium (M) to High (EH) by the voice call, and in accordance with the feedback rule. This, therefore, leads to the third consensus process with the results shown in Figure 4.4.

In the third consensus process, all the criteria associated with the grouped-multiple calls achieved the minimum criterion threshold, therefore, WiMAX (RAT5) is selected as the most appropriate access network capable of providing the required QoS for the group of handoff calls comprising of voice, file-download and video-streaming in heterogeneous wireless networks. The ranking of the available RATs during the first, second and third consensus process is shown in Table 4.7.

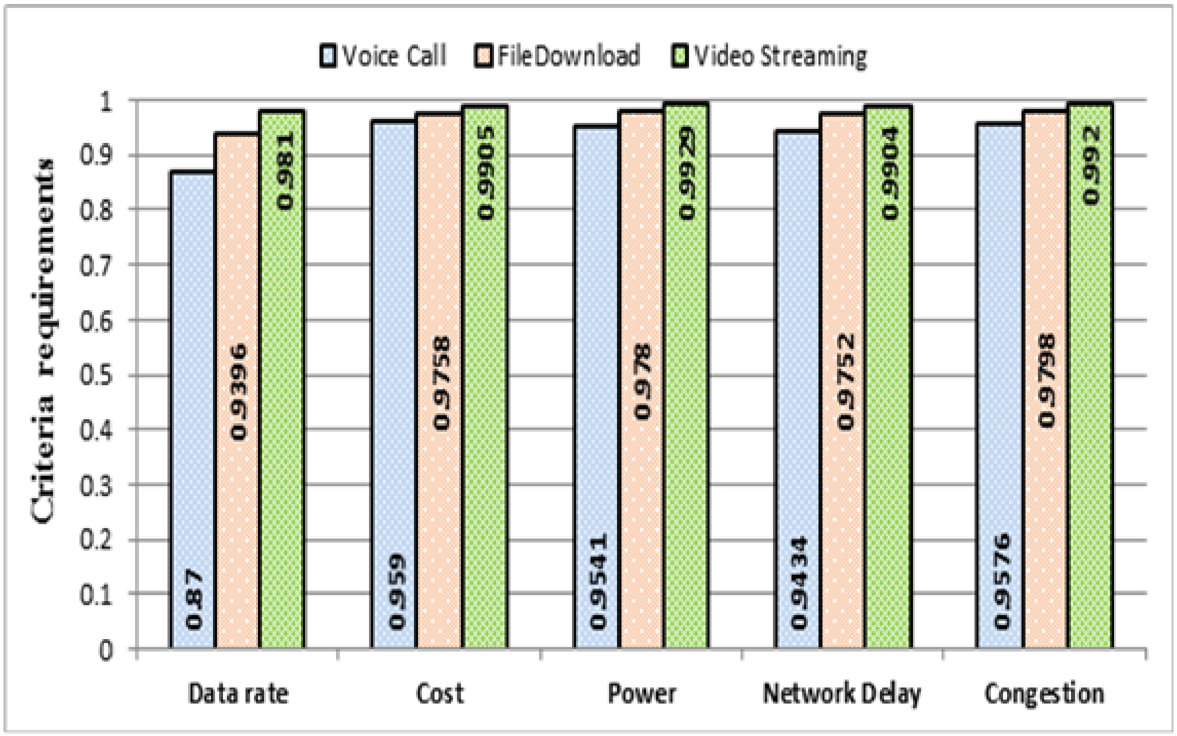

Figure 4.3: Achievable proximity measures for the second consensus process

Table 4.7: RAT ranking for different consensus process

Consensus Trials RATs		**First Consensus**($\pi = 0.9$)	**Second Consensus** ($\pi = 0.9$)	**Third Consensus**($\pi = 0.9$)
LTE	Ranking No	5	5	5
	Ranking Index	0.4787	0.5827	0.5898
HSPA	Ranking No	2	3	2
	Ranking Index	0.7450	0.8263	0.8114
WLAN1	Ranking No	4	2	3
	Ranking Index	0.6597	0.8286	0.8100
WLAN2	Ranking No	1	4	4
	Ranking Index	0.7521	0.7917	0.7644
WiMAX	Ranking No	3	1	1
	Ranking Index	0.7268	0.8358	0.8263

4.10 Scenarios and Numerical Results for Soft Coincidence among Solutions

The performance evaluation of the method of soft coincidence among preferences has been carried out through numerical simulations in Section 4.8 and Section 4.9. The results show the capability of the solution method to achieve the required consensus degree among

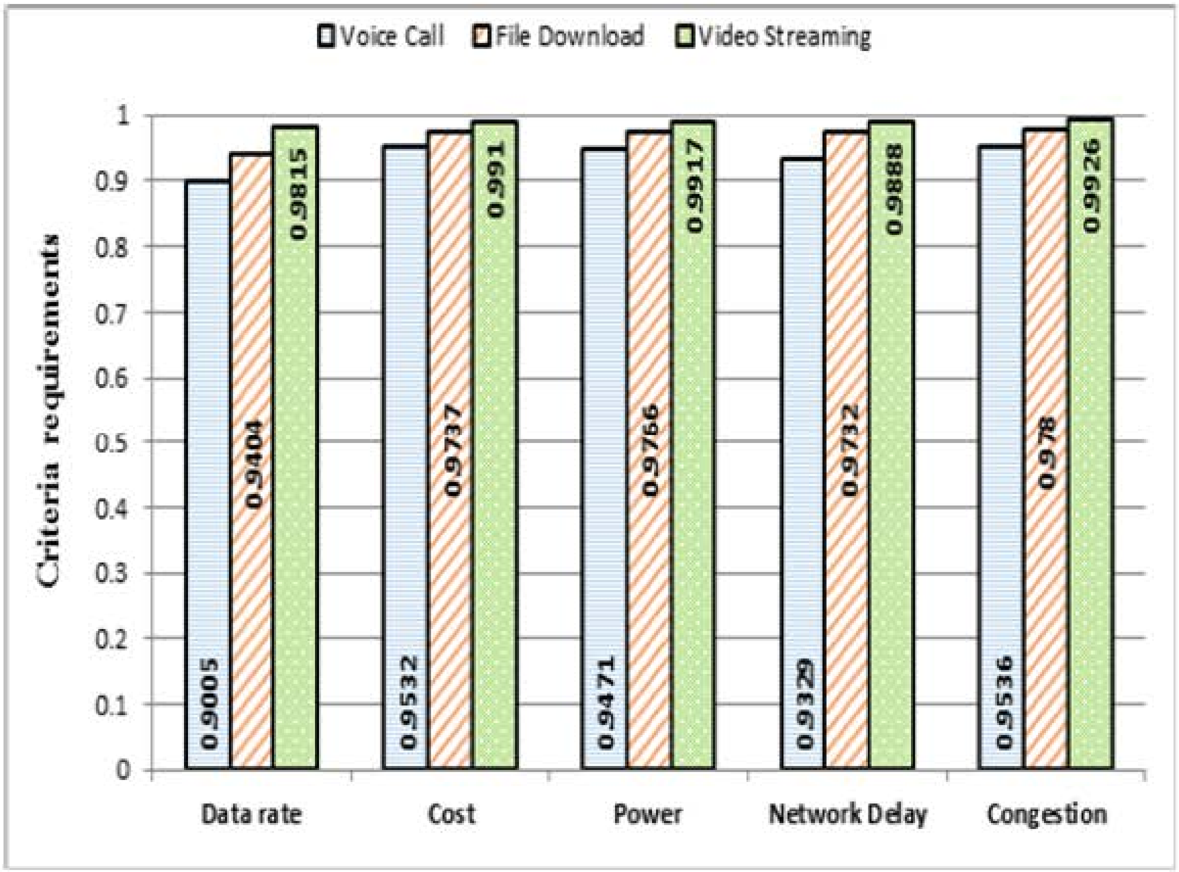

Figure 4.4: Achievable proximity measures for the third consensus process

the alternative RATs, and also achieve the minimum criterion requirements for handoff of grouped-multiple calls. However, key considerations in this approach are the number of consensus processes needed to achieve the required threshold and the inconsistency in the selection of the appropriate RAT for each consensus cycle. To address these problems, the method of soft coincidence among solution was proposed in [79].

This approach presents the coincidence between the individual solution and collective solution to achieve the selection of best alternative among available alternatives. In general, the selection process is used to obtain a temporary collective and individual solutions and a dissimilarity measure applied to obtain the level of closeness among them. The selection process involves two stages of aggregation and exploitation. The aggregation phase provides the collective preference relation obtained by the aggregation of individual preference relations. In the exploitation stage, the quantifier guided dominance degree (QGDD) [79, 80] is applied to rank the alternatives using the global information of the alternatives obtained from the aggregated individual preference relations.

The coincidence degree among solutions is then used to compute the consensus level. The procedure for the consensus MAGDM algorithm using the coincidence among solution is outlined below:

Step 1: Obtain the individual fuzzy preference relation (p_f^1 = voice call, p_f^2 = file-download and (p_f^2 = file download) as given in Section 4.7.

Step 2: Determine the collective preference relation,$P^c = p_{ij}^c$ through the aggregation of the individual preference relation.

Step 3: Using OWA aggregation operation, -as many as, determine the dominance vector matrix $Vec - P^c$, $Vec - P_f^1$, $Vec - P_f^2$, $Vec - P_f^3$, respectively:

$$Vec - P^c = \begin{bmatrix} 0.6596 & 0.5000 & 0.4830 & 0.4437 & 0.4112 \\ 0.5000 & 0.3263 & 0.2968 & 0.2913 & 0.2564 \\ 0.6866 & 0.5249 & 0.5000 & 0.4941 & 0.4465 \\ 0.7377 & 0.5718 & 0.5476 & 0.5325 & 0.5000 \\ 0.6617 & 0.5000 & 0.4650 & 0.4628 & 4152 \end{bmatrix}$$

$$Vec - P_f^1 = \begin{bmatrix} 0.8317 & 0.7152 & 0.7099 & 0.5920 & 0.5000 \\ 0.5000 & 0.3834 & 0.3781 & 0.2601 & 0.1681 \\ 0.6166 & 0.5000 & 0.4947 & 0.3768 & 0.2848 \\ 0.7399 & 0.6234 & 0.6179 & 0.5000 & 0.4080 \\ 0.6219 & 0.5053 & 0.5000 & 0.3821 & 0.2901 \end{bmatrix}$$

$$Vec - P_f^2 = \begin{bmatrix} 0.6138 & 0.5000 & 0.4387 & 0.4040 & 0.3862 \\ 0.5000 & 0.3862 & 0.3249 & 0.2902 & 0.2724 \\ 0.7098 & 0.5960 & 0.5347 & 0.5000 & 0.4822 \\ 0.7276 & 0.6138 & 0.5525 & 0.5178 & 0.5000 \\ 0.6751 & 0.5613 & 0.5000 & 0.4653 & 0.4475 \end{bmatrix}$$

$$Vec - P_f^3 = \begin{bmatrix} 0.6619 & 0.5000 & 0.4749 & 0.4349 & 0.4048 \\ 0.5000 & 0.3381 & 0.3179 & 0.2729 & 0.2429 \\ 0.7271 & 0.5651 & 0.5450 & 0.5000 & 0.4700 \\ 0.7571 & 0.5952 & 0.5750 & 0.5300 & 0.5000 \\ 0.6821 & 0.4201 & 0.5000 & 0.4550 & 0.4250 \end{bmatrix}$$

Step 4: Using the results of step 3 above in QGDD procedure, determine the global ranking (α_j) and individual ranking (ϕ_j) of the alternative RATs.

The ranking results in Table 4.8 show that WLAN2 has the highest ranking index for the global solution. For the individual ranking of RATs, file-download and video-streaming also maintain WLAN2 as the best RAT while voice ranked LTE as the best RAT.

Table 4.8: Global and individual ranking of RATs

Ranking \ RATs		**LTE (RAT1)**	**HSPA (RAT2)**	**WLAN1 (RAT3)**	**WLAN2 (RAT4)**	**WiMAX (RAT5)**
Global Ranking	Ranking No	4	5	2	1	3
	Ranking Index	0.4371	0.2826	0.4821	0.5249	0.4505
Voice Ranking	Ranking No	1	5	4	2	3
	Ranking Index	0.5752	0.2433	0.3599	0.4832	0.3652
File Ranking	Ranking No	4	5	2	1	3
	Ranking Index	0.4015	0.2877	0.4974	0.5153	0.4628
Video Ranking	Ranking No	4	5	3	1	2
	Ranking Index	0.4297	0.2678	0.4949	0.5242	0.4999

Step 5: Determine the proximity (p_r^j) of each alternative $j \in \{1, \cdots, n\}$, by comparing the ranking position of that alternative in the global solution/ranking (α_j) and in the individual solution/ranking (ϕ_j) according to the given expression:

$$P_r^j = \left(\frac{|\alpha_j - \phi_j|^b}{n-1} \right); b \in [0, 1] \tag{4.18}$$

Table 4.9: Normalized user preference weight on applications

Solutions \ $\alpha_j - \phi_j$	**D1**	**D2**	**D3**	**D4**	**D5**
Voice	3	0	-1	-1	0
File-download	0	0	0	0	0
Video-streaming	0	0	-1	0	1

Step 6: Calculate the consensus degree of the calls on each alternative using the expression in Equation 4.19

$$C(j) = 1 - \sum_{i=1}^{m} \frac{P_r^j}{m} \tag{4.19}$$

The computed values of $C(j)$: $=$ 0.7427 1.0000 0.8214 0.9043 1.0000

Step 7: Aggregate the consensus degree in Equation 4.19 to determine the consensus measure over the set of the alternatives, C_X. In order to attribute a more important weight to the consensus degree in the aggregation, the S-OWA OR-LIKE operator is used and defined in [79].

$$C_x\left(j_1,\ldots,\jmath_n\right)=\left(1-\beta\right)\frac{1}{n}\sum_{i=1}^{n}j_i+\beta max\left(j_i\right);\beta\in\left[0,1\right] \tag{4.20}$$

The parameter β controls the OR-LIKE behaviour of the aggregation operator. Optimum values of β are 0.7, 0.8 and 0.9.

For β =0.9, the computed value of $C_x = 0.9032$, and the proximity measures obtained are 0.8851, 1.000, and 1.000 for the voice, file-download and video-streaming, respectively. In this approach, the value of $C_x \geq \pi$ (0.9000) is just sufficient to rank the alternatives, and for $C_x < \pi$,the feedback rules are applied as in Section 4.9.4. Therefore, in the first consensus process of the method of coincidence among solutions, the consensus threshold is attained and the selected RAT is WLAN2.

For the purpose of comparison, we apply the second consensus process, in which voice call is required to change the evaluation of the given alternatives to a higher value according to the feedback rules. For the second consensus process, the consensus degree for the available RATs are given, respectively as: $C\left(j\right) = 0.9043$, 1.0000, 1.0000, 1.0000 and 0.9043, while the consensus measure is obtained as = 0.9962. The ranking of the RATs for the second consensus degree is shown in Table 4.10, where WLAN2 (RAT4) is selected as the best RAT for the group of handoff calls. The method has demonstrated consistency in the ranking of the RATs and the selection of WLAN2 (RAT4) as the best RAT in a single round of consensus process.

This method has proved to be efficient when compared with the method of coincidence among preferences, where the consensus threshold and proximity measures were attained after the third round of the consensus process with inconsistency in the ranking of the RATs.

Table 4.10: Global and individual ranking of RATs

RATs Ranking		**LTE (RAT1)**	**HSPA (RAT2)**	**WLAN1 (RAT3)**	**WLAN2 (RAT4)**	**WiMAX (RAT5)**
Global Ranking	Ranking No	4	5	2	1	3
	Ranking Index	0.4161	0.2666	0.4963	0.5177	0.4333
Voice Ranking	Ranking No	3	5	2	1	4
	Ranking Index	0.4898	0.2421	0.4973	0.5095	0.4031
File Ranking	Ranking No	4	5	2	1	3
	Ranking Index	0.4015	0.2877	0.4974	0.5153	0.4628
Video Ranking	Ranking No	4	5	2	1	3
	Ranking Index	0.4125	0.2723	0.4903	0.5392	0.4403

4.11 Complexity Analysis for Group Handoff Calls

In this section, the complexity of the proposed Consensus-based MAGDM techniques are evaluated in MATLAB using the execution time for varying numbers of trials. This analysis is performed in order to determine the execution time for the selection of appropriate RAT for a grouped-multiple calls comprising of voice, file-download and video-streaming.

The analysis is carried out on HP Pavilion Laptop with the following specifications: Intel(R) Core(TM) 2 Duo CPU 2.00GHz, 4.00GB on 64-bits Windows 7 Enterprise. The results show a reduced execution time for the method of coincidence among solutions as compared with the method of coincidence among preferences.

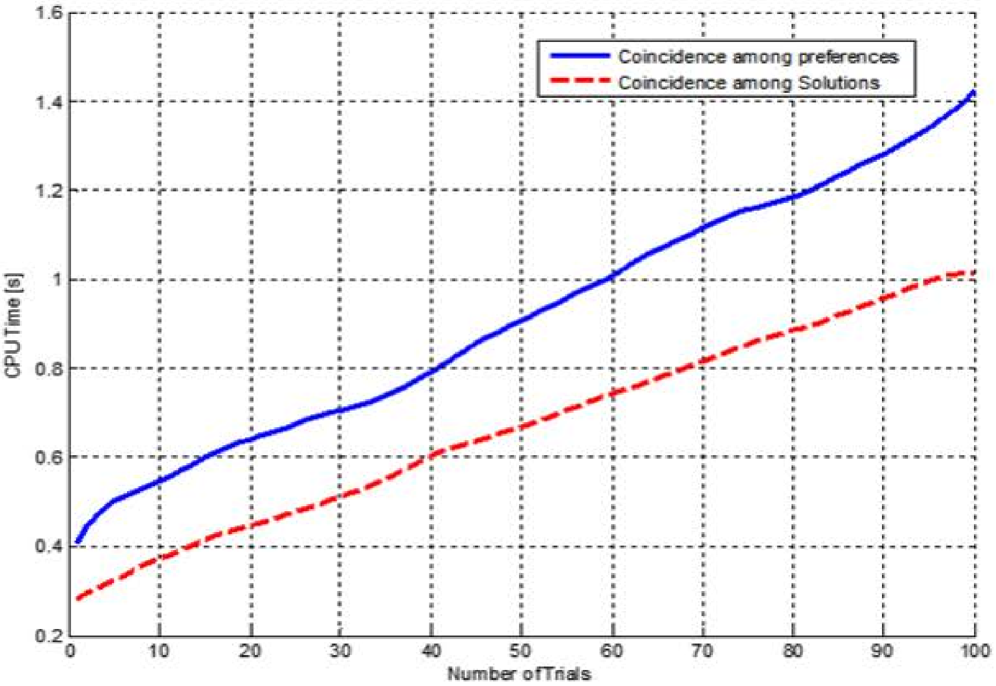

Figure 4.5: Time complexity for coincidence among solutions and coincidence among preferences method

4.12 Comparison of COPRAS and Consensus-Based RAT selection Methods for Group Multiple Calls

The performance of the three RAT selection methods for group multiple calls in heterogeneous wireless environment is presented in the Table 4.11. For the purpose of comparison, the results are obtained under the network scenario described in Table 4.1. The results show that COPRAS method selects WLAN1 as the best network for the group multiple calls. In the consensus-based RAT selection approach, the method of coincidence among preferences, selects WiMAX as the best RAT, while the method of coincidence among solutions selects WLAN2 as the best RAT.

The choice of the optimum RAT by any method depends on the evaluation technique employed, and for group multiple calls, the aggregation techniques plays a major role in determining the best RAT among the available alternatives. The COPRAS method uses the cumulative aggregated weight, which is the product of the normalized weight of each criterion and the priority assigned to each call for evaluation and ranking of each alternative. For the consensus-based approach, a more robust aggregation technique, OWA aggregation method, has been used. As discussed in Section 4.5.1.2, the OWA aggregation technique allows the individual application (voice, file-download and video-streaming) to evaluate and rank each RAT and compare the ranking results with the global solution.

Table 4.11: Ranking comparison for COPRAS and consensus-based methods

RATs Ranking		**LTE (RAT1)**	**HSPA (RAT2)**	**WLAN1 (RAT3)**	**WLAN2 (RAT4)**	**WiMAX (RAT5)**
COPRAS	Ranking No	3	5	1	4	2
	Ranking Index	0.1395	0.0852	0.1566	0.1208	0.1456
Coincidence Among Preferences	Ranking No	5	2	3	4	1
	Ranking Index	0.5898	0.8114	0.8100	0.7644	0.8263
Coincidence Among Solutions	Ranking No	4	5	2	1	3
	Ranking Index	0.4164	0.2666	0.4963	0.5177	0.4333

While each of the selected RAT by the three methods may have the capacity to sustain the group multiple calls, choosing the best RAT among WLAN1, WLAN2 and WiMAX depends on which RAT can best meet the QoS requirements of the group calls. The network configuration in Table 4.1 shows that WLAN2 has lower delay budget than WLAN1 and WiMAX. Since voice and video-streaming applications are delay sensitive, WLAN2 therefore, is the preferred RAT for the group calls. Figure 4.6 shows the distribution for 1000 group calls, consisting of voice, file-download and video among the five alternative access networks.

The multiple call distribution among the RATs shows that no call has been admitted into HSPA, 3.8% of the calls are admitted into LTE, 15.1% admitted into WLAN1, 3.8% WiMAX,

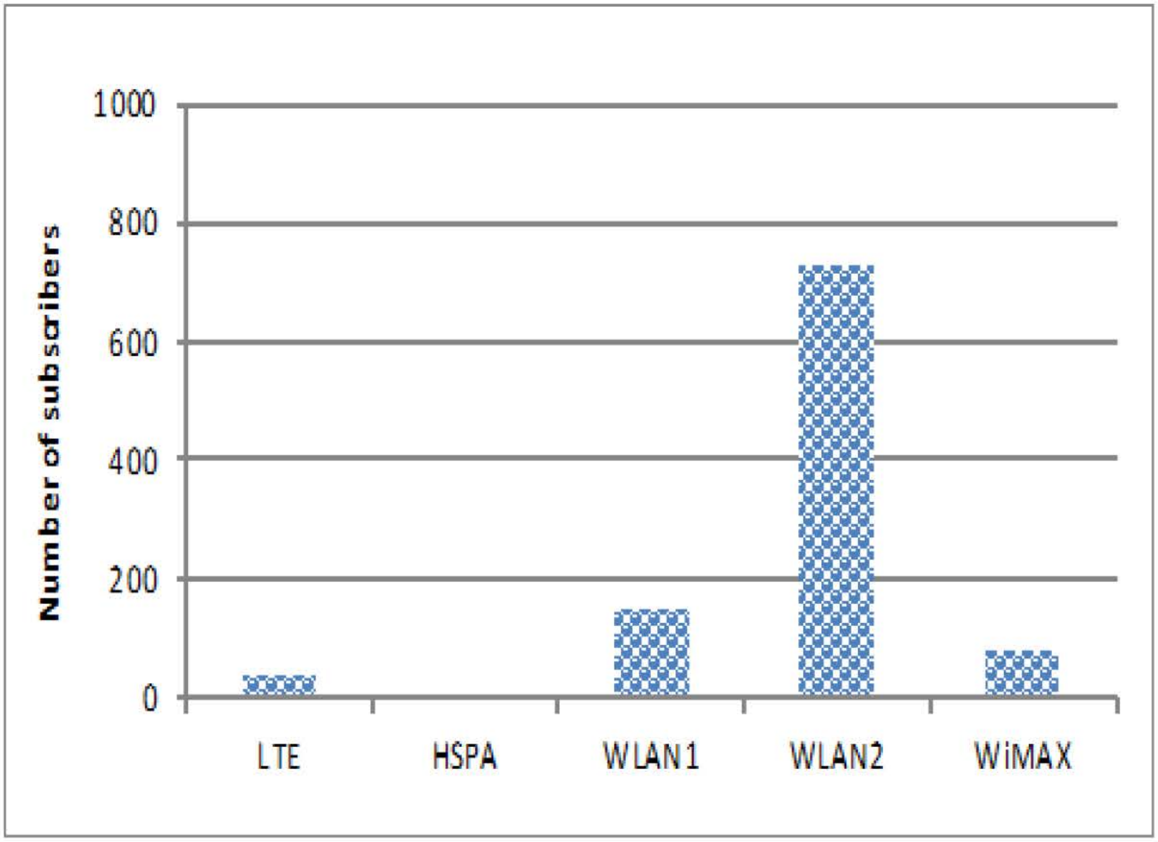

Figure 4.6: Grouped call distribution on available RATs

while 73 % are admitted into WLAN2. WLAN2 has a very low cost, low power consumption, average delay and acceptable network congestion as compared to other alternative access networks. The choice of WLAN2 as the appropriate RAT is justified due to its low power consumption, very low cost, average delay and acceptable network congestion.

4.13 Conclusion

In this chapter, a novel method for the selection of appropriate RAT that can support the QoS requirements for grouped-multiple calls has been proposed. The proposed method uses a consensus-based MAGDM process called the method of coincidence among preference and method of coincidence among solutions. The performance of the two methods of coincidences, discussed in this chapter has been evaluated using numerical examples which are typical of the heterogeneous wireless networks, and application QoS requirements. The results of the two methods show that the method of coincidence among solution outperforms the method of coincidence among preference in terms of the number of consensus cycle, consistency in the ranking of alternative RATs and time complexity.

Chapter 5

Efficient Multiple RAT Selection Scheme for Multi-Homing Services in Heterogenous Networks

5.1 Introduction

In Chapter 3 and chapter Chapter 4, different algorithms for selecting the best RAT for group multiple calls were proposed. In order to validate the proposed algorithms, different scenarios were created and simulations have been carried out with various network performance criteria. In this chapter, the problem of associating the respective interfaces of a multi-homed terminal to the appropriate subset of RATs in a heterogeneous wireless environment will be considered. Subsequently, the assignment of the respective user applications between the various interfaces of the multi-homed mobile terminal and the selected subset of RATs for parallel streaming shall be thoroughly investigated.

5.2 Network-Interface Assignment Problems for Parallel Streaming in HetNets

The choice of the appropriate RAT or subset of RATs for multiple/parallel streaming of user applications will require the association of the selected RATs to the various interfaces of the multi-homing device. Once the selected RATs are associated with appropriate terminal interfaces, uplink or downlink traffic flows of user application request can be established. Hence, in Next Generation HetNets, the mobile terminal will play a major role in determining the appropriate RAT that is most suitable for the user traffic [86–88]. The effectiveness of any RAT selection method, therefore, which may be terminal controlled, network controlled or a hybrid of both, will require an efficient smart mobile terminal.

The availability of mobile terminals with multi-mode/multi-homing support comes with various advantages, such as the ability of the user to subscribe to multiple services from different networks. However, the multi-mode mobile terminals also come with some drawbacks, such as energy efficiency problems. Energy inefficiency in multi-mode/multi-homed terminal can occur due to battery consumption from multiple interfaces during uplink, downlink or idle state of the mobile terminal [89–91]. Similarly, a multi-mode/multi-homed terminal can experience power degradation as a result of signalling procedures that occur during network authentication, authorization and subscriptions to different RATs.

The cost of subscribing to multiple RATs during parallel streaming of user application request is a major factor to be considered by the mobile users who subscribe and pay for these services. Similarly, the response of the network operator to such application request will also depend on the users willingness to pay. Therefore, network service cost remains a major factor to be considered during multiple/parallel streaming of user applications [92–94]

The network load or congestion level of the selected subset of RATs for multiple/parallel streaming of user application plays a major contribution to the overall achievable QoS for the various applications [95, 96]

5.3 Related Work

In addition to the existing MADM RAT selection methods, such as TOPSIS, SAW, MEW, etc; new MADM schemes such as COPRAS and MULTIplicative-form with Multi-Objective Optimization Analysis (MULTIMOORA) method have proposed for user single call, group multiple calls and multi-homing service request[4, 97].

Generally, some MADM techniques suffer from ranking abnormality which is reflected in the results of sensitivity analysis carried out on most MADM RAT selection methods. An alternative approach to RAT selection scheme is the use of the utility-based approach. Most utility-based RAT selection techniques consider the degree of satisfaction of each application on the available RATs and provide the mobile terminal with optimum network-interface association that minimizes the terminal energy consumption. However, the performance of this method lies in the selection of suitable utility function [98, 99]. To enhance the efficiency of RAT selection for user applications, a hybrid of MADM and utility-based RAT selection schemes has been developed in the literature [48, 100, 101]

In [102] the authors modelled access network selection in heterogeneous wireless networks as a flow scheduling optimization problem. Using a multi-homed capable device, the access network strategy considers the selection of the most appropriate terminal interface that can be associated with the best access network for the assignment of designated traffic flow subject to the constraint imposed on the application, user, mobile terminal and network operator. The objective of the flow assignment problem is to maximize the total user utility. The multi-constraints optimization problem was solved as a binary integer programming problem using the branch-and-bound method.

The authors of [103] proposed a terminal-controlled network selection scheme for parallel transmission in heterogeneous wireless networks. The selection of the most appropriate network depends on the total utility score of the different access networks. The utility values are calculated based on the user preference and access network criteria. Access network with the highest utility score is selected for transmission for a given video application. The network selection problem is formulated as a multi-constraint knapsack problem and solved using the exhaustive search method.

The authors in [104] proposed a hybrid approach to RAT selection in heterogeneous wireless networks in which utility and cost functions have been defined for the different traffic class. The scheme uses a normalized traffic class, throughput demand and cost tolerance with the user preference weights as inputs, to find aggregate utility functions for each alternative access network. The RAT with the highest utility value is selected for transmission. This scheme is designed to satisfy user preference and operator objectives.

In this chapter, a network architecture, which integrates the selection of the subset of RATs for the user multiple service request and the assignment of the various traffic flows to the respective interfaces of the multi-homed terminal will be considered. The RAT selection approach in this chapter considers the application of utility-based RAT selection method for the selection of appropriate RAT or subset of RATs in an overlapped region of the heterogeneous wireless network. The utility-based technique evaluates the level of satisfaction (utility) derived by the applications, mobile terminal and network user before selecting the best RATs. The selected RATs will minimizes the total interface energy and cost for the multi-mode terminal and provide the required application QoS.

5.4 Network-Assisted Interface Manager for Multi-mode/Multi-homed Terminal

Low energy efficiency has been identified as one major problem associated with multi-mode/multi-homed terminal as discussed in Section 5.2. The distance of the user from the access networks, mobile terminal speed, the number of active interfaces and requested applications are factors that drastically drain the battery level of the mobile terminal. In order to fully maximize the capability of the multi-mode/multi-homed terminal, excessive battery consumption incurred due to simultaneous use of the multiple interfaces and other related factors must be minimized. Similarly, the battery level of the mobile terminal must be maintained at a minimum threshold value in order to guarantee long-term availability. The cost of using any network depends on the RAT type, user subscription profile, and the requested applications. Subscribing for multiple applications from different RATs will imply additional cost which the user seeks to minimize.

In order to achieve energy efficiency for the mobile terminal, and maintain acceptable subscription cost for the user, we proposed a Network-assisted Interface Manager (NIM) module in the network. The primary function of NIM is to assist the mobile terminal in the selection of a subset of RATs that will minimize battery power consumption and cost of subscription. The Network Interface Manager will also assist the terminal in selecting a subset of RAT with minimum congestion level. The multi-mode/multi-homed terminal will present the desired energy level, cost and acceptable congestion levels to the NIM module, these threshold values are used in a search algorithm to determine the best RAT combinations that meet these required values. The framework for the Network-Assisted Interface Manager is shown in Figure 5.1. The NIM module has in real-time, the dynamic state information of the available RATs (LTE, FAP, WLAN, UMTS, etc.) in the vicinity of the user. It can be collocated in the ANDSF or MIH described in Subsection 2.3.1 or in the base station of the cellular network. The mobile terminal communicates with the NIM through a defined logical interface similar to the UE-ANDSF S14 interface. The result of the search algorithm for the best RAT combinations that minimize terminal interface power consumption and cost is sent to the mobile terminal. The mobile terminal uses the network identifiers of the selected RATs to assign the respective interfaces to the selected RATs for multiple streaming of users application. The description of the system model for the search algorithm is presented in Section 5.4.1

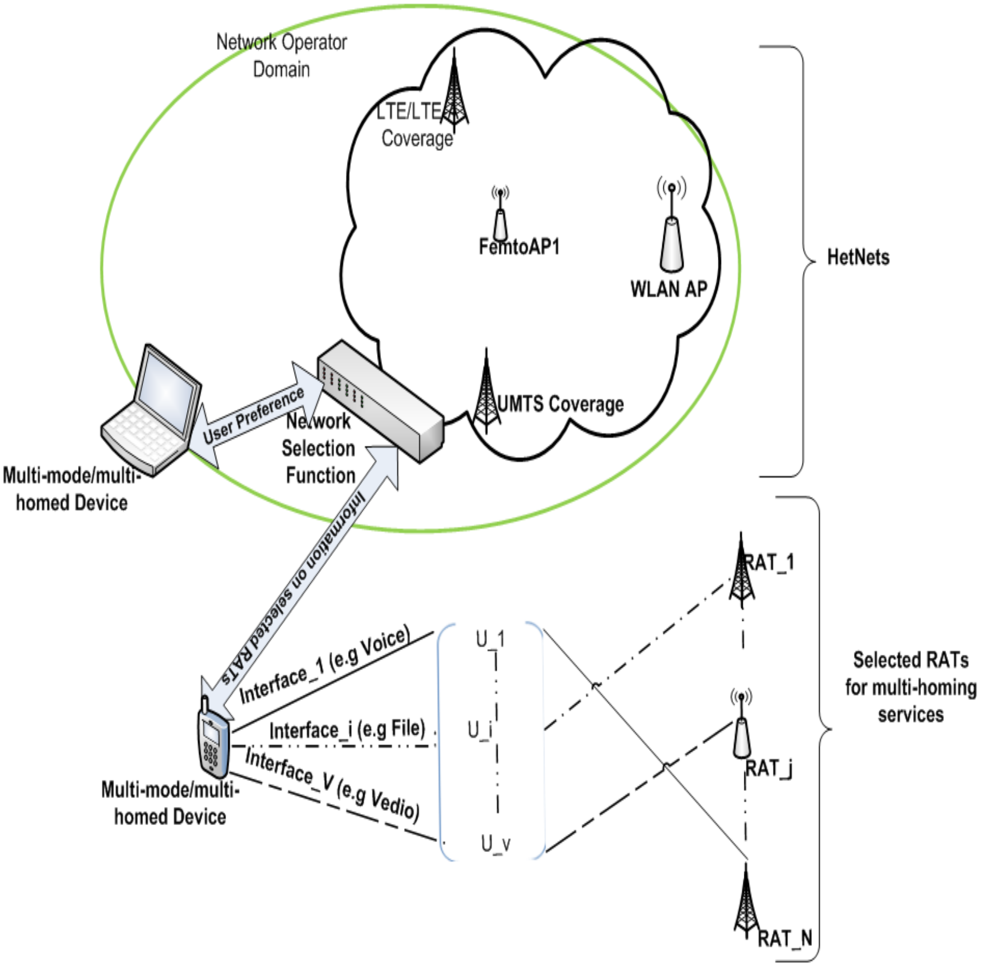

Figure 5.1: Framework for Network-Assisted Interface Manager

5.4.1 System model and problem formulation

The search algorithm employed by NIM is based on utility optimization. We consider a multi-mode/multi-home terminal in a HetNets environment. The HetNet consists of alternative access networks; (LTE, HSPA+, WLAN1, WLAN2, and WiMAX), denoted as R. where $R = \{r_1, r_2, \cdots, r_n\}$; $(r \geq 2)$, is the maximum number of RATs. We consider a set of criteria(C), where $C = \{c_1, c_2, \cdots, c_v\}$, $(v \geq 2)$. The mobile terminal support a finite set of network interface card (NIC), denoted as K, where $K = \{k_1, k_2, \cdots, k_u\}$; $(u \geq 2)$. The mobile terminal contains a graphical user interface (GUI) which allows users to manually specify their interface power, cost, acceptable network congestion requirements, and preference weighting. The criteria weights are specified in Equation 5.1 and normalized as described in Section 2.5.1.2.

$$W = \{w_{s,j}\}, s = \{1, \ldots, m\}, j = \{1, \ldots, v\} \tag{5.1}$$

The multiplicative utility function which has been applied for RAT selection [99, 103] is adopted for modelling the utility of each RAT based on specified criteria, according to the given equation:

$$U_i^{|R|} = \prod_{i=1}^{n} [u_v(x_i)]_i^w \tag{5.2}$$

Where $u(x_i)$ is the utility of each RAT with respect to each decision criterion, w is the user defined preference weight assigned to each criterion and U_i is the aggregate utility of RAT_i . The normalized bell-shaped sigmoidal function described in Equation 5.3 is used to compute the utility values for benefit (maximizing) criteria.

$$u(x) = \begin{cases} 0, & x < x_l \\ \frac{(\frac{x-x_l}{x_m-x_l})^{\mu}}{1+(\frac{x-x_l}{x_m-x_l})^{\mu}}, & x_l \leq x \leq x_m \\ 1 - \frac{(\frac{x_u-x}{x_u-x_m})^{\rho}}{1+(\frac{x_u-x}{x_u-x_m})^{\rho}}, & x_l \leq x \leq x_m \\ 1, & x > x_u \end{cases} \tag{5.3}$$

For cost (minimizing) criteria, the utility values can be obtained as $1 - u(x)$. Where x_l and x_u are the lower and upper bounds of each criterion x and x_m is the midpoint of the utility function while μ and ρ are the tuning parameters set by the users. $u_m = 0.5$, while the values of μ and ρ are computed based on Equation 5.4 and Equation 5.5, respectively. The values of x_l, x_u, and x_m are specified by users.

$$\rho = \frac{\mu(x_u - x_m)}{x_m - x_l} \tag{5.4}$$

$$\mu \geq max\{\frac{2(x_m - x_l)}{x_u - x_m}, 2\} \tag{5.5}$$

Using the above formulations, the NIM module computes the aggregate utility of each access network and selects the combination (or subset) of access networks that maximizes the total interface utility of the mobile terminal such that the total power consumption and cost are minimized. The multi-constraint optimization problem is formulated in Equation 5.6

$$f_{max} = max\{U_i^{|R|z}\} \tag{5.6}$$

Subject to:

$$\sum_{i=1}^{n} p_i.z \leq \widehat{P} \tag{5.7}$$

$$\sum_{i=1}^{n} c_i.z \leq \widehat{C} \tag{5.8}$$

$$\sum_{i=1}^{n} l_i.z \leq \widehat{L} \tag{5.9}$$

Where Equation 5.7, Equation 5.8 and Equation 5.9 are the constraints imposed on power consumption, cost and network congestion, respectively. $U_i^{|R|}$ is the total utility of each feasible combinations of RATs, and z is a selection factor, that is $z \in [0, 1]$. Therefore, z =1, (if selected) and z = 0,(if not selected). The parameters p_i, c_i and p_l represent the interface power, cost and network congestion of RAT_i , respectively. The parameters; $\widehat{P}$, $\widehat{C}$ and $\widehat{L}$ represent the upper bound on the UE interface power,cost and network congestion, respectively. The procedures for the RAT selection are described in the flow chart shown in Figure 5.2

Step 1: From the flow chart shown in Figure 5.2, the user specifies the supported interfaces, required RAT combinations, the preference values for each network criteria, and constraints on interface power and required service cost to the NIM module

Step 2: The NIM takes these parameters as input into the search algorithm, computes the possible RAT combinations that meet the user requirements, and select the best combinations for the mobile terminal. The network identifier and other layer 2 information about the selected RATs are sent to the mobile terminal. The search algorithm can also be applied to multi-mode terminals or mobile terminals with a single interface as shown in the flow chart.

Step 3: For the selection of RAT combinations that satisfy the power consumption, cost and congestion constraints, the NIM module computes the total number of RATs in the

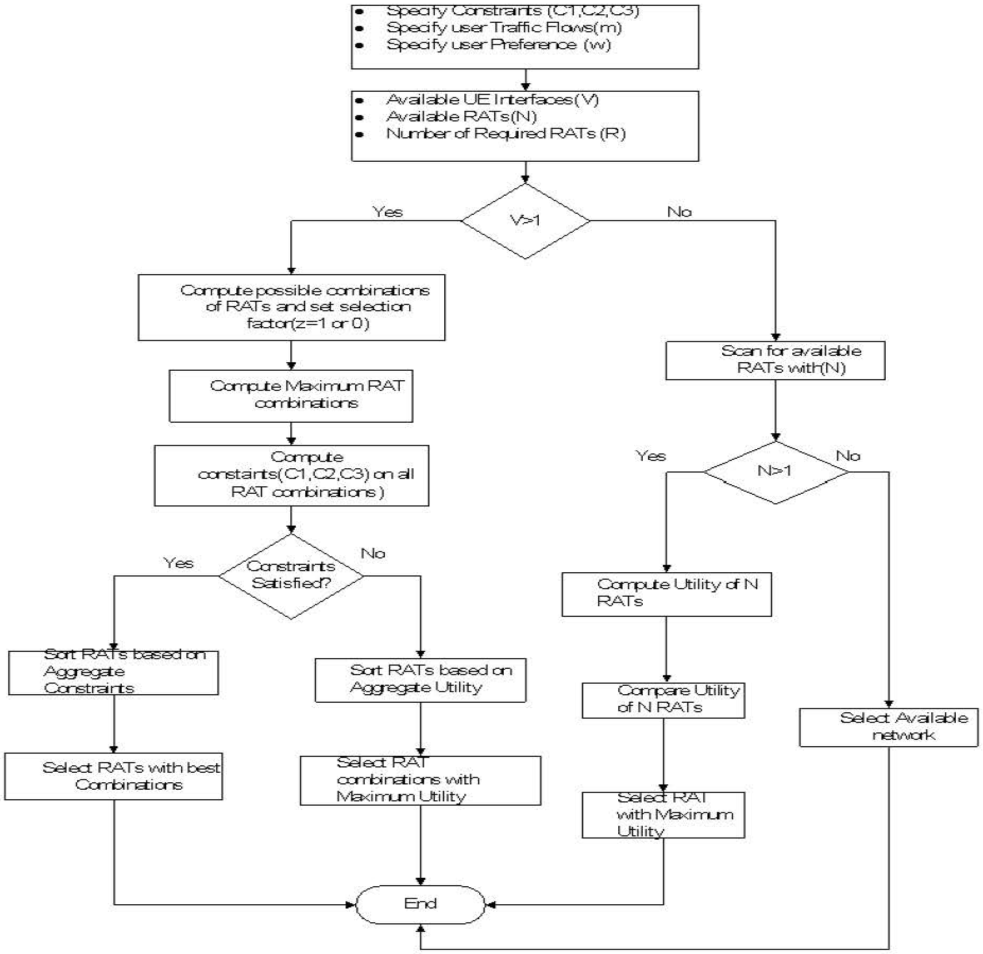

Figure 5.2: Flow chart for optimum RAT selection

search space (2^N) and set the selector factor, z =1 or $z = 0$. The module then computes the maximum possible RAT combinations.

Step 4: The algorithm computes the constraints on the selected RAT combinations and checks if the constraints are satisfied. The combinations which best satisfy the constraints are then selected for parallel transmission.

Step 5: If the constraints are violated on all the possible combinations, the RAT combinations are then sorted based on the aggregate utility values. The combination with maximum aggregate utility value is selected for multi-homing services.

5.4.2 Scenario and performance evaluation

To validate the above algorithm description, we consider the selection of RAT combinations that optimizes the terminal interfaces subject to constraints imposed on power consumption, cost and network congestion. The scenarios assume that the UE is within an overlapped coverage of five RATs and is equipped with three interfaces which support 3G/4G, WLAN and WiMAX networks. The user is within the vicinity of overlapped heterogeneous networks which consists of LTE (RAT1), HSPA+(RAT2), WLAN1(RAT3), WLAN2(RAT4) and WiMAX(RAT5). WLAN1 and WLAN2 are the IEEE 802.11a and 802.11b standard, respectively. For the purpose of simplicity, these RATs are refereed to as R1, R2, R3, R4 and R5, respectively. The network criteria parameters are given in Table 5.1. The parameters used for the simulation are: Power ($\widehat{P}$) = 7W, network cost ($\widehat{C}$) = 70unit/Mbps and acceptable congestion level ($\widehat{L}$) for the subset of RATs is taken as 80% (0.8).

Table 5.1: RAT criteria configuration.

Criteria RATs	**Data rate (Mbps)**	**Delay (ms)**	**Congestion(%)**	**Power (Watts)**	**Service price(Unit/Mb)**
LTE(R1)	$1-22$	25	5	5	50
HSPA(R2)	$1-8$	30	60	4	40
WLAN1(R3)	$1-54$	100	60	2	10
WLAN2(R4)	$1-11$	100	40	1	20
WiMAX(R5)	$1-25$	60	35	3	15

The user preference weights are assigned through the GUI of the mobile terminal using fuzzy preference relations. In real time, the wireless network environment is dynamic in nature; therefore the network simulation parameters are dynamically generated in order to obtain different network performance measure at different time instances. For three simulation instances, the results are shown in Table 5.2

Table 5.2: Optimum criteria values for RAT combinations

RAT Combinations	Scenario 1			Scenario 2			Scenario 3		
	Power(W)	Cost(Unit/Mb)	Congestion(%)	Power(W)	Cost(Unit/ Mb)	Congestion(%)	Power(W)	Cost (Unit/ Mb)	Congestion(%)
R1 R2 R3	5.018	106.029	0.561	4.037	71.763	0.779	5.929	35.087	0.692
R1 R2 R4	4.991	58.507	0.615	5.541	43.771	0.967	7.111	12.448	0.720
R1 R3 R4	3.733	101.224	0.767	5.648	41.846	0.684	5.717	28.178	0.682
R2 R3 R4	5.305	70.320	0.426	5.614	71.367	0.698	6.423	30.767	0.664
R1 R2 R5	5.023	72.009	0.613	3.663	47.510	1.08	7.029	15.942	0.663
R1 R3 R5	3.765	114.72	0.764	3.77	45.585	0.797	5.634	31.666	0.625
R2 R3 R5	5.338	83.822	0.423	3.736	75.106	0.810	6.340	34.261	0.607
R1 R4 R5	3.737	67.203	0.818	5.274	17.593	0.985	6.817	9.027	0.653
R2 R4 R5	5.310	36.3	0.478	5.240	47.114	.999	7.523	11.622	0.635
R3 R4 R5	4.052	79.017	0.629	5.347	45.189	0.716	6.128	27.346	0.597
Selected RAT	R2 R4 R5			R1 R3 R4			R2 R4 R5		

The ten possible RAT combinations and their corresponding power, cost and congestion values are shown in the first scenario. The results show that the best RAT combination which satisfies the constraints on power, cost and congestion level are RAT2, RAT4 and RAT5. In the situation where none of the RAT combination meets the constraint requirements, the best combination is selected based on aggregate utility values. In this scenario, therefore, RAT1, RAT4 and RAT5 are selected according to the utility results in Figure 5.3

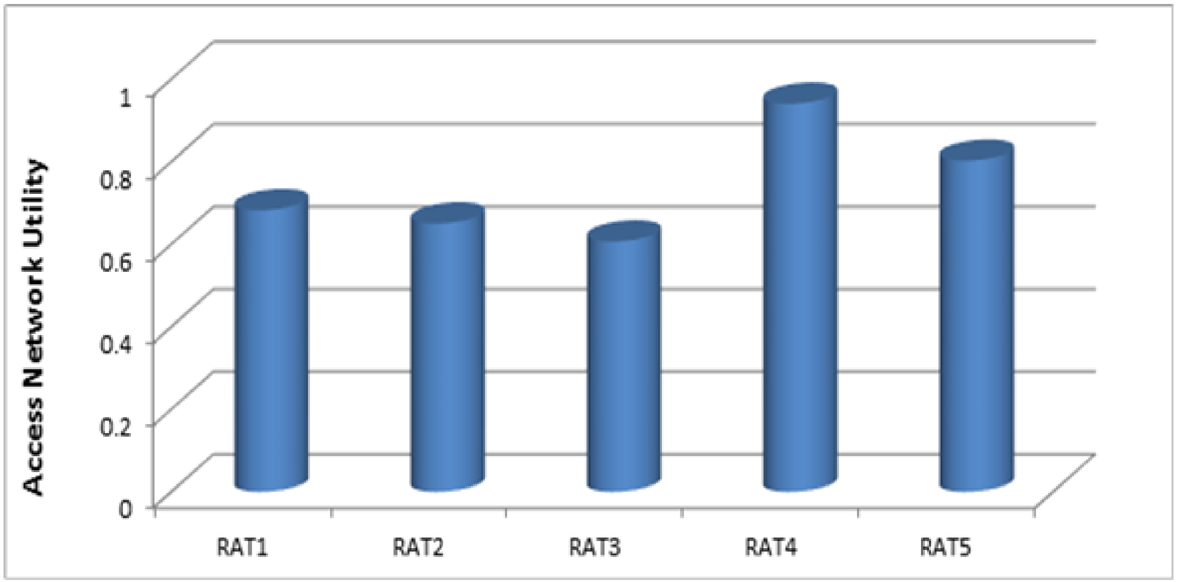

Figure 5.3: Available RATS in Scenario 1

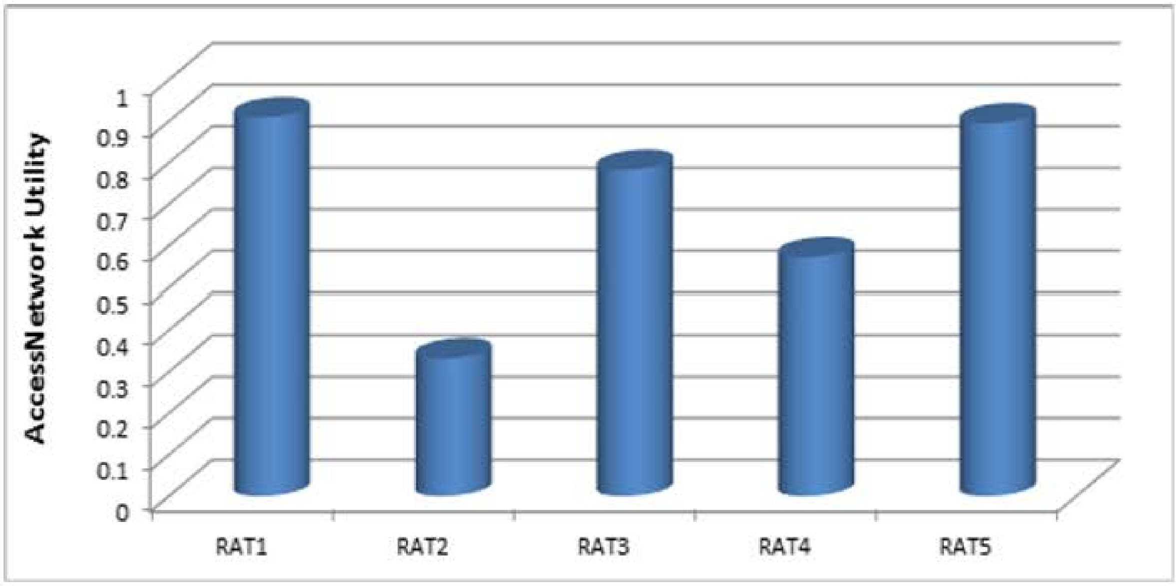

Figure 5.4: Available RATS in Scenario 2

The utility values are due to the contribution of other criteria such as data rate and delay. In the second scenario, the results in Table 5.2 show that the best RAT combination which satisfies the constraints on power, cost and congestion level are RAT1, RAT3 and RAT4. Similarly, for the third scenario, the best RAT combination are RAT1, RAT3, and RAT5. The computed aggregate utility for the second and third scenario are shown in Figure 5.4 and Figure 5.5, respectively.

5.5 Flow - Interface Assignment for Parallel Streaming in HetNets

The flow-interface assignment problem defines the technique for associating the subscribed applications for parallel streaming to the interfaces of the mobile terminal for uplink and downlink flows. In the context of this thesis, the flow-interface assignment problem assigns

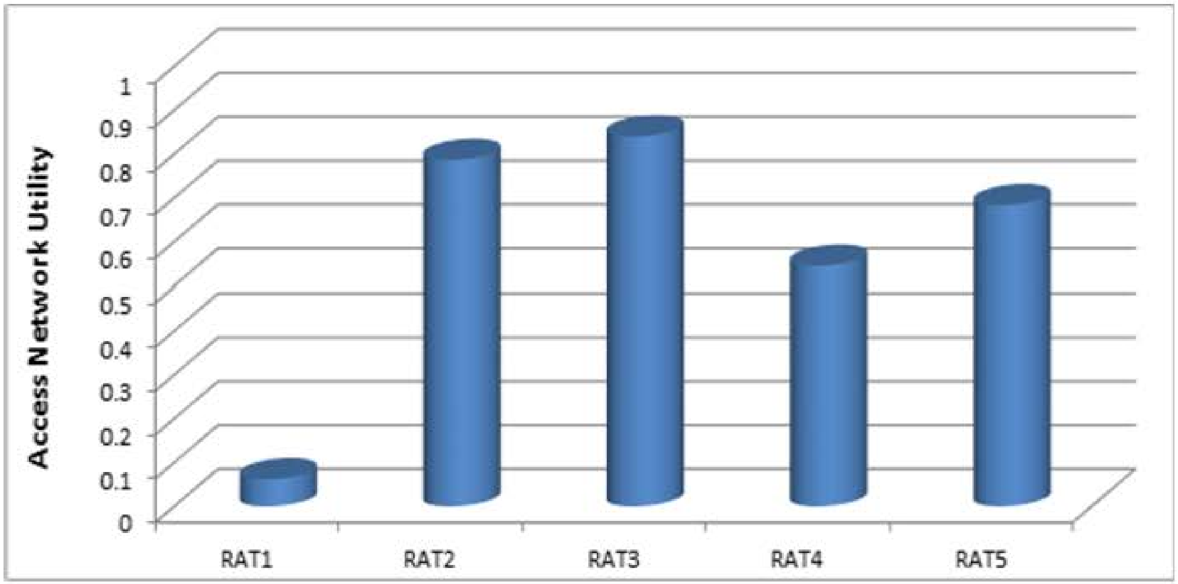

Figure 5.5: Available RATS in Scenario 3

each traffic flow from the most suitable RAT to the appropriate interfaces of the mobile terminal. The problems of assigning flows to multi-mode/multi-homed terminal interfaces from the most suitable RAT can be addressed in three solution steps:

- The first step is to determine the number of RATs needed to provide services to the user applications for parallel streaming.
- The second step provides the method of selecting the subset of RATs that optimizes the user terminal interfaces subject to the power, cost and congestion constraints imposed on the mobile terminal interfaces.
- The third step considers each application QoS requirements, the capability of each selected subset of RATs, and assigns each application to the appropriate RAT for parallel streaming.

The solution approach to the network-interface assignment problem discussed in this section, can be used to provide the required solution to the first two steps, while the third solution step can be addressed using the reward function defined in Equation 5.10.

$$R_{ij} = \sum_{i=1}^{s}(w_j.ln\frac{B_i - b_j}{\widehat{B}} + w_j.ln\frac{d_j - D_i}{\widehat{D}} + w_j.ln\frac{C_i}{\widehat{C}}) \tag{5.10}$$

Equation 5.10 describe the reward associated with assigning any application i to a given RAT j, where i = 1,2,..,s, and j=1,2,..n; s and n are the maximum numbers of requested applications and corresponding RATs, respectively. The utility value is computed for each application on each selected subset of RATs, using three QoS parameters: data rate, delay and network service cost. In Equation 5.10, B_i, D_i, and C_i are the available bandwidth, delay and cost of the selected subset of RATs, while b_j, and d_j, are the allowable data rate, and delay for the three applications, respectively. To evaluate R_{ij}, the simulation parameters in Table 5.3 and Table 5.4 have been defined, using standard values obtained from different network specifications. Table 5.3 provides the user defined criteria preferences on each application, while Table 5.4 are the default application characteristics.

Table 5.3: Normalized user preference weight on applications

Criteria RATs	**Data rate (Mbps)**	**Delay (ms)**	**load (%)**	**Power (Watts)**	**Service price(Unit/Mb)**
Voice	0.3350	0.1659	0.1659	0.2500	0.0850
File-download	0.2359	0.1761	0.1761	0.2359	0.1761
Video-streaming	0.2659	0.0675	0.0675	0.3330	0.2659

Table 5.4: Normalized user preference weight on applications

Criteria Applications	**Data rate (Mbps)**	**Delay (ms)**	**Service price(Unit/Mb)**
Voice	0.02	150	1.5
File-download	0.2359	0.05	2.0
Video-streaming	0.10	250	2.5

To evaluate the performance of the proposed flow-interface assignment of multi-mode/multi-homed terminal for parallel streaming of user applications, we implement the network-interface assignment solution described in Subsection 5.4.2. The solution provides the selection of RAT combinations that meets the user mobile terminal energy and cost requirements, and aggregate congestion level. Two simulation scenarios are carried out and the results are given in Figure 5.6 and Figure 5.7, respectively.

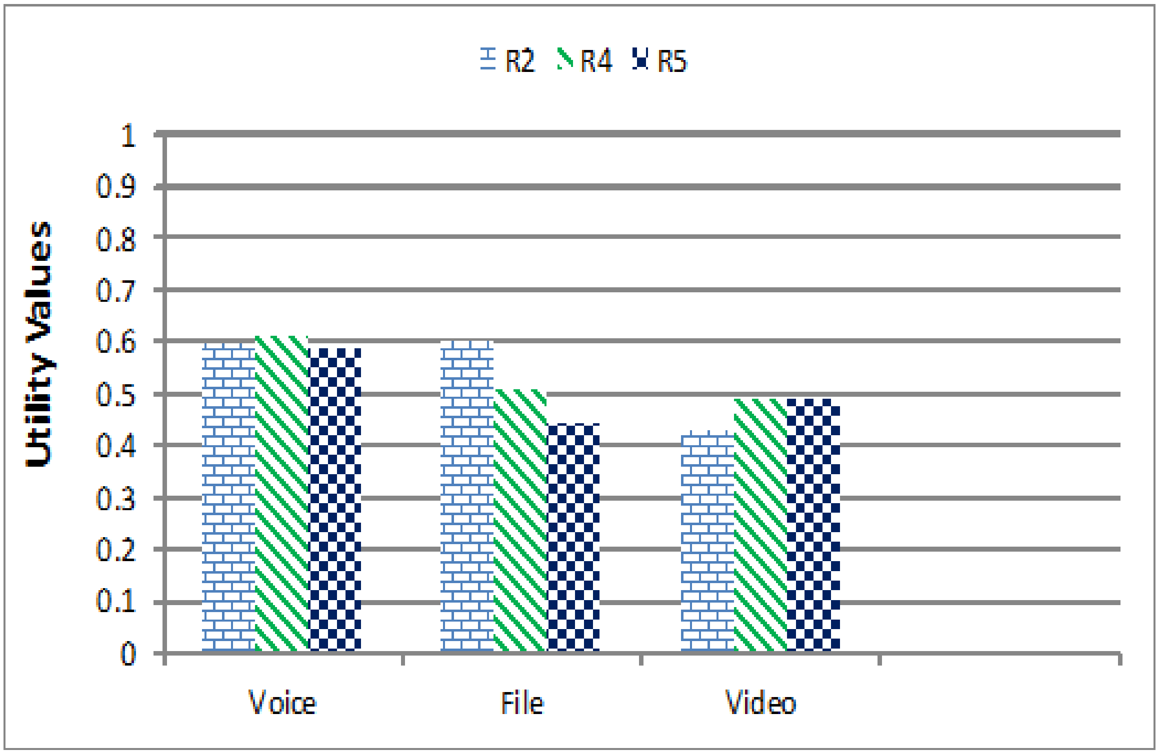

Figure 5.6: Plot of Utility values for voice, file-download and video in Scenario 1

Figure 5.6 presents the results of the first scenario, in which the best RAT combination for the parallel streaming of voice, file-download and video traffic is obtained as R1, R4 and R5, which represents LTE, WLAN2 and WiMAX access networks, respectively. Using the utility function defined in Equation 5.10 and the simulation parameters given in Table 5.3 and Table 5.4, the computed utility of voice on R1, R4 and R5 is given as 0.4421, 0.1772 and

0.4147, respectively. For file-download, the computed utility values on R1, R4, and R5 are given as 0.4421, 0.3286, and 0.4785, respectively. Similarly, the computed utility values of video-streaming, on R1, R4, and R5 are obtained as 0.4314, 0.5252, and 0.4380, respectively.

These results show that for parallel streaming of the three applications (voice, file-download and video-streaming), LTE is selected RAT for voice, WiMAX is selected for file-download and WLAN2 is selected for video-streaming. Considering the network and application criteria such as delay and congestion, LTE is the most suitable for voice, WLAN2 for file-download and WiMAX for video-streaming applications.

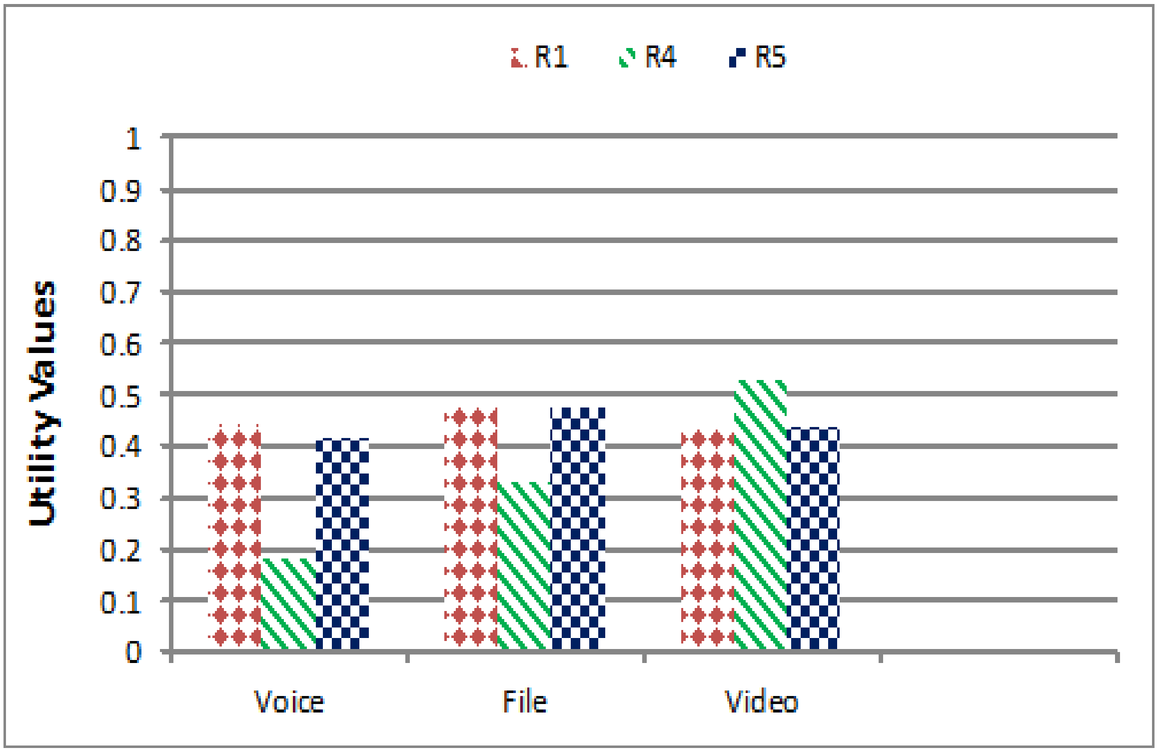

Figure 5.7: Plot of Utility values for voice, file-download and video-streaming in Scenario 2

In the second scenario, the best RAT combination for the parallel streaming of voice, file-download and video traffic is obtained as R2, R4 and R5, which represents HSPA, WLAN2 and WiMAX access networks, respectively. The computed utility of voice on R2, R4 and R5 is given as 0.5967, 0.6094 and 0.5903, respectively. For file-download, the computed utility values on R2, R4, and R5 are given as 0.6049, 0.5051, and 0.4438, respectively. Similarly, the computed utility values of video-streaming, on R2, R4, and R5 are obtained as 0.4334, 0.4921, and 0.4916, respectively.

These results for parallel streaming of the three applications (voice, file-download and video-streaming), show that WLAN2 is the selected RAT for voice, HSPA is selected for file-download and HSPA is selected for video streaming. To avoid the selection of two RATs for the same application, priority is assigned to each application, e.g file-download can be given a higher priority over video-streaming and the RAT selection is based on application priority level. In this scenario, therefore, HSPA is selected for file-download, while WiMAX access network, which is the RAT with the next higher utility value, is assigned to video-streaming.

5.6 Conclusion

In this chapter, the challenges associated with multi-mode/multi-homed mobile terminal during parallel transmission of user traffic has been considered. Basically, battery power consumption is the major factor that must be considered in order to enhance the efficiency of smart mobile devices. While network service cost remains a subjective criteria, the choice of congested RAT can adversely affect the QoS of the requested services. This chapter, therefore, presented a viable solution to the choice of a suitable RAT or subset of RATs that can minimizes mobile terminal power consumption, network congestion and service cost. Through this solution approach, the selection of congested or overloaded RAT can be avoided, which will further enhance the user QoE. The utility-based approach to RAT selection discussed in this chapter has been validated through different simulation.

Chapter 6

Conclusion and Future Works

6.1 Summary of Contributions

The need to provide telecommunication services that can meet the required level of satisfaction, or improve the perceived QoE of mobile users has been the primary goal of the network and service providers over the years. With the increasing demand for mobile services and the availability of smart mobile devices, the traditional cellular networks lack the resources to meet the numerous users service demands due to its limited capacity. A novel solution to this capacity limitation is the deployment of multiple RATs with different service capabilities such as data rate, service cost, mobility support, end-to-end delay and jitter, etc;. This solution which provides the mobile user with the flexibility to choose the most appropriate RAT among the available networks, has been the focus of this thesis. The choice of such RAT is considered against the user application request and capability of the mobile terminal as well as the service level agreements between the user and network operator.

In this work, we have considered various factors which determine the overall user perceived QoE on the requested applications. Various criteria such as the current status of the available networks, application requirements, terminal capabilities and user preferences have been considered as major factors needed to develop efficient schemes for the selection of appropriate RAT in a heterogeneous network. Specifically, the thesis has focused on providing efficient RAT selection schemes for multiple calls in HetNets. In most cases, new RAT selection algorithm has been proposed, performance evaluations have been carried out and performance comparison of the existing solutions with the proposed solutions have also been carried out under different network scenarios. A precise summary of the contribution of this work is outlined below:

- An extensive survey of recent and relevant literature on the evolution, the present and future trends of the wireless communication systems has been carried out. Specific methods on the choice of appropriate RAT or subset of RATs that can meet the user service request in a heterogeneous wireless network have been presented. Existing RAT selection techniques have been explored in order to provide more efficient RAT selection schemes.

- The Complex PRoprtional ASsesment (COPRAS) MADM method has been proposed as a new MADM algorithm, for the selection of approximate RAT for group multiple calls in heterogeneous networks. The performance of COPRAS method has been evaluated against existing MADM methods using different performance indicators such as ranking abnormality, ranking consistency ratio, handoff margin, and time complexity. The simulation results under different network scenarios show that

COPRAS method provides outstanding performance and improvement over existing solutions. The technique is simple, less complex and reduces handoff probability in heterogeneous wireless network.

- A new consensus-based MAGDM method has been proposed for the selection of the best RAT that can guarantee the QoS requirements of a grouped-multiple call. The consensus-based MAGDM method aggregates the QoS of the individual application into a collective QoS for the group calls. Two consensus-based MAGDM algorithms have been explored and their suitability for RAT selection for group calls has been evaluated under different network scenarios. Based on the performance evaluations of the two schemes; the method of coincidence among solution outperforms the method of coincidence among preferences using performance indicators such as ranking consistency, the number of consensus iterations and time complexity.
- Development of a multiple RAT selection scheme for simultaneous multiple application requests or parallel streaming in a heterogeneous wireless network environment: The scheme allows the user to specify criteria constraints on terminal battery usage, cost and network load or congestion state. It can be adaptively used to specify other network criteria, and select the best combination of RATs for parallel streaming based on the user specifications. Using a simple utility function, the assignment of the requested applications can be mapped to the appropriate terminal interfaces. The effectiveness of the scheme has been validated through simulation under dynamic network scenario.

6.2 Future Work

This thesis presented RAT selection schemes for multiple calls in next generation wireless networks. The solutions proposed for selecting a single RAT for grouped-multiple calls or a subset of RATs for multi-homing services have shown to be efficient for each class of call. However, there are more open issues that require further investigations, which will provide an improvement to the outcome of this work. Some research challenges that require further works are outlined below:

- An enhanced performance of MADM and MAGDM techniques for RAT selection: An enhanced performance of MADM technique for RAT selection can be achieved by investigating the suitability of some existing MADM methods for RAT selection or through the development of a generic MADM technique. The performance of such methods can be measured using other performance indicators, in addition to the ones provided in this thesis. A detailed complexity analysis can be carried out on such newly developed schemes.

- Use of packet level simulation for real-time performance evaluation: The work carried out in this thesis did not consider the use of packet level simulation. A Real-time performance evaluation of the RAT selection schemes proposed in this thesis can be carried out using packet level simulations tools such as NS3, OMNeT++, or a testbed setup.

- Use of learning algorithm such as Q-learning, Genetic algorithm, Simulated annealing, etc, can be explored to evaluate the effectiveness of the proposed RAT selection methods. Although some of these techniques may introduce additional complexity, some improved performance measures can be a trade offs.

6.3 Concluding Remarks

As the global search for simple, reliable and efficient RAT selection algorithms in HetNets continues to grow, this thesis has proposed some RAT selection schemes and provide suggestions for future works. The thesis, therefore, serves as a platform for contribution to existing solutions.

Appendix

Appendix A

COPRAS-G Method

A.1 COPRAS-G Ranking and Selection Procedures

Given a set of alternatives (X), where X is associated with a given set of criteria (C) and weight values (W) as described in Subsection 3.3.1, the procedures for COPRAS-G is given as follows:

Step 1: For the set of alternatives (X), with grey or interval values, construct the decision matrix as described below;

$$\otimes X = \begin{array}{c} \begin{bmatrix} \underline{d}_{1,1}; \overline{d}_{1,1} & \underline{d}_{1,2}; \overline{d}_{1,2} & \cdots & \underline{d}_{1,j}; \overline{d}_{i,j} & \cdots & \underline{d}_{1,n}; \overline{d}_{1,n} \\ \underline{d}_{2,1}; \overline{d}_{2,1} & \underline{d}_{2,2}; \overline{d}_{2,2} & \cdots & \underline{d}_{2,j}; \overline{d}_{2,j} & \cdots & \underline{d}_{2,n}; \overline{d}_{2,n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ \underline{d}_{i,1}; \overline{d}_{i,1} & \underline{d}_{i,2}; \overline{d}_{i,2} d_{i,2} & \cdots & \underline{d}_{i,j}; \overline{d}_{i,j} & \cdots & \underline{d}_{i,n}; \overline{d}_{i,n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ \underline{d}_{n,1}; \overline{d}_{n,1} & \underline{d}_{n,2}; \overline{d}_{n,2} & \cdots & \underline{d}_{n,j}; \overline{d}_{n,j} & \cdots & \underline{d}_{n,v}; \overline{d}_{n,v} \end{bmatrix} \end{array} \begin{array}{c} x_1 \\ x_2 \\ \vdots \\ x_i \\ \vdots \\ x_n \end{array}, \tag{A.1}$$

The parameter $\underline{d}_{n,v}; \overline{d}_{n,v}$ define the lower and upper limits of the respective criteria specification.

Step 2: The normalization process of the decision matrix is obtained as shown:

$$\widehat{\underline{d}}_{i,j} = \frac{2\underline{d}_{i,j}}{\sum_{j=1}^{v}(\underline{d}_{1,j} + \overline{d}_{i,j})}, \ \widehat{\overline{d}}_{i,j} = \frac{2\underline{d}_{i,j}}{\sum_{j=1}^{v}(\underline{d}_{1,j} + \overline{d}_{i,j})} \tag{A.2}$$

Step 3: A new matrix is formed which is the normalized decision matrix.$(\otimes X)$ The weighted normalized decision matrix is obtained by multiplying the normalized decision matrix by the respective weight of each criterion.

$$\widetilde{\underline{d}_{i,j}} = \widehat{\underline{d}}_{i,j} w_j, \ \widetilde{\overline{d}_{i,j}} = \widehat{\overline{d}}_{i,j} w_j \tag{A.3}$$

Step 4: Determine the sum of the maximizing and minimizing criteria:

$$S_i^+ = \frac{1}{2}\sum_{i=1}^{l}(\widetilde{\underline{d}_{i,j}} + \widetilde{\overline{d}_{i,j}}) \tag{A.4}$$

$$S_i^- = \frac{1}{2}\sum_{i=l+1}^{v}(\widetilde{\underline{d}_{i,j}} + \widetilde{\overline{d}_{i,j}}) \tag{A.5}$$

Step 5: The relative significance of each alternative is determined as follows:

$$Q_i = S_i^+ + \frac{minS_i^- \sum_{j=1}^{v} S_i^-}{S_i^- \sum_{j=1}^{v} \frac{minS_i^-}{S_i^-}} \tag{A.6}$$

The alternatives are ranked in descending order based on the values of Q_i and the utility degree of each value is obtained according to Equation 3.9.

Appendix B

Accompanying CD-ROM

B.1 Chapter Three Codes

The Accompanying CD-ROM contains the following MATLAB codes for chapter Three results:

- Ranking Comparison for SAW, MEW ,TOPSIS and COPRAS MADM Method.
- Ranking Comparison for Group Calls using the Method of TOPSIS and COPRAS.
- Ranking Results with dynamic criteria.
- Processing time and handoff margin for Group Calls using the Method of TOPSIS and COPRAS.

B.2 Chapter Four Codes

The Accompanying CD-ROM contains the following MATLAB codes for chapter Four results:

- RAT Selection for Group Calls using method of Coincidence Among Preferences.
- RAT Selection for Group Calls using method of Coincidence Among Solutions.
- Processing Time for Soft Coincidence Methods.

B.3 Chapter Five Codes

The Accompanying CD-ROM contains MATLAB codes for Chapter Five results:

- Utility-based RAT selection for parallel streaming.

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