CONTEXT-AWARE MULTI-ATTRIBUTE DECISION MAKING FOR RADIO ACCESS TECHNOLOGY SELECTION IN ULTRA DENSE NETWORK

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Abstrak

Rangkaian Ultra Padat (UDN) merupakan kepadatan ekstrem pelbagai Teknologi Capaian Radio (RAT) yang diletakkan berdekatan antara satu sama lain dalam koordinasi selaras atau tidak selaras. Kepadatan RAT ini membentuk pertindihan zon liputan isyarat yang menyebabkan kekerapan penyerahan perkhidmatan antara RAT yang mengakibatkan pengurangan prestasi sistem secara keseluruhan. Pendekatan pemilihan RAT semasa lebih cenderung kepada kriteria berpusatkan rangkaian yang berkaitan dengan kekuatan isyarat. Namun, anjakan paradigma daripada pendekatan berpusatkan rangkaian kepada pendekatan berpusatkan pengguna memerlukan proses pemilihan pelbagai kriteria, dengan metodologi yang mengaitkan pilihan rangkaian dan pengguna dalam konteks rangkaian generasi masa hadapan. Oleh itu, pendekatan pemilihan yang berkesan diperlukan bagi mengelak penyerahan RAT yang tidak perlu. Tujuan utama kajian ini adalah untuk mencadangkan pembuatan keputusan Peka Konteks Pelbagai-Atribut untuk pemilihan RAT (CMRAT) bagi menyelidik keperluan dalam memilih RAT yang baharu dan seterusnya menentukan kaedah yang terbaik di kalangan kaedah yang ada. CMRAT terdiri daripada dua mekanisma iaitu Proses Analisis Hierarki Peka Konteks (CAHP) dan Teknik Peka Konteks untuk Keutamaan Susunan Keserupaan dengan Penyelesaian Ideal (CTOPSIS). Mekanisma CAHP mengukur keperluan menukar daripada RAT semasa, manakala CTOPSIS pula membantu dalam membuat keputusan untuk memilih sasaran RAT yang terbaik. Satu siri kajian eksperimental telah dijalankan untuk mengesahkan keberkesanan CMRAT bagi memperbaiki prestasi sistem. Kajian ini menggunakan senario pusat membeli belah dan rangkaian bandar yang padat bagi menilai prestasi pemilihan RAT melalui simulasi. Dapatan kajian menunjukkan bahawa pendekatan CMRAT mengurangkan kelengahan dan bilangan serahan yang membawa kepada peningkatan daya pemprosesan dan nisbah penghantaran paket berbanding pendekatan A2A4-RSRQ yang selalu digunakan. Pendekatan CMRAT adalah berkesan untuk pemilihan RAT dalam persekitaran UDN dan seterusnya menyokong penggunaan pelbagai RAT dalam rangkaian 5G masa hadapan. Dengan pemilihan peka konteks, ciri berasaskan pengguna juga telah diberikan penekanan.

Kata kunci: Pemilihan peka konteks, Rangkaian pelbagai, Teori pembuatan keputusan pelbagai-atribut.

Abstract

Ultra Dense Network (UDN) is the extreme densification of heterogeneous Radio Access Technology (RAT) that is deployed closely in coordinated or uncoordinated manner. The densification of RAT forms an overlapping zone of signal coverage leading to the frequent service handovers among the RAT, thus degrading overall system performance. The current RAT selection approach is biased towards network-centric criteria pertaining to signal strength. However, the paradigm shift from network-centric to user-centric approach necessitates a multi-criteria selection process, with methodology relating to both network and user preferences in the context of future generation networks. Hence, an effective selection approach is required to avoid unnecessary handovers in RAT. The main aim of this study is to propose the Context-aware Multi-attribute decision making for RAT (CMRAT) selection for investigating the need to choose a new RAT and further determine the best amongst the available methods. The CMRAT consists of two mechanisms, namely the Context-aware Analytical Hierarchy Process (CAHP) and Context-aware Technique for Order Preference by Similarity to an Ideal Solution (CTOPSIS). The CAHP mechanism measures the need to switch from the current RAT, while CTOPSIS aids in decision making to choose the best target RAT. A series of experimental studies were conducted to validate the effectiveness of CMRAT for achieving improved system performance. The investigation utilises shopping mall and urban dense network scenarios to evaluate the performance of RAT selection through simulation. The findings demonstrated that the CMRAT approach reduces delay and the number of handovers leading to an improvement of throughput and packet delivery ratio when compared to that of the commonly used A2A4-RSRQ approach. The CMRAT approach is effective in the RAT selection within UDN environment, thus supporting heterogeneous RAT deployment in future 5G networks. With context-aware selection, the user-centric feature is also emphasized.

Keywords: Context-aware selection, Heterogeneous networks, Multi Attribute Decision Making Theory.

Declaration Associated with This Thesis

Some of the works presented in this thesis have been published or submitted as listed below.

[1] Adib Habbal, **Swetha Indudhar Goudar** and Suhaidi Hassan. “Context-aware Radio Access Technology Selection in 5G Ultra Dense Networks”, 2017. IEEE Access , vol.PP, no.99, pp.1-1 doi: 10.1109/ACCESS.2017. 2689725.

[2] **Swetha Indudhar Goudar**, Adib Habbal, and Suhaidi Hassan. “5G: Next Wave of Digital Society Challenges and Current Trends”. Journal of Telecommunication, Electronic and Computer Engineering, e-ISSN: 2289-8131 Vol. 9, pp-63-66, 2017.

[3] **Swetha Indudhar Goudar**, Adib Habbal, and Suhaidi Hassan. Context-aware Multi-criteria Framework for RAT Selection in 5G Networks. Advanced Science Letters, 2017. [Accepted for publication in the SCOPUS INDEXED Journal]

[4] **Swetha Indudhar Goudar**, Adib Habbal, and Suhaidi Hassan. “Context-aware Multi- Attribute Radio Access Technology Selection for 5G Networks”. In proceedings of the 4th International Conference on Internet Applications, Protocols and Services (NETAPPS), 2015, ISBN 978-967-0910-06-2.

[5] **Swetha Indudhar Goudar**, Suwannit Chareen Chit, Benzitouni Mounira, Moumen Radia, and Suhaidi Hassan. “Implementation of an Offloading Strategy in Heterogeneous Environment”. In proceedings of the 4th International Conference on Internet Applications, Protocols and Services (NETAPPS), 2015, 978-967-0910-06-2.

[6] **Swetha Indudhar Goudar** and Suhaidi Hassan. Active Queue Management in Long Term Evolution all IP networks. In proceedings of Computer Science, Communication and Instrumentation Devices, Research Publishing Services, 2014.

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List of Abbreviations

1G	First Generation
2G	Second Generation
3G	Third Generation
3GPP	Third Generation Partnership Project
4G	Fourth Generation
5G	Fifth Generation
ANDSF	Access Network Discovery Selection Function
AP	Access Point
AC	Actual Context
ANOVA	Analysis of Variance
AHP	Analytic Hierarchy Process
ANP	Analytical Network Process
CDMA	Code Division Multiple Access
CR	Coherence Ratio
CI	Consistency Index
CAHP	Context-aware Analytical Hierarchy Process
CMRAT	Context-aware Multiple Attribute Radio Access Technology
CTOPSIS	Context-aware Technique of Order Preference by Similarity to Ideal Solution
DF	Degree of freedom
DS-I	Descriptive Study-I
DS-II	Descriptive Study-II
DRM	Design Research Methodology
D2D	Device to Device
DIA	Distance to Ideal Alternative
EPC	Evolved Packet Core
EC	Expected Context
FDMA	Frequency Division Multiple Access
GPRS	General Packet Radio Services
GSM	Global System for Mobile
GRA	Grey Relational Analysis

HeNB	Home evolved Base station
HT	Horizontal Techniques
IT	Information Technology
ITU	International Telecommunication Union
IoT	Internet of Things
LTE	Long Term Evolution
LTE-A	Long Term Evolution-Advanced
M2M	Machine to Machine
MST	Mean Square for Treatment
MSE	Mean Square of Error
MIH	Media Independent Handover
METIS	Mobile and wireless communications Enablers for the 2020 Information Society
MCHO	Mobile Controlled Handover
MME	Mobility Management Entity
MN	Moving Networks
MADM	Multiple Attribute Decision Making
MIMO	Multiple Input Multiple Output
MEW	Multiplicative Exponent Weighting
NIST	National Institute of Standards and Technology of the United States
NCHO	Network Controlled Handover
NS-3	Network Simulator 3
NGN	Next Generation Network
PDR	Packet Delivery Ratio
PGW	Packet Gateway
PoA	Point of Attachment
PC	Power Consumption
PS-I	Prescriptive Study-I
QCI	Quality Channel Index
QoE	Quality of Experience
QoS	Quality of Service
RAT	Radio Access Technology
RSRQ	Radio Signal Receiving Quality

RI	Random Index
RIF	RAT Initiation Factor
RSS	Received Signal Strength
RC	Research Clarification
SGW	Serving Gateway
SINR	Signal into Interference Noise Ratio
SAW	Simple Additive Weighting
SSE	Sum of Squares of Errors
SST	Sum of Squares Treatment
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
TDMA	Time Division Multiple Access
UDN	Ultra Dense Networks
UMTS	Universal Mobile Telecommunication Systems
UE	User Equipment
V2V	Vehicle to Vehicle
VHO	Vertical Handover
VOIP	Voice Over IP
WPM	Weighted Product Method
WRMA	Weighted Rating of Multiple Attributes
Wi-Fi	Wireless Fidelity
WiMAX	Worldwide Interoperability for Microwave Access
WWW	World Wide Web
WWWW	Wireless World Wide Web

CHAPTER ONE
INTRODUCTION

The recent societal development and explosion of smart phone usage with ubiquity support are leading to the avalanche of mobile and wireless traffic volume forecasted to intensify thousand fold over the next decade [1]. This phenomena is compelling academia and industry alike toward investigating new approaches in mobile wireless communication systems infrastructure. Furthermore, the increased demand for service support for a plethora of existing and new applications has accelerated the evolution of wireless networks into the Fifth Generation (5G) technology, which is more of a revolution rather than evolution from previous generations [2].

In short, the 5G technology is an augmentation of legacy wireless Radio Access Technologies (RATs), such as Wireless Fidelity (Wi-Fi), Global System for Mobile Communications (GSM), Universal Mobile Telecommunications System (UMTS), Worldwide Interoperability for Microwave Access (WiMAX), Long Term Evolution (LTE), and Long Term Evolution-Advanced (LTE-A) to support the thousand fold increase in traffic with massive connectivity [3]. Figure 1.1 shows the transformation in support of traffic types and evolution from the First Generation (1G) to 5G Technology. Initially, the 1G aimed at achieving voice-only communication, while the Second Generation (2G) enhanced voice communication with short text messages. Next, the Third Generation (3G) introduced multi-media applications with voice and text, but encountered bandwidth limitation issues.

Meanwhile, the Fourth Generation (4G), also known to be the all Internet Protocol (IP) or the mobile Internet era, camouflaged all issues of the previous generation for better coverage and service with all voice, text, and multi-media applications being supported [4]. The superior expectations of the users are converging toward the future generation of wireless broadband technology, namely the 5G with different dimensions of communication strategies.

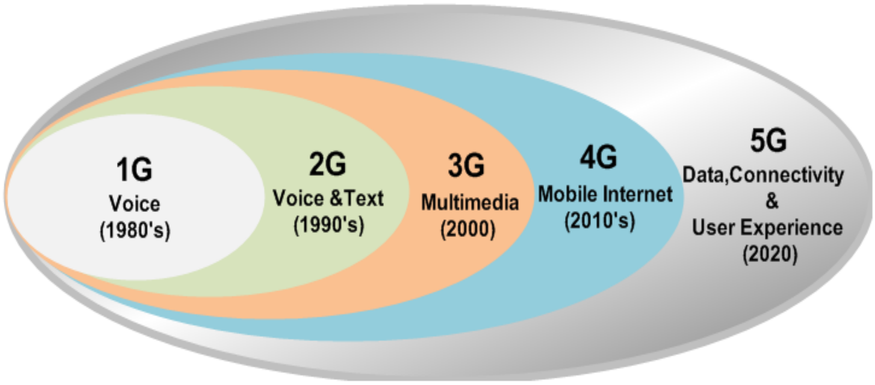

Figure 1.1. Evolution from 1G to 5G Technology [5]

This chapter aims to frame the thesis of this work within its context, where the general background of the research is described briefly. This chapter begins with an introductory overview of wireless communication network and research challenges, followed by a brief description of the features of 5G. Section 1.2 discusses some motivating factors that drive the need for studying the design and concept of RAT selection. The problem statement is stated in Section 1.3 where the current issues and challenges of RAT selection are addressed. In Section 1.4, the research questions are presented, so as to frame the research objectives, scope, and research steps, of which are presented in Section 1.5, 1.6, and 1.7, respectively. Meanwhile, the research significance is highlighted in Section 1.8, and finally, the dissertation organisation is outlined in Section 1.9.

1.1 The 5G Wireless Communication

The 5G wireless communication technology does not substitute the existing technologies, but rather integrates and supports them with new technology. The main design objectives behind the 5G technology are the realisation of the required massive capacity and connectivity, support for diversified set of services, applications, and consumer and network operator requirements to cater for the massive demand of services, while having efficient utilisation of all available non-contiguous spectrum of resources; in short transforming from World Wide Web (WWW) to Wireless World Wide Web (WWWW) [3].

Current human-centric scenarios of communication will in the near future converge toward the Internet of Things (IoT), dominated by machine to machine and device to device scenarios. Further co-existence of human and machine type communication leads to diversity in communication standards while increasing the data traffic with diverse types of applications. The 5G technology promises to integrate multiple communication standards, expecting to be an ultra-broadband network infrastructure [6]. Figure 1.2 represents a clear picture about the evolution of 5G technology and its capacity. The symbiotic integration of existing new technologies to meet 1000X times increased demands. The 5G technology is the integration of technical concepts namely, massive Multiple Input Multiple Output (MIMO), Ultra-Dense Networks (UDN), Moving Networks (MN), Device-to-Device (D2D), ultra-reliable, multi-Radio Access Technology (RAT), and Machine-to-Machine (M2M) communication for sustaining the expected voluminous data and vast range of applications to overcome system limitations. Initial research directions were analysed based on scenarios and research challenges as reported in [7, 8].

1.1.1 Ultra Dense Networks

One of the driving feature in 5G networks is the UDN, which is the extreme deployment of base stations and access points in very close proximity to give a uniform experience to users across the network, with the heterogeneity feature to satisfy the exponential growth of traffic that is said to explode to 1000X times more than the current by 2020 [1]. The main motivation in 5G is toward energy efficiency, cell coverage, and hyper-fast response.

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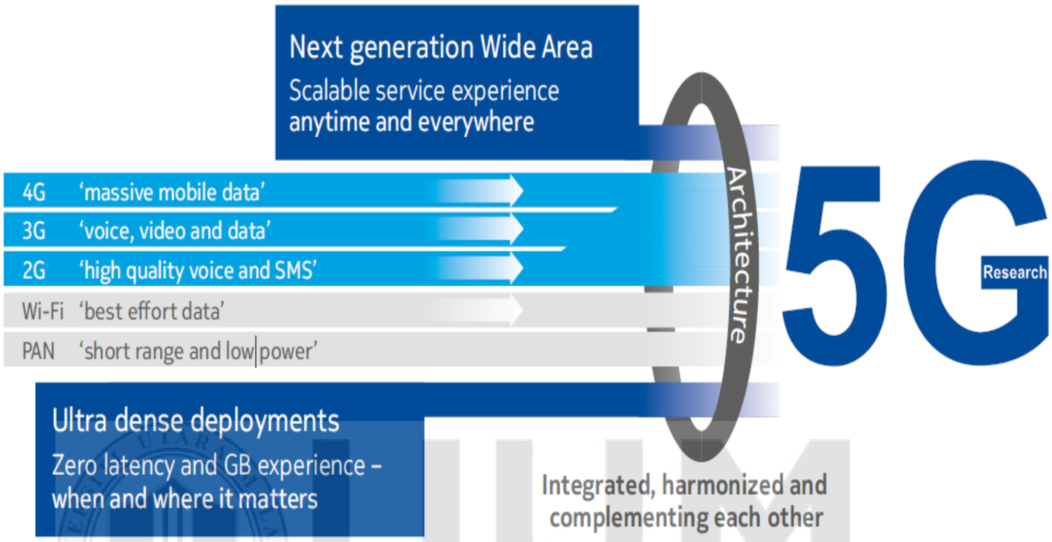

Figure 1.2. Integration of 1G to 4G to Evolve as 5G Technology [9]

All these requirement demands are difficult to be achieved by a macro base station or the central core network. Hence, next generation digital wave needs a holistic approach to handle heterogeneous environment significantly, which gave rise to the concept of small cells, like micro, femto, and pico base stations, to offload the traffic [8]. The small cells are comprised within the macro cell region to handle the increased traffic in an efficient manner, where each small cell aids in managing the traffic across the network by handling the voluminous demand.

The concept of small cells enables better network resource utilisation and cost efficiency for providing better Quality of Experience (QoE) to the user [10, 11]. The small base stations require less power; consequently, the energy efficiency problems are resolved. This situation possesses a win-win opportunity to the user and operators. However, due to the random close deployment of RAT access points, there is frequent handovers, which may result in a dynamic on-off of carrier selection. Frequent handovers will not only degrade system performance, but also consume power. Hence, it is an open research area for introducing an efficient decision making approach in handling unnecessary handovers in the UDN.

1.1.2 Heterogeneous Multi-RAT Environment

The UDN introduced earlier, is the extreme densification of the RAT. The infrastructure of RAT deployment is not only dense, but also heterogeneous in nature. Hence, UDN consists of multi-RAT, which is heterogeneous. In short, the upcoming deployment of RAT for future generation is the multi-RAT heterogeneous environment [12, 13] of licensed and unlicensed networks deployed in an uncoordinated manner.

There will be numerous devices and networks being interconnected in driving the heterogeneity feature by enabling different cell sizes and access points of diverse RAT to provide a smooth operating environment [14, 15]. The vision of multi-RAT in small cells and WLAN implementation is to balance the load and attain high spectral efficiency along with uniform user experience.

The 5G devices are designed for multi-interface to different RATs. The challenge encountered by a multi-RAT environment is appropriate RAT selection to serve diverse applications. The max-Received Signal Strength (RSS) and Signal into Interference Noise Ratio (SINR) based techniques will not be efficient for the emerging complete wireless technology.

1.2 Research Motivation

According to the survey by Ericsson [16], social networking contributes the second largest traffic volume which is expected to increase in the future. This forces operators to adopt advanced and sophisticated redesigned network techniques to support this new phenomenon which cannot be met with a single wireless network [17, 18]. Heterogeneous networks, which is the integration of different RATs, offer the flexibility for mobile devices to move across multiple RATs with varying strengths to cater for numerous applications [12]. This mobility between multiple RATs necessitates Vertical Handover (VHO) for convenience rather than connectivity reasons (for example, according to user choice for a particular service). Two of the major challenges in VHO management are seamlessness and automation aspects in network switching.

Transition to 5G technology era with enabled architecture for assorted applications anywhere, anytime with multiple interfaced devices is allowing seamless mobility in dynamic scenarios. This approach is the proactive management of user, terminal, and network demand instead of simply reacting to instantaneous channel demand. The choice of serving RAT among available multiple RATs efficiently in the 5G technology environment is of paramount importance [19]. Being the heterogeneous ultra dense network, there is a close deployment of access points to serve users with better coverage. This feature provides the coverage, while frequent handovers are encountered due to the overlapping coverage of RATs, resulting in the degradation of overall system performance.

Traditionally, the handover is based on RSS only, tailoring toward the requirements of a new generation of communication standards and patterns, where there is a need to consider a few more aspects of utilising network resources along with preserving user preference for good service seamlessly with the context. The 5G technology is claimed to be a more user-centric approach, co-existing with device and machine communication. Most devices use a multiple RAT environment to achieve the task. This motivates the triggering of an improved framework of networks, devices, and applications with a very closely co-ordinated multiple RAT environment to achieve co-optimised service between both the network and device [20].

The Mobile and wireless communications Enablers for the Twenty-twenty Information Society (METIS) [21] is a project co-founded by the European Commission with an objective to lay a foundation for future mobile and wireless communications system for 2020 and beyond. A path toward the 5G technology by METIS is committed to contribute via partners with individual or joint contributions to the standardisation and regulatory bodies, in particular in CEPT, 3GPP, ITU, ITU-R, ETSI, and IEEE [22]. Vertical handover is one of the open research areas METIS is exploring as part of smart mobility management because it is going to be the platform to support several new applications like Vehicle to Vehicle (V2V), Device to Device (D2D) and Machine to Machine (M2M) concepts in future 5G technology.

Vertical handover decision gains momentum because of the availability of different wireless access networks mapping to serve mobile terminals with multiple access interfaces. Further, VHO is scaled to RAT selection because the architecture of multi-interface multi RAT UDN enables the terminal to choose among the multiple RATs. So, enhancing the selection of RAT in multiple RAT and multimodal interface in an ultra-dense environment is vital. Figure 1.3 depicts the multiple RAT connected to different mobile terminals. A balanced mapping of a mobile device to appropriate RAT in available RATs is very critical.

With the heterogeneous network, there is a VHO; the handover between the two different RATs. However, in the case of a UDN environment, it is not only the VHO, but the User Device (UD) needs to choose among the multiple RATs available due to the extreme densification of access point deployment.

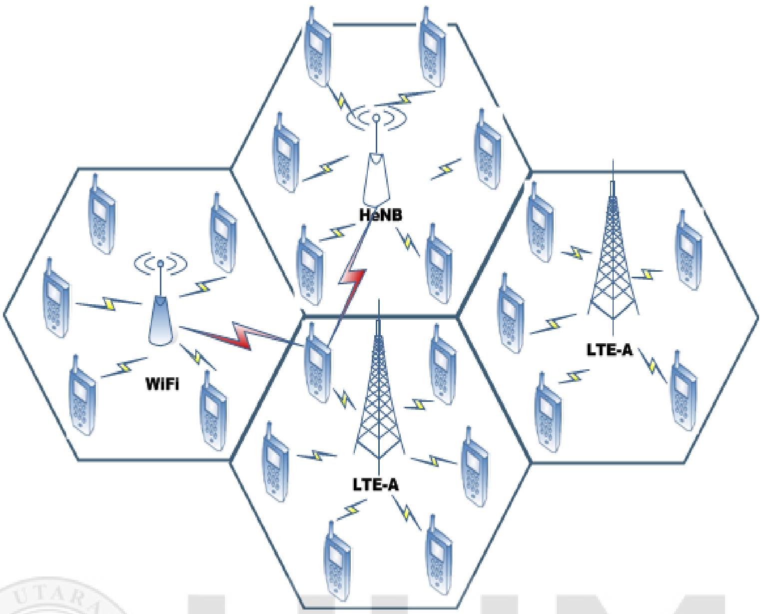

Figure 1.3. Multiple RAT Connected with Numerous Mobile Terminals

In the case of VHO, the UD knows the target to switch, while in the case of RAT selection, it needs to choose among the ones which are available. The RAT selection is the enhancement of the VHO. The UD is multi-interfaced, therefore, it can access more than one RAT at a time in a multi-RAT environment. The UD is in the overlapping coverage scope of more than one RAT, and at this junction, it cannot be just handed over, but a selection is required to be made wisely.

1.3 Problem Statement

The convergence of wireless access technologies toward a new generation of wireless networks should overcome several challenges before practical implementation. The vertical handover, switching between two different RATs, is an implicit challenge in a multi RAT environment, where the aim is to achieve better service and staying connected while moving. Numerous VHO approaches had been proposed for selecting an appropriate RAT based on gathered information, primarily focusing on RSS and a few combined criteria, like available bandwidth, power consumption, and user preference of the application [23, 24, 25, 26]. The majority of these approaches are simply based on RSS to make a handover, hardly considering many criteria to initiate the VHO process. This would be an inadequate solution for the future 5G networks due to the required support for a plethora of new applications and horizontal views, necessitating the consideration of more criteria, rather than just RSS and bandwidth only. Like the previous generation, it is not the decision of VHO only, but the UDN infrastructure influences the VHO enhancement toward RAT selection in choosing the most appropriate RAT among the multiple RATs available.

The imperative method of RAT selection based on RSS quality or power will not be efficient in a multi-RAT UDN environment. In the imperative approach based decision, the VHO is triggered either when the current RAT RSS value diminishes or when the neighbour RAT RSS value is sensed to be better than the current serving RAT. As such, RAT selection will degrade the performance of the UDN multi-RAT environment. The close deployment of RATs will only lead to frequent handovers with the imperative approach. Hence, an appropriate mechanism with multi-criteria is essential, which is difficult to achieve with just a single or a few criteria [27]. Multiple Attribute Decision Making (MADM) is the recommended approach for efficient VHO in a heterogeneous environment [28], where it can resolve the issue of considering many criteria, but the right situation to react still remains an area to be investigated. MADM is a quantitative computational technique incorporated in decision making over available alternatives, usually suited for problems that are conflicting and complex in nature to resolve.

The mechanism in obtaining the multi-criteria information without demanding extensions on the network infrastructure was proposed by Kaloxylos et al. [19] in realising the need for better RAT selection. The literature revealed that most future wireless infrastructures should converge toward situation based decisions depending on the differentiated applications demand [29, 30, 31]. A good survey and analysis of different approaches to handle VHO in RAT selection issues were discussed and mainly highlighted that the prominence of context-aware strategy as an efficient decision making [32, 33] was to be recommended. A recent definition of context was defined as "any information that can be used to characterise the situation of an entity, where an entity can be a person, place, or physical or computational object" and they went on to define context-awareness or context-aware computing as "the use of context to provide task-relevant information and/or services to a user, wherever they may be" [34].

The traditional approaches tend to achieve RAT selection by considering RSS or a few criteria, which are strongly intended for horizontal handover. However, this is inadequate for future wireless communications of 1000X traffic and multi-RAT heterogeneous UDN. Hence, there is a need to have an efficient RAT selection approach for the UDN environment, where context-awareness in analysing more criteria other than just RSS, is utilised for realising a user-centric paradigm. Decisions need to be made at two points, firstly to measure the need to switch from the current RAT, which is the intra-RAT assessment. Secondly, is the inter-RAT assessment, i.e., to chose the correct RAT to serve the UD demand for differentiated applications efficiently. The approach should involve effective decision in triggering the handover, and later in the decision making of the target RAT.

1.4 Research Questions

The main question of this research is regarding how to design mechanisms for VHO initiation and decision making based on context information with reduced complexity.

More specifically:

i. How to initiate RAT selection in multiple RAT UDN environment?
ii. How to determine the best RAT among the available multiple RATs?
iii. What is the implication of the proposed RAT selection approach on the performance in the UDN environment?

1.5 Research Objectives

The main aim of the research is to propose an approach that impacts on seamless RAT initiation and decision making in the UDN environment. More specifically, the objectives are:

i. To design a context-aware initiation triggering mechanism for RAT selection in UDN heterogeneous environment based on contextual information of the user and network:
    a. to design the analytical model for Context-aware Analytical Hierarchy Process (CAHP) mechanism to measure the need of handover initiation based on context repository information, and
    b. to verify and validate the CAHP mechanism by implementing it in MATLAB for formal testing with different test cases and random runs;
ii. To design a context-aware decision making mechanism to determine the efficient RAT among the available ones:
    a. to design the analytical model for Context-aware Technique for Order Preference by Similarity to Ideal Solution (CTOPSIS) mechanism, make network discovery of RAT, and determine the best target RAT,

b. to verify and validate the CTOPSIS mechanism by implementing it in MATLAB for formal testing with different test cases and random runs focusing on ranking abnormality and number of handover issues, and

c. to evaluate and accredit the CAHP and CTOPSIS of decision making by comparing the results with the parallel approaches; and

iii. To propose and evaluate the performance of the proposed Context-aware Multi-RAT selection approach (CMRAT) in UDN heterogeneous environment using Network Simulator-3 (NS-3):

a. to incorporate the proposed CAHP and CTOPSIS into CMRAT, and

b. to measure the performance enhancement of CMRAT and compare it with the standard A2A4-RSRQ approach to reveal the strengths and weaknesses of the proposed CMRAT in terms of throughput, packet delivery ratio, number of handovers, and average network delay. The experimental test was conducted in two different scenarios, namely shopping mall and urban city, varying the environment parameters to measure the performance of the approach.

1.6 Research Scope

The overall goal of this research was to propose a context-aware RAT selection approach based on the integration of Context-awareness and MADM theory for the UDN heterogeneous environment. The scope of the research is confined to and focused toward a UDN multi-RAT environment, further magnifying into RAT selection. Figure 1.4 depicts the research plan, where the blocks highlighted are the scope of this proposed research. The RAT selection is the enhancement of the VHO, so the VHO procedure is followed, but the decision point includes not one RAT but multiple RATs to chose from.

The UDN is formed with the heterogeneous multiple RATs closely deployed infrastructure, leading to frequent handovers. This handover is vertical due the hetero-RAT environment. The focus of this research is to carefully decide the need of handover and to which RAT through a proposed RAT selection approach. The VHO comprises three phases, namely an initiation which is triggered after measuring the network, a decision making process is executed after analysing the neighbour RATs to accommodate the mobile terminal, and the final execution. However, this proposed research focuses on the first two phases only. It considers all the four flows of traffic types, namely the background, conversational, streaming, and interactive, during RAT selection. The main focus of this research is confined to the decision making only.

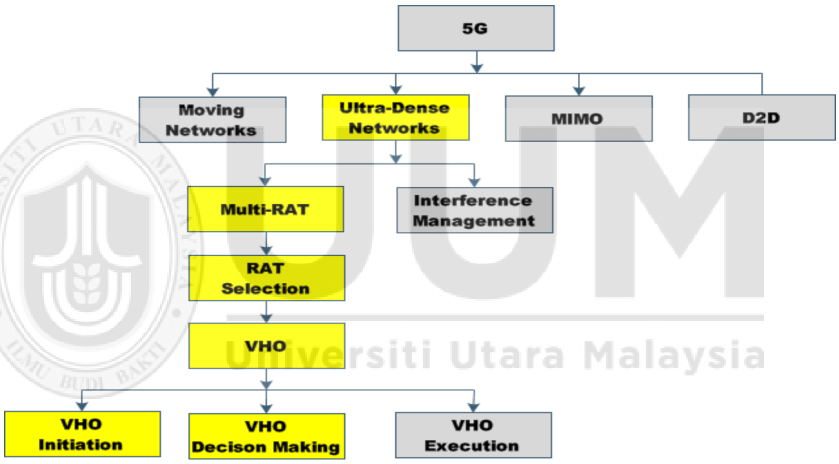

Figure 1.4. Scope of Research Plan

The proposed approach performance was evaluated by implementing the approach in two different scenarios, e.g., shopping mall and urban city. The shopping mall depicts the small area with UDN and the urban city covers a wider area for UDN environment. The scenarios can give a better experimental system model to evaluate the performance. The analytical model for the proposed approach was implemented in MATLAB and the integrated model was further tested using the NS-3 simulator. The proposed multi-criteria approach was evaluated in comparison with the imperative approach of RAT selection.

1.7 Research Steps

To accomplish the goal of the proposed research, the following research steps were planned:

i. review the background literature on VHO and smart mobility related issues,

ii. perform an in-depth study on identifying research problems, while analysing ways in which to tackle them,

iii. perform a detailed study on network discovery framework to gather information from multiple RATs and to initiate handover based on context information,

iv. perform a comprehensive study on Multiple Attribute Decision Making (MADM) to map the context information to available multiple RATs at the verge of handover decision making,

v. implement mechanisms for decision making based on MADM approach with the available context information,

vi. simulate the proposed mechanism in a network simulator environment and obtain the desired results, and

vii. repeat the simulation based on the multi-criteria approach until the attainment of a confidence interval.

1.8 Significance of the Research

The proposed research facilitates new requirements for a new generation of wireless communication systems for new usage scenarios. The versatility is in the support of RAT selection in UDN, scaling from the small to wide area of dense deployment of access points and connected devices, along with context-awareness for mobility, resource, and network management and inter-RAT collaboration.

This research proposed a CMRAT that determines the efficient RAT selection during the VHO in UDN heterogeneous environment. Furthermore, this proposed approach is the integration of operational research theories and computer networks in addressing the issue. The amalgamation of theories gave a new interdisciplinary approach to resolve the RAT selection related issues. The implications of the research are significant in providing reliable RAT selection within UDN, thus supporting heterogeneous RAT deployment in future 5G networks. The optimal RAT selection with advanced neighborhood discovery give rise to better network performance through more efficient resource utilisation and lowering the number of handovers with increased mobility.

The efficient RAT selection, with context-awareness feature will maximise the network resource utilisation facilitating the same infrastructure to cater for 1000X devices, which will benefit the OPEX and CAPEX costs. This approach creates a win-win situation for the network, users, and operators.

1.9 Organisation of the Dissertation

This dissertation is organised in seven chapters, which are described in the following.

Chapter One presents an overview of the whole thesis. In particular, it introduces the evolution of 5G, along with its features and challenges. This chapter also discusses the motivation for proposed research, problem statement, research questions and objectives, and the significance of the proposed research.

Chapter Two delves into a critical overview of the evolution of mobility management within heterogeneous wireless networks. Four basic questions define this chapter to clearly understand the purpose of this research study: How have wireless access networks evolved? Why are heterogeneous wireless networks necessary? What is the impact of RAT selection in UDN environment? What are the different mechanisms for handover management within heterogeneous wireless networks?

Chapter Three illustrates the Design Research Methodology (DRM) as the research framework to conduct this study and combines several methods adopted to propose and implement RAT selection.

Chapter Four is concerned about the analytical modelling of a handover initiation and proposes a Context-aware Analytical Hierarchy Process (CAHP) mechanism. The chapter discusses the design and implementation of the designed model in MATLAB for numerical analysis, as well as its verification and validation.

Chapter Five elaborates the analytical modelling of handover initiation and proposes the Context-aware Technique for Order Preference by Similarity to Ideal Solution (CTOPSIS) mechanism. The chapter discusses the design and implementation of the designed model in MATLAB for numerical analysis, along with its verification, validation, and evaluation.

Chapter Six introduces CMRAT and presents in detail its performance evaluation through simulation.

Chapter Seven finishes with the conclusion and contributions of this research work presented in this thesis, and then suggests the future directions for further research study.

CHAPTER TWO
LITERATURE REVIEW

Chapter One introduced and described the overall research plan, while this chapter shall delve into greater detail on the background and several important past research efforts related to Vertical Handover (VHO) implemented in heterogeneous networks, which would assist in defining the general framework of this research. In this chapter, Section 2.1 briefs about the evolution of technology from 1G to 5G, and touches upon the research exploration in mobility management. Section 2.2 states the role of mobility management and types. Section 2.3 reveals the overview of VHO followed by VHO approaches. Section 2.4 discusses the VHO mechanisms for decision making and Section 2.5 states the VHO execution phase of handover. Finally, Section 2.6 concludes the overall literature review done across this chapter.

2.1 Evolution of Wireless Technology from 1G towards 5G

Both the telecommunication and Internet technologies have undergone significant development toward delivering the best connected service. The early evolution of mobile networks focused more on the technology rather than user preferences. The emphasis was on increasing data and elevating communication experiences. The First Generation (1G) technology focused on voice using an analog signal transmission with a frequency of 40MHz, employing Frequency Division Multiple Access (FDMA). However, 1G technology had challenges of low capacity, poor voice link, unreliable hand off, low battery life, and minimal security. In early the 1990s, the Second Generation (2G) technology was initiated with the digitised signal mechanism to support voice and short messages with a speed of 64kbps using Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA) techniques. It was allied to the Global System for Mobile (GSM) services and General Packet Radio Services

(GPRS), which is an initiative from circuit switched to packet switched radio services. The Third Generation (3G) technology in telecommunication network was known as the Universal Mobile Telecommunication Systems (UMTS), which aimed to foster global access with integrated voice and affordable Internet. The 4G is the new era of wireless network technology, integrating all types of data on common IP-core network platform that facilitates voice, data, and streamed multimedia. A higher bandwidth range of new applications is also offered [35, 36].

Mobile communication's evolution from simple voice to current sophisticated communication etches a need and support for massively advanced technology to create a totally connected network society. The development of 3G and 4G technologies had primarily been to satisfy data services over the Internet. However, today's era of diverse applications and demand from a huge population for data are pressing toward more promising wireless network enhancements in terms of data rate, speed, efficiency, Quality of Experience (QoE), and battery life. To satisfy these diverse requirements, a new digital wave Fifth Generation (5G) is set to be deployed by early 2020 [7, 20].

The 5G technology is the next generation ultra-broadband network infrastructure; an integration of multiple Radio Access Technologies (RAT) for massive mobile data traffic focusing on massive capacity. The 5G technology emerges to introduce advanced feature technologies to cater 1000 times more service to the user [37, 3]. The International Telecommunication Union (ITU) stated the requirements of the 5G technology, which is summarised in Table 2.1, which underlies their vision for the 2020 project.

The 5G technology is not just broadening the horizon of technical aspects like the increasing coverage, speeding up of the data rate, or increasing the spectrum frequency only. It is going to be a revolution in a communication of interfacing diverse applications and giving more prominence to the artificial intelligence-based applications. Changing the telecommunications landscape enables technology to drive toward more human-centric and machine-centric approaches, thus redefining new challenges to mobility. The air interface, spectrum, and network devices are the main building blocks of wireless technology.

Table 2.1
Requirements for 5G Technology [38]

Parameter Standards	**Forecasted**
Data Rate	1-19 Gbps (resp 100s of Mbps)
Capacity	36TB/month/user (resp. 500 GB)
Spectrum	Higher frequencies & flexibility
Energy	~10% of today's consumption
Latency reduction	~ 1ms (e.g. tactile internet)
D2D capabilities	NSPS, ITS, resilience
Reliability	99.999% within time budget
Coverage	>20 dB of LTE (e.g. sensors)
Battery	~10 years
Devices per area	300.000 per access node

However, there is a paradigm shift from the last decade to the next on how these categories are emphasised. In the last decade, more focus was on the air interface and spectrum to have coordinated multi-point receivers and transmitters, 3D or full dimensional Multiple Input Multiple Output (MIMO), new modulation and coding schemes, more licensed and unlicensed spectrum, and also sharing of unlicensed spectrum.

However, the next decade is focused on last category of network devices and Information Technology (IT) for telecommunications. IT for telecommunications includes features like cell densification, WLAN offloading, integrated multiple RAT operations, Device-to-Device (D2D) direct communication, joint scheduling, and non-orthogonal multiple access. Figure 2.1 depicts the transformation from the last decade to the next decade, where ’x’ represents the emphasis times on each aspect. The next decade is focused on utilisation of available network resources, supporting more and more device to device communication. The control is from virtual cloud based systems to artificial intelligence based approaches [39, 40]. The new horizons are featured in 5G to support smart grids, cities and homes, and e-health applications. These applications require a different type of communications approach to acquaint into a single wireless technology to seamlessly support voice and Internet services.

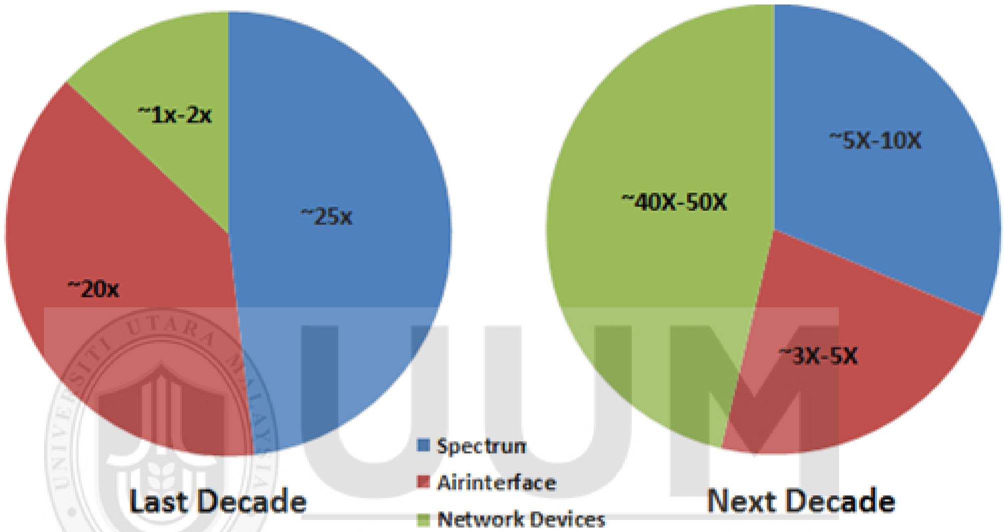

Figure 2.1. Transformation from Last Decade to Next Decade

Visionaries of the 5G technology laid the foundation by dividing the whole system into five Horizontal Techniques (HT), namely mobile networks, massive multi-antenna systems, context-aware approach, interference and mobility management, air interface with adaptability for new applications, and device to device communications. Focusing toward the network and transport functionality of the system, all applications are looking toward smart mobility service to be promising one which aids to be the foundation for all new applications envisioned to run on it [21, 41, 42]. Table 2.2 summarises the leading edge between the current and the future 5G network.

Table 2.2
Specifications of Current and 5G Technology Features

Criteria	**4G**	**5G**
Development	2010	2015
Data Bandwidth	200Mbps-1Gbps	1 Gbps and above
Standards	Single unified	Single unified
Technology	Unified IP, seamless combination of LAN,WAN,PAN and WLAN	Unified IP, seamless combination of LAN,WAN,PAN,WLAN and WWWW
Service	Dynamic information retrieval, diverse devices	Dynamic information retrieval, diverse devices with AI capabilities
Multiplexing	CDMA	CDMA
Switching	All Packet	All Packet
Core Network	Internet	Internet
Web Standard	WWW (IPv4)	WWWW (IPv6)
Handoff	Horizontal and Vertical	Horizontal and Vertical
Others	HetNet, Relay, SON, V2V	Massive MIMO, Ultra-dense HetNet, SDN/NFV , D2D, M2M etc

To enable all new horizontal features, the 5G wireless technology needs to be an ultra-broadband network worth rethinking, reconstructing, and redesigning of approaches in mobile networks. The fundamental theory for 5G should be based on massive capacity and massive connectivity. The new horizontal features mentioned above will enhance the connectivity and it is expected to provide a hyper response. In reality, all these feature deployments are accompanied by many challenges from both network and user perspectives. Horizontal features are the new paradigm approach toward the upcoming complete wireless digital wave. Its fundamental goal is to provide anytime connectivity with user satisfaction of service while maintaining efficient network resource utilisation. These features are a new school of thought for connecting and decentralising the services into multi-tier components, and controlling the applications with more Artificial Intelligence-based approaches.

One of the driving features of the 5G networks is the multi-RAT environment, where the access points deployed are of different RATs. Thus interoperability between them is vital in seamless communication. In short, the wireless communication evolution is in a multi-direction state to achieve such a myriad service, a challenge which is multi-fold in nature. Based on the previous literature presented across Chapters One and Two, it can be concluded that 5G technology is an integration of multiple heterogeneous (RATs deployed are different) networks serving the demand with diverse levels of QoS. Each RAT has its own advantage and disadvantage in rendering requested service.

With the heterogeneity feature to satisfy the exponential growth of traffic said to explode 500 times more than the current by 2020 [43], the main motivation in 5G is toward energy efficiency, cell coverage, and hyper-fast response. All these requirement demands are difficult to be achieved by a macro base station. Hence, the next generation digital wave needs a holistic approach to handle the heterogeneous environment significantly. The macro base stations are further divided into smaller micro, femto, and pico base stations to offload the traffic [8]. The concept of small cells enables better network resource utilisation and cost efficiency, thus providing better Quality of Experience (QoE) to the user [11] through the formation of an Ultra Dense Network (UDN) with multi-RATs. The typical UDN scenario is outlined in Figure 2.2.

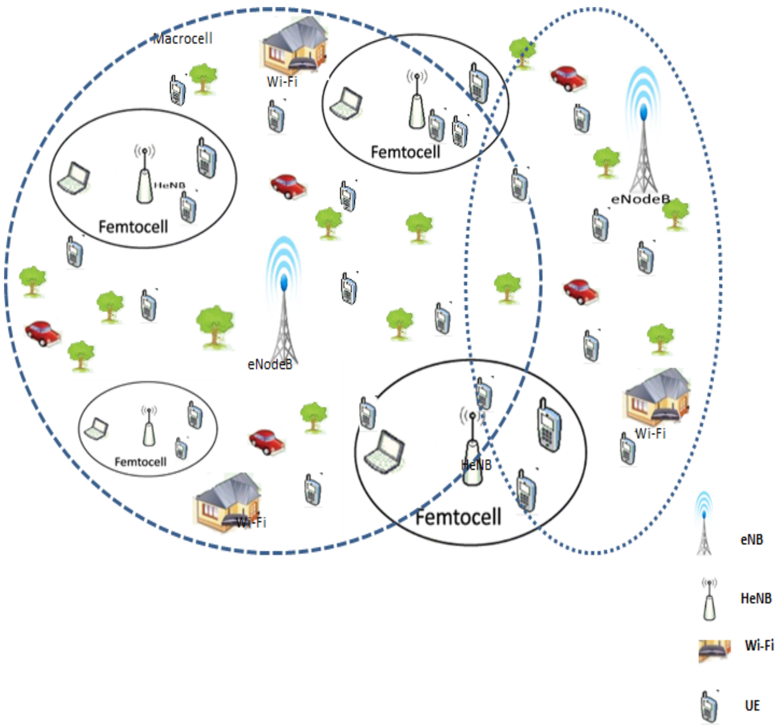

Figure 2.2. Heterogeneous Multi-RAT Environment

The small base stations require less power; consequently, the energy efficiency problems are inherently resolved. This context provides a win-win opportunity to both the users and operators. Due to the random close deployment of multi-RAT access points, there is frequent handover, which may result in a dynamic on-off of carrier selection. Frequent handovers will not only degrade system performance, but also consume power. Hence, this is an open research area to for the introduction of artificial intelligence in handling unnecessary handovers in the UDN environment.

The approach is quite different when a heterogeneous network exist, where in a heterogeneous network the inter-networking of different RATs is vital which helps in mobility management, providing smooth interfacing for better service. The coupling of heterogeneous RATs is important for always providing best service with increased mobility. The further section discusses the importance of mobility management.

2.2 Mobility Management

The 5G technology is envisioned to be a heterogeneous access network comprising varying strengths in terms of bandwidth, latency, and cost. Due to the advances and diversity of network technology with a rapid exponential growth of mobile devices along with sophisticated services, the prominence of mobility management is now coming to the forefront. Furthermore, there is still the need to have good interoperability to achieve seamless service in order to always remain connected while being on the move. Hence mobility management becomes an imperative issue in the Next Generation Network (NGN), resulting in the investigation of handover, which is a component of mobility management [44]. Figure 2.3 depicts the clear hierarchical classification of mobility management. This research focused on the vertical handover, switching between two different RATs seamlessly in the 5G network.

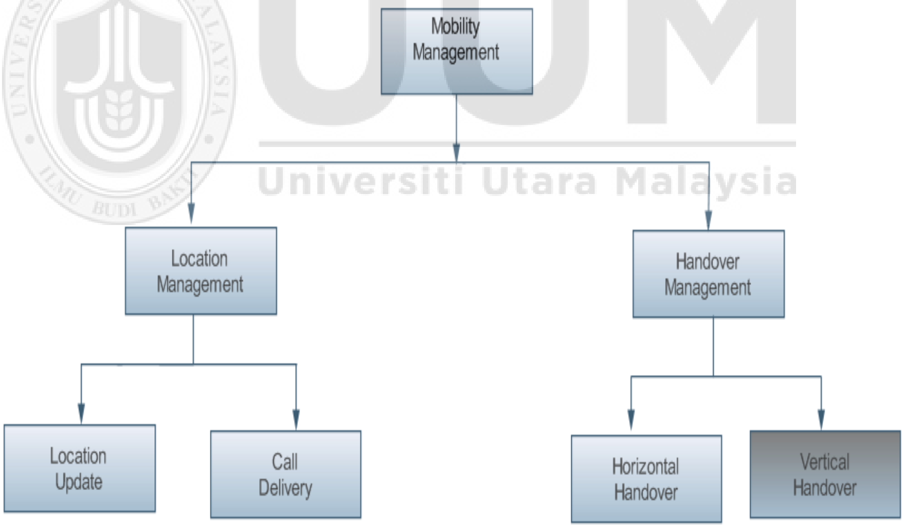

Figure 2.3. Mobility Management

A handover is an event triggered when a mobile device moves from one cell to another, while considering mobility scenario, metrics, decision mechanism, and procedure. Handover management is classified based on the cellular radio access technology. Horizontal handover is moving in between the cell having the same RAT, while vertical handover is moving in between the cells with different RATs. With the evolution of wireless communication networks toward 4G, apparently converging toward 5G technology is more of a heterogeneous nature with multi-RATs in close deployment. Hence vertical handover gains momentum as an open research issue. The clear illustration of horizontal and vertical handover is depicted in Figure 2.4.

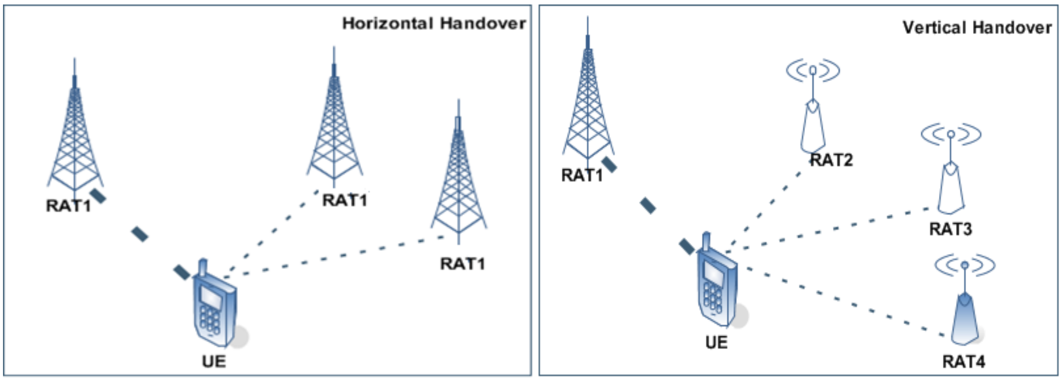

Figure 2.4. Horizontal and Vertical Handover

2.3 Overview of Vertical Handover (VHO)

VHO was fostered since the integration of diverse wireless network to attain "Always Best Connected" paradigm with heterogeneity, along with integration and interoperability [45, 46]. The context in heterogeneity is mapping devices with multiple interfaces with multiple wireless networks seamlessly. VHO comprises three phases, namely initiation, decision, and execution. Figure 2.5 shows the exact break down and processes carried out in each phase. Adnan et al. [47] made a survey on different approaches of VHO Algorithm based on different RSS, bandwidth, and combined criteria, which concluded that current VHO algorithms lack deliberation of various network parameters. The open challenge was to formulate various parameters based on network context and user preference for intelligent decision making.

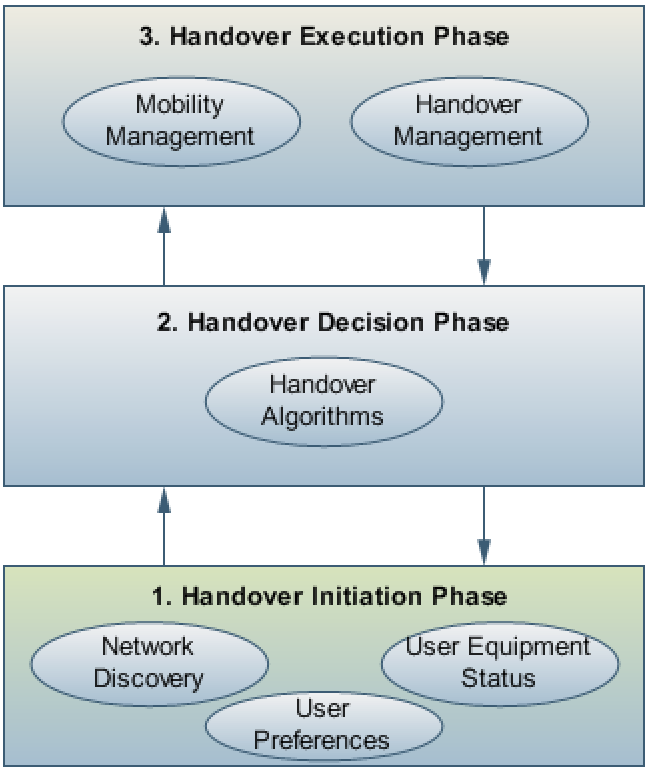

Figure 2.5. Handover Management Phases

Handover Initiation: This is the first phase of VHO, also known as handover information gathering, system discovery, and system detection [48, 49, 50, 51]. Initiation is triggered based on the listed criteria analysis to choose the new point of attachment when the current one fails to attain the required service threshold. Traditionally RSS is the main criterion which initiates handover. However, due to the integration of different RATs, only signal based decision is not adequate. This obligates researchers to consider multiple criteria based on the context during initiation. In short, multiple VHO criteria need to be accessed for handover initiation based on user preferences and network capacity. Due to the many factors in heterogeneous networks, a single criterion decision is not efficient, hence multi-criteria is required for consideration to trigger the initiation.

Handover Decision: Decision making is the crucial phase of VHO. This phase chooses the target RAT based on the aforementioned preferences of UE and network from the initiation phase. Handover decision is also known as network selection, handover preparation, and system selection according to various researchers [49, 50]. Decision making needs an intelligent mechanism to evaluate and decide based on the requirements for the desired seamless communication.

Handover Execution: This is the final phase in VHO completion, where a target RAT is chosen based on the synthesis of the previous two phases (initiation and decision). After logically processing multiple parameters, it necessitates binding the UE to the selected network seamlessly. Execution is attaching the user to the new RAT and releasing the old one [52, 53].

2.3.1 Vertical Handover Criteria

The literature revealed several approaches for addressing VHO and different criteria to address the issue, which are either related to the user or network for decision making. The traditional approach is based on RSS only for decision making, but with heterogeneous networks serving with multiple RATs, it is inadequate as information to make a decision [54, 55, 56, 50]. The number and combination of criteria can be employed in making handover initiation and decision making in UDN heterogeneous network. Some of the classic criteria are described below:

Throughput (T): it represents the data rate supplied to a mobile terminal in any connected RAT.

Available Bandwidth (AB): it notifies the available data communication resource expressed in bits per second (bit/s). Advantageous in the case of delay sensitive applications, where it is actually a good indicator of traffic conditions. Thus, in the context of heterogeneous networks, available bandwidth offered by different RATs becomes a vital factor in making VHO decision.

Received Signal Strength (R): is the primary and mandatory criterion in horizontal handover, as well as VHO. This is easy to measure and unswervingly related to the quality of service. It offers information about the strength or the power of the signal received from an Access Point (AP). The strength of the signal may be reduced as the UE moves away from the AP due to mobility, so to maintain connection, there is a need to connect to another AP swiftly.

Cost (C): the different networks specify and employ different charging policies. Cost is incurred based on the different policies of service accounting QoS trade-offs. Hence cost also becomes a prime factor in handover decision.

Security Level (SL): is the prime issue raised especially when integrating different networks. Each network differs in their policies that the user needs to comply during the handover process. Congruent to all factors for achieving security in heterogeneous networks is unavoidable. The security level varies accordingly based on application confidentiality.

Power Consumption (PC): it signifies the available battery life. If power diminishes quickly, switching to a network which consumes less energy would extend battery life.

Delay (D): is defined as the time required to send a packet from source to destination.

Response Time (RT): is the time required to respond to a message in a network back to the source.

Bit Error Rate (BER): determines the number of received bits that have been affected by noise and interference, divided by the total number of transferred bits during a specific time interval.

Jitter (J): is defined as the difference between the maximum packet delay and the minimum packet delay over a short time slice.

Burst Error (BE): is the state when more than a single bit of data unit gets corrupted.

Packet Loss Rate (PLR): is defined as one or more packets of data transmission across a computer network that fails to reach the destination.

Dropping Probability (DP): is the rate at which the connections are lost due to numerous reasons, thus unable to connect to a serving station.

Mobile Node Velocity (MNV): is the speed at which the terminal is moving.

Device Memory Size (DMS): is the capacity of the device to hold data for current and future usage.

Network Utilisation (NU): is the ratio of current network traffic to the maximum traffic that the base station can handle.

Total Bandwidth (TB): is a measurement of available data communication resources expressed in bits per second.

Signal into Interference Noise Ratio (SINR): is quantification to give theoretical upper bounds of channel capacity in wireless networks, which is defined as power of a measured usable signal divided by the sum of the interference power and the power of some background noise.

The RAT selection involves measuring and gathering of information necessary for initiating the handover from current RAT and decision making for new target RAT. The mechanism to trigger the handover is initiated based on the three different approaches [50, 57], namely:

- Network Centric Approach: the choice for network access selection is made at the network side with the goal of improving network operator's benefit,
- User Centric Approach: the decision is taken at the user terminal based on several parameters with different relative importance, such as network and application characteristics, user preferences, service, and cost without consideration of the network side, and
- Collaborative Approach: the selection of network access takes into account the benefits for both the users and the network operator, which mainly deals with the problem of selecting a network from a set criteria belonging to both user and network constraints.

2.3.2 Classification of VHO Control Approach

The VHO decision depends on the gathered information to measure the need to trigger a handover. The decision can either be controlled by a network entity or mobile entity, as described in the following.

Mobile Controlled Handover (MCHO): The mobile device decides upon measuring the required criteria from the current RAT and triggers handover when it finds better criteria from a predefined threshold than the current residing one. Hence, the handover is said to be user-centric. However, this approach is probabilistic to a single point of network failure. The main drawback being the overall complexity, handover latency, and signaling overhead [58].

Network Controlled Handover (NCHO): The network entity takes the initiative in triggering the handover based on network entities. Hence, the handover is said to be network-centric [59, 60, 61]. However from the two methods, user-centric handover networks are prone to instability if not implemented carefully.

An integration of both mobile and network driven entity is required in heterogeneous systems where accompanying network measurements have to balance both entities [62, 61]. For the "Always Best Connected" goal, two objectives need to be met, namely, when and under what context and criteria should a handover be triggered and how is the selection of the best network done among the available RATs.

2.4 VHO Decision Making Algorithms

The VHO decision is a process to evaluate available RATs, resulting in the selection of a RAT suitable for a mobile terminal to switch from the current RAT. VHO algorithms are complex and their reliability relies on the dynamism and availability of selected criteria. A few popular ones are discussed in the following subsections.

2.4.1 Radio Signal Strength based Algorithm

This approach falls into the category of network condition based decision making. The traditional and simpler approach is easy to determine, due to the simplified network requirement, thus it is more suitable for horizontal handover. The literature revealed numerous strategies to compare RSS of current to destined Point of Attachment (PoA). In the current RAT, the RSS is measured to be compared with a predefined threshold. If the current RSS value is greater than or equal to the defined threshold, it will resume with the same RAT network. Otherwise, it will initiate network discovery to find a RAT with a better RSS value [23, 63, 64]. Mohanty and Akyildiz [65] proposed a handover decision algorithm between WLAN and 3G on the basis of RSS value comparison, by calculating the dynamic RSS threshold and comparing with the current to initiate handover.

Yan et al. [66] designed an algorithm based on the premise of reducing false handover initiation and failure probabilities, but resulted in wasting network resources with increased handover failure. A similar approach of dynamic calculation for comparison with RSS values to initiate handover between two networks, which also resulted in wastage of network resources with increased handover failure. So with all the above related work, it can be concluded that RSS alone is not enough to initiate a handover decision, since this aids better in horizontal handover. The complex heterogeneous UDN with multi-RAT requires considering multi-criteria to initiate handover to determine right RAT for demanded service [67, 65, 68, 64].

The handover algorithms in 4G networks optimise the handover management exclusively for LTE, which are NO-OP and A2A4-RSRQ (Reference Signal Received Quality) algorithms. NO-OP is the first algorithm in LTE mobility management. It is simple to implement with no interface to handle the handover, which is a manual handover triggering algorithm that overrides automatic triggering. The A2A4-RSRQ algorithm utilises reference signal quality in decision making either to initiate the handover or choose a new target RAT. The A2 event is triggered when the serving RAT RSRQ values become worse than the set threshold. The A4 event is triggered when the neighbouring RAT RSRQ becomes better than the serving RAT [19]. The A2A4-RSRQ is again the type of RSRQ based approach which triggers the decision imperatively based on signal quality.

2.4.2 Quality of Service (QoS) Based Algorithm

In QoS based algorithms, the focus is toward QoS criteria like delay, throughput, latency, and etc. However, they consider the primary criteria such as signal and SINR for optimisation in allocation and reservation of resources during handover [69]. Researchers focused on QoS, based on user preference, and proposed a VHO model to optimise end-to-end QoS while considering different wireless networks [70, 71].

QoS approach focuses much toward user preferences and network core criteria are overlooked, which may not yield a good decision mechanism to all performance metrics for next generation communication systems. The issues of packet loss and ping pong effect due to the bias toward a single preference approach are not resolved. Lee et al. [72] proposed a QoS based algorithm in VHO, with the main criteria in the decision making being bandwidth and user preference type of application. The approach works well by achieving high system throughput and lower handover latency. However with high bandwidth, the decision becomes difficult. Yang et al. [73] devised a QoS based approach in VHO decision by measuring Signal to Interference Noise Ratio (SINR). Comparing the SINR of WLAN to WCDMA, the handover is done to the network with high signal. This approach is more efficient than RSS based approach in terms of throughput. However, QoS based approaches are prone to more handover toggling to and fro between networks with the variation of SINR degrading the overall system performance of the network [73].

2.4.3 Cost Function-Based Algorithm

The cost function based algorithm combines different metrics to form a function. Metrics like available bandwidth, reliability, service cost, battery life, and etc. are considered as the cost to calculate network function. The cost function result is compared to the candidate network to make a handover decision. Hong et al. [74] proposed a cost function based algorithm which calculates the cost of all targeted RATs in the proximity. All active applications are characterised by the use of cost function, user satisfaction, and reduced handover blocking probability based on active application priority. Nasser et al. [75] proposed a cost function algorithm between heterogeneous network to provide methods for QoS normalisation with weight distribution, which showed significant results with high throughput and user satisfaction. Meanwhile, another cost function based approach for a heterogeneous network with available bandwidth and network traffic was aimed to reduce unnecessary handover with the balance of traffic load. However, this approach encountered increased connection breakdown because the RSS parameter was overlooked [76].

Wang et al. [77] considered the input criteria as network condition, user defined policies, and stability period to form a cost function, claiming to have a good decision for seamless handover. The adopted methodology was claimed to deliver user satisfaction with less handover blockage. Similar mechanisms were proposed by Taiwal et al. [76] to achieve reduced handover delay, low rate of handover blocking, and high throughput. This approach is good with limited mobile terminals, but scaling to more terminals will put excess load on network with high latency during the process of Point of Access (PoA). The cost based algorithms overlooked overall performance and focused on the policy of charging only. The cost based approach enhances the throughput while reducing decision delay and blocking rate. However at times, they are prone to additional latency and excessive load to the network [76, 52, 78, 79].

2.4.4 Multiple Attribute Decision Making (MADM) Mechanisms

MADM is a robust tool for decision making and offers an elasticity to handle an extensive range of decision criteria [80]. Several decision making schemes were proposed in the literature [17]. MADM is applicable on diverse problems, but all follow a common analysing technique. The characteristics of MADM are:

i. selection of alternatives,
ii. definition of multiple attributes in different units of measurement, and
iii. definition of a set of weights representing the relative priority among alternatives.

MADM algorithms are mathematical optimisation approach in realising the RAT selection. The MADM approach calculates the quantitative value for attributes with assigned weighted function to evaluate the target RAT [81]. MADM chooses the best alternative among the set of alternatives based on their attributes weights [82]. MADM is a generic methodology which can be applied to any domain. The approach is used to take an explicit account of conflicting multiple criteria and structures the problem conceptually simple and transparent.

Several decision making schemes of this type were proposed in the literature [83, 84], and the most classic ones are picked and analysed in the following subsections which explore the extensive review of classic MADM's strengths and limitations.

2.4.4.1 Simple Additive Weighting

The Simple Additive Weighting (SAW) algorithm is the simplest among most of the approaches of MADM. It employs a linear additive function to determine the preferences of decision making. The input criteria are assigned the weights based on the intensity of their importance, with the total weight for each alternative RAT is computed by multiplying the comparable rating for each criterion by the importance weight assigned to the criteria and then summing their products for over all the attributes. The weights are summed attribute values multiplied by weight [50, 85, 86]. The choice is made based on the weight [87]. The mechanism can be expressed in an equation, as in the following,

$$A^{*}_{SAW} = arg\ max_{i \in M} \sum W_j * r_{ij} \tag{2.1}$$

where,

M is available alternatives,

W_j is the weight, and

r_{ij} is the matrix of alternative.

It takes into account the dynamicity in decision making, combining linear approach with other MADM which would yield in better results. The SAW mechanism determines the score of the alternatives by mathematical multiplicative operations of the normalised alternative criteria with the relative importance [88].

The SAW mechanism has been extensively used in VHO decision making, for example Singh et al. [89] applied SAW mechanism in VHO decision making among the RATs WLAN and WiMAX in 4G. The advantage of using SAW is the simplicity of implementation and ability to transform the criteria evaluation data into a linear operation [90]. Ismail and Roh [91] proposed a VHO technique based on fuzzy MADM and evaluated SAW, TOPSIS, Maxmin, ELECTRE, and AHP mechanisms to choose the best alternative RAT. Meanwhile, Taiwo and Falowo [92] made a relative analysis of different MADM mechanisms in a modified approach to choose an efficient RAT in a heterogeneous network. They analysed SAW, MEW, TOPSIS, and DIA mechanisms. Drissi and Oumsis [93] outlined the application of MADM in decision making of the best RAT in WiMAX and WLAN environments. The VHO decision mechanisms SAW, MEW, and TOPSIS were compared. Tawil et al. [76] presented a distributed SAW based VHO decision mechanism to choose a RAT for a mobile terminal to reduce overall processing overhead of the visiting network. Pink et al. [94] presented a distributed VHO decision making mechanism which co-ordinates the mobile terminal with RAT for optimal Quality of Service. The SAW mechanism was used to evaluate the feasibility of the mechanism for varying user-group requirements.

2.4.4.2 Weighted Product Method

The Weighted Product Method (WPM) is also known as Multiplicative Exponent Weighting (MEW). Where SAW is a mechanism based on addition, WPM is based on multiplication, and the formula is defined by,

$$WP^* = max \prod_{j=1}^{m} x_{ij}^{w_j} \qquad (2.2)$$

where,

x_{ij} denotes attributes of j of candidate network i, and

w_j denotes the weight of attribute j.

m is the number of alternatives.

TalebiFard and Leung [95] implemented the dynamic decision mechanism with WPM in a heterogeneous wireless network. The weight distribution was based on sensitivity analysis to obtain the criteria importance. They evaluated WPM in comparison with classic TOPSIS method. Savitha and Chanrashekar [96] described a VHO decision mechanism with lower processing delay during the decision of handover. They compared the SAW and WPM mechanisms. Several strategies were adopted in making the RAT selection.

MADM is also one promising strategy. SAW, MEW, TOPSIS, ELECTRE, VIKOR, GRA and WMC mechanisms were compared and numerical illustration of all these mechanisms for voice and data connections in 4G networks is presented [97], with context-aware dynamic RAT selection for multi-interface mobile device. WPM with weight assignment using sensitivity analysis for dominant criteria based on user preference was obtained [98].

2.4.4.3 Technique for Order Preference by Similarity to Ideal Solution

The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) approach was designed to measure the relative efficiency among available alternatives. Hwang et al. [99] were the pioneers to present TOPSIS. It takes limited inputs and ranks based on the closeness toward the ideal solution. Depending on the closeness, it calculates the positive and negative ideal solutions. TOPSIS carefully chooses a targeted network which is probabilistic to be the adjoining ideal solution and distant from the worst case solution among the available alternatives [86, 100].

$$A^*_{TOPSIS} = avgmax_{i \in M} C^*_i \tag{2.3}$$

where,

$C^*_i is$ relatively similar available network.

The decision matrix is formulated based on the score across alternatives and criteria to choose the best one based on rank. However, this method is a probabilistic approach toward finding the ideal solution.

Yang et al. [101] applied TOPSIS to determine the target network. The mechanism performs contrast evaluation with the traditional approach published in National Institute of Standards and Technology of the United States (NIST). Four metrics, namely packet drop rate, delay, jitter, and average throughput were examined to measure the comparisons of the mechanisms. The proposed mechanism Weighted Rating of Multiple Attributes (WRMA) approach performs better than the NIST method. Bari and Leung [102] employed iterative TOPSIS which ventures to reduce the ranking abnormality phenomena. The iteratively repeated application of MADM mechanism performs decision making accurately and consistently.

Chamodrakas et al. [103] employed a fuzzy TOPSIS mechanism to determine energy efficient RAT in a heterogeneous wireless network. The proposed mechanism attempted to resolve ranking abnormality issue of conflicting criteria. Labhy et al. [104] proposed enhanced TOPSIS (E-TOPSIS), which is an improved VHO decision mechanism integrating Analytical Network Process (ANP) and TOPSIS to lower ranking abnormality phenomena and a number of handoffs. Also, modified TOPSIS was evaluated with classic MADM methods, like SAW, MEW, and TOPSIS. The E-TOPSIS evaluation considers all the traffic classes.

2.4.4.4 Analytic Hierarchy Process

Analytic Hierarchy Process (AHP) is one computational technique based on the divide and conquer paradigm. The main problem is decomposed into sub-problems and assigned weight to each; weight being a decision factor in selecting among the set of alternatives [105, 106]. The whole technique is divided into three hierarchy levels to reduce the complexity of multiple input processing. Figure 2.6 illustrates the hierarchy structure of AHP working. The AHP is structured across three levels, top is the main goal, followed by level2 which determines the importance of the criteria by comparing with each other. After knowing the importance of the criteria, level3 compares the criteria with an alternative in the list. The whole process leads toward the main goal.

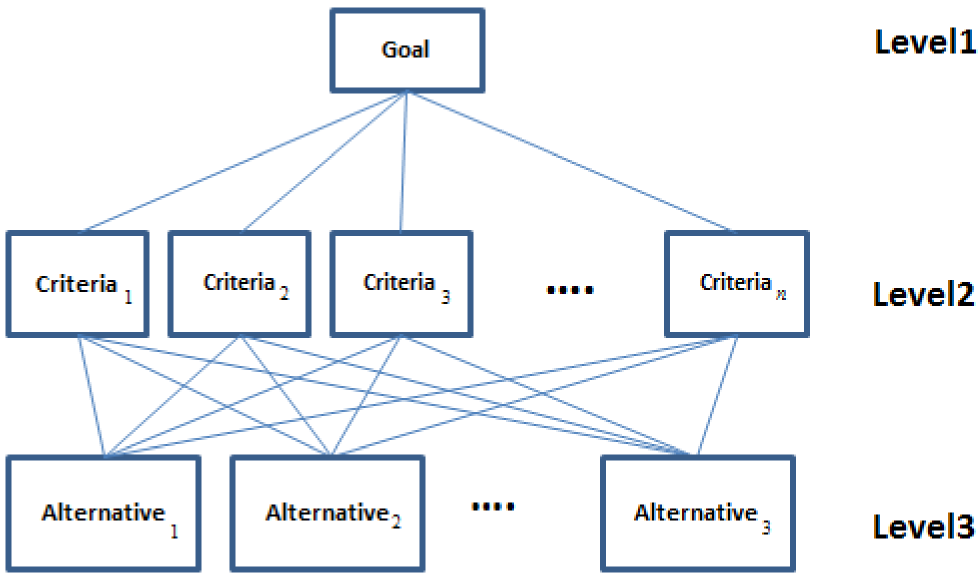

Figure 2.6. An example of the AHP Hierarchy Structure

The phases of the AHP approach are as follows:

i. divide the problem into sub-problem,
ii. compare each factor with the other in the same level of hierarchy, and
iii. calculate the sum of products of weights from a different level and choose a solution with the highest score.

Extensive application of AHP in VHO for heterogeneous networks was done by many researchers. Panjanda and Wongwirat [105] proposed a AHP mechanism with linear programming technique to optimise VHO decision with network factors. The linear programing is a replacement of human knowledge based criteria assessment to improve the scoring. Gupta [107] employed AHP to choose a network among 3G and WLAN based on user preference. User preference was the main priority for network discovery and decision making of target RAT. Ismail and Roh [91] applied fuzzy MADM method with TOPSIS, SAW, Maximin, ELECTRE, and AHP to find best target RAT. Guo and Li [79] illustrated the adaptive VHO decision mechanism using AHP. The handover was based on cost function. The proposed mechanism adjusted the weights of criteria to meet the requirement. This adaptive method implementation results revealed the reduction in a number of handovers and handover delay, while improving user experience.

AHP is a well proven mathematical approach compared to other conventional approaches. The current heterogeneous networks need input from both the terminal and network, i.e., the system is multi-input interfaced for high expectations and accessibility. However, this approach is not optimised to handle uncertain conditions [108]. AHP is best suited in context aware selection, because it compares the pair of alternatives to determine which is the better among the two. Due to the layered approach, there is a refinement in decision making input to a greater extent. Goyal and Kaushal [109] implemented a utility function to obtain the normalised values and further employed fuzzy based AHP mechanism in network selection in heterogeneous environment, comprising WLAN, WiMAX, and UMTS networks.

2.4.4.5 Grey Relational Analysis

Grey Relational Analysis (GRA) is a MADM approach that is based on grey relational system theory for analysing the relationship of criteria and alternatives. The comparative series of the alternatives are compared to obtain the relational grade co-efficient. Inwhee et al. [110] proposed a network selection mechanism examining power consumption criteria in decision making. The alternative RATs were CDMA, WiBro, and WLAN, analysed with AHP and GRA integrated mechanisms to choose a target network. Song et al. [111] presented an efficient network selection mechanism which is the integrated approach of AHP and GRA in decision making to choose among LAN and UMTS.

A non-monotonic utility mechanism in network selection using MADM mechanism analysed TOPSIS, ELECTRE, and GRA mechanisms in RAT selection [102]. Markaki et al. [112] proposed an integrated MADM mechanism of AHP and GRA to enhance the QoE for heterogeneous network users. The main QoS criteria of delay, jitter, packet loss probability, and throughput were considered in decision making. AHP was applied to assign the weights of criteria and GRA to choose the best RAT among the General Packet Radio Service (GPRS) and WLAN.

A modified integrated approach of AHP and GRA in decision making for the best RAT was presented, where the AHP was modified with fuzzy AHP, and GRA was applied to determine the best RAT among WiMAX and LTE. This approach reduced the blocking probability and balance the network load. However, this approach introduced complexity due to the introduction of the least square and Lagrange function optimisation [113]. Khan et al. [114] presented a study of enabling VHO in heterogeneous wireless network by introducing the GRA mechanism in contrast with the IEEE 802.21 Media Independent Handover (MIH) framework standard. The heterogeneous network consisted of Wi-Fi, WiMAX, and LTE in determining the best RAT to serve for three different applications, namely elastic, Voice Over IP (VOIP), and streaming. GRA outerformes MIH mechanism in terms of energy consumption, reducing handover delay, and avoiding frequent unnecessary handovers.

2.4.4.6 Distance to Ideal Alternative

The Distance to Ideal Alternative (DIA) is another MADM based on closeness to ideal solution theory. The positive ideal solution space based mechanism follows the same steps of the TOPSIS mechanism but further follows another two more computational steps to fine tune the accuracy of result. The applied formula is,

$$R_j = \sqrt{(D_j^* - min(D_j^*))^2 + (D_j^- - max(D_j^-))^2} \tag{2.4}$$

where,

R_j *is* the ranking order, and

D^* *and* D^- represent the closeness to positive and negative solutions, respectively.

To obtain ranking and determine the best RAT dynamically, the DIA mechanism was applied by Tran and Boukhatem [115] in network selection, taking advantage of fault redundancy, load balancing, and multi-interface mobile terminal. The mechanism improves the ranking abnormality phenomena. Lahby et al. [116] proposed a RAT selection mechanism based on mahalanobis distance, which determines the co-relation among the criteria and further determines the rank of the RAT. This novel method of DIA ensures the reduction of ranking abnormality and unnecessary handoffs.

The mechanism was validated by comparing it with other mechanisms, including TOPSIS, SAW and MEW. Cinemre et al. [117] proposed a MADM method based on autonomous agent at the mobile node. The historical data were combined with MADM mechanism in RAT selection by autonomous intelligent user agent. The ranking of the network was done by the application of DIA and TOPSIS.

2.4.4.7 MADM Approach based on Access Type

The MADM approach in UDN heterogeneous environment for RAT selection can be grouped into three different categories, namely single, modified, and integrated. The details of each category are as follows:

i. Single MADM mechanism

   a. This approach is an application of an independent MADM method for RAT selection ranking. The single MADM mechanism was adopted in [102, 76, 94, 118]. The right and consistency in weight determination with co-relation of the criteria needed to be assigned in order to obtain an accurate ranking for decision making.

ii. Modified MADM mechanism

a. Single based approach is adapted from the classic MADM in decision making. However, modified is the enhancement to the classic one for efficient and consistent ranking. The SAW and MEW are simplest to implement, and mechanisms like TOPSIS and DIA are robust, but demands computational space. TOPSIS and GRA are prone to ranking abnormality. Hence, DIA with a modified TOPSIS with ideal space theory would reduce ranking abnormality issue. There is no single MADM mechanism that performs best in all scenarios. However, integrating while balancing the advantages and limitations of MADM approaches can perform more efficiently. The modified MADM was exhibited by researchers in [112, 119, 95, 120].

iii. Integrated MADM mechanism

a. The integrated approach utilises both the advantages of the single and modified approaches, and enhanced more by integrated potential to strengthen decision making. The weight assignment to criteria is usually done by AHP and ANP mechanisms. The traditional mechanism is adapted or modified according to the need, and implemented in obtaining the relative importance of the criteria. Usually fuzzy logic is applied to modify AHP. The ranking of the RAT is done with modified MADM. The whole process of RAT selection would integrate two or more MADM in modified or traditional forms to yield a consistent and accurate selection decision when multiple interfaces are available. The integrated approach was implemented in [110, 121, 122].

Obayiuwana and Falowo [123] in their review of MCDM approach in network selection analysed the different approaches and showed that integrated approach tackles decisions by 44% better than the other two forms.

After the comprehensive review of different approaches and mechanisms that follow at initiation and decision phases of VHO, the strength and limitations of each one can be inferred. In UDN heterogeneous environment, single criteria approach such as RSS or SINR is inadequate in triggering VHO, due to the heterogeneous collaborative network parameter standards involvement [124, 93]. Hence, UDN environment needs multi-criteria handover mechanisms. The multi-criteria criteria mechanism sometimes results in conflict in a dynamic and complex problem in decision making. Hence, the MADM with context-awareness would resolve the conflict and aid in dynamic decision making in UDN.

2.4.5 Context-Awareness

Context is the concept that the system should be able to sense dynamically and react to the changes in the circumstance [34, 125]. In case of RAT selection, context information defines the relevant information that can be utilised in decision making based on the interaction of user and network parameters to decide the next Point of Attachment (PoA). Context awareness is highly essential in order to optimise the initiation and decision process. However, implementing context-aware based RAT selection poses the following challenges [126]:

i. The heterogeneity of the wireless networks and technologies.
ii. The diversity of different applications which differs significantly in QoS requirements.
iii. The fact that the next generation of wireless is user-centric, thus user preferences are a must in decision models.

RAT selection ensures the connectivity of each user to the best RAT to serve, depending on the context of user and network references. The procedure takes into consideration several criteria to evaluate the best RAT. The available RAT will be different from the current serving RAT, that means there is a vertical handover among the heterogeneous RAT. This selection needs to consider network resource availability along with efficient service to the user. To overcome these challenges, an understanding of context is must which aids in determining the behaviour of the context in choosing the best RAT. Each preference of the user and network has its own QoS requirement and can impact the RAT selection decision.

The context-aware framework contains two tasks, namely managing context repository and evaluating context information, which eventually helps in handover decision making. Balasubramaniam et al. [127] showed the use of context-aware concept in pervasive computing. Ahmed et al. [27] proposed handover architecture which deals with multi-mode mobile terminals. The literature exposed that the context-aware concept was applied by different researchers in different ways, in combination with MADM technique for efficient decision making. Context-aware technique comprises components, namely mobile terminal, network, and user preference contextual information, for wise decision making. Kassar et al. [50] explored an algorithm based on context awareness for decision making in handoff.Vaidya et al. [128] employed context-aware technique with AHP to make choice among multiple alternatives with predefined objectives, considering both network and terminal side contexts. All the approaches are summarised with the pros and cons of each scheme in Table 2.3.

From the descriptions presented in the Table 2.3, the comparison of different approaches in RAT selection can be inferred. The RSS based approaches are simple and considers the RSS power and quality in the selection decision. RSS based ap-

Table 2.3
Summary of VHO Algorithms

Handover Decision Class	**Network Dynamics employed**	**Complexity**	**Handover Target Criteria**	**Advantages**	**Disadvantages**
RSS based	RSS with threshold, timer and hysteresis	Simple	RSS	minimized handover failure	long packet delay, wastage of resources
Bandwidth based	Bandwidth, RSS	Simple	Bandwidth	High throughput, low latency	ping-pong effect, application blocking, connection breakdown
QoS based	Bandwidth, RSS and SINR	Usually Simple	Network candidates with highest overall performance	low HO latency, high throughput, assured QoS	high packet loss, increased HO latency, ping-pong effect
Cost based	Bandwidth, RSS, Cost, BER etc	Little Complex	Network candidates with highest overall performance	Increased user satisfaction, high throughput	difficult to make algorithm realistic, hard to estimate security and interfernce levels
MADM based	Variable input parameters based on technique	Complex	Network candidates with highest overall performance	high success rate in finding candidate network, reduced HO delay	training delay, high HO dropping rate, fixed weight may result in failure
Network Intelligence based	Variable input parameters based on technique	Complex	Network candidates with highest overall performance	high success rate in finding candidate network, reduced HO delay, high throughput	high latency, high signaling overhead
Context Aware	Variable input parameters based on technique	Very Complex	Network candidates with highest overall performance	low HO failure, high throughput, low ping-pong effect, low latency	Signaling cost high, might compramise on QoS if a low cost network available, handover delay

proaches are simple to implement and has less chances of handover failure, but leads to the unnecessary handover and wasting of network resources. The bandwidth based approach is exclusively based on the available bandwidth, but yields high throughput. Bandwidth is the primary criteria in decision making where the application bandwidth requirement is prioritised. However, this approach will lead to the ping-pong effect, application blocking, and connection breakdown in the situation when there is conflict in decision. Next category is a QoS based approach focused toward the QoS, and this approach provides the user with good overall performance, consequently, leading to low handover latency, high throughput, and assured QoS. In turn, this leads to high packet loss, increased HO latency, and ping-pong effect due to the criteria considered in the decision making. The cost based approaches are more focused toward the monitory aspect of the decision, and the cost is computed considering the criteria of bandwidth, RSS, Cost, BER, and etc. where the computing is a bit complex but yields better user satisfaction in complex cases when decision making becomes cumbersome.

MADM based approach considers variable input parameters based on the technique employed. Due to many parameters, it is complex in nature for decision making. However, network candidates attain high overall performance with reduced HO delay, but the fixed weight may result in failures as the weights may not differentiate the situation of decision making. Network intelligence based approach is another well known approach in decision making with AI capabilities for variable input. The decisions are based on fixed designed rules which may not differentiate the user requirement priority, dynamically leading to high overheads. Finally, the context-aware approach is the one which acts according to the situation, where multiple contextualised decision leads to complexity in decision making. However when employed, it attains low HO failure, high throughput, low ping-pong effect, and low latency.

2.4.6 Comparison of Various VHO Algorithms

The VHO decision techniques require intelligent considerations due to the complex scheme which is supposed to be flexible and efficient in making an appropriate choice considering user and network information. The techniques account for criteria, like multi-criteria, efficiency, and requested service with the advancement. The specifications are not confined to user and network fixed criteria, but a new context-aware component is also relevant.

Comprehending a few common characteristics from all the approaches, some similarities like efficiency, flexibility, and complexity can be surmised. Table 2.4 summarises the characteristics of all the approaches discussed in the previous sections.

Table 2.4
VHO Strategies Serving Capability

VHO Strategy	**RSS**	**QoS**	**Cost**	**MADM**	**NI**	**CA**
Multi-Criteria	-	Yes	Yes	Yes	Yes	Yes
User-Consideration	-	High	Low	High	Moderate	High
Efficiency	Low	Moderate	Moderate	High	High	High
Flexibility	Low	High	High	High	Moderate	High
Complexity	Low	Low	Low	Moderate	High	Moderate
Requested Service	NRT	NRT	NR & RT	NR & RT	NR & RT	NR & RT

NRT-Non Real Time, NR-Non Real and RT-Real Time

2.5 VHO Decision Execution

This is the final stage of the handover procedure where the terminal gets attached to the next PoA and keeps the service ongoing seamlessly. This phase is concerned with attaching the mobile terminal to the selected RAT which is the next Point of Attachment (PoA). It is done by taking into account the type of service and which protocol needs to be employed to achieve the execution without disturbing the executing application.

In this phase, different mobility management protocols such as MIPv4 and MIPv6 need to be employed. After that, the resources of the old RAT are eventually released and the user device continues the service from the new target RAT.

2.6 Summary

This chapter gave a detailed background description on issues that were covered in this proposal, comprising the evolution of communication from simple analog to today's heterogeneous networks. The focus of this research domain and the approaches to accomplish it were reviewed critically and analysed for the best fit to contribute toward achieving optimised performance. The next chapter focuses on the research methodology for fulfilling the objectives of this research and the evaluation of it is presented.

CHAPTER THREE
RESEARCH METHODOLOGY

The main aim of this thesis is designing a Radio Access Technology (RAT) selection approach for the UDN environment. Specifically focusing on the mechanisms, Context-aware Analytical Hierarchy Process (CAHP) measures the need to trigger RAT initiation and Context-aware Technique for Order Preference by Similarity to Ideal Solution (CTOPSIS) to determine the best target RAT amongst the available once. In order to accomplish these objectives, this research requires an authentic research framework to facilitate the systematic attainment of goal with accurate verification, validation technique and later evaluation of the designed and implemented mechanisms.

The research methodology, which is the focus of this Chapter is an iterative process where new ideas have been added to the existing solutions found in literature and published previously. Suggestions from supervisors, examiners and reviewers at meetings, feedback from conferences and journals has been taken into account during the attainment of the designed objectives of this research. The Design Research Methodology (DRM) [129], approach has been adopted in this research which aids to realize the objectives with the clear description phase by phase. DRM is a clear guidance to obtain framework of research acceptable at academia and industry, hence adopted in this research.

The chapter is organized as follows: Section 3.1 presents the overall bird view of the whole phenomena in this research. Section 3.2 elaborates the stage of research clarification, the phase which determines methods employed to obtain research plan. Section 3.3 the third stage of methodology, called Descriptive Study-I which gives a deep understanding of the current scenario and aids to comprehend conceptual model, a blueprint of whole research. Section 3.4 focuses on the methods adopted to design handover initiation and decision making mechanisms in VHO. Finally, Section 3.5 discusses the performance evaluation procedure including simulation setup, scenarios and metrics. Finally, Section 3.6 summarises the chapter.

3.1 Research Approach

The foremost aim of this research is to design a Radio Access Technology (RAT) selection approach for Ultra Dense Network (UDN) in 5G technology. It intends to serve User Equipment (UE) with multimodal interface in multiple RAT environment. This needs a profound understanding of VHO phases for actual implementation of mechanism efficiently for triggering the initiation and decision making.

DRM is a guideline with schematic framework which helps to organize the idea and set the outcomes intact for the following purposes, namely: a systematic design for planning and execution of research, helps to map variety of inputs in analyzing and amalgamation towards right communication in attainment of research output and assists to employ various research methods suitable. Also, helps to make design research more rigorous, effective and efficient towards outcome academically as well as practically [129]. Due to this iterative frame worked feature, DRM has been adopted for conducting this research.

The DRM approach includes four main stages as depicted in Figure 3.1, namely Research Clarification (RC), Descriptive Study-I (DS-I), Prescriptive Study-I (PS-I) and Descriptive Study-II (DS-II). The process in the Figure 3.1 shows three phases horizontally namely: methods, stages and deliverables. Method represents the process adopted, stages represent the objective and deliverable represent the outcome of the process in the respective stage. Dark arrows show the input and output for each stage, light arrows represent the flow direction across each stage iteratively.

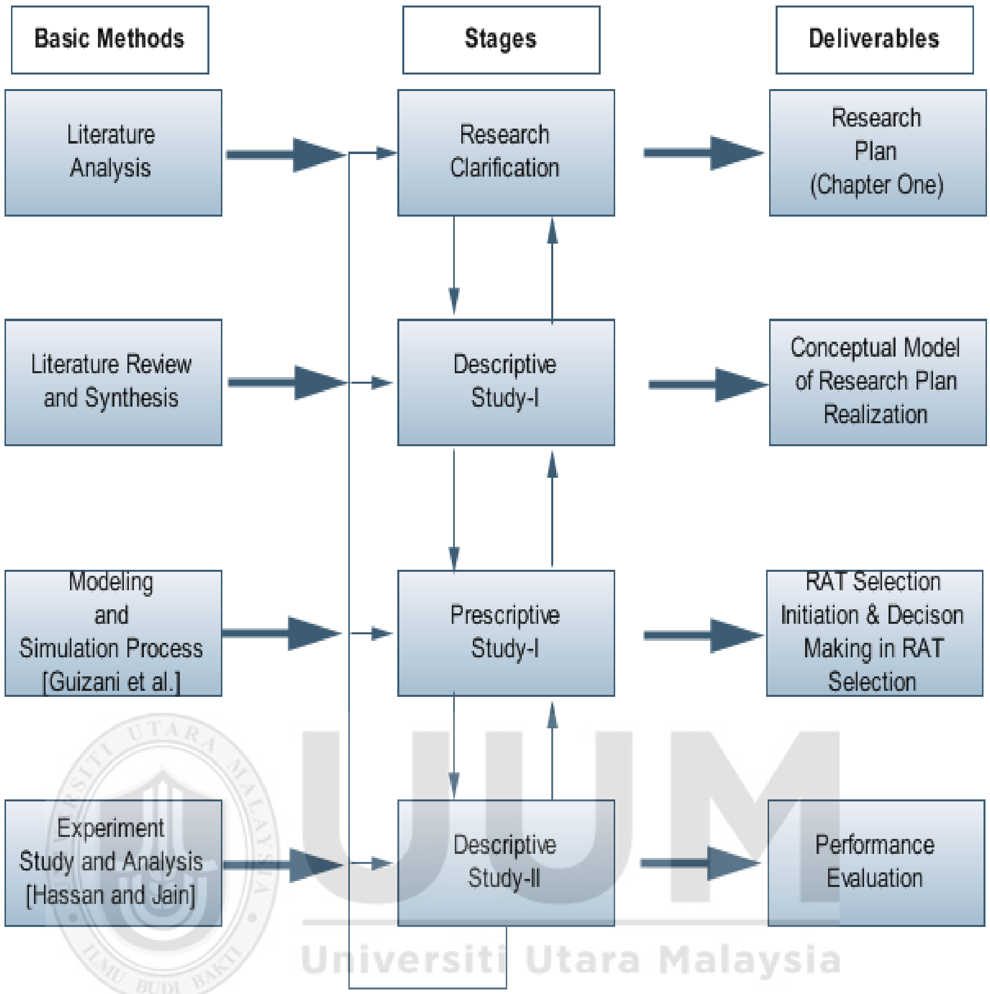

Figure 3.1. Research Approach [130]

3.2 Research Clarification (RC)

The RC is the first step of DRM process. The RC stage of research plan focuses on understanding the domain of this research precisely. This stage consists of five iterative steps in order to derive a relative initial research plan as shown in Figure 3.2. This phase starts the review primarily from main domain of research that is 5G UDN environment and focuses on RAT selection. Based on the literature, the research approach, scope, relevant mechanisms and expected contributions are outlined.

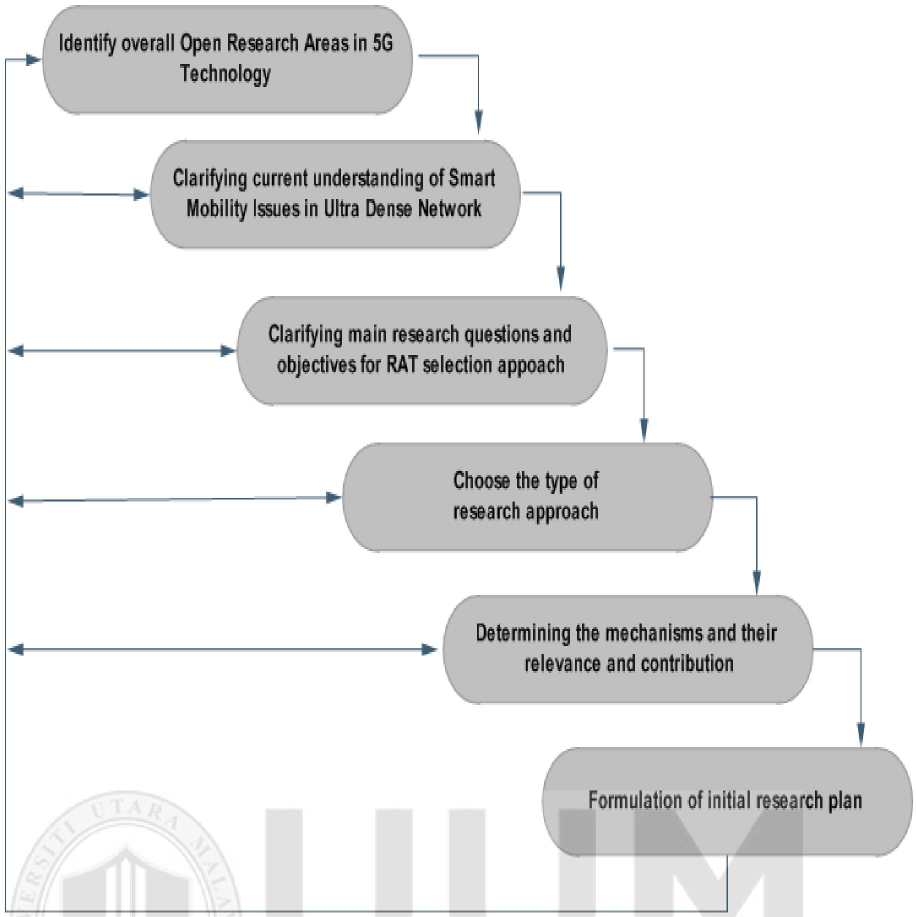

Figure 3.2. Main Steps in Research Clarification

The general outcomes of RC are outlined below:

i. Research Motivation
ii. Research Problem, Objectives and Questions
iii. The scope of the research and well-defined contributions to the domain from the focused research problem.

3.3 Descriptive Study-I (DS-I)

On completing the first stage RC, a condensed research plan is formulated. The second stage DS-I magnifies into the current context and embeds the critical review of the exhaustive literature in the research area. The DS-I comprises of four steps with many iterations as illustrated in Figure 3.3. Each step aids deeper understanding and refining to achieve a good conceptual model towards the accomplishment of the goal systematically. First of all, the evolution of wireless access networks and the RAT selection mechanisms within the heterogeneous environment are reviewed. Then, a survey is carried out on the various relevant VHO approaches scaling towards the VHO decision to choose the best RAT among the available once. Finally, with the acquired knowledge formulation of a more refined research plan for optimized RAT selection approach in the ultra dense heterogeneous network is attained.

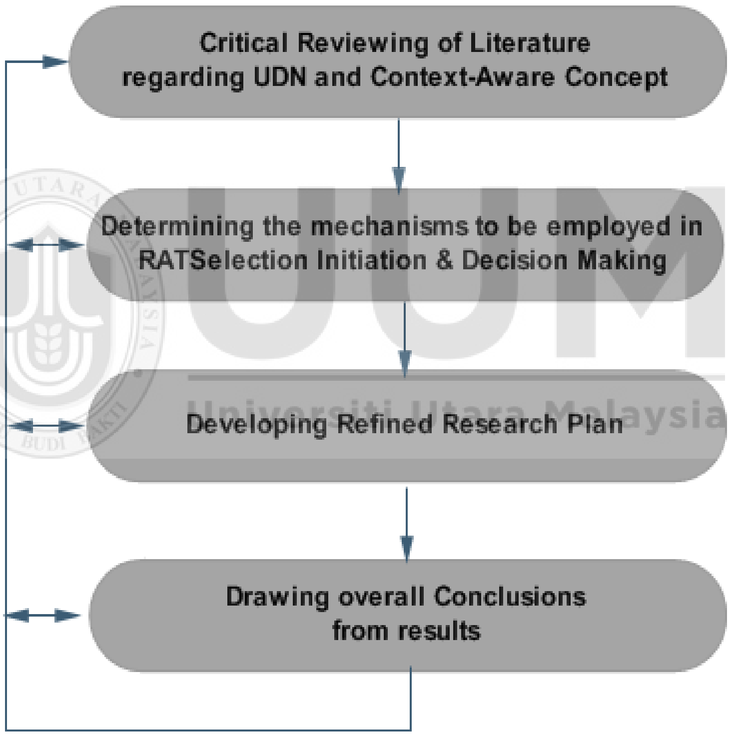

Figure 3.3. Steps in Descriptive Study-1

The outcomes of DS-I are:

i. Critical review of background works to determine the refined research plan as presented in Chapter Two, and

ii. A conceptual model of proposed RAT selection approach consisting of initiation and decision making mechanisms for RAT selection in UDN.

- **Conceptual Model**

In order to reduce the number of unnecessary handovers in UDN multi RAT environment, the proposed approach of RAT selection was formulated with the critical review of the earlier employed mechanisms. This research designed a novel approach to address the RAT selection based on the multi-criteria theory. In an avenue to address the RAT selection approach comprising of two mechanisms for the respective phase of handover, a conceptual model comprising of all the approach and its effect towards the main goal is shown in Figure 3.4. The model also addresses the performance metrics measure after employing the proposed RAT selection approach.

Initiation of RAT selection is a preliminary step, It starts with balancing the selected parameters based on the context. The proposed approach will consider the criteria based on user and network preferences to initiate handover. The context information is available has a database comprising of the RAT context information repository. Initiation needs several iterative process to determine the necessity of handover. Figure 3.4 (A) portray the mechanism, Context-aware Analytical Hierarchy Process (CAHP) which determines the necessity of handover requirement triggering the initiation. The initiation triggering reviews and processes the priority of the criteria according to the available data information in context repository in lined to the user and network preferences at the context of RAT.

If the handover is initiated then only the next phase of RAT selection decision making is triggered else continues in the same RAT. In decision phase, the primary focus is to determine the best RAT among the available neighbour RATs based on their data in context information repository. Context information helps to map each mobile terminal to alternative available RATs, which needs to be handovered to available RAT.

The Figure 3.4 (B) outlines mechanism, Context-aware Technique for Order Preference by Similarity to an Ideal Solution (CTOPSIS) which determines the next target RAT. The network discovery is made to know the RAT and their information of the aforementioned criteria with the context and updated in the context information repository. The requirement of the mobile terminal is matched with the information of the available RAT and target is determined. The performance of the approach is measured by four success factors; the number of handovers, packet delivery ratio, throughput and average network delay. All these measurable factors implicitly contribute an efficient and maximum utilization of the network resources with context-awareness.

3.4 Prespective Study (PS)

The PS is the focal point of the DRM as it includes the design of the proposed research mechanisms. Proposed research network modeling and simulation process is shown in Figure 3.5 , describes the main steps in PS according to the research phenomena from conceptual model till the whole system model validation and verification. Figure 3.5 describes the methodology of both employed mechanism in RAT selection approach. The main aim is RAT selection, it comprises of two mechanisms within it, first one CAHP mechanism which initiates the RAT selection measuring the intra-RAT criteria.

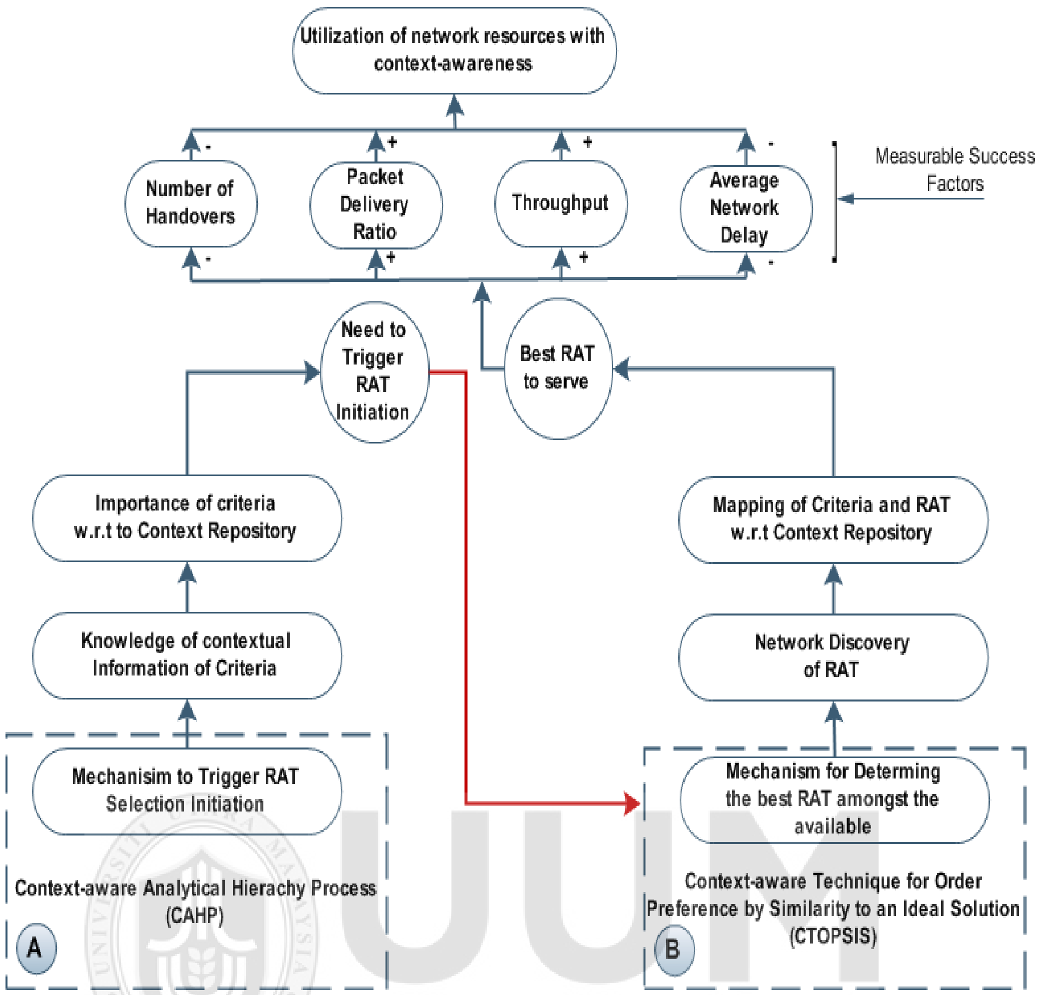

Figure 3.4. Conceptual Framework

Secondly, CTOPSIS mechanism to determine the RAT among the multiple available RAT. Both the mechanism implementation follow the same procedure in Figure 3.5, the conceptual design of the mechanism is done, later the conceptual model is transformed into the analytical model with the mathamatical equation formulations. The formulated equations are transformed into the programmable code of MATLAB tool, for ruuning the experiment multiple times. The designed and implemented mechanisms undergo the verification and validation process attain the accrediation.

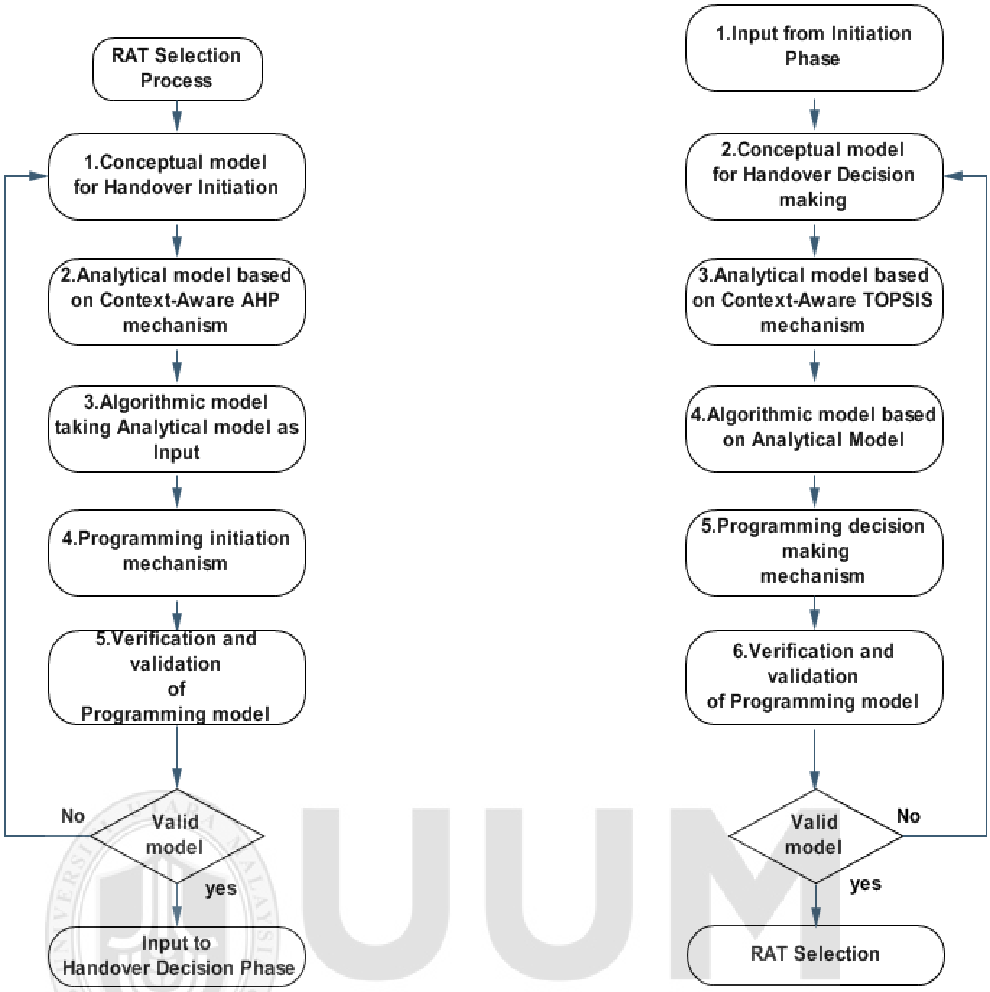

Figure 3.5. Prespective Study

Further, the accrediated model is transformed to the NS-3 simulator for further evaluation of the proposed approach.

The expected outcomes from PS are

i. Realization of objectives One and Two.
ii. Design and implementation of the proposed research mechanisms.
iii. Verification and validation of the proposed mechanisms.

- **Verification and Validation**

Verification is the process of determining whether the implemented model with its associated data accurately meets the developers conceptual description and specification. Generally "Have we built the model right"? the question is asked to verify the correctness of the model. Validation is a process of determining the degree to which level simulation model realizes the accurate data to real world perspectives intended use of the model. " Have we built the right model"? the question is triggered. Confidence Internal is very important factor in simulation setup which accurate the results obtained with a number of executions in the experimental setup. Special formula based on the context is used to calculate the interval.

Verification is the process done to ensure that:

i. The model is programmed appropriately
ii. The procedures have been applied correctly
iii. The model conversion from conceptualization to the program design is free from errors, oversights, or bugs.
iv. A high level statistical certainty is realized by testing more cases.

Model verification is a determination that the model is transformed with sufficient consistent accuracy from phase to phase [131], phases are clearly depicted in Figure 3.6. The model verification evaluates the accurate transformation from pseudo code to actual implementation i.e executable program code. In this proposed research mechanisms were transformed to C++ code, since NS-3 simulator requires C++ as the programming language. All mechanism must be verified to ensure the code is bug free [132]. Additionally, C++ code in NS-3 is capable of assisting the researchers by highlighting and indicating possible syntax errors during the compilation of the code.

Verification determines the syntax error freeness when the raw data is programmed into the programming code. If the compilation is done it means the verification is done correctly. The semantic error free determines the correctness of the foreseen results obtained from the process of transforming the raw data to the programmable code. On the execution of the code results are obtained.

They are validated by comparing with the standards and further accredited by evaluating with the contemporary mechanisms. This evaluation results not only evaluates the performance progress but also implicitly validates the proposed mechanism.

Validation is the process of in sculpting a simulation model and its related facts are an exact illustration of the actual world from the perception of the designer, in obtaining the desired results with the employed mechanisms [133].

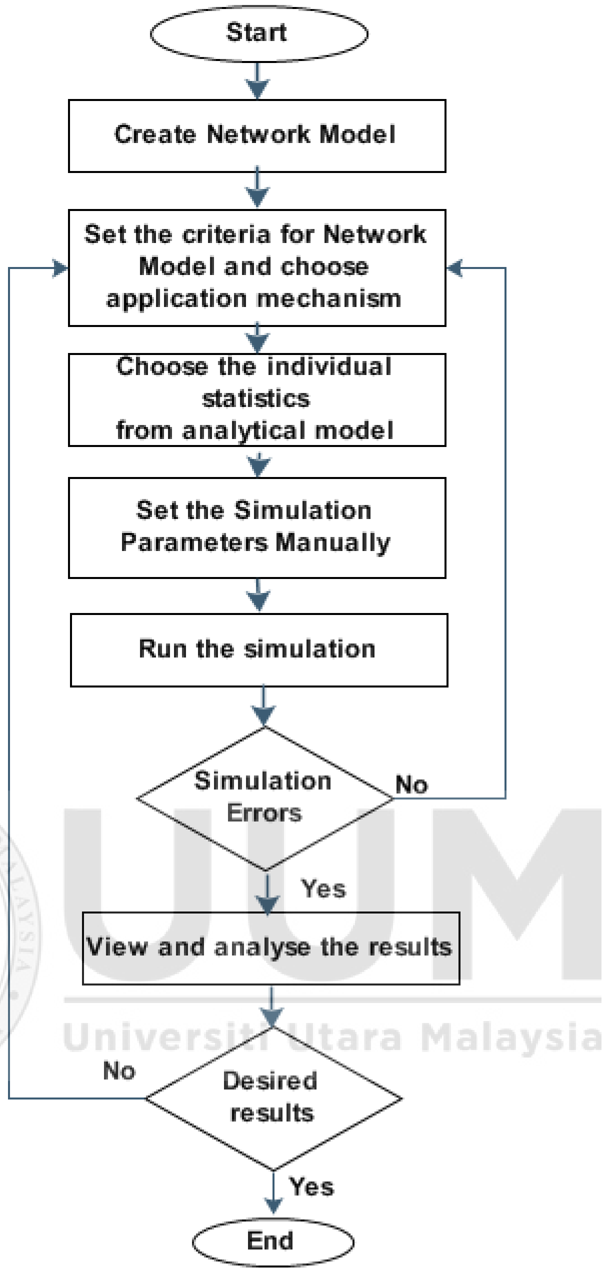

Figure 3.6. Main Steps in the Verification and Validation Stage

There are different ways the validation and accreditation of the developed conceptual model can be done. The Table 3.1 below illustrates the various ways a model validation can be done in brief. This proposed research follows the two methods of validation (1): Evaluation with/to Other Models and (4): Constraint Changeability – Sensitivity Analysis from Table 3.1. The mechanisms proposed and implemented in RAT selection are firstly, designed the analytical model based on the integration of context-awareness and MADM theory. The analytical formulation of equations is transformed to the programmable code of the MATLAB.

Table 3.1
Model Validation Approaches

Sl.no	Validation Method	Description
1	Evaluation with/to Other Models	Results of the simulation are endorsed by comparing with the cognate results of the valid model.
2	Appearance Validity	Taking the expert opinion about the correctness of the model.
3	Previous Data Validation	The historical data is used to build and test the model
4	Constraint Changeability – Sensitivity Analysis	This approach consists of changing the input parameters of a model to determine the effect on the model's behavior of output in accordance to the real system. Those parameters that are sensitive should be made adequately accurate prior to injecting into the model.
5	Predictive Validation	The model is used to forecast the system's behavior, and then the system's behavior and the model's forecast are compared to determine if they are the same. The system's data may come from an operational system or be obtained by conducting experiments on the system, e.g., field tests

The first level of validation is implicitly done by the theory adopted by the consistency range acceptable for the mechanism implementation. The final result of the proposed mechanism are compared with the parallel contemporary mechanisms and evaluated for validating the proposed model. The results obtained for many cases to rigorously examine the validation of the proposed mechanism 3.6. The detailed numerical analysis of the validation, evaluation and final accreditation of the results are presented in Chapter Four and Five for respective mechanisms. To check for the sensitivity of the constraint changeability, the simulation is run randomly for numerous decision points.

3.5 Descriptive Study-II (DS-II)

The DS-II focuses on the evaluation of the designed mechanisms and the expected performance outcomes. This is a crucial stage of research which actually outlines the quantifying contribution of the research to the domain by meeting accurately the design specifications. Conventionally modeling, simulation measurement are methods used to evaluate performance.

3.5.1 Evaluation Approach Consideration

Evaluation techniques aids to measure the performance of the system are vital. Selecting the right evaluation technique and the tool is of paramount importance [134]. Table 3.2 outlines the strength and weaknesses of performance evaluation techniques as stated in [135]. The table illustrates the different techniques of performance evaluation. The technique is broadly classified into two streams the performance modeling and performance measurement.

Table 3.2
Comparison of Performance Evaluation Techniques

Criteria	**Performance Modeling**		**Performance Measurement**
	Analytical Modeling	**Simulation**	
Time Required	L	M	H
Accuracy	L	M	H
Tool	Formal Method	Computer Programming	Instrumentation
Trade-off evaluation	Easy	M	Difficult
Cost	Small	M	H

Low-L, High-H and Medium-M

Performance measurement is done when the system of research interest is available has an actual system with real-time parameters. The measurement can be in the form of test bed, on chip performance monitoring, software monitoring, off-chip hardware monitoring, etc. Performance modeling is done by simulating the actual system. Analytical modeling is the mathematical formulation of the theory or mechanism which are based on operational laws, queuing networks, process algebra, stochastic networks etc. [134, 136]

After examining closely the different evaluation technique approaches this research chose the performance modeling technique to accomplish the research objectives stated in Chapter One. Performance modeling is the normalized technique considering the all the criteria from time to cost for a researcher [137].

3.5.1.1 Analytical Modeling

Analytical modeling is a description of the system in terms of mathematical concepts and language, which includes the logical model based on some theory to agree with the results of repeatable experiments. An analytical model is defined a set of equations with mathematical notations to represent an actual system [138]. An analytical model is the abstraction of the actual model formulated using mathematical symbolism. An analytical models are adapted to use when the observed facts are measurable. Which can be further investigated using computer programming. Also, translates the equations to an executable code and further can be transferred into the graph. Users have a liberty to vary the conditions in input parameters of the code to obtain desired results. According to Jain [135], modeling has several advantage such as low cost, less time required and easy in trade-off evaluation.

This research also embarks with the analytical modeling as a formal method of verification and validation of the mechanisms and further the actual replica of the model is done through the simulation for performance evaluation. To verify the analytical model is being done to both the mechanisms and transformed to the MATLAB code for the numerical analysis.

3.5.1.2 Network Simulation

Network simulation is a technique used to imitate the dynamic responses and behaviors of real systems using the computer programming. It is a more flexible tool to studying the performance of various protocol and other working components of the network. In this proposed research plan, simulation of the actual scenarios with UDN environment is created and Vertical Handover concept with context aware parameter are realized using open source simulator NS-3.

Advantages of employing simulator are as follows :

i. Aid researchers to investigate a wide range of scenarios in a short period and predict the performance.
ii. Simulation needs a single computer to run simulation setup to conduct experiments and analyze the results, gives liberty to vary the input to obtain expected outcome.
iii. Complex topologies can be easily realized via simulation environment with varying workload and network conditions.
iv. Simulation can embed more details than analytical model producing results closer to reality.
v. The use of open source tools is cost saving as well.

3.5.2 Evaluation Environment

Numerous simulators are available for researchers to realize functionality ranging from open source to commercial softwares. The commercial simulators are very user friendly and easy to implement due to the click, drag and drop component usage however are available with a high cost. Hence, most of the researcher opt for the open source though it is not Graphical User Interface (GUI) based at times.

3.5.2.1 MATLAB

MATLAB is a tool providing an interactive environment for numerical computation, visualization, and programming. MATLAB application is built around the MATLAB tool, and most use of MATLAB involves typing MATLAB code into the Command Window, or executing text files containing MATLAB code, including scripts and functions. As part of this proposed research MATLAB will be used to realize the proposed theory of Multi Attribute Decision Making (MADM) and context-awareness.

3.5.2.2 Network Simulator 3 (NS-3)

The NS-3 simulator is a discrete event simulator which fundamentally for research and education purpose. It is an open source not bound to any company but driven by the research community to develop new models. The suggestions from NS-3 mailing lists are considered in improving simulator greatly. NS-3 is an open source and licensed under GNU GPLV2 welcoming the open contribution from both academia and industry.

NS-3 runs on Linux operating system but there is flexibility to setup virtual environment on any other operating systems well. NS-3 is written in C++ and interfaced by python interface. The primary focus is towards realism with the Internet node representation is close to the actual system. The key interface like sockets, network devices, use of IP address and gateways are configured very close to actual system. This proposed research uses NS-3, which comprises of all the required models for designing and implementing the UDN environment for RAT selection. NS-3 incorporates the LTE-A and WiFi modules which provide a considerable essential feature close to the actual system.

3.5.2.3 Experiment Steps

According to Hassan and Jain [139] segregates the performance evaluation into 10 phases as shown in Figure 3.7. Step 1 formulates the main issue and objectives with the main criteria to analysed with the contextawareness, Step 2 formulates the design for contextual environment in triggering the decision of RAT selection initiation followed by decision making, Step3 outlines the metrics to measure the performance of the designed approach and Step 4 focuses on the varying parameters in different scenario to test the working of the proposed approach decision making. Step 1 to 4 specifies the presoftware stage, later Step5 to 8 specify the software stage which mainly focuses on constructing and configuring the mechanisms to execute in the simulator and interpret the results to measure the performance of the implemented approach.

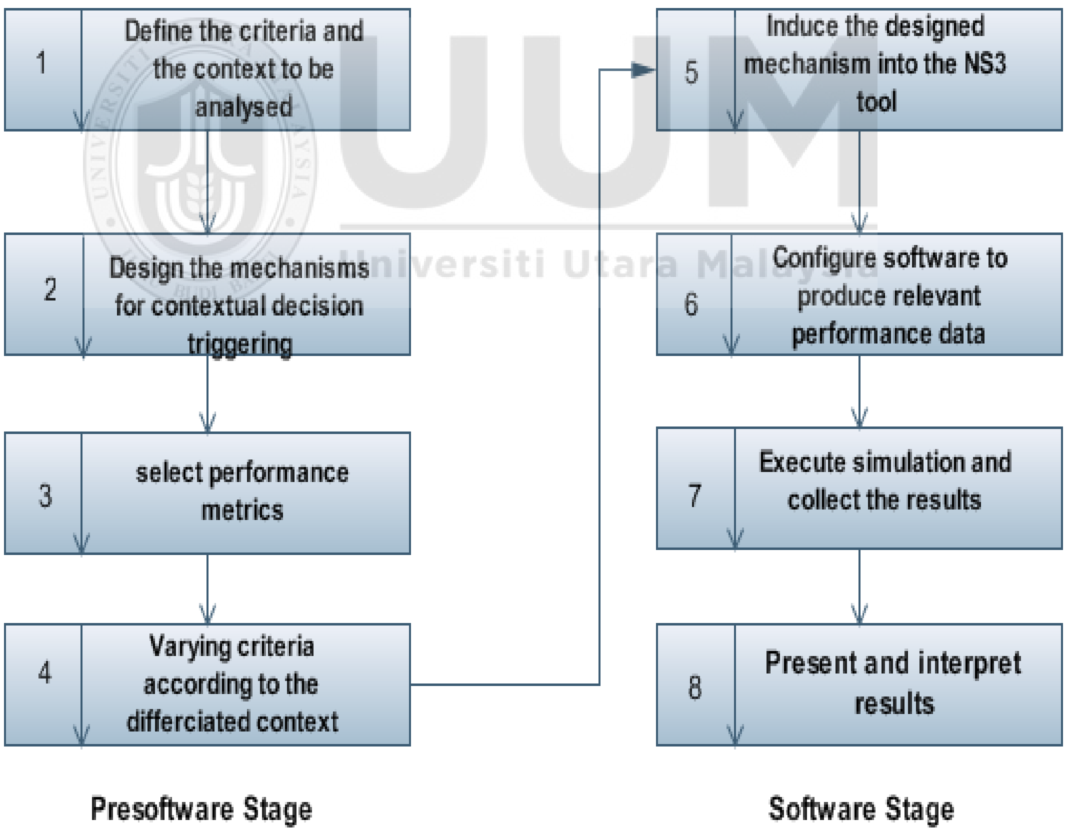

Figure 3.7. Steps of a Systematic Simulation Study

The initial phase of the simulation does the system discovery for the decision criteria according to the context, the values are input to the mechanisms and the execution of the code performance data is obtained. The obtained result is presented in the graph form to known the significance of the performance w.r.t the time.

3.5.2.4 Experiment Setup

All the experiments presented in Chapter Four, Five and Six were performed using the MATLAB and NS-3. The analytical model presented in Chapters Four and Five were transformed from mathematical equations into a programmable code for multiple iterations and matrix analysis in MATLAB. The whole performance of the proposed mechanisms analytical model is incorporated into a NS3 simulator and presented in Chapter Six.

The NS3 version 3.21 on Red Hat Linux 6.1 operating system was used to implement the whole proposed approach. The implementation is touched across by different modules of NS-3. Few main modules are presented below:

LTE Model: LTE is a software library module that allow a simulation of LTE radio access technology, including the Evolved Packet Core (EPC). The process involves the defining the network scenario to be simulated. The simulation code with the described topology is designed. The NS3 library for LTE model using ns3::LteHelper API defined in src/lte/helper/lte-helper.h. The parameter configuration of all the component objects during the simulation are done via configuration file ns3::configstore.

The EPC model includes core network interfaces, protocols and entities. These entities and protocols reside within the Serving Gateway (SGW), Packet Gateway (PGW) and Mobility Management Entity (MME) nodes, and partially within the eNB and HeNB nodes. It supports for the interconnection of multiple UEs to the Internet, via a radio access network of multiple eNBs connected to a single SGW/PGW node.

WiFi Model: The WifiNetDevice models a wireless network interface controller based on the IEEE 802.11 standard [ieee80211]. The infrastructure and adhoc modes 802.11a, 802.11b, 802.11g, 802.11n (both 2.4 and 5 GHz bands) and 802.11ac physical layers are supported. This proposed mechanism incorporates IEEE 802.11n has part of the implementation.

Mobility Model: The mobility support in ns-3 includes a set of mobility models which are used to track and maintain the current cartesian position and speed of an object. a "course change notifier" trace source which can be used to register listeners to the course changes of a mobility model a number of helper classes which are used to place nodes and setup mobility models (including parsers for some mobility definition formats). The directory src/mobility specifies the source for mobility. In this proposed approach the ns3::RandomWalk2dMobilityModel is used to track the movement of the user randomly in the specified scenarios.

Flow monitor: It is a network monitoring framework for the NS-3. It is easy to use, it is activate with some lines of code, it is also detect passing flows automatically. It also minimizes the output file size generated from simulation along with better CPU performance. In order to manage huge output file result we use Flow monitor to reduce time/memory overhead and automatic result generation from the trace files generated for the desired metrics.

3.5.2.5 Cardinality of Input Decision Criteria

The cardinality of criteria defines the number of criteria incorporated in triggering the initiating and decision making of handover. Cardinality is the vital aspect in decision making because the magnitude of the criteria defines the design and implementation complexity. Low magnitude of criteria will definitely reduce the computational load. However, on the other dimension, the important criteria in decision making may be excluded. On the other hand, large magnitude of criteria may decrease the efficiency of the mechanism. Hence, a survey and review of the cardinality for the range of criteria are done, ranging from three [76, 140, 94] to ten [141], but from the literature review cardinality five [112, 142, 113] is most frequently chosen magnitude. The average five yields better results and the impact is more significant in obtaining the weight and further ranking the alternative.

This research also chose five criteria in triggering initiation and decision making. The detailed description of the chosen in design and implementation is presented in Chapter Four of Section 4.2.2. To further, emphasize on the fact of chosen criteria and review of the possible criteria considered in MADM RAT selection. Based on the list of criteria mentioned in Chapter Two Section 2.3.1, a detailed review of the combination of criteria is presented in Table 3.3 .

The Table 3.3 showed the comprehensive combination of the criteria most likely used by the researchers. However, after the review magnitude, five is confirmed to be implemented for the proposed research. The five chosen criteria are radio signal strength, Data rate, Delay, Jitter and packet loss. The justification is outlined in Table 3.3, as well as requirement to measure the performance in UDN RAT selection. The Table 3.3 justifies that the chosen criteria for this research are most used criteria in decision making. The RSS gives the quality and power of the signal a basic criterion for RAT,

Table 3.3

Combination of Criteria in Network Selection in Heterogeneous Networks

Authors⇓ ╲Criteria⇒	**T**	**AB**	**R**	**C**	**S**	**PC**	**D**	**RT**	**BER**	**J**	**BE**	**PLR**	**DP**	**MNV**	**DMS**	**NU**	**TB**
Stevens-Navarro et al. [143]		×					×		×	×							
TalebiFard et al. [95]		×		×	×	×	×			×			×				
Chantaksinopas et al. [144]			×	×			×					×					
Lahby et al. [104]		×		×	×		×			×		×					
Bari and Leung [145]		×		×			×			×		×				×	×
Martinez-Morales et al. [97]		×					×			×		×					×
Inwhee et al. [110]		×		×		×	×		×	×							
Kaleem et al. [121]	×		×	×	×		×			×		×		×		×	
Mehbodniya et al. [106]	×		×	×	×		×			×		×		×		×	
Zhang et al. [113]	×			×	×		×	×	×	×	×	×					
Song and Jamalipour [146]	×			×	×		×	×	×	×	×						
Mehbodniya et al. [147]		×	×		×		×					×					
Charilas et al. [148]	×			×			×		×	×		×					
Dhar et al. [119]		×		×			×			×		×				×	×
Khan et al. [114]	×	×		×			×			×							
Singh, NP and Manisha [149]		×		×			×			×		×					

T-Throughput, AB-Available Bandwidth, R-RSS, C-Cost, S-Security, PC-Power Consumption, D-Delay, RT-Response Time, BER-Bit Error Rate, J-Jitter, BE-Burst Error, PLR-Packet Loss Rate, DP-Dropping Probability, MNV-Mobile Node Velocity, DMS-Device Memory Size, NU-Network Utilization, TB-Total Bandwidth datarate signifies the available band for data transmission, delay and jitter signifies the quickness to the data transmission in attainment of user satisfaction and packet loss is important to ensure the correct transmission of the data without discrepancies during the transit. In spite of these criteria user preference and the contextual dynamicity of the criteria in decision making is vital.

3.5.2.6 Performance Metrics

Performance metrics aids to measure the performance in a quantifying manner. Literature reveals few metrics relevant to RAT selection in this section ahead as follows:

i. Packet Delivery Ratio (PDR): It is the ratio between the total received and total transmitted packets.

$$PDR = \sum rx / \sum tx \tag{3.1}$$

where,

rx: is the total number of received packets.

tx: is the total number of transmitted packets.

ii. Throughput: It is measured by the data are sent by the mobile node after a set of matching decision during a definite period.

$$Throughput = RxBytes/((LastRxPacket - FirstTxPacket) \tag{3.2}$$

where,

RxBytes: are the recieved bytes.

LastRxPacket: is the time of the last packet received.

FirstTxPacket: is the time of the first packet transmitted.

iii. Number of Handovers: The handover event reflects the number of handovers achieved by a mobile terminal.
iv. Average Network Delay: It refers to the time taken for a packet to be transmitted across a network from source to destination. It is computed for the time of simulation begin to end in performing handover.

3.6 Summary

This chapter has described in great detail the research approach in ensuring that the research objectives can be achieved. This research concentrates on developing optimized RAT initiation and decision making technique for heterogeneous UDN environment. Four main activities of the research were outlined in this chapter, in line with DRM. The first activity is the Research Clarification (RC) stage, which discusses methods to support the initial stage of this research.

The aim of RC are to identify and refine a research problem, objectives, and research questions that are both academically and practically worthwhile and realistic. The second activity is called Descriptive Study-I (DS-I), which discusses steps to obtain sufficient understanding of the current situation, designs a reference model, and proposes a conceptual model. The third activity highlights the methods adopted in designing the proposed RAT selection approach, named as Perspective Study (PS). The last activity named DS-II focuses on the evaluation of the designed mechanisms .

CHAPTER FOUR
CONTEXT-AWARE RAT INITIATION

After establishing the research methodology in Chapter Three as a guideline to achieve the objectives of this research, and in addition to the rigorous literature review in Chapter Two, it was inferred that Multiple Attribute Decision Making (MADM) methods are recommended for future generation of wireless networks in choosing the RAT. However, MADM only on its own will not be adequate in decision making for future UDN architecture, so MADM should be integrated with context-awareness for efficient decision making. The selection of RAT involves three phases, initiation, decision making, and execution. The focus of this chapter is the first phase in the selection, i.e., the initiation. This research combines the context-aware concept along with one of the classic MADM mechanism, namely AHP, that has been customised for the initiation in RAT selection. This chapter proposes a novel mechanism for Radio Access Technology (RAT) initiation. The RAT Initiation mechanism, Context-aware Analytical Hierarchy Process (CAHP), was designed to know the need of selecting a new RAT by measuring the current Radio Access Technology context information.

The chapter is organised as follows; Section 4.1 introduces the concept of UDN realisation in the next digital wave, where the context-aware concept is integrated with MADM methodology in conquering the RAT selection coherently. The system model is presented in Section 4.2 that describes the whole environment of implementation of the proposed mechanism. This is followed by context-aware initiation in triggering the RAT selection in Section 4.3. Further, Section 4.4 presents the verification and validation of CAHP mechanisms with quantitative analysis and illustrating the different case and the contextual decisions triggered in each case. Finally, Section 4.5 summarises Chapter Four.

4.1 Integration of MADM and Context-awareness Theory

After a rigorous background study of several classic MADM mechanisms, this research of RAT selection mechanism for the UDN will integrate MADM theory and context-aware concept, namely, the Analytical Hierarchy Process (AHP) method [150], to ascertain weights of the criteria differentiating user requirement and traffic class demand priority. The AHP method helps to review and relate the criteria at all levels of the hierarchy of the problem [151].

However, just MADM mechanisms only cannot serve the purpose due to the involvement of heterogeneous networks that are densely deployed, which involves many criteria with different contextual requirements. Hence, the integration of MADM with context-awareness in better for the decision making of RAT selection. Extreme densification infrastructure involves many complex criteria to consider for RAT selection initiation. The operational technique can analyse the criteria but the criteria need to be analysed and a decision needs to be triggered for a collaborative approach between the user and network. Hence, an integrated approach of the context-aware concept with MADM methodology would serve this purpose. The AHP mechanism alone determines the weight of the listed criteria, and this fixed and static process of weight assignment may not be efficient in triggering the RAT selection decision. Hence, the context-awareness concept is merged with AHP to make the initiation with dynamicity of the criteria with differentiated user priority. The integrated mechanism will consider the intra-assessment of the criteria within the current serving RAT with the context-awareness of user priority in triggering the RAT selection initiation. The next section describes the system model of the experiment in implementing the designed mechanism.

4.2 System Model

The system model defines the overall environment considered in the design of RAT selection in the UDN environment. Also, the system model describes the assumptions and considerations in formulating the analytical modelling and validation through the numerical analysis of the proposed mechanisms with multiple cases of triggering decisions. The system model outlines all the RATs in forming the UDN environment for RAT selection, where it is designed to considered for both RAT initiation presented in this Chapter and decision making, presented in Chapter Five.

4.2.1 Network Environment

The 1000X increase in data traffic forecast in the future forces researchers to rethink the system design to accommodate the extreme demand. The design is not an evolutionary change of spectrum, but rather an infrastructure densification. This paradigm shift is realised by small cell deployment in UDN. To satisfy seamless coverage, a dense deployment of small cell architecture is proposed in 5G networks. The small cell increases the throughput while reducing power consumption [152]. The small cell in a dense heterogeneous network comprises femtocell and macrocell structures. A femtocell is a low power base station confined to the home or small business. Macrocell is the central network base station covering a larger area. The benefits of small cells are for both operators and the consumer. Femtocell enhances both coverage and capacity in indoors. Coverage can be enhanced by improving loss of signal through the building, and capacity is increased by reducing the attempts to connect to the main network base station, while handling the services in an offloaded manner [153].

The small cell scenario comprises the Home evolved base station (HeNB), which is the LTE femtocell. The macrocell is a high power network base station of LTE, and it is known as the evolved node Base station (enB). In this wireless network scenario, different types of small cells (femto cell and WiFi) are deployed in an unconditional manner with a macro coverage range, as shown in Figure 4.1. The main aim of this proposed network environment is ultra densification and sharing of the traffic load from central base station to HeNB or WiFi, depending on the contextual-awareness of user and network preferences. This research made the following assumptions to design the system model for implementing the proposed mechanism.

i. The UDN heterogeneous RAT is formed with the RAT, such as, IEEE 802.11n, IEEE 802.11ac, and Home evolved base station (HeNB), LTE (release 13) in the design and implementation of the proposed mechanism of this research.
ii. All classes of traffic are considered in triggering and decision making of the serving RAT, where the traffic classes and their requirements are described in Table 4.2.
iii. This study focused exclusively on vertical handover only in UDN environment. The vertical handover is the prominent scope of study due to the multi-RAT close deployment architecture.

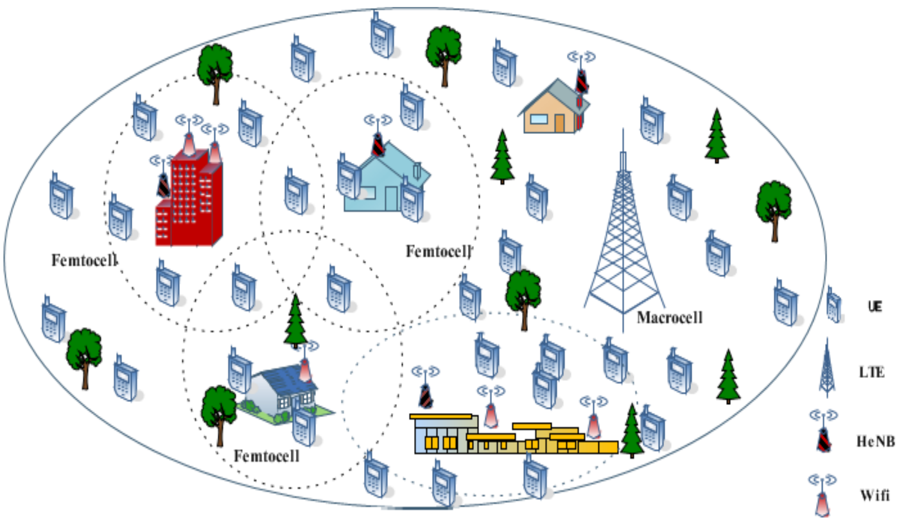

Figure 4.1. System Model of the UDN Small Cell Deployment

The proposed mechanism involves multi-attributes in decision making with the context-awareness of both user and network. The criteria employed in different approaches were elaborated upon in Chapter Two and later criteria cardinality was discussed in Chapter Three. From the rigorous literature review and analysis seen in previous chapters, the cardinality or the magnitude of the criteria was chosen to be five. The five shortlisted criteria are to measure the need to switch from current RAT and further determining the best one among the multiple choices. The main input criteria considered in RAT selection are broadly classified into the network related and user related criteria, as described below.

Network-related criteria are the criteria related to the core network resources that help in providing service according to the demand of the user, and these include:

i. Received Signal Strength (RSS): This is the received power of the mobile terminal and it differs from RAT to RAT. It will be reduced when the terminal moves away from the access point, expressed as network coverage. This metric determines the availability of the signal for the terminal.

ii. Data Rate (DR): In the case of coexistence of two different networks with an acceptable signal, the difference in bandwidth becomes the vital criterion. It is important for sensitive applications to delay to encounter the QoS requirements. Data rate is the maximum transfer rate maintained in between two endpoints (transmitter and receiver).

User-related criteria are the parameters which the user perceives in attaining better experience, which include:

i. Packet Delay (D): This attribute is a measure of the average delay variability within the access system. It can be measured in milliseconds.

ii. Packet Jitter (J): This attribute is a measure of the average delay variability within the access system. It can be measured in milliseconds.

iii. Packet Loss (L): This attribute is a measure of the average packet loss rate within the access system over a considerable duration of time. It can be measured in packet losses per million packets.

The collaborative (user and network) criteria for each RAT described in the system model are stated in Table 4.1.

Table 4.1
Network Parameter with Expected Standard Values for each RAT

Criteria⇒ Network ⇓	**RSS (dBm)**	**Data rate (Mbps)**	**Delay (ms)**	**Jitter (ms)**	**Packet Loss (per 10^6)**
802.11n	-72 to -92	7.2 - 72.2	100-150	1-30	10-20
802.11ac	-57 to -62	7.2 - 96.3	80-100	1-20	10-15
HenB	-75 to -120	75 - 300	80-100	1-20	10-15
LTE-enB	-75 to -120	75 - 300	80-100	1-20	10-15

4.2.2 User Preferences

User preference specifies the kind of application requested by the mobile terminal. The application can be just a simple email, a voice over IP, a finance transaction, and etc. These applications are broadly classified into four categories. The four traffic classes defined by 3GPP [154] were considered, namely background, conversational, streaming, and interactive. The complete description of each class is presented in Table 4.2. The background traffic or the simple data based traffic is one dimensional, like email, SMS, FTP, and etc. where the data is transferred from source to destination. For such applications the data should be received without any intermediate packet loss [155].

The conversational class of traffic is the two-dimensional communication like VOIP, video conferencing, and etc. where both the ends are conversing live. In such applications, delay is not tolerated, and it is highly sensitive to delay and jitter. Interactive is the third class of traffic described in the table, where such applications follow a request-response pattern of communication. Example of interactive traffic applications are all online transactions related to booking, trading, or buying, and etc. The PLR and delay are very critical issues in such applications. Finally, the streaming class of traffic is also one-dimensional traffic involving broadcasting applications, such as live video streams, sports events, concerts, and etc. where such applications are not much delay sensitive but requires high throughput [156].

Table 4.2
Classes of Traffic [156]

Traffic Classes	**Description**	**Requirement**
Background	One-dimensional transport. Example: User Sending SMS or emails	Packet Loss Rate (PLR) is a critical aspect. Delay, Jitter, and Throughput are relatively less vital.
Conversational	Two-dimensional transport. Example. VOIP and video conferencing	Delay and Jitter are very important. PLR and Throughput are relatively less critical.
Interactive	Two-dimensional transport based on request/response mechanism. Example: Chatting, online financial transaction	Delay and PLR are very important. Jitter and Throughput are relatively less critical
Streaming	One-dimensional transport. Example: Watching a video or live match on the web	Delay is not important. Jitter and Throughput play a vital role

The user preference is one important aspect to provide an input to the context-aware decision making. The preferred class will define criteria importance and the expected service quality to be achieved seamlessly. The criteria are in congruence with the application preference for RAT selection.

The performance and peak requirement need to be configured according to the requirements of the application context. To elaborate, more details are provided in Table 4.2. For example, very high data rate applications such as streaming high definition video may have relaxed delay and reliability requirements as compared to driverless cars on public safety applications, where delay and reliability are paramount but lower data rates can be tolerated. Knowing the importance of each class of the defined traffic is paramount, so that priority can be given during the intra and inter assessment of RAT in triggering the decision.

4.3 Context-aware Analytical Hierarchy Process

The proposed mechanism integrated the context-aware concept and MADM theory in the RAT selection Initiation of UDN architecture. The mechanism would trigger the RAT selection after measuring the collaborative (user and network) criteria with contextual awareness. The weight assignment was done by the CAHP mechanism by prioritising the user preference in line with the available network resources. The whole procedure of initiation of the RAT selection is explained in this section.

The initiation mechanism measures the context capability of the current serving RAT to continue service to the User Equipment (UE). The current RAT values of the shortlisted collaborative criteria are accessed with the differentiated application request of the user. Based on the context, collaborative criteria priority weight of each criterion is generated by the CAHP mechanism.

The CAHP mechanism bifocates its working into the hierarchy structure that comprises the main goal of process at the top, followed by shortlisted criteria, and the last level with the outlined RATs, as in Figure 4.2. The CAHP method follows the divide and conquer method for resolving complicated problems in decision making by dividing the problem into sub-problems and arranging them into a hierarchical model consisting of of goal, criteria, and alternatives (Figure 4.2).

The CAHP works in two phases to trigger the RAT initiation. Phase one is the criteria versus criteria comparison based on the context of the input formed with user and network contexts for differentiated applications. The priority of the criteria vary with the class of application demanded by the UE. The relative importance of the criteria is recorded based on the Saaty's table of importance to plot the values to form a pairwise matrix, which is presented in Table 4.3.

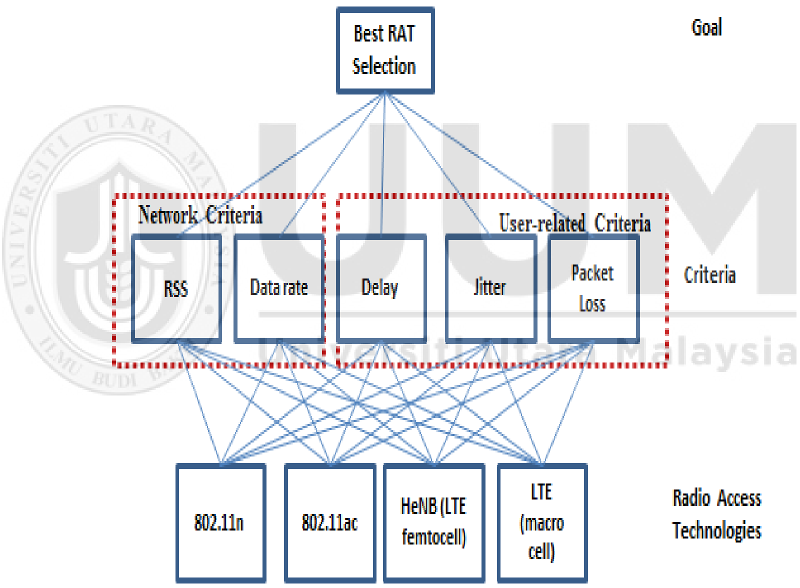

Figure 4.2. CAHP Hierarchy Process Model

Table 4.3
The Saatys scale of importance [157]

Intensity of Importance	Definition
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate values

In the CAHP mechanism, phase one of criteria comparison captures the priority of the context of UE request according to the respective weight of the criteria to be generated. At the phase two of CAHP, the comparison of the criteria with the RAT that has the UE is currently attached, is made. Phase two of CAHP generates the actual vales of the criteria of UE attached RAT through the experiment for the particular application. CAHP is an amalgamation of a set of evaluated criteria as an initiation condition. The condition is framed by comparing the context measured through criteria analysis of the actual current serving RAT values with the expected requirement context, based on the chosen decision criteria. If the expected value is greater than the actual value of the serving RAT, then RAT selection is initiated. Otherwise, it is expected to continue in the current residing RAT. Phase two will generate the RAT Initiation Factor (RIF) which decides the triggering of handover from the current RAT.

RIF comprises two components, namely the Actual Context (AC) which is the value generated after the analysis of the current RAT from the two phases of CAHP, and the Expected Context (EC), which is the expected value to serve the requirement of the current user requirement range, as stated in Table 4.1, for the chosen RAT and shortlisted criteria in the system model. To generate the values of AC and EC, the context repository information is integrated and analysed, i.e., weight of criteria and the prefered application. To be specific, the application requirement is mapped with the aforementioned criteria importance and the weights generated in level one calculation to generate the values. The readings generated during the experiment were considered to trigger RAT initiation.

The whole mechanism is illustrated in Figure 4.3 and the pseudocode in Figure 4.1. The initial value of RIF is set to zero, meaning there is no handover and current serving RAT is able to serve the UE. The randomly generated AC and EC values are compared.

If EC value is greater than AC value, the expected value is higher than the actual. Hence, RIF is set to one, meaning the initiation is triggered. If the AC value is greater the EC value, the RIF is set to zero meaning the current RAT can continue to serve the user. The decision point of the RAT selection is made by the RIF value. The flag set in RIF is the decision maker. RIF value is generated considering the context aware input of criteria to the respective RAT and its capability to serve the attached UE. Further, the next sections illustrate the proposed CAHP mechanism to trigger initiation with numerical analysis. The multiple cases of context based triggering of initiation is also explained.

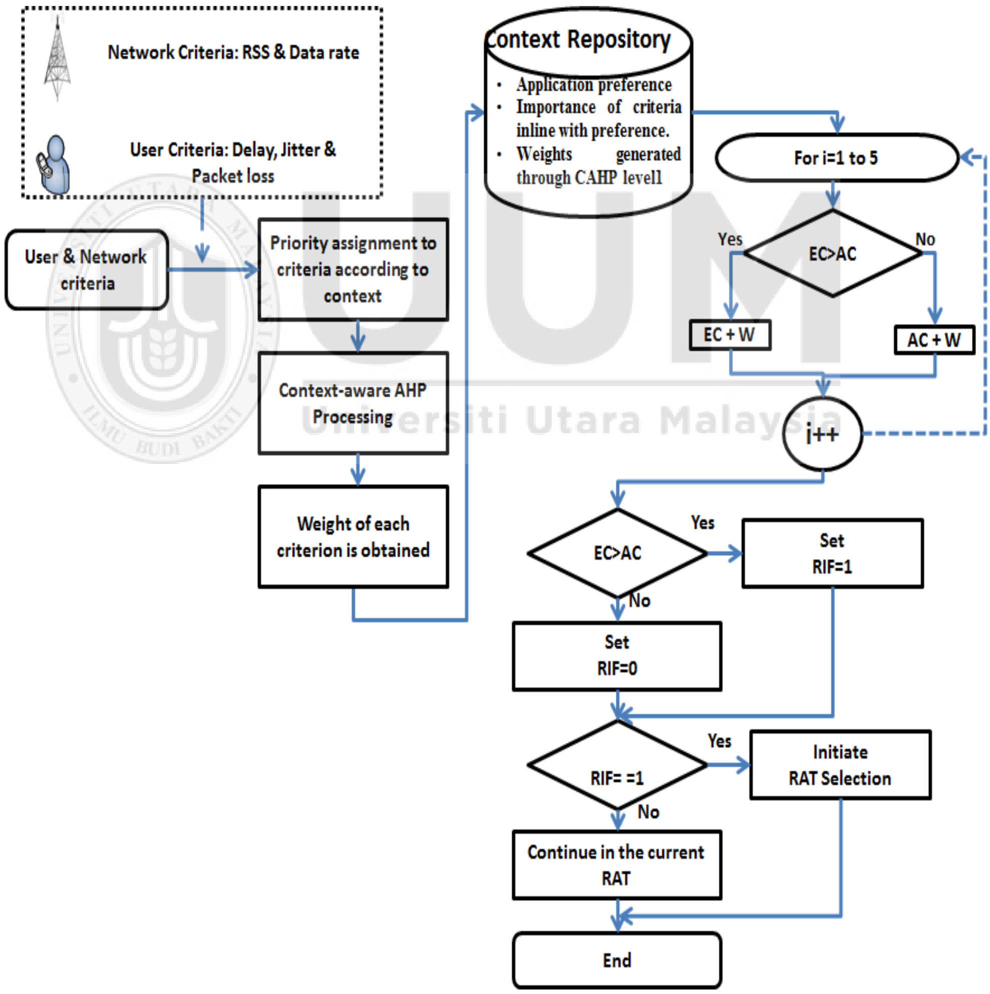

Figure 4.3. CAHP for RAT Initiation in UDN

The phase one comparison of the proposed mechanism is prioritised with the importance of criteria based on user application requirement [156]. The CAHP primarily refers the integers from 1 to 9 from Table 4.3 to interpret the intensity of importance of each criteria. The shortlisted criteria are mentioned at level one hierarchy of the figure, RSS, Data rate, Delay, Jitter, and Packet loss. The RATs at phase two are RAT's IEEE 802.11n, IEEE 802.11ac, HeNB (femtocell of LTE), and LTE macrocell (enB-evolved base station). The deatiled working of the mechanism is described below:

Algorithm 4.1 Psuedocode for RAT selection Initiation

Step 1. Begin
Step 2. Input the context-aware collaborative criteria.
Step 3. CAHP phase one, compares criteria versus criteria and generates
    the weight for each criteria.
Step 4. Phase two compares the criteria versus RAT to which currently UE is connected.
Step 5. Phase two computes the actual value of the criteria of the UE attached RAT
    w.r.t the weight generated in phase one
Step 6. The expected value is generated through the experiment in congruence
    with the network parameter table.
Step 7. The RIF is computed based on actual and expected values generated
    through step 2 to 6.
Step 8. The RIF is set to zero,
Step 9. If AC < EC
        RIF=0
    else
        RIF=1
Step10. If RIF=0, there is no initiation triggered. If RIF=1, RAT initiation is triggered.
Step 11. End.

Step 1: Determination of the objective and decision factor.

A pairwise matrix (n*n) is constructed comparing the criteria versus criteria based on Saaty's scale for importance. Table 4.3 defines the Saatys 1-9 scale of the pairwise comparison matrix [83]. The CAHP enables application specific prioritizing to the input criteria, for instance, an outline of more priority for delay in delay-sensitive applications. Similarly, priority for different applications are sensed and weights are assigned according to the Saaty's Table 4.3 in line with the differentiated application QoS requirements, as stated in Table4.2. Assuming the consistency, weight ordering of the factors in each level is computed and then they are synthesised into the overall weight ordering of all criteria toward the main goal [28].

The first phase of CAHP is an extension of the basic AHP. It is assumed C= [Cj, j=1,2,...,n] to be the set of criteria. The resulting (n*n) pairwise matrix A in which every element a_{ij} (i, j = 1,2,...,n) is the quotient depending upon the importance of criteria according to the context. The priorities assigned are of different units, hence the values are normalised and converted into dimensional values. The weights obtained at the end of the CAHP mechanism for each category of criteria are validated mathematically to check for consistency which can be derived from Equations 4.1 to 4.7. The eigen vector method used by CAHP can determine the weights [156]. The value 0.1 is the accepted upper limit for Coherence Ratio [158, 159, 160, 161], which determines the consistency in the prioritisation of the qualitative based input in the pairwise matrix, which should be less than 10%. If the CR value > 0.1, the process needs to be repeated for attaining consistency. The measured consistency can be used to evaluate the consistency of decision making. The C1, ..., Cn represent the criteria, while the Context-aware AHP (CAHP) approach is trailed to obtain the weights W1,...,Wn. The following convention is assumed during the representation of the numerical results: Criteria [C1=RSS, C2=DR, C3=D, C4=J, C5=P]. The input pair-wise matrix is constructed corresponding to criteria versus criteria mapping, as seen in Figure 4.2.

The pairwise matrix is expressed as,

$$A = \begin{matrix} C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \end{matrix} \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{21} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \; where, \; a_{ii} = 1, a = \frac{1}{a_{ij}} \tag{4.1}$$

where a_{ij} represents the importance of criterion versus another criterion in the constructed pairwise matrix A, based on the intensity of importance drawn from Table 4.2. The determination of the co-relation of the criteria against each other is performed. In each level, the decision factors are compared in the pairwise matrix according to their level of influence with respect to Tables 4.1 and 4.2.

Step 2: Normalisation and calculation of relative weights:

The pairwise matrix comprises different units of measurement, hence it needs to normalise for harmonising the process.

The normalised matrix A_{norm} is constructed from Equation 4.2. In short, each element of the comparison matrix A is divided by its respective column sum to obtain elements of the normalised matrix in Equation 4.7.

$$A_{norm} = \begin{bmatrix} \frac{a_{11}}{\sum a_{i1}} & \frac{a_{12}}{\sum a_{i2}} & \cdots & \frac{a_{1n}}{\sum a_{in}} \\ \frac{a_{21}}{\sum a_{i1}} & \frac{a_{22}}{\sum a_{i2}} & \cdots & \frac{a_{2n}}{\sum a_{i3}} \\ \vdots & \vdots & \vdots & \vdots \\ \frac{a_{n_1}}{\sum a_{i1}} & \frac{a_{n2}}{\sum a_{i3}} & \cdots & \frac{a_{nn}}{\sum a_{in}} \end{bmatrix} \tag{4.2}$$

Calculating the weight of the criteria, the decision factor W_i is computed by,

$$W_i = \frac{\sum_{j=1}^{n} a_{ij}}{n}, \quad W = \begin{bmatrix} W_1 \\ W_2 \\ \vdots \\ \vdots \\ W_n \end{bmatrix} \quad where, W_k = Avg(k^{th} row of A_{norm}) \tag{4.3}$$

where n is the number of comparable criteria. The column sum should yield 1, as in Equation 4.3, signifying the consistency in computed weight, or else there is a need to revise the pairwise matrix until the attainment of consistency.

To check the consistency of the pairwise matrix, Coherence Ratio (CR) is calculated. The values of Random Index (RI) are taken from Table 4.4, depending upon the number of input criteria the RI value is picked. In this proposed research, the magnitude of criteria is established as five. Hence the chosen RI value is 1.12 for further computation of CR.

Table 4.4
Value of Random Index [151]

Number of Criteria	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

CR is calculated as the ratio of CI, which is the consistency Index to the RI based on the chosen magnitude of the criteria.

$$CR = \frac{CI}{RI} \tag{4.4}$$

where, Consistency Index (CI) and is the Random Index (RI) are determined by following steps,

$$\Lambda = \frac{(A * W)}{W} = \begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \vdots \\ \vdots \\ \lambda_n \end{bmatrix} \tag{4.5}$$

$$\lambda_{max} = \frac{\lambda_1 + \lambda_2 + \cdots + \lambda_n}{n} \tag{4.6}$$

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{4.7}$$

If CR < 0.1, the pairwise comparison is acceptable. Thus, the relative weights are calculated by finding the correct Eigen vector (W) corresponding to the largest Eigen vector λ_{max}.

4.4 Verification and Validation of CAHP Mechanism for Initiation

This section describes the verification and validation of CAHP, signifying the correctness of the mechanism both in syntax and semantics of the analytical model transformation into a programmable model. This also assures the correctness of the executed results with the numerical analysis illustration of of different cases in triggering the handover to select RAT with respect to the context-awareness.

4.4.1 Verification of CAHP

Verification is the process performed to ensure that:

i. the mechanism is programmed appropriately, where the analytical model is transformed into MATLAB programmable code and free from compilation errors,
ii. the mechanism conversion from conceptualisation to the program design is free from errors, oversights, or bugs, and
iii. a high level of statistical certainty is realised by testing more cases to trigger initiation, as described with numerical analysis in Section 4.4.2.

4.4.2 Validation of CAHP through the Numerical Analysis

This section elaborates the numerical analysis of the proposed mechanism CAHP, as elaborated in Section 4.3.1, where the implicit validation of the mechanism is performed by computing the Coherence Ratio (CR). The CR value adheres to the upper limit 0.1.

The pairwise matrix was constructed based on Saaty's table, as in Equation 4.1

$$A = \begin{matrix} C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \end{matrix} \begin{bmatrix} 1.0000 & 2.0000 & 3.0000 & 3.0000 & 4.0000 \\ 0.5000 & 1.0000 & 2.0000 & 2.0000 & 3.0000 \\ 0.3300 & 0.5000 & 1.0000 & 1.0000 & 2.0000 \\ 0.3300 & 0.5000 & 1.0000 & 1.0000 & 2.0000 \\ 0.2500 & 0.3300 & 0.5000 & 0.5000 & 1.0000 \end{bmatrix}$$

The sum of the column is calculated to form the normalised matrix,

$$ColumnSum = \begin{bmatrix} 2.4100 & 4.3300 & 7.5000 & 7.5000 & 12.0000 \end{bmatrix}$$

A_{norm} matrix is constructed by dividing each element of the matrix by respective column sum,

$$A_{norm} = \begin{bmatrix} 0.4149 & 0.4619 & 0.4000 & 0.4000 & 0.3333 \\ 0.2075 & 0.2309 & 0.2667 & 0.2667 & 0.2500 \\ 0.1369 & 0.1155 & 0.1333 & 0.1333 & 0.1667 \\ 0.1369 & 0.1155 & 0.1333 & 0.1333 & 0.1667 \\ 0.1037 & 0.0762 & 0.0667 & 0.0667 & 0.0833 \end{bmatrix}$$

weight W=[W_1,. . . .,W_5] is calculated using Equation 4.3, inferring the weight of each criteria,

$$W = \begin{bmatrix} 0.4020 & 0.2443 & 0.1371 & 0.1371 & 0.0793 \end{bmatrix}$$

λ_{max}, is calculated as in Equation 4.6,

$$\lambda_{max} = 5.0271$$

Consistency Index (CI), is computed by applying Equation 4.7,

$$CI = 0.0068$$

and finally, the Coherence Ratio (CR), is given by Equation 4.4

$$CR = 0.0061$$

The value of CR < 0.1, to be acceptable,

$$0.0061 < 0.1$$

The CR value 0.0061 is below the range of the upper limit acceptable for consistency. Hence, this has implicitly accredited the CAHP mechanism.

Further, RAT Initiation Factor (RIF) needs to be computed to infer the need to choose a new serving RAT. A numerical illustration of computing the RIF is as follows.

It is currently assumed that the terminal is connected to RAT 802.11n that is serving the background application. The experiment generates the following values, as shown in Table 4.5. The first row represents the actual values of respective criteria. The second row represents the expected standard value. After considering the above values, the AC and EC values are computed and RIF is generated after the calculations which decide the triggering of handover initiation for new RAT as a Point of Attachment (PoA).

Table 4.5
Initiation Illustration

Criteria	RSS	DR	D	J	PL
Actual	-89.4019	44.1735	123.4695	1.3452	13.3712
Expected	-82.0000	39.7000	125.0000	15.5000	15.0000

$$AC = 0.6511$$

$$EC = 0.3489$$

The value of actual and expected for criteria generated are compared with the standard values described in respective RAT criteria in Table 4.1, all of which adhere to the range of criteria. The value of Actual Context (AC) is greater than Expected Context (EC), hence it can be inferred that handover is not triggered and the current RAT can serve the context demand.

4.4.2.1 Multiple Context-aware Case Analysis for Initiation

This section illustrates the different cases of initiation triggering assuming the terminal is attached to one of the RATs (802.11n, 802.11ac, HeNB, LTE) and for each RAT the case is considered for all the four classes (background, conversational, streaming, and interactive) of traffic. The combination of RAT and type of traffic is explored with numerical analysis of each case.

The validation of the mechanism and results are through the constraint changeability – sensitivity analysis as mentioned in the Chapter Three 3.4. The inputs are varied through the experiment and the impact of the change is measured through the RIF factor which determines the triggering of initiation for each context.

Case One: Traffic Type-Background Traffic and RAT currently serving is IEEE 802.11n

Table 4.6 depicts the statistics generated as an illustration when a serving RAT is 802.11n and the traffic class is background. Comparing AC and EC values, EC value is higher, meaning the initiation has been triggered. The actual value RSS is high in spite of the handover being initiated with the comparing of average of all criteria. The decision is not biased to signal but based on context-awareness in triggering the handover. Hence the initiation for new RAT is triggered based all criteria and user application requirements, and not merely on the RSS alone.

Table 4.6
Case One

Criteria	RSS	DR	D	J	PL
Actual	-78.3441	10.3819	96.9826	18.7459	13.3937
Expected	-88.0000	51.7500	90.0000	10.5000	12.5000

$$AC = 0.4719$$

$$EC = 0.5281$$

Case Two: Traffic Type-Background Traffic and RAT currently serving is IEEE 802.11n

Table 4.7 illustrates the handover triggering decision, where AC value is higher compared to expected EC, meaning the initiation is not triggered. The actual values are more promising toward better performance compared to the expected one. The current RAT context is able to serve the user requirements at this junction. Hence, the control still remains with the current serving RAT.

Table 4.7
Case Two

Criteria	RSS	DR	D	J	PL
Actual	-72.0201	73.4131	87.8445	13.4541	10.8559
Expected	-88.0000	51.7500	90.0000	10.5000	12.5000

$$AC = 0.8911$$

$$EC = 0.1089$$

Case Three: Traffic Type-Conversational Traffic and RAT currently serving is IEEE 802.11n

Case Three and Four illustrate the the conversational type of traffic scenario in triggering the RAT initiation for handover. Case Three does not trigger the handover, where AC value is better than the expected EC. The signal is not good compared to the expected, but the conversational application is keen on delay and jitter for better service, so these criteria are better suited in this case. Hence, the initiation is not triggered. The decision of RAT initiation with the criteria values to trigger or otherwise are presented in Table 4.8.

Table 4.8
Case Three

Criteria	**RSS**	**DR**	**D**	**J**	**PL**
Actual	-83.2251	32.0013	138.2758	24.0608	11.8687
Expected	-82.0000	39.7000	125.0000	15.5000	5.5000

$$AC = 0.2547$$

$$EC = 0.7454$$

Case Four: Traffic Type-Conversational Traffic and RAT currently serving is IEEE 802.11n

In Case Four, EC value is high, meaning the initiation is triggered. Though the signal is better, the delay is high in actual in comparison to the expected context. The conversational traffic is delay sensitive, and considering this context, the initiation is triggered. The decision of RAT initiation with the criteria values to trigger or otherwise are presented in Table 4.9.

Table 4.9
Case Four

Criteria	RSS	DR	D	J	PL
Actual	-82.2047	36.1631	132.3157	21.5716	17.5469
Expected	-82.0000	39.7000	125.0000	15.5000	5.5000

$$AC = 0$$

$$EC = 1.000$$

The traffic type streaming is considered for Cases Five and Six with the values for criteria in respective cases are outlined in Tables 4.10 and 4.11. Jitter is a vital criteria for streaming applications, thus the triggering decision will prioritise the jitter value during the initiation.

Case Five: Traffic Type-Streaming Traffic and RAT currently serving is IEEE 802.11n

In Case Five, the handover is triggered, where the actual context value illustrates a higher value of jitter whereas signal is very good. Inspite of the better signal, the context-aware cumulative decision is interpreted.

Table 4.10
Case Five

Criteria	RSS	DR	D	J	PL
Actual	-76.9747	23.7812	125.2979	21.2732	18.9090
Expected	-82.0000	39.7000	125.0000	15.5000	5.5000

$$AC = 0.3685$$

$$EC = 0.6316$$

Case Six: Traffic Type-Streaming Traffic and RAT currently serving is IEEE 802.11n

In Case Six, the handover is not initiated due to the higher AC values. The current serving RAT criteria values generated during the experiment are capable of serving the UE requirements.

Table 4.11
Case Six

Criteria	RSS	DR	D	J	PL
Actual	-76.8452	55.5036	119.6114	20.0089	11.7119
Expected	-82.0000	39.7000	125.0000	15.5000	15.0000

$$AC = 0.8908$$

$$EC = 0.1093$$

Cases Seven and Eight illustrate the interactive traffic in the 802.11n RAT, where the delay and packet loss are critical for this type of traffic. The statics of the criteria with respect to the experiment execution for RAT initiation triggering is illustrated in Tables 4.12 and 4.13. The handover is not triggered as the actual value of AC is higher than the expected value.

Case Seven: Traffic Type-Interactive Traffic and RAT currently serving is IEEE 802.11n

Table 4.12
Case Seven

Criteria	RSS	DR	D	J	PL
Actual	-88.7564	58.8285	115.5608	16.3275	11.6565
Expected	-82.0000	39.7000	125.0000	15.5000	15.0000

$$AC = 0.5555$$

$$EC = 0.4444$$

Case Eight: Traffic Type-Interactive Traffic and RAT currently serving is IEEE 802.11n

Table 4.13
Case Eight

Criteria	**RSS**	**DR**	**D**	**J**	**PL**
Actual	-79.9604	24.2931	132.7040	20.9872	17.4815
Expected	-82.0000	39.7000	125.0000	15.5000	15.0000

$$AC = 0.2222$$

$$EC = 0.7777$$

Similarly, Cases Nine and Ten illustrates the background class of traffic in which the UE is connected to the serving IEEE 802.11ac RAT, where the experiment executed a triggering of RAT selection initiation with CAHP computing the AC and EC values. The computed values of AC and EC for case nine is presented in Table 4.14. The AC values is lower than EC value.

Hence, the initiation is triggered because the background traffic is sensitive to packet loss criterion, though the expected and actual values match the signal of the expected to be better. However in Case Ten, the initiation is not triggered because the AC value of the IEEE 802.11ac is better for the background traffic.

Case Nine: Traffic Type-Background Traffic and RAT currently serving is IEEE 802.11ac

Table 4.14
Case Nine

Criteria	RSS	DR	D	J	PL
Actual	-62.2780	74.6665	95.0746	8.2285	12.8391
Expected	-59.5000	51.7500	90.0000	10.5000	12.5000

$$AC = 0.3103$$

$$EC = 0.6897$$

Case Ten: Traffic Type-Background Traffic and RAT currently serving is IEEE 802.11ac

Table 4.15
Case Ten

Criteria	RSS	DR	D	J	PL
Actual	-61.9458	57.8822	89.3878	1.2261	11.6856
Expected	-59.5000	51.7500	90.0000	10.5000	12.5000

$$AC = 0.5281$$

$$EC = 0.4719$$

Cases Eleven and Twelve illustrate the cases in which the UE is connected to IEEE 802.11ac, requesting conversational traffic application. Based on the contextual demand, the experiment generated the values for Case Eleven, as shown in Table 4.16, where the AC value is high compared to the expected value of EC. The conversational type of traffic is more sensitive to delay and jitter compared to other criteria.

The experimental values generated in Case Eleven revealed that the current serving RAT can serve the UE demand with the high AC value. Therefore, handover to a new target RAT is not triggered, whereas in Case Twelve (Table 4.17), the EC value is higher than the AC value, hence, the RAT selection initiation is triggered.

Case Eleven: Traffic Type-Conversational Traffic and RAT currently serving is IEEE 802.11ac

Table 4.16
Case Eleven

Criteria	RSS	DR	D	J	PL
Actual	-62.9447	77.9708	86.2243	11.0421	10.8282
Expected	-59.5000	51.7500	90.0000	10.5000	12.5000

$$AC = 0.5042$$

$$EC = 0.4958$$

Case Twelve: Traffic Type-Conversational Traffic and RAT currently serving is IEEE 802.11ac

Table 4.17
Case Twelve

Criteria	RSS	DR	D	J	PL
Actual	-61.6771	30.6307	93.0816	14.0951	13.7408
Expected	-59.5000	51.7500	90.0000	10.5000	12.5000

$$AC = 0.2479$$

$$EC = 0.7521$$

Cases Thirteen and Fourteen results are tabulated in Table 4.18 and Table 4.19, respectively. The UE is connected to RAT IEEE 802.11ac and the assessment in the performed experiment is done to the UE demand for streaming traffic application, which requires better throughput than the other criteria for such applications.

In the contextual decision making, triggering the handover is based on the AC and EC values generated to set the RIF factor, which makes the decision to trigger the selection of new target RAT when needed. In Case Thirteen, the AC value is better hence, the RIF is set zero meaning the current serving RAT can serve the UE. Conversely, Case Fourteen causes the initiation to be triggered due to high EC value, which sets the RIF to one, indicating the initiation for a new target RAT.

Case Thirteen: Traffic Type-Streaming Traffic and RAT currently serving is IEEE 802.11ac

Table 4.18
Case Thirteen

Criteria	**RSS**	**DR**	**D**	**J**	**PL**
Actual	-60.1409	14.7232	87.9957	5.9375	14.0003
Expected	-59.5000	51.7500	90.0000	10.5000	12.5000

$$AC = 0.5871$$

$$EC = 0.4130$$

Case Fourteen: Traffic Type-Streaming Traffic and RAT currently serving is IEEE 802.11ac

Table 4.19
Case Fourteen

Criteria	**RSS**	**DR**	**D**	**J**	**PL**
Actual	-60.5637	84.6539	91.5941	11.4473	10.7248
Expected	-59.5000	51.7500	90.0000	10.5000	12.5000

$$AC = 0.4210$$

$$EC = 0.57612$$

Cases Fifteen and Sixteen illustrate the UE demand for interactive traffic connected to RAT IEEE 802.11ac. The RAT initiation criteria analysis with respect to the connected RAT, are tabulated in Table 4.20 and Table 4.21, respectively. Depending on the AC and EC values generated, Case Fifteen triggers the handover with RIF value set to one, and in Case Sixteen, the RIF value is set to zero because the AC value is high resulting in no handover to new target RAT.

Case Fifteen: Traffic Type-Interactive Traffic and RAT currently serving is IEEE 802.11ac

Table 4.20
Case Fifteen

Criteria	**RSS**	**DR**	**D**	**J**	**PL**
Actual	-60.2280	93.6798	99.1433	10.2221	14.0014
Expected	-59.5000	51.7500	90.0000	10.5000	12.5000

$$AC = 0.3162$$

$$EC = 0.6837$$

Case Sixteen: Traffic Type-Interactive Traffic and RAT currently serving is IEEE 802.11ac

Table 4.21
Case Sixteen

Criteria	**RSS**	**DR**	**D**	**J**	**PL**
Actual	-61.0201	73.4131	87.8445	13.4541	10.8559
Expected	-59.5000	51.7500	90.0000	10.5000	12.5000

$$AC = 0.8418$$

$$EC = 0.1581$$

The Case Seventeenth and Eighteenth cases illustrate the context when the UE is connected to the HeNB femtocell and the UE demands background application. The experiment results illustrated in Table 4.22 reveal that the handover is not triggered, while Case Eighteen results in Table 4.23 illustrated the RAT selection to be initiated. The expected values are better in signal though the packet loss is same. This reiterates the fact that the triggering decision is contextual with multi-criteria assessment.

Case Seventeen: Traffic Type-Background Traffic and RAT currently serving is HeNB

Table 4.22
Case Seventeen

Criteria	**RSS**	**DR**	**D**	**J**	**PL**
Actual	-113.2303	279.8957	83.6369	6.0123	10.7277
Expected	-105.0000	187.5000	90.0000	10.5000	12.5000

$$AC = 0.5281$$

$$EC = 0.4719$$

Case Eighteen: Traffic Type-Background Traffic and RAT currently serving is HeNB

Table 4.23
Case Eighteen

Criteria	**RSS**	**DR**	**D**	**J**	**PL**
Actual	-114.7212	221.0510	94.6344	13.3072	12.2546
Expected	-105.0000	187.5000	90.0000	10.5000	12.5000

$$AC = 0.3103$$

$$EC = 0.6897$$

The RAT selection initiation illustrated in Cases Nineteen and Twenty experimental results for actual and expected values are tabulated in Table 4.24 and Table 4.25, respectively. The UE is connected to the HeNB and the conversational application is requested. Conversational application requires lower delay as the application is a two-dimensional live communication.

Based on this context, the weights of the criteria is accessed and the AC and EC values are generated. In Case Nineteen, the initiation is triggered due the HeNB criteria values to be low AC values in comparison to the expected ones. The RIF value is set to one and initiation is triggered. Unlike Case Nineteen, the initiation is not triggered in Case Twenty because the current UE connected RAT is capable of meeting the contextual need for the UE demand. Hence, the RIF is set to value zero.

Case Nineteen: Traffic Type-Conversational Traffic and RAT currently serving is HeNB

Table 4.24
Case Nineteen

Criteria	RSS	DR	D	J	PL
Actual	-112.9787	157.9090	92.5124	15.8243	10.4056
Expected	-105.0000	187.5000	90.0000	10.5000	12.5000

$$AC = 0.1568$$

$$EC = 0.8432$$

Case Twenty: Traffic Type-Conversational Traffic and RAT currently serving is HeNB

Table 4.25
Case Twenty

Criteria	RSS	DR	D	J	PL
Actual	-110.0709	142.7804	94.2284	5.3793	14.2215
Expected	-105.0000	187.5000	90.0000	10.5000	12.5000

$$AC = 0.6072$$

$$EC = 0.3928$$

Cases Twenty-one and Twenty-two illustrate the streaming traffic demand by UE connected to RAT HeNB. The throughput is important meaning that the data rate offered is very vital for this class of applications. Based on the requirement, the experiment results are tabulated in Table4.26 and Table 4.27 for the Cases Twenty-one and Twenty-two, respectively.

The initiation is triggered in Case Twenty-one with the EC value higher than the actual value, and the main criteria of triggering for streaming is the data rate, but the decision is not based only on the data rate since it is in congruence with the context. Though the data rate is high the RSS value is very low hence RAT selection is initiated, whereas in Case Twenty-two, the RAT selection is not initiated because the expected value is lower than the actual value of the serving RAT. Hence, the RIF is set to zero, indicating that the initiation is not required.

Case Twenty-one: Traffic Type-Streaming Traffic and RAT currently serving is HeNB

Table 4.26
Case Twenty-one

Criteria	**RSS**	**DR**	**D**	**J**	**PL**
Actual	-115.5381	253.7140	86.2243	11.0421	10.8282
Expected	-105.0000	187.5000	90.0000	10.5000	12.5000

$$AC = 0.4607$$

$$EC = 0.5391$$

Case Twenty-two: Traffic Type-Streaming Traffic and RAT currently serving is HeNB

Table 4.27
Cases Twenty-two

Criteria	RSS	DR	D	J	PL
Actual	-90.7566	93.9981	87.9957	5.9375	14.0003
Expected	-105.0000	187.5000	90.0000	10.5000	12.5000

$$AC = 0.6762$$

$$EC = 0.3236$$

Similarly, Case Twenty-three and Twenty-four illustrate the interactive type of application with the UE connected to HeNB. The experimental results generated for this context is expressed based on the delay and packet loss criteria values, because interactive traffic is more sensitive to delay and packet loss. Table 4.28 illustrates the numerical values generated during the experiment and the RIF is set to zero due to the high AC value of the serving RAT. On the other hand, Case Twenty-four triggered initiation of RAT selection with the current serving RAT unable to serve the UE demand. The EC value is higher than the AC value, according to the proposed CAHP mechanism, and the RIF is set to one, triggering the initiation.

Case Twenty-three: Traffic Type-Interactive Traffic and RAT currently serving is HeNB

Table 4.28
Cases Twenty-three

Criteria	RSS	DR	D	J	PL
Actual	-117.6677	282.7604	88.6041	4.5115	14.5244
Expected	-105.0000	187.5000	90.0000	10.5000	12.5000

$$AC = 0.5185$$

$$EC = 0.4813$$

Case Twenty-four: Traffic Type-Interactive Traffic and RAT currently serving is HeNB

Table 4.29
Cases Twenty-four

Criteria	RSS	DR	D	J	PL
Actual	-113.6125	133.9976	92.0569	14.5131	11.1087
Expected	-105.0000	187.5000	90.0000	10.5000	12.5000

$$AC = 0.4813$$

$$EC = 0.5185$$

Table 4.30 and Table 4.31 illustrate Cases Twenty-five and Twenty-six, respectively. The context of these two cases illustrate the UE connected to LTE and the UE demands background traffic. The results revealed that Case Twenty-five initiated RAT selection due to the higher EC value, where the packet loss is better and the signal strength is also higher than the currently serving RAT. However in Case Twenty-six, the initiation RAT selection is not triggered due to the better criteria values of the actual RAT.

Case Twenty-five: Traffic Type-Background Traffic and RAT currently serving is LTE

Table 4.30
Cases Twenty-five

Criteria	RSS	DR	D	J	PL
Actual	-114.7381	134.0585	96.0203	1.5552	14.6443
Expected	-105.0000	187.5000	90.0000	10.5000	12.5000

$$AC = 0.1089$$

$$EC = 0.8911$$

Case Twenty-six: Traffic Type-Background Traffic and RAT currently serving is LTE

Table 4.31
Cases Twenty-six

Criteria	**RSS**	**DR**	**D**	**J**	**PL**
Actual	-107.3603	184.9370	91.5705	5.5084	12.2942
Expected	-105.0000	187.5000	90.0000	10.5000	12.5000

$$AC = 0.8089$$

$$EC = 0.1911$$

The conversation class traffic based application from UE connected to the LTE macro cell scenario results are presented for CAHP mechanism in tabular form in Table 4.32 and Table 4.33 for Case Twenty seven and Twenty-eight, respectively. Case Twenty-seven does not trigger the RAT selection initiation because the criteria values vital for conversational traffic are better in the actual connected RAT as compared to the expected EC value. However in Case Twenty-eight due to the AC values falling short to meet the contextual need and the RIF is set to one, the triggering of the initiation occurs.

Case Twenty-seven: Traffic Type-Conversational Traffic and RAT currently serving is LTE

Table 4.32
Cases Twenty-seven

Criteria	**RSS**	**DR**	**D**	**J**	**PL**
Actual	-120.1128	227.8055	87.9103	7.9813	14.9399
Expected	-105.0000	187.5000	90.0000	10.5000	12.5000

$$AC = 0.9074$$

$$EC = 0.0927$$

Case Twenty-eight: Traffic Type-Conversational Traffic and RAT currently serving is LTE

Table 4.33
Cases Twenty-eight

Criteria	**RSS**	**DR**	**D**	**J**	**PL**
Actual	-110.4713	274.1628	98.2657	16.1275	10.4936
Expected	-105.0000	187.5000	90.0000	10.5000	12.5000

$$AC = 0.2782$$

$$EC = 0.7219$$

Tables 4.34 and Table 4.35 present the results for streaming class data demand with the UE connected to the LTE macrocell base station. The data presented for Case Twenty-nine triggers the initiation of RAT selection due to the conflicting high data rate and the bad signal, but with the context aware decision making, the initiation is triggered. In the test Case Thirty, initiation is not triggered because of the good signal along with data rate, and all other criteria are congenial with the currently serving connected RAT .

Case Twenty-nine: Traffic Type-Streaming Traffic and RAT currently serving is LTE

Table 4.34
Cases Twenty-nine

Criteria	**RSS**	**DR**	**D**	**J**	**PL**
Actual	-112.1886	222.0954	89.8835	15.8020	13.5752
Expected	-105.0000	187.5000	90.0000	10.5000	12.5000

$$AC = 0.3162$$

$$EC = 0.6837$$

Case Thirty: Traffic Type-Streaming Traffic and RAT currently serving is LTE

Table 4.35
Case Thirty

Criteria	RSS	DR	D	J	PL
Actual	-117.6283	159.6612	83.8185	9.1368	12.4101
Expected	-105.0000	187.5000	90.0000	10.5000	12.5000

$$AC = 0.8418$$

$$EC = 0.1581$$

The interactive traffic with the UE connected to the LTE RAT is illustrated in the test Cases Thirty-one and Thirty two. The tabulated results in Table 4.36 reveal the initiation for new RAT to be triggered. The EC value is higher than the AC value. The interactive class of applications demands lower delay and packet loss, with good signal quality. The current serving RAT values fall short in providing the demand in the experimental context, as tabulated. Whereas in the test Case Thirty-two tabulated in Table 4.37, the serving RAT is able to cater for the UE demand and the RIF is set to zero, meaning that the AC value is high compared to the expected EC value.

Case Thirty-one: Traffic Type-Interactive Traffic and RAT currently serving is LTE

Table 4.36
Case Thirty-one

Criteria	RSS	DR	D	J	PL
Actual	-110.5266	207.6392	84.5238	8.3078	12.9149
Expected	-105.0000	187.5000	90.0000	10.5000	12.5000

$$AC = 0.3926$$

$$EC = 0.6074$$

Case Thirty-two: Traffic Type-Interactive Traffic and RAT currently serving is LTE

During the validation of CAHP mechanism with numerous contextual cases and differentiated multiple executions, it was detected that certain cases had a little ambiguity of decision triggering. Table **??** below is one instance, where the application is streaming that requires good data rate. Even though the datarate is high, the signal was very bad, but the RAT initiation was not triggered.

Table 4.37
Case Thirty-two

Criteria	RSS	DR	D	J	PL
Actual	-114.2537	96.2016	91.9705	9.9476	13.4797
Expected	-105.0000	187.5000	90.0000	10.5000	12.5000

$$AC = 0.8611$$

$$EC = 0.1389$$

All the test cases illustrated throughout this section elaborated different combination of traffic with the RAT available, and stated the triggering of RAT initiation in different contexts. It can be concluded that the proposed CAHP mechanism performed well in contextual decision compared to just the imperative based decision on the signal quality or power.

Furthermore, the weights generated through CAHP were incorporated as an input to the second phase of RAT selection, i.e., decision making. The decision making phase is active only if the initiation is triggered. All the test cases illustrated the working CAHP mechanism in triggering RAT selection in almost all possible cases. It was observed that the decision was purely context-aware rather than imperative in nature. The initiation triggering is based on user preferred application, but not isolated from the other criteria. The test cases strongly determined the effective cases of triggering of initiation from the current serving RAT. The deteriorating signal strength may not be efficient with high data rate preferred by the application. With the signal being the primary criteria, only data rate may not attain good performance. Such cases need a better decision context.

4.5 Summary

The UDN is one of the features driving the future wireless heterogeneous network. The close deployment of RATs in UDN facilitates uniform access to all users, however there is a frequent switch between the RATs. This chapter proposed CAHP mechanism that triggers the RAT selection based on multiple criteria assessment with context-awareness. The analytical modelling of the mechanism with mathematical formulation was presented. The numerical analysis of the mechanism with multiple context illustration was made. The chapter presented a novel RAT selection mechanism which triggered a decision based on the context and not biased to any single criteria.

CHAPTER FIVE
TARGET RAT SELECTION

While Chapter 4 explained the first phase of handover, this chapter elaborates the second phase, i.e., decision making. The decision making in UDN is a challenge because the decision is not just to switch from the current RAT to new target RAT, but to choose among the multiple RATs the best one to serve according to the context requirement. This decision needs to access the user requirement with the network resources available at the moment of raised request and which available RAT can serve best among the available ones. This Context-aware Technique for Order Preference by Similarity to an Ideal Solution (CTOPSIS) mechanism presented in this chapter answers all the above questions in decision making.

The chapter is organised as follows, Section 5.1 introduces the concept of UDN realisation in next digital wave, and how the context-aware concept is integrated with MADM approach in determining the RAT selection coherently. Section 5.2 introduces the mechanism to make the choice of RAT in UDN with the integration of MADM and context-aware concept. The design of CTOPSIS mechanism in determining the best RAT followed by the ranking order of the RAT for a particular context is presented. Section 5.3 presents the verification of the CTOPSIS method followed by the illustration of handover events and ranking abnormality metrics measurement of CTOPSIS compared to TOPSIS, SAW and GRA in Section 5.4 with multiple cases. The sensitivity analysis of the mechanism is presented in Section 5.5 and finally, the whole chapter is summarised in Section 5.6.

5.1 Conceptual Analysis

Subsequently realising the potential of UDN described in Chapter Two, the focus on UDN architecture is vital to form a system model for this research environment. UDN for a future wireless network is the integration of licensed and unlicensed band RATs close deployment in an uncoordinated manner. The emerging next digital wave is yet to be formed into a complete standard architecture. Hence, the design is an arbitrary integration of operator-deployed and user-deployed nodes for dedicated access in UDN. The UDN increases spatial reuse of system resources, on the contrary, poses new challenges of uncoordinated deployment like interference management, unnecessary handovers among the RATs, and so on. The system model for the proposed mechanism in this chapter to determine the best RAT in heterogeneous UDN environment is the same as for initiation mechanism in Chapter Four Section 4.2.

Singh et al. [89] proposed VHO in 4G networks and analysed SAW, TOPSIS, and GRA mechanisms in RAT selection, and numerical analysis results revealed that there is the standard deviation of 41.00%, 56.00%, and 20.35% in SAW, TOPSIS, and GRA respectively. The corresponding standard deviation of TOPSIS was observed high, meaning that it is the best mechanism in decision making compared to the other classic ones. TOPSIS method provides a proportional linear transformation of weights resulting in the relative order of magnitude of the standardised ranking scores to identify an alternative that will have the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution. The deviation from the negative solution yields better results in decision making. It can be ascertained that TOPSIS is one of the best mechanisms for determining the RAT ranking.

Also, knowing the fact from the discussion in Chapter Two Section 2.4.4.7, integrating the two MADM mechanism gives a better ranking and choice while optimising the criteria abnormalities encountered during a ranking compared to single MADM mechanism. Therefore this proposed research integrates the MADM mechanism, i.e., TOPSIS, and context-aware concept, which is recommended for future wireless network in decision making to determine the new target RAT conquering the benefits of MADM and evicting the rank reversal problem. The proposed Context-aware Technique for Order Preference by Similarity to an Ideal Solution (CTOPSIS) mechanism determines the best target RAT among the available ones based on the contextual information. The contextual information includes the user and network collaborative preference as well as priority to the differentiated traffic class of demanded application from the UE. The CTOPSIS mechanism is designed to reduce the number of unnecessary handovers in overlapping Ultra Dense Networks (UDN); also, less prone to rank reversal issue usually encountered by Multi Attribute Decision Making (MADM) methodology. This chapter presents the analytical modelling of efficient RAT decision making in UDN heterogeneous environment. The CTOPSIS mechanism, its numerical analysis with different cases, and the sensitivity analysis are projected across this chapter.

5.2 Context-aware Technique for Order Preference by Similarity to an Ideal Solution

This is the second phase of RAT selection, with the best RAT as the next target RAT to serve the demanded services from UE. This is achieved by Context-aware Technique for Order Preference by Similarity to an Ideal Solution (CTOPSIS), which is a classic MADM mechanism based on Euclidean Theory that confers the chosen outcome to be near to the positive ideal solution while far from the negative ideal solution. Figure 5.1 portrays the whole CTOPSIS mechanism working. The requirements of the user and network are collaborated to form a context information.The priority of the criteria according to the contextual information is assigned and the weight of the criteria is computed. The weight computation is done by CAHP mechanism, and the detailed description of the whole procedure is demonstrated in Chapter Four. The weights of the obtained criteria are mapped to the available RATs in the context of decision making. The mapping of the criteria versus the alternative toward obtaining the ranking to choose the best alternative is done by the CTOPSIS mechanism. The whole procedure of CTOPSIS is presented further in this section. The one with the best rank is chosen to be the best alternative for the required context.

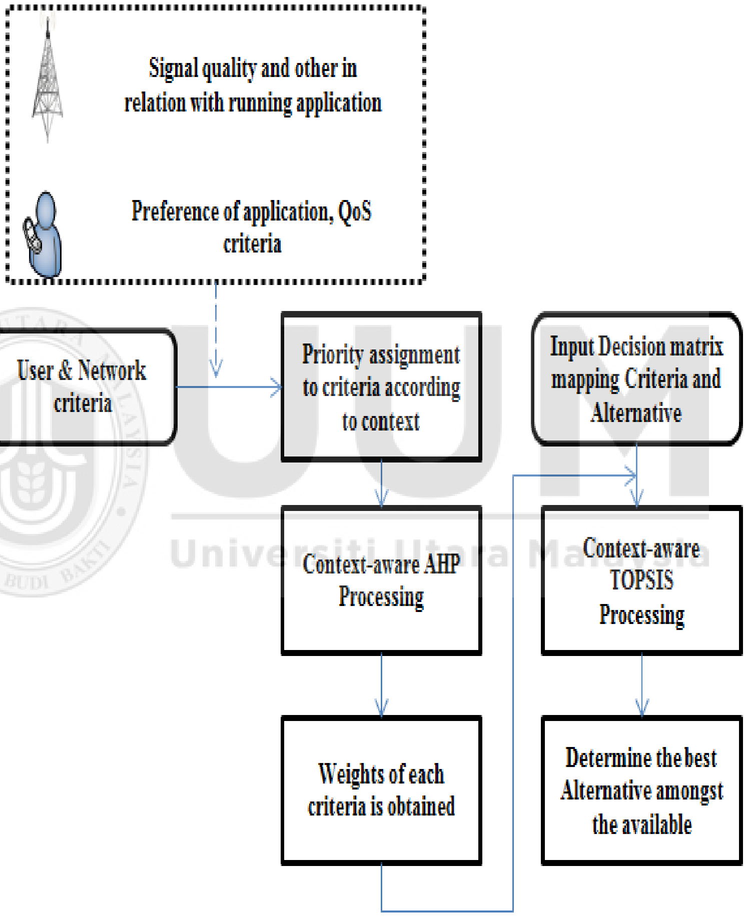

Figure 5.1. RAT Selection by CTOPSIS

The ranking of RATs is done by mapping the alternative (A1, . . . , An), i.e., available RATs versus the criteria (C1, . . . , Cn) forming a decision matrix and further CTOPSIS is applied to obtain the rank of the RATs, which in turn specifies the best RAT when chosen in descending order of the obtained rank vector. The complete procedure of ranking is briefed in this section. The procedure to compute the rank of the RATs via the CTOPSIS method should adhere to the following steps:

The decision matrix D is formed by the co-ordinated mapping of alternatives (RATs) to the shortlisted criteria of this research. Each element is the intersection of the alternative (A) with the respective criteria (C), i.e., $A_iC_j$where i=1, ..., 4 and j=1, ..., 5.

$$D = \begin{bmatrix} A_1C_1 & A_1C_1\cdots & \cdots & \cdots & A_1C_n \\ \vdots & \cdots & \cdots & \cdots & \vdots \\ \vdots & \cdots & \cdots & \cdots & \vdots \\ A_nC_1 & \cdots & \cdots & \cdots & A_nC_n \end{bmatrix}$$

Normalising the pairwise decision matrix: The decision matrix is normalised to apply the CTOPSIS mechanism. The normalisation is done as in Equation 5.1.

$$R_{ij} = \frac{d_{ij}}{\sqrt{\sum_{i=1}^{m}}} where, i = 1, ..., m; j = 1, ..., n \tag{5.1}$$

where d_{ij}corresponds to the value of action i for j in decision matrix.

Generating the normalised matrix by multiplying the normalised decision criterion R_{ij} with its assigned weight W_k. The weights obtained from CAHP mechanism in Chapter 4 is the input to obtain V_{ij} matrix (Equation 5.2). The V_{ij} is the actual data formed with the integration of alternatives and criteria weights. Furthermore, computation computes the ideal positive and negative solutions for the formed data. The computations are done through the Equations from 5.3 to 5.9.

$$V_{ij} = R_{ij} \star W_k where, \sum_{k=1}^{m} W_k = 1 \tag{5.2}$$

Determining the positive ideal solution A^+ and negative ideal solution A^-

$$A^+ = V_1^+, ..., V_m^+ \, and \, A^- = V_1^-, ..., V_m^- \tag{5.3}$$

for desirable criteria,

$$V_1^+ = max\{V_{ij}, j = 1, ..., n\} \tag{5.4}$$

$$V_1^- = min\{V_{ij}, j = 1, ..., n\} \tag{5.5}$$

and for undesirable criteria,

$$V_1^+ = min\{V_{ij}, j = 1, ..., n\} \tag{5.6}$$

$$V_1^- = max\{V_{ij}, j = 1, ..., n\} \tag{5.7}$$

Calculating similarity distance,

$$S_j^+ = \sqrt{\sum_{j=1}^{n}(V_i^+ - V_{ij})^2} where, j = 1, ..., n \tag{5.8}$$

$$S_j^- = \sqrt{\sum_{j=1}^{n}(V_{ij} - V_i^-)^2} where, j = 1, ..., n \tag{5.9}$$

Ranking: Once the positive and negative ideal solutions are obtained, the final rank vector C is computed as in Equation 5.10. The rank vector determines the ranking order of the RATs among the available ones. The best RAT from the vector is chosen in descending order of ranking. The one with highest rank is the best RAT.

$$C_j^* = \frac{S_j^-}{S_j^+ + S_j^-} where\, j = 1, ..., n \tag{5.10}$$

For the better understanding and clarity, the numerical analysis is presented for all the steps of CTOPSIS mechanism described.

5.2.1 Numerical Analysis of CTOPSIS

The values in the decision matrix D are generated from network parameter values, referring to Table 4.4 and normalised matrix R_{ij} which is generated and varied at each iteration randomly. Similarly, values V_{ij}, are computed using the Equation 5.1 to 5.10. Alternatives [A_1= 802.11n, A_2= 802.11ac, A_3= HeNB, A_4= LTE] and Criteria [C_1=RSS, C_2=Datarate, C_3=delay, C_4=Jitter and C_5=Packetloss] are considered in forming the decision matrix D.

$$D = \begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \end{array} \begin{bmatrix} C_1 & C_2 & C_3 & C_4 & C_5 \\ -103.6719 & 9.5213 & 142.4565 & 28.0858 & 16.7874 \\ -72.0201 & 73.4131 & 87.8445 & 13.4541 & 10.8559 \\ -110.2745 & 82.1624 & 85.5385 & 1.8773 & 10.4857 \\ -96.1851 & 231.3364 & 86.3420 & 19.0542 & 10.1722 \end{bmatrix}$$

$$R_{ij} = \begin{bmatrix} -0.5365 & 0.0371 & 0.6887 & 0.7683 & 0.6780 \\ -0.3727 & 0.2863 & 0.4247 & 0.3680 & 0.4384 \\ -0.5706 & 0.3204 & 0.4136 & 0.0514 & 0.4235 \\ -0.4977 & 0.9022 & 0.4174 & 0.5212 & 0.4108 \end{bmatrix}$$

$$V_{ij} = \begin{bmatrix} -0.1872 & 0.0036 & 0.1270 & 0.1417 & 0.1250 \\ -0.1759 & 0.0577 & 0.0462 & 0.0401 & 0.0477 \\ -0.2693 & 0.0645 & 0.0450 & 0.0056 & 0.0461 \\ -0.2349 & 0.1817 & 0.0455 & 0.0568 & 0.0447 \end{bmatrix}$$

$$S_j^+ = \begin{bmatrix} 0.1960 \\ 0.1133 \\ 0.0609 \\ 0.1884 \end{bmatrix}$$

$$S_j^- = \begin{bmatrix} 0.1784 \\ 0.1954 \\ 0.2322 \\ 0.1542 \end{bmatrix}$$

$$C_j^* = \begin{matrix} A_1 \\ A_2 \\ A_3 \\ A_4 \end{matrix} \begin{bmatrix} 0.4765 \\ 0.6330 \\ 0.7922 \\ 0.4501 \end{bmatrix}$$

The final rank is given by C. According to the array C, alternate A3 is ranked highest. Hence, LTE is the chosen RAT for current generated context requirement.

The performance of the proposed mechanism is evaluated by simulation using MATLAB. The alternative RATs, 802.11n, 802.11ac, Home eNodeB (HeNB), and LTE (eNB), and the criteria considered are as mentioned in network parameter Table 4.4. For each iteration of simulation, the measure of each criterion for RAT is randomly varied according to the ranges in Table 4.4. According to Kassar et al. [50] and Tran et al. [162], all handover algorithms based on MADM still pose two weaknesses, ranking abnormality and handover, (i) Ranking Abnormality is the condition to investigate the ranking order of the access network due to the removal of a RAT. (ii) A number of handovers: unnecessary handoffs should be minimised as they waste network resources and increase processing overheads. The CTOPSIS performance is evaluated with the contemporary classic MADM approaches such as TOPSIS, Simple Additive Weight

(SAW), and Grey Relational Analysis (GRA) mechanisms considering the ranking abnormality and number of handover metrics. Both the chosen metrics, the number of handovers and ranking abnormality, are reduced remarkably with CTOPSIS which is illustrated in Section 5.4 with multiple case illustrations considering differentiated traffic classes of decision making.

To illustrate the efficiency of CTOPSIS mechanism for RAT selection with differentiated context, the research analysed the results provided by the following four mechanisms.

- CTOPSIS: This mechanism is based on new context weighting method with CAHP and integrates with CTOPSIS in final ranking to choose the RAT among the available ones.
- TOPSIS: This mechanism is designed to measure the relative efficiency among the available alternatives.
- SAW: This mechanism employs linear additive function to determine the preferences of decision making.
- GRA: This mechanism is based on grey relational system theory for analysing the relationship of criteria and alternatives.

5.2.2 Ranking Order of RATs with Differentiated Traffic Classes

The ranking order for each traffic flow context is elaborated in the tables below.

Table 5.1 shows the ranking order of the RAT for background flow of user context, where the alternative selection in each mechanism is varying. This means that there is a sensitivity for what kind of context input is provided and analysis is made. Similarly, Table 5.2, 5.3, and 5.4 represent the ranking order for conversational, streaming, and interactive flows, respectively.

The ranking order for background flow in the proposed and other mechanisms are shown in Table 5.1, where the ranking order is different in different adapted approaches represented by alternative 'A'. Each mechanism follows a different way of analysing the criteria and also the level of sensitivity is different in decision making. The ranking order is in the descending order, higest to lowest.

Table 5.1
Ranking Order for Background Flow

CTOPSIS	$A_4 > A_2 > A_3 > A_1$
TOPSIS	$A_3 > A_1 > A_4 > A_2$
SAW	$A_1 > A_4 > A_2 > A_3$
GRA	$A_4 > A_1 > A_3 > A_2$

Similarly, Table 5.2, shows the ranking order of the alternatives with different mechanisms. The rank vary according the mechanism criteria selection and decision making mechanism.

Table 5.2
Ranking Order for Conversational Flow

CTOPSIS	$A_4 > A_3 > A_2 > A_1$
TOPSIS	$A_1 > A_2 > A_3 > A_4$
SAW	$A_2 > A_3 > A_4 > A_1$
GRA	$A_3 > A_2 > A_1 > A_4$

The RAT choice for streaming flow is illustrated in Table 5.3, where the choice is made in CTOPSIS according to context-awareness. The ranking order follows the same constraints in determining the target RAT.

Table 5.3
Ranking Order for Streaming Flow

CTOPSIS	$A_2 > A_4 > A_3 > A_1$
TOPSIS	$A_2 > A_3 > A_4 > A_1$
SAW	$A_2 > A_3 > A_1 > A_4$
GRA	$A_3 > A_2 > A_4 > A_1$

The interactive type of traffic flow ranking order in each of the mechanism is exhibited in Table 5.4. Further sections evaluate the ranking order significance with two different metrics, namely ranking abnormality and handovers at numerous decision points.

Table 5.4
Ranking Order for Interactive Flow

CTOPSIS	$A_3 > A_2 > A_1 > A_4$
TOPSIS	$A_2 > A_3 > A_1 > A_4$
SAW	$A_1 > A_2 > A_4 > A_3$
GRA	$A_4 > A_3 > A_1 > A_2$

Observation from these tables of the ranking order can be inferred that the order is different for each class of traffic as well as each mechanism. The high specifies the highest ranked alternative (RAT) and low denotes the lowest ranked alternative. Due to input sensitivity and dynamicity, the experiment varies the input according to the context to make a choice of the RAT. Depending on the priority of the criteria and according to the context, the RAT choice is made. The sensitivity analysis of the choice determination is presented through the Analysis of Variance (ANOVA) to validate the statistical analysis made for the CTOPSIS mechanism. The complete procedure and the results of sensitivity analysis for all the classes of traffic are presented in Section 5.5.

5.3 Verification of CTOPSIS Mechanism for Determining new Target RAT

Verification of CTOPSIS mechanism was done using the method illustrated in Chapter Three Section 3.4. The verification of the mechanism inferred the following:

i. CTOPSIS has been programmed correctly, and
ii. CTOPSIS implementation is bug free, meaning it is compiled correctly with no syntax error.

The verification certifies the correctness of the transformation of analytical equations into programmable code. The compilation successfully completed, thus this is the verification confirmation after the programmable code execution.

5.4 Validation of CTOPSIS

Validation of the mechanism CTOPSIS was done with the multiple case illustrations to know the correctness of the proposed model. The mechanism is compared with the other classic mechanisms to know the relative performance in reduction of ranking abnormality and unnecessary handovers.

5.4.1 Multiple Case Illustration for Handover

A number of handovers is the quantification of the number of times the user equipment moves from one RAT to another. In the proposed mechanism, one of the objectives is to reduce the number of unnecessary handovers. Hence the multiple case illustration made in this section graphically illustrates the number of handovers in each of the mechanisms, e.g., TOPSIS, SAW and GRA in comparison with the proposed CTOPSIS.

Figure 5.2 showcases that the number of handovers is comparatively less in CTOPSIS compared to TOPSIS, SAW, and GRA mechanisms. The user priority here is background traffic, meaning the data connection is for email, FTP, transfers, and etc. The applications are more toward reliability of transferring rather than the delay. The handover is tested in the context of differentiating the class of application requested by the user. Figure 5.2 is the interpretation of different approaches employed to background traffic at thirty decision points. CTOPSIS out performs by reducing the number of handovers. The handover was reduced by 22.22%, 16.66%, and 11.11% when comparing the number of handovers in the classic TOPSIS, SAW, and GRA respectively with proposed CTOPSIS.

The CTOPSIS decision is based purely on the contextual information for the differentiated traffic. The priority of traffic is on packet loss rather than other criteria.

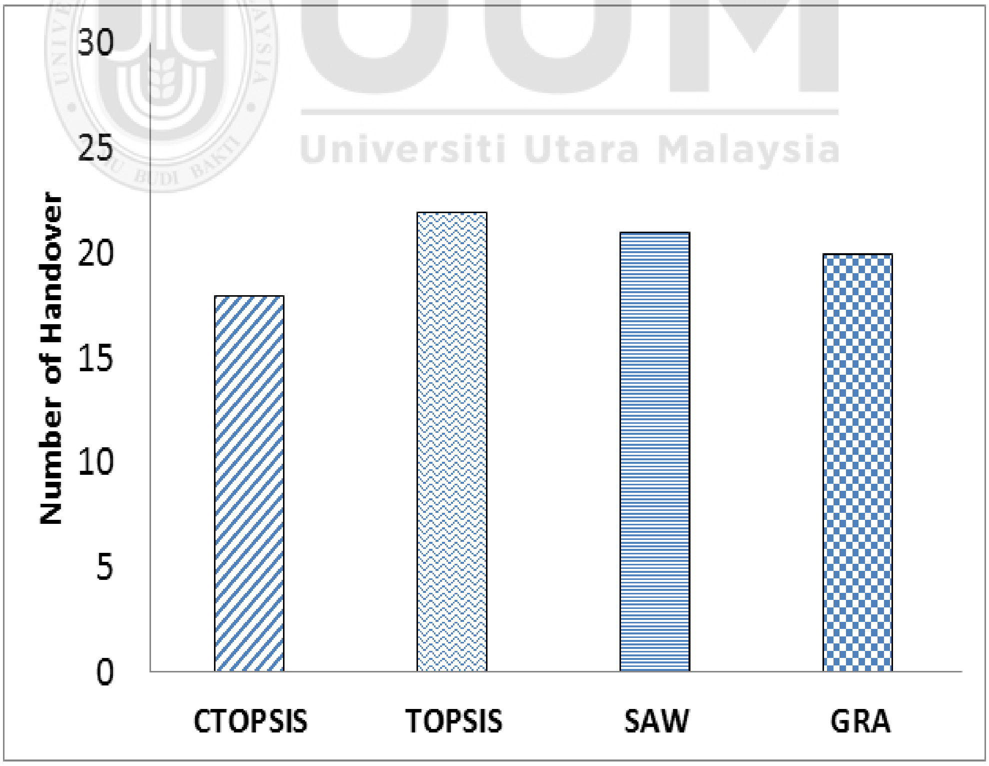

Figure 5.2. Change in Number of Handover for Background Traffic

Figure 5.3 showcases that the number of handovers with the conversational flow in CTOPSIS as compared to TOPSIS, SAW, and GRA mechanisms. When the user preference is conversational, delay and jitter are very crucial for such applications, and packet loss and throughput take the back seat. So, the context of the criteria should be considered during the weight computation and when determining the ranking. With the CTOPSIS, the number of handovers for a conversational class of traffic is reduced by 58.33% when compared against TOPSIS and SAW, and for GRA by 41.66%.

The application is delay sensitive, so the contextual decision is implied in congruence to the RAT with all the criteria and higher priority to the delay criteria, than just the signal alone. The contextual decision prioritises the criteria preference for the requested application. However it does not isolate other criteria, rather the decision is harmonising all the shortlisted criteria with the priority to the application sensitivity in determining the RAT.

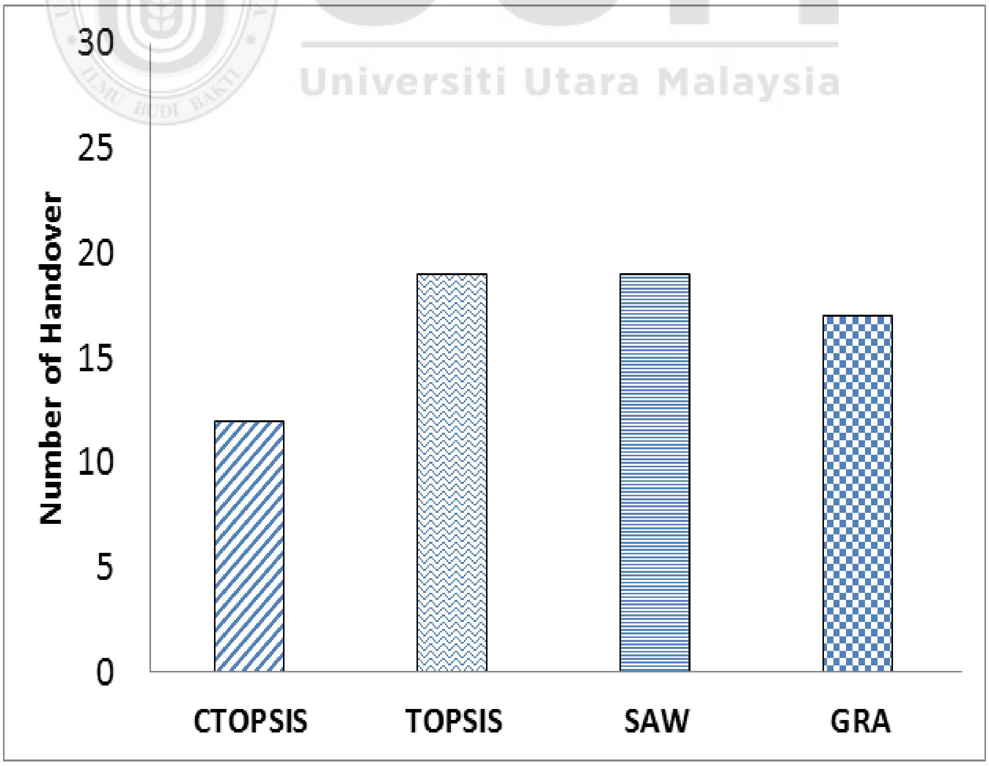

Figure 5.3. Change in Number of Handover for Conversational Traffic

Similarly, Figures 5.4 and 5.5 showcase that the number of handovers with streaming and interactive traffic respectively in CTOPSIS, TOPSIS, SAW, and GRA mechanisms. For streaming traffic the handovers are reduced by CTOPSIS in comparison with other three by 50%, 45%, and 54% respectively, followed by an interactive type of application with 57%, 55% and 52%, when compared to TOPSIS, SAW, and GRA. In general, the context based design is more efficient compared to the imperative approach.

The decision in the case of streaming data prefers the high data rate in congruence with the other criteria along with the available RAT, whereas for the interactive class applications, the mechanism prioritises delay and packet loss with the other criteria. Hence, the decision is made with the preference of collaborative criteria, but mainly prioritising the differentiated class of applications.

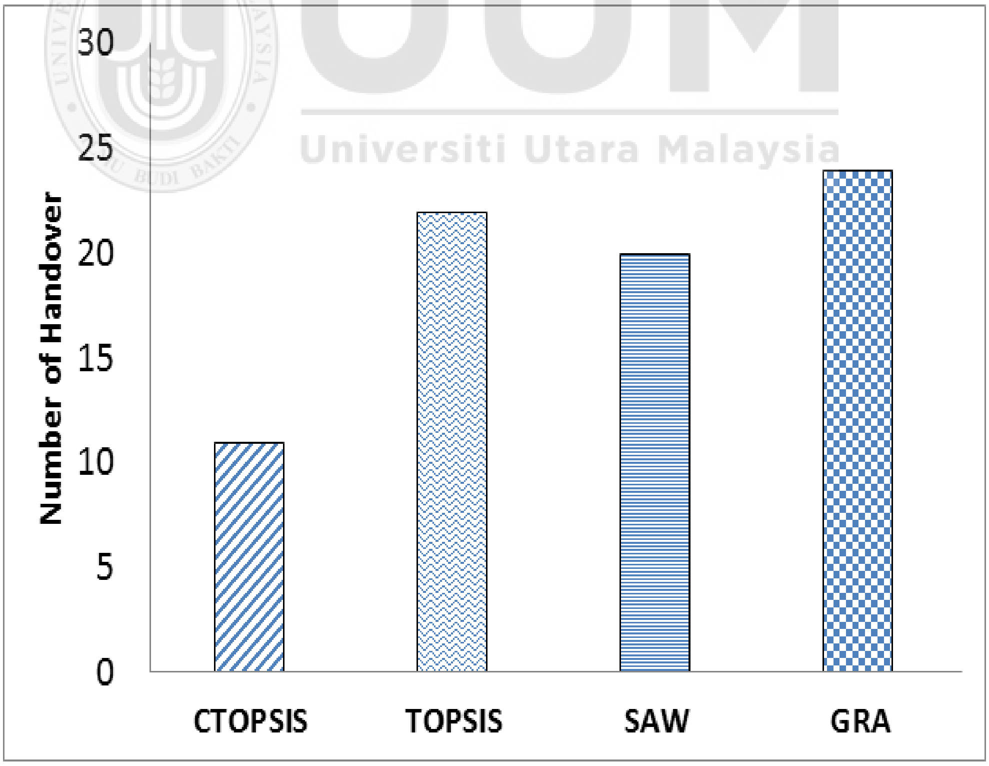

Figure 5.4. Change in Number of Handover for Streaming Traffic

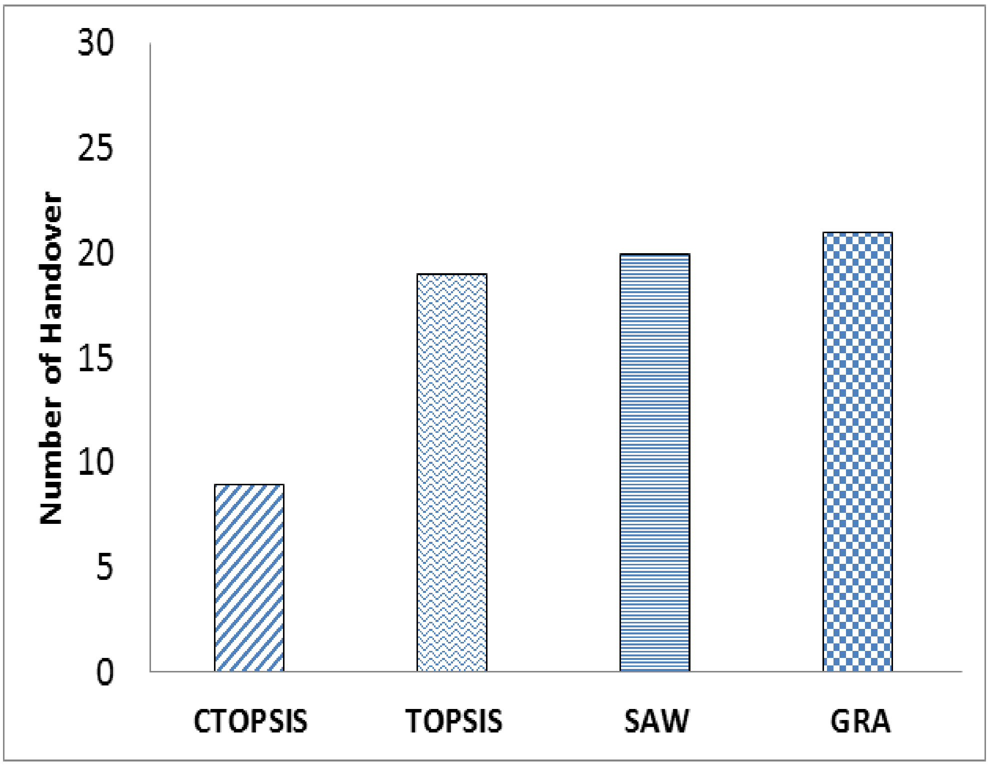

Figure 5.5. Change in Number of Handover for Interactive Traffic

Hence, from the multiple case illustration and experimental results, it can be ascertained that the context-aware mechanism of ranking reduces the number of handovers quantitatively, because the decision is not imperative or based on a single criteria, but rather based on collaborative with context-awareness. The handover is triggered exclusively based on context-awareness of user and network.

5.4.2 Multiple Case Illustration for Ranking Abnormality Problem

As stated earlier, the rank reversal is the state of RAT ranking order when one of the RAT is removed. The ranking of the remaining available RATs should be unchanged. If the removal of RAT affects the ranking order, it can be concluded that there is a rank reversal issue. The proposed CTOPSIS mechanism reduces the rank reversal problem quantitatively in comparison to other MADM mechanisms, in order to determine the validation multiple case with varying context, which is illustrated in this section.

In the experiment design of this proposed mechanism, the RAT with the lowest is evicted and the experiment is run to check for rank reversal. The illustration of this is presented in Table 5.5, where the lowest ranked RAT, i.e., 802.11n (A_1) is removed. The A_2, A_3 and A_4 alternatives are only three RATs (802.11ac, HeNB, and LTE) remaining for the next round of execution to test the rank reversal by employing CTOPSIS for new context and checking for the ranking order. If the ranking order is still the same or not affected by the removal of a RAT, then there is no abnormality, but if the ranking order is not the same, it means that there is abnormality in ranking. However, in the experiment carried out to check rank reversal for data connection, as illustrated in Table 5.5, the ranking order remained the same after removing the lowest ranked RAT from the first run. The results presented in the table show no ranking abnormality for the background traffic context tested using CTOPSIS.

Table 5.5
Ranking Order of RAT with Data Connection

RAT	C_j^*	Ranking Order
802.11n	0.4067	4
802.11ac	0.6452	2
HenB	0.5892	3
LTE-enB	0.7326	1

$\Rightarrow$

RAT	C_j^*	Ranking Order
802.11ac	0.6032	2
HenB	0.2868	3
LTE-enB	0.7549	1

Similarly, Table 5.6 illustrates the ranking order of RATs for conversational flow. The ranking order for RATs is shown in run one and the RAT with lowest ranked RAT is 802.11n alternative A_1, and the remaining A_2, A_3 and A_4 RATs are considered for next run. The results with three alternatives show the same ranking order with no ranking abnormality.

Table 5.6

Ranking Order of RAT with Conversational Traffic

RAT	C_j^*	Ranking Order
802.11n	0.2346	4
802.11ac	0.5350	3
HenB	0.4135	2
LTE-enB	0.7575	1

⇒

RAT	C_j^*	Ranking Order
802.11ac	0.3602	3
HenB	0.1500	2
LTE-enB	0.8319	1

Table 5.7 illustrates the ranking order of RATs for streaming flow. The ranking order for RATs is shown in run one and the RAT with lowest ranked RAT is HenB alternative A_3, and the remaining A_1, A_2 and A_4 RATs are considered for next run. The results with three alternatives are shown to have the same ranking order after removal of the RAT with lowest rank.

Table 5.7

Ranking Order of RAT with Streaming Traffic

RAT	C_j^*	Ranking Order
802.11n	0.6304	2
802.11ac	0.6100	3
HenB	0.3577	4
LTE-enB	0.8141	1

⇒

RAT	C_j^*	Ranking Order
802.11n	0.3589	2
802.11ac	0.3556	3
LTE-enB	0.6419	1

Table 5.8 illustrates the ranking order of RATs for interactive flow. The ranking order for RATs is shown in run one and the RAT with lowest ranked RAT is LTE-enB alternative A_4, and the remaining A_1, A_2 and A_3 RATs are considered for next run. The results with three alternatives are shown to have the same ranking order after removal of the RAT with lowest rank.

Table 5.8

Ranking Order of RAT with Interactive Traffic

RAT	C_j^*	Ranking Order
802.11n	0.5000	3
802.11ac	0.7175	2
HenB	0.7353	1
LTE-enB	0.4604	4

⇒

RAT	C_j^*	Ranking Order
802.11ac	0.3985	3
HenB	0.5997	2
LTE-enB	0.6015	1

The eviction of the RAT should not make any difference in the ranking order of RAT selection. If the operation is effected and rank order changes, it means that there is a ranking abnormality. This metric is measured in the current research and the proposed CTOPSIS approach is evaluated with the other classic MADM approaches, namely TOPSIS, SAW and GRA. The ranking abnormality for background flow is outlined in Figure 5.6.

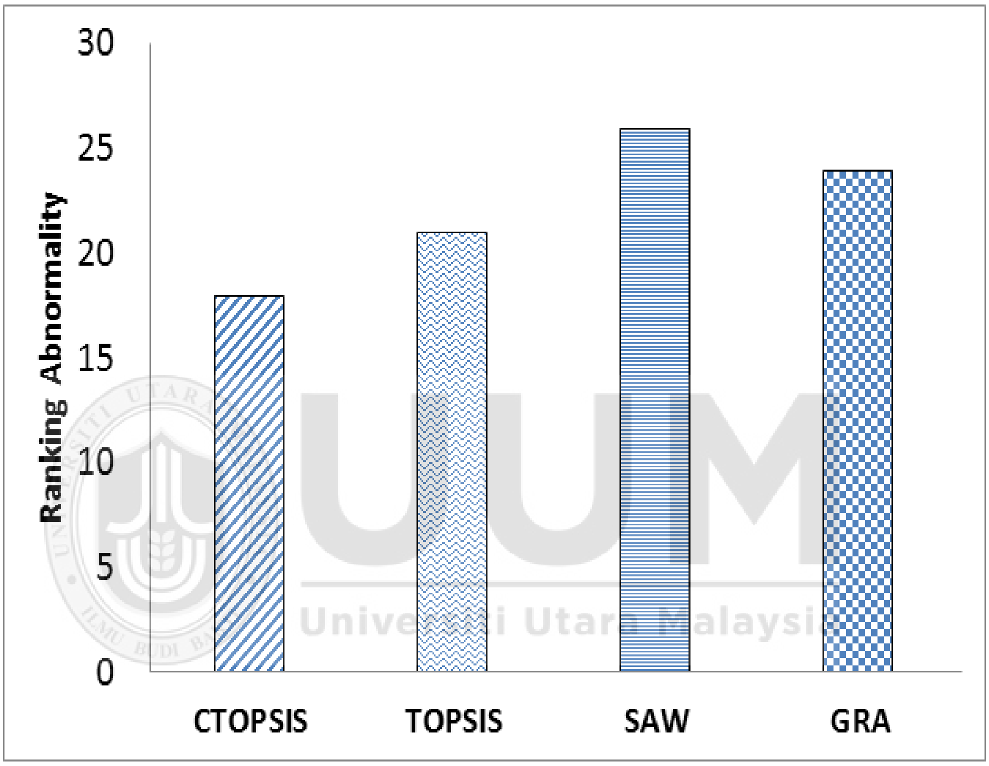

Figure 5.6. Change in Ranking Abnormality for Background Traffic

The background traffic was considered and evaluated, Figure 5.6 outlines the evaluation of ranking abnormality in CMRAT to the TOPSIS, SAW, and GRA. The data flow is not stringent to any criteria like other classes of traffic. The CMRAT is less prone to ranking abnormality in comparison to other mechanisms. CTOPSIS is less prone to RA 14%, 30%, and 25% than TOPSIS, SAW and GRA, respectively.

Simulation analyses the data connection or the conversational flow, in order to compare the performance of the proposed CTOPSIS mechanism with the other three mechanisms (TOPSIS, SAW and GRA). From Figure 5.7, while considering the conversational traffic, such as VOIP application which is delay sensitive. The determining RAT should be very critical and CTOPSIS outperforms in this context also by 36%, 47%, and 42% compared to TOPSIS, SAW, and GRA, respectively. The context-awareness with integration of MADM approaches aids in efficient decision making in RAT selection.

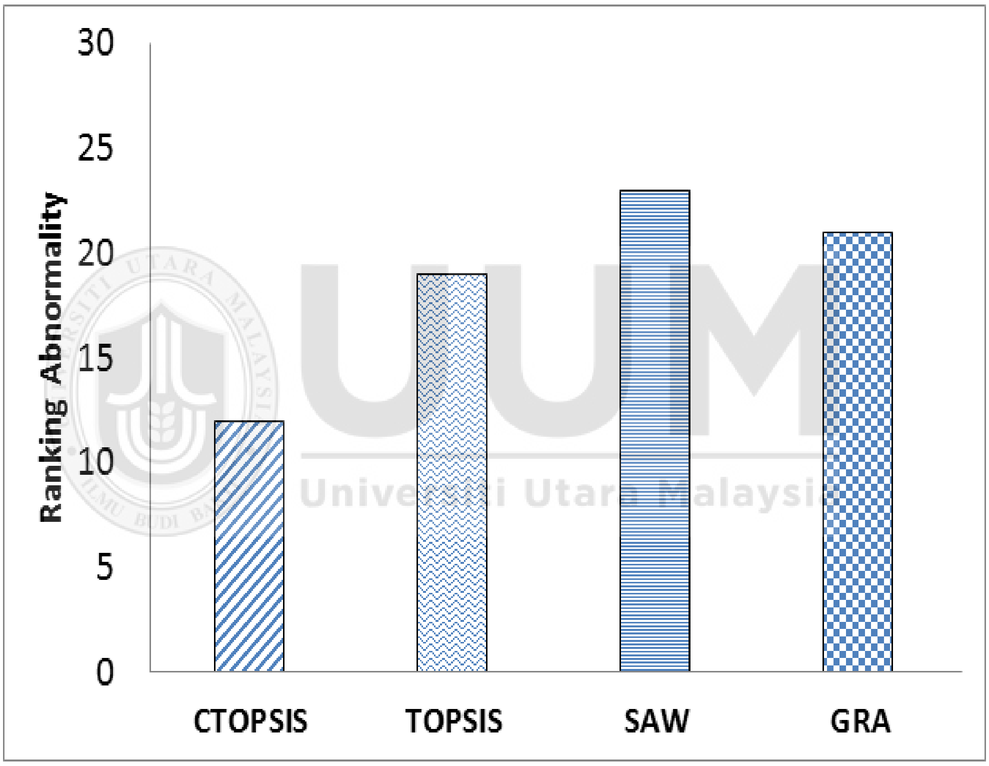

Figure 5.7. Change in Ranking Abnormality for Conversational Traffic

In the context of streaming, the application priority is jitter and throughput, indexing this preference into the criteria during the computation of weights through CAHP. Later, the weights of CAHP are induced in CTOPSIS for RAT selection. The integration of these to MADM approaches with context-awareness not only makes an efficient decision, it also performs better in terms of RA by 13%, 20%, and 29% as compared to TOPSIS, SAW, and GRA respectively. Figure 5.8 presents the ranking abnormality in the context of streaming type of traffic.

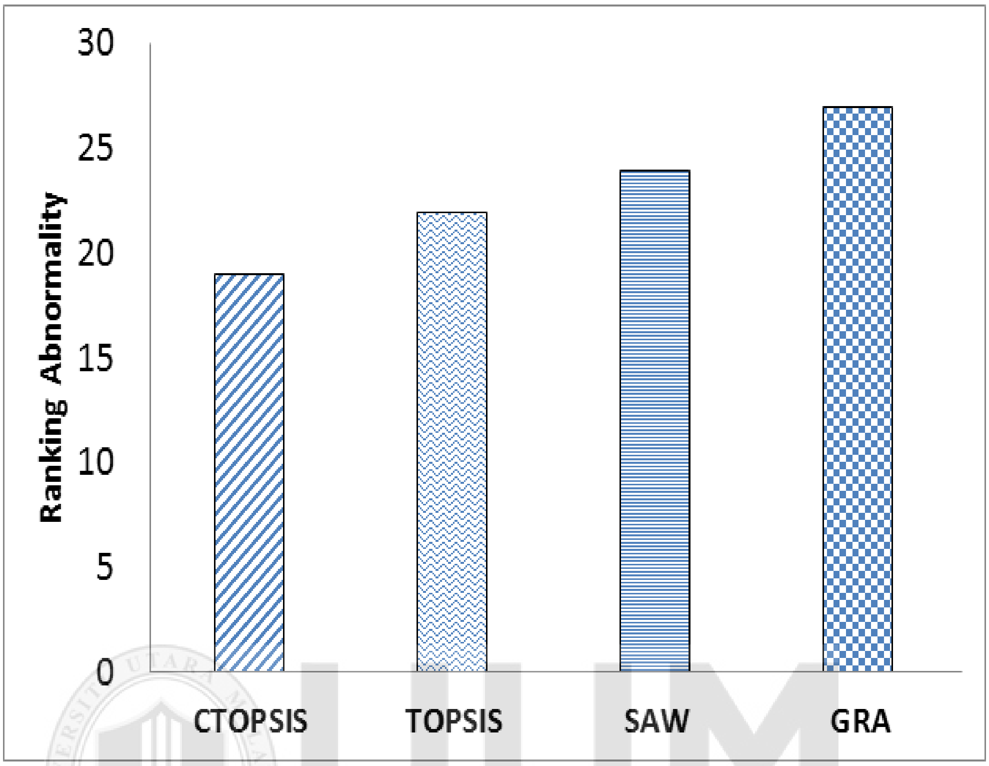

Figure 5.8. Change in Ranking Abnormality for Streaming Traffic

Finally, Figure 5.9 considers the interactive traffic, which is delay sensitive, and packet loss rate should be low. The mechanism takes care in the process of assigning the weight and determining the RAT according to the requirements and the availability at the context during the decision making. Furthermore, based on this theory, the CTOPSIS performs better 52%, 35%, and 59% than TOPSIS, SAW, and GRA, respectively.

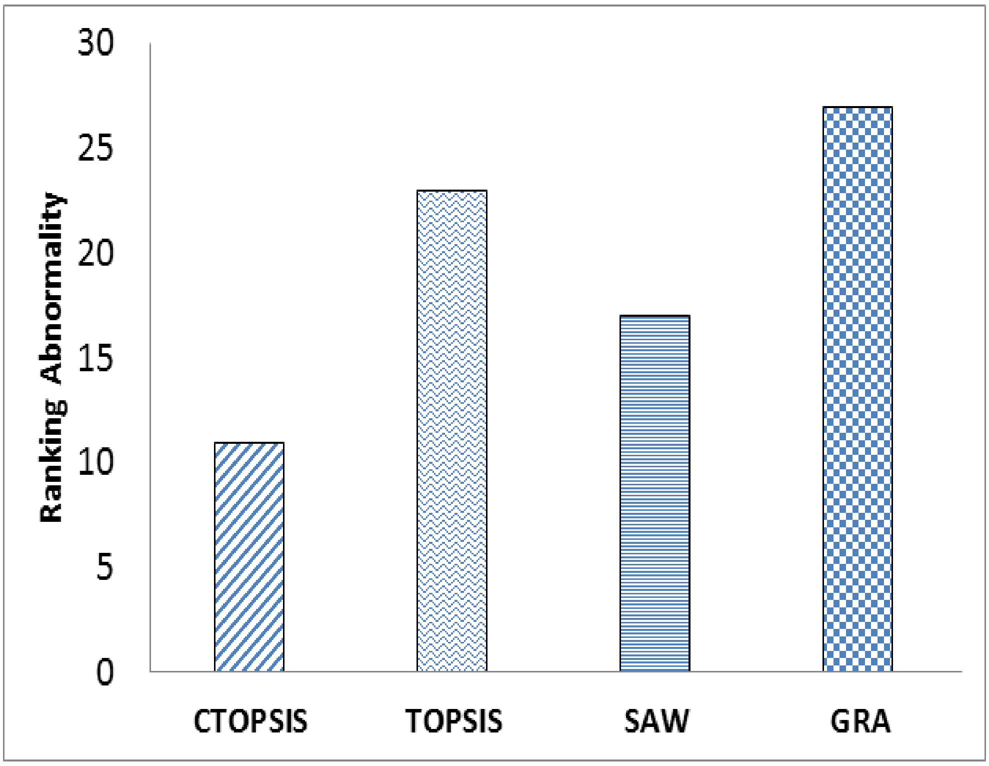

Figure 5.9. Change in Ranking Abnormality for Interactive Traffic

From the case illustration, it can be ascertained that the ranking abnormality is comparatively reduced in case of CTOPSIS. However, there is a scope to improve toward zero. The CTOPSIS is less prone to abnormality issue. From the above evaluation, it can be deliberated that CTOPSIS is performing better and less prone to ranking abnormality compared to other approaches irrespective of the traffic classes. The reduced ranking abnormality is due to the integration of MADM mechanisms while harnessing the benefits of the mechanism. Also, the decision is not just multi-attribute based, but rather it is context-aware.

5.5 Sensitivity Analysis of CTOPSIS Mechanism

Sensitivity analysis may be used to identify which set of input data signals has a significant impact on the set of system state information. This approach consists of changing the input parameters of a mechanism to determine the effect on the mechanisms behaviour of output in accordance to the actual system. The sensitivity analysis of the CTOPSIS procedure is comparing the different mechanism, calculating the mean, standard deviation, and variance of the mechanisms to know the degree of freedom.

The statistical analysis procedure of sensitivity analysis is elaborated below. The outcomes of the mechanism ranking order values generated from the experiment are considered to calculate the respective mechanisms mean, standard deviation, and variance. Table 5.9 presents the summary of values in sensitivity analysis. Alternative specifies the RAT under consideration in decision making and R value represents the ranking for each alternative with respective mechanism.

Table 5.9
The Experiment Values to Calculate Degree of Freedom

	Mechanism	**Mechanism**	**Mechanism**	**Mechanism**
Alternative_1	R_{value1}	R_{value1}	R_{value1}	R_{value1}
Alternative_2	R_{value2}	R_{value2}	R_{value2}	R_{value2}
Alternative_3	R_{value3}	R_{value3}	R_{value3}	R_{value3}
Alternative_4	R_{value4}	R_{value4}	R_{value4}	R_{value4}
Mean	$\overline{Y_1}$	$\overline{Y_2}$	$\overline{Y_3}$	$\overline{Y_4}$
Standard Deviation	SD_1	SD_2	SD_3	SD_4
Variance	V_1	V_2	V_3	V_4

Step 1: The mean of each set is given by,

$$\overline{Y_1} = \frac{R_{value1} + R_{value2} + R_{value3} + R_{value4}}{n} \quad where\ n\, is the total\, number\, of\, alternatives \tag{5.11}$$

Step 2: The overall mean is given by,

$$\overline{Y} = \frac{\overline{Y_1}+\overline{Y_2}+\overline{Y_3}+\overline{Y_4}}{a} \quad where,\ a\, is\, the\, number\, of\, mechanisms \tag{5.12}$$

Step 3: Calculate Sum of Squares Treatment (SST),

$$SST = n(\overline{Y_1}-\overline{Y})^2 + n(\overline{Y_2}-\overline{Y})^{2+} n(\overline{Y_3}-\overline{Y})^2\, where\, n\, is\, the\, data\, values\, per\, mechanism \tag{5.13}$$

Step 4: Sum of Squares of Errors (SSE),

$$SSE = (n_1-1)V_1^2 + (n_2-1)V_2^2 + (n_3-1)V_3^2\, where\, V\, is\, the\, variance \tag{5.14}$$

Step 5: Sum of Square Total (SS_{total},),

$$SS_{total} = SST + SSE \tag{5.15}$$

Step 6: Mean Square for Treatment (MST),

$$MST = \frac{SST}{k-1}\, where\, k\, is\, the\, number\, of\, mechanisms \tag{5.16}$$

Step 7: Mean Square of Error (MSE),

$$MSE = \frac{SSE}{n-k} \tag{5.17}$$

Step 8: The value of Freedom (F),

$$F = \frac{MST}{MSE} \tag{5.18}$$

Table 5.10 formulates all the procedures of sensitivity analysis, where the alpha (α) value is the minimum error considered. In computing the sensitivity analysis for CTOPSIS, α is set to 0.05, meaning a confidence interval of 95% is assumed. The P value presented in the table determines the statistical significance of the mechanism. To determine the statistical significance of a mechanism, a comparison between the P and α value is performed.

The significance level, denoted by α=0.05, is adopted with a confidence interval of 95%, accommodating the 5% error risk in all mechanisms freedom.

i. P-value $\leq \alpha$ means the difference between the means of the formulated hypothesis is statistically significant.

ii. P-value > α means the difference between the means of the formulated hypothesis is not statistically significant.

Table 5.10

Summary Table of Sensitivity Test $\alpha = 0.05$

Source of Variation	**Degree of freedom (DF)**	**SS**	**MS**	**F**	**P**
Treatment	k-1	SST	MST	$\frac{MST}{MSE}$	(k-1, n-k, F)
Error	n-k	SSE	MSE	⋰	⋰
Total	n-1	SS_{total}	⋰	⋰	⋰

On the standard approach of sensitivity analysis formulated in Table 5.10, the computation for all the four traffic flows for the proposed mechanism is presented in Tables 5.11, 5.12, 5.13, and 5.14, where they represent the P-value for background, conversational, streaming, and interactive data flows respectively. The important aspect is the P-value in all the tables which will determine the sensitivity. All the P-values in the four cases are below the α value. Hence, the statistical analysis is significant for the proposed mechanism.

Table 5.11

Sensitivity Analysis of CTOPSIS for Background Flow

Source	DF	SS	MS	F	P
Treatment	3	1.266	0.422	50.0227	0.0002
Error	12	0.101	0.008	*NA*	*NA*
Total	15	1.367	*NA*	*NA*	*NA*

Table 5.12

Sensitivity Analysis of CTOPSIS for Conversational Flow

Source	DF	SS	MS	F	P
Treatment	3	1.220	0.407	49.1574	0.0002
Error	12	0.099	0.008	*NA*	*NA*
Total	15	1.320	*NA*	*NA*	*NA*

Table 5.13

Sensitivity Analysis of CTOPSIS for Streaming Flow

Source	DF	SS	MS	F	P
Treatment	3	1.075	0.358	42.1395	0.0002
Error	12	0.102	0.009	*NA*	*NA*
Total	15	1.177	*NA*	*NA*	*NA*

Table 5.14
Sensitivity Analysis of CTOPSIS for Interactive Flow

Source	DF	SS	MS	F	P
Treatment	3	1.286	0.429	62.4967	0.0003
Error	12	0.082	0.007	*NA*	*NA*
Total	15	1.368	*NA*	*NA*	*NA*

The numerical analysis results revealed that there is standard deviation of 56.00%, 51.00%, 28.00%, and 19.00% in CTOPSIS, TOPSIS, SAW, and GRA respectively. The corresponding standard deviation of CTOPSIS is observed high, meaning that it is the best mechanism in decision making compared to the other classic ones [89][163].

5.6 Summary

This chapter describes the Context-aware Technique for Order Preference by Similarity to an Ideal Solution (CTOPSIS) mechanism to determine the best RAT among the all available alternative RATs in the UDN heterogeneous environment. The CTOPSIS is sensitive to the context information in determining the RAT. Along with the best RAT selection, two other measurements are also done, namely number of handovers and ranking abnormality. The CTOPSIS computation toward ranking the RAT and its complete numerical analysis with different cases are presented.

The sensitivity analysis of the mechanism is presented to know the statistical sensitivity of the proposed operational mechanism. Furthermore, the mechanism is injected into the performance modelling via simulation in Network Simulator3 (NS-3). The implications are presented in the following chapter.

CHAPTER SIX
CMRAT PERFORMANCE ANALYSIS

In heterogeneous Ultra Dense Network (UDN), users can move between the different Radio Access Technologies (RATs). They will benefit from the different characteristics, like coverage, bandwidth, latency, cost, and etc. However, the handover process becomes more complex in such an environment compared to a homogeneous network. Hence, the handover decision to choose the appropriate RAT, will influence the RAT selection performance in the UDN environment.

The RAT selection method had been defined and discussed in previous chapters, comprising different phases; the appropriate context to trigger RAT selection comprising of RAT initiation and decision making. The decision made should satisfy the network and user requirements by deciding which RAT to connect as target RAT at any point of time when multiple RATs are available for differentiated service.

This chapter presents the next level of performance modelling, i.e., performance evaluation with simulation, where the analytical models presented in Chapters Four and Five are incorporated into a network simulator to measure the performance of context-aware multiple attribute based RAT selection. This chapter is organised as follows, Section 6.1 elaborates an overview of the comprehensive working of Context-aware Multiple attribute Radio Access Technology (CMRAT). Section 6.2 describes the design and implementation of the CMRAT for RAT selection. Section 6.3 illustrates the scenarios in which the simulation for CMRAT was implemented to evaluate the performance of RAT selection. The performance is evaluated in comparison with the standard A2A4-RSRQ approach of RAT selection. Finally, Section 6.4 summarises the findings in this chapter

6.1 CMRAT: A Review

RAT selection is triggered imperatively with the network event occurrence primarily based on the radio signal strength. However, in UDN environment the imperative decision will trigger unnecessary handover frequently, thus decreasing system performance due to the close deployment of RATs. The close deployment leads to a conflicting environment to the User Equipment (UE) in choosing the RAT. Hence, the proposed CMRAT will resolve the issue of imperative decision making by replacing the decision initiation based on the context of user and network requirements in line with the RAT capability to accommodate the UE for specific services.

Based on the synthesis of RAT selection and vertical handover decision mechanisms previously built, the proposed approach was built taking the advantage of the most interesting of solutions and particularly the best of each mechanism that were discussed in Chapter Two.

Context-aware multiple criteria based RAT (CMRAT) selection was constructed, which is conscious of the possibilities offered by each RAT and senses the UE movement while taking into account the QoS requirements for demanded services. The context information gathered needs to be compared and evaluated to initiate or decide the RAT selection. Figure 6.1 describes the whole procedure of the CMRAT approach in triggering and decision making of RAT selection comprising CAHP and CTOPSIS mechanisms, respectively.

The figure represents the whole procedure with the phases involved in RAT selection in the CMRAT approach. Firstly, the information gathering about the network and user requirements was made and stored in the context repository to apply different mechanisms toward decision making. The network discovery for context information is made every 2 ms and context repository is updated, which aids in monitoring and measuring the need for the RAT selection process. The CAHP mechanism is employed to trigger the RAT initiation. The CAHP compares and prioritises the criteria with the RAT capability to serve the particular request from UE (the detailed working of the CAHP was presented in Chapter 4). The CAHP works in a hierarchical fashion.The level one is the assessment of RAT with criteria versus criteria to obtain the weights depending on the differentiated traffic, and collaborative user and network preferences. At the second level of hierarchy is the comparison of criteria versus alternatives (RATs). Both these levels together decide the need for triggering RAT initiation.

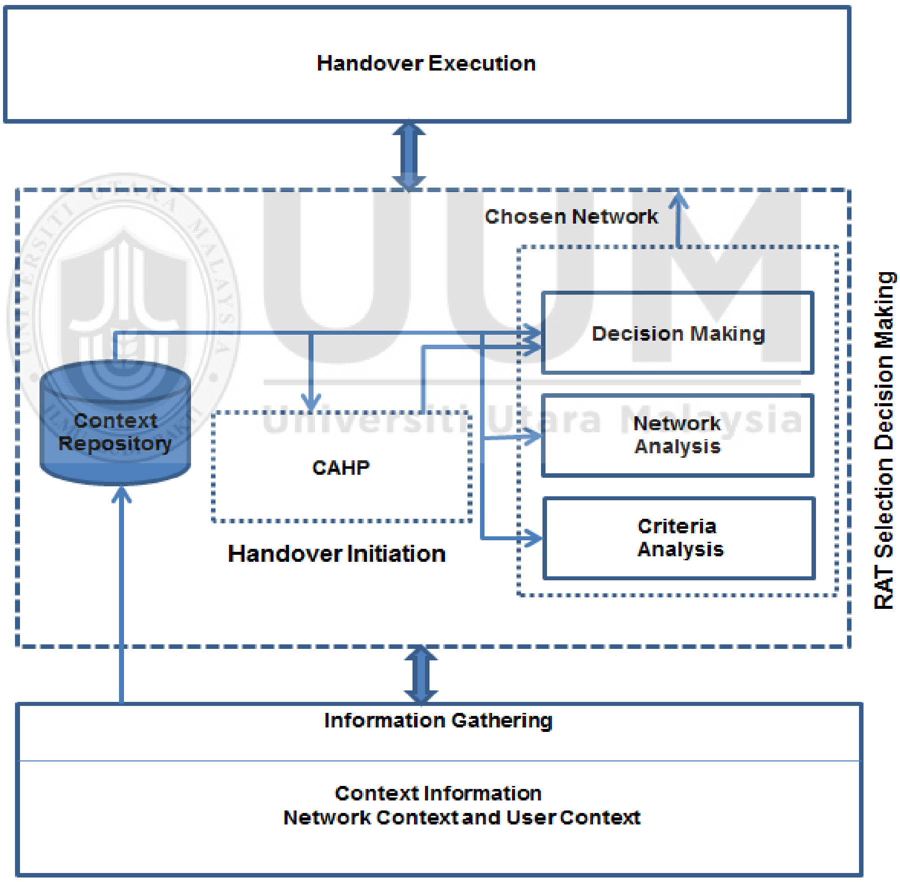

Figure 6.1. RAT Selection Comprehensive Overview

The information in the context repository facilitates the CAHP mechanism, where the measurements taken from the residing RAT is analysed according to the UE requirement. If the current serving RAT is unable to meet the requirements at that moment, the initiation is triggered. Otherwise the UE stays attached to the current RAT. If initiation is triggered by CAHP mechanism, the UE will need to choose the next target RAT to obtain service.

Furthermore, determining the best RAT among the available ones in UDN is a challenge and critical also. The handover initiation is an intra RAT analysis, however in contrast, the decision making is the inter RAT analysis to decide the best fit among the available ones. The context repository contains all the updated information about the RAT and request of the UE. Once the initiation is triggered, the mechanism Context-aware Technique for Order Preference by Similarity to an Ideal Solution (CTOPSIS) is employed to chose the RAT. This mechanism maps the requirement with the network information from the context repository and ranks the RAT according to the best fit to the requirement criteria. The detailed working of the CTOPSIS is presented in Chapter 5. Once the ranking is obtained from the CTOPSIS, the one with the highest rank is chosen to be the best RAT that fits the requirement.

As in Figure 6.1, the input to the context repository comes from the information gathering phase and the information is updated every 2 ms. The CAHP mechanism gets the input from the network node of repository to trigger the RAT selection initiative. The CTOPSIS mechanism makes the collaborative assessment of the criteria from the repository with the network's, i.e., RATs are available in the neigbourhood and to choose the best one among the available that best suits the UE at the context of decision making. The fact is reiterated that the CMRAT approach is not imperative or biased to the criteria or the RAT, but rather it is a context-awareness based decision approach.

Finally, the third phase is handover execution which connects the control from current RAT to the target RAT. The CMRAT processes event triggering and evaluation with the standard imperative approach of RAT selection, which is presented in further sections.

6.2 Design and Implementation of CMRAT

The overview of the working CMRAT is presented in the previous section, and this section introduces the design of CMRAT and the event triggered during the selection of RAT during transition from one state to another. It is presented via state transition diagram with the events trigger a transit from one state to another, as in Figure 6.2. To begin, the phase starts when the User Equipment (UE) joins the current network zone. It can be a macro or femto base station in this research. The new request is transmitted from the UE at different instances of time continuously and the base station is supposed to serve the request. When the current serving RAT fails to meet the context requirement of UE, the handover is triggered. The triggering of handover is not imperative based, but rather based on the context constraint to trigger the handover. Once the handover initiation is triggered, the next phase is to determine the RAT to determine target point of attachment.

Determining the RAT phase is when there is a need to measure the capability of each RAT with respective criteria for decision making in order to choose among all available RATs, thus instigating a network discovery event. This event helps to map the criteria to alternatives. Once the match is found, a new target RAT is determined and the control of UE is attached to the new target RAT. If the target RAT is not determined, the UE is bound to continue with the current serving RAT. The target RAT determination completes the handover execution and exits the transition phase. During this process of transiting states, the complete performance of the designed approach is measured in terms of throughput, packet delivery ratio, delay, and number of devices.

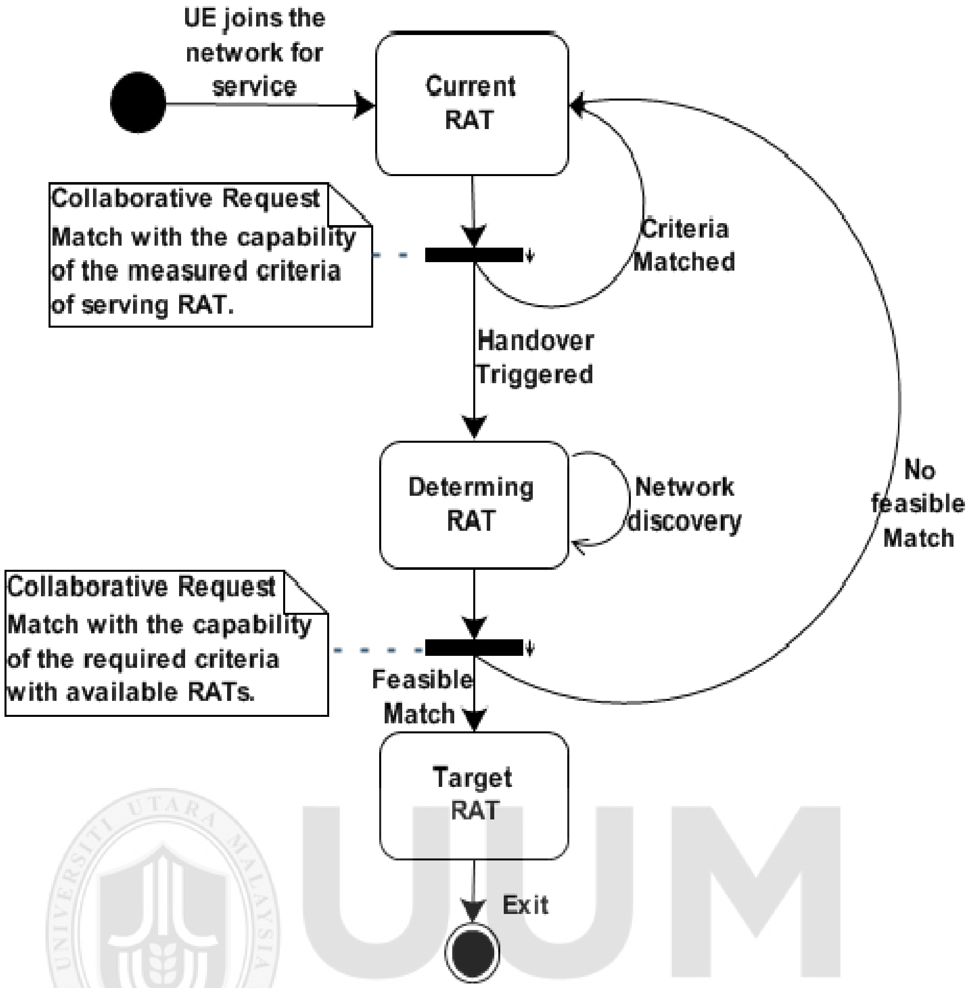

Figure 6.2. State Diagram for CMRAT Design

6.3 Performance Evaluation of CMRAT

To represent the actual simulation environment, two scenarios were considered, namely shopping mall which depicts the small area of UDN environment and urban city which replicates the wider area of UDN environment. It is contemplated that in UDN environment of 5G networks, several small cells will be available and connections of UE are handed to the Home evolved Node Base Stations (HeNBs) [164]. Also, femto WiFi (IEEE 802.11n) is integrated to form UDN environment. The proposed approach system comprises Long Term Evolution release 13 (LTE) macrocell, HeNB, and WiFi as a femtocell in RAT selection.

The proposed CMRAT is implemented in two scenarios to measure the performance evaluation of the approach. To validate the proposed model, the evaluation with the other model approach was adopted. The details of this validation is mentioned in Chapter Three Section 3.4.

The model was chosen to juxtaposed LTE A2A4-RSRQ [19] approach in RAT selection. The A2A4-RSRQ approach is formed by two events, namely event A2 which occurs when serving cell Radio Signal Receiving Quality (RSRQ) becomes greater than the threshold, and event A4 occurs when the neighbour cell RSRQ becomes better than the threshold. In short, A2A4-RSRQ mainly is an imperative approach in RAT selection merely based on the link quality. In contrast, the CMRAT amalgamates the multiple criteria in RAT selection. The further sections measure the performance of the CMRAT and A2A4-RSRQ approaches in terms of number of handover, packet delivery ratio, throughput, and delay by varying the number of devices with time.

This chapter presents a novel approach in decision making of RAT selection not based on two events of signal quality, but considers the context of UE and resource available at the junction of the requirement of the service while considering the context-awareness of both the network and user for the RAT selection to be made. The decision is not imperative, it is with context-awareness considering multiple criteria. This approach follows the deployment of UDN with small cell, and the consideration of differentiated traffic demand. In general an attempt to maximise the network resource utilisation efficiently, providing uniform access to the UE and facilitating the multi-modal feature. The approach is presented further with the two scenarios to draw the findings and performance impact in the UDN environment.

6.3.1 Simulation Using Shopping Mall Scenario

The shopping mall is one of the scenario chosen to replicate the smaller UDN environment with multiple RATs. Figure 6.3 represents the graphical view of shopping mall scenario. The detailed description of the simulation parameters is provided in Table 6.1.

The shopping mall test case is formed with four rows of femto cells, assuming each shop there is an access point and a pedestrian corridor in the middle. The femtocell is formed from HeNB or WiFi AP. The macrocell is the LTE release 13 central base station that co-exists at a distance of around 1200 metres in a typical urban suburb location. It is further assumed that several UE's are either static or moving at pedestrian speed varying from 0.4m/s, 0.8 m/s, and 1.4 m/s randomly. The shopping mall single floor is considered for implementation simplicity. The focus is purely on RAT selection during the handover and the impact of the proposed CMRAT on the number of handovers, attainment of throughput, packet delivery ratio, and the delay.

The performance of CMRAT is compared with the A2A4-RSRQ approach within the same environment. This comparison will show the enhancement in decision making with context-awareness overriding the traditional imperative approach.

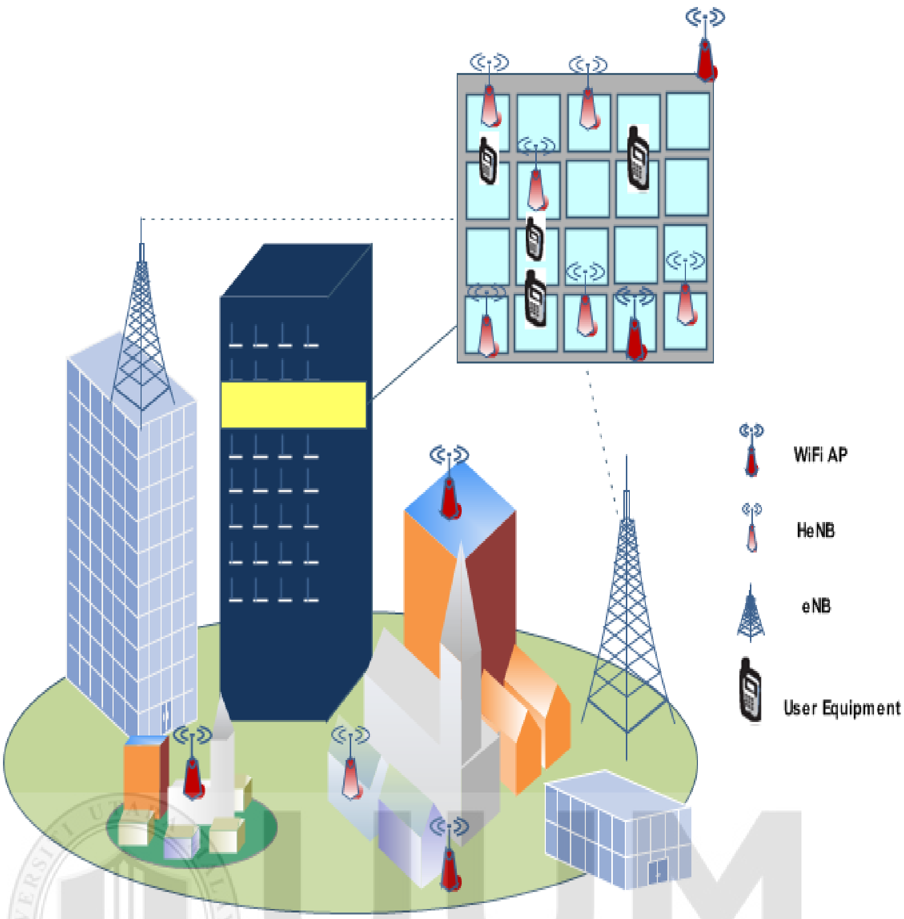

Figure 6.3. Shopping Mall Simulation Scenario

Table 6.1
Simulation Parameters for Shopping Mall Scenario

Environment	Shopping mall 1 floor 100*200 meters per floor 20 rooms per floor (2 rows of 10 equal rooms)
User Equipments	Number of user Equipments vary with time
RATs	LTE-A and 802.11n
Number of Wifi Access points	20
Number of (H)eNBs	2 eNBs,3 HeNBs
Simulation Time	600-3600 s
UE mobility	0.4m/s, 0.8 m/s, 1.4 m/s (randwalk ranging)
HeNB load	Varying depending on the number of associated UEs (very low, low, medium, high, very high)

6.3.1.1 Performance Evaluation of CMRAT versus A2A4-RSRQ for UDN in Small Area

The performance evaluation of the CMRAT approach in comparison with the A2A4-RSRQ approach was made. The performance was measured in terms of packet delivery ratio, throughput, number of handovers, and delay. Figure 6.4 to Figure 6.7 present the performance evaluation for shopping mall for the above mentioned metrics. The detailed network parameters of the simulation are mentioned in Table 6.1 for the shopping mall scenario of UDN. The Figure 6.4 articulates the impact of varying the UEs on the packet delivery in both approaches. The graph represents the number of devices on the x-axis and the respective PDR on the y-axis. The time of simulation is fixed to 600 seconds to measure the PDR. The PDR is the ratio of the data packets delivered to destination to the packets sent from the source. The results taken for the presented scenario of varying UE exhibit better hit rate of PDR in the given time slice of CMRAT approach.

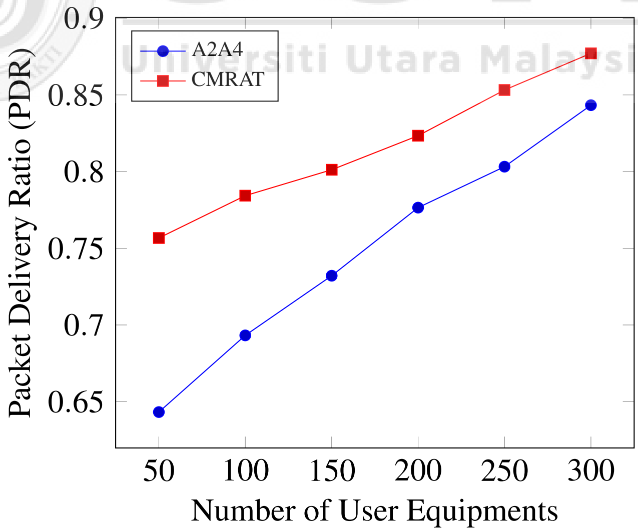

Figure 6.4. The Impact of Varying User Equipments in PDR

It can be inferred that CMRAT, in spite of combining multiple attributes, outperformed the imperative link based approach in RAT selection. The increase in the number of

UEs does not effect the performance of the CMRAT. This is because the priority of the criteria sensitivity at the instance of taking the call to trigger the initiation and decision making, overrides the increase in UE criteria within the mechanism to achieve better PDR. The context prioritises the flow of packets based on the traffic type, which is maintained by the Quality Channel Index (QCI) indicated from the standard for any type of flow to attain better PDR, in turn serving the user demand efficiently across the small cell.

Figure 6.5 describes the throughput attained within the time slice of 600 seconds by the UE ranging from 50 to maximum 300, CMRAT with the increase in devices attains better throughput comparatively. The A2A4-RSRQ throughput is also increasing with the devices increase, however it was not able to attain the performance of CMRAT, iterating the fact that imperative A2A4-RSRQ is fundamentally depending on the link quality only. The CMRAT approach prioritises the application requirement and collaboratively determines the triggering and determining the RAT. The attainment of throughput is due to the priority to the UE demand and also, right map of the demand to network resource which can serve better rather than just switching RATs and assuming the signal strength is sufficient to provide satisfactory servicee. The context based decision serves the UE with better service attaining a higher throughput in comparison to the A2A4-RSRQ approach.

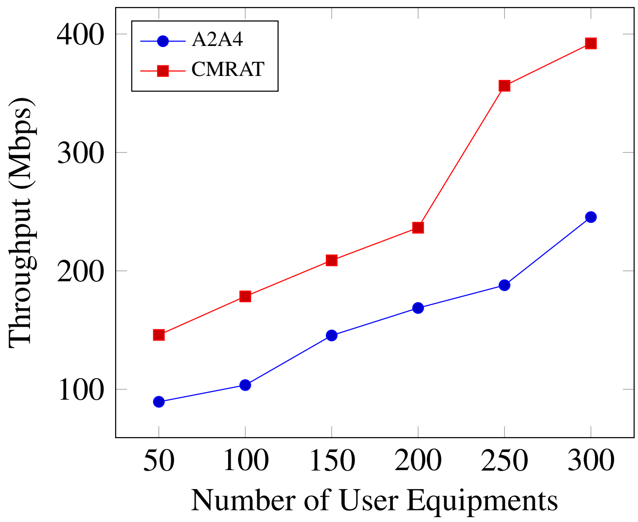

Figure 6.5. The Impact of Varying User Equipments for Throughput

Figure 6.6 depicts the number of handover measurement in the case of both the approaches, which is one of the important metrics in UDN heterogeneous scenario. The CMRAT reduces the number of handovers caused by the imperative link based handover in A2A4-RSRQ approach. The traditional approach handover is imperative, meaning the system is programmed such that first, the handover is triggered if the current serving RAT signal strength is diminishing or second, if the neighbouring RAT signal is better than the current RAT. In both the cases handover is triggered irrespective of the requirement of the event at that moment of UE and network. This is a serious issue in case of UDN because the RATs are closely deployed and imperative approach will cause unnecessary handovers very frequently. This can be checked by the proposed context-aware MADM approach, where the decision is based on different criteria and priorities with the collaborative assessment of network resource availability and UE demand. As a result of the CMRAT approach, the number of handover is reduced comparatively with the imperative approach.

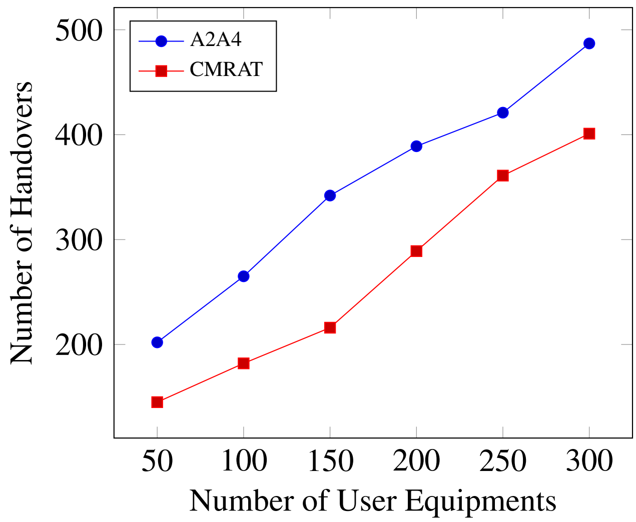

Figure 6.6. The Impact of Varying User Equipments for Handover Event Occurrence

The findings for average network delay of RAT selection is compared between both approaches, and CMRAT reduces the delay in spite of multiple criteria, due to the priority in criteria and context based decision, whereas, the link based approach delay is noticeably high in comparison with CMRAT for 300 UEs. The findings in terms of network delay is the end-to-end delay of network since the beginning of the simulation to the end to find the RAT selection within the execution duration of the proposed approach. The delay is reduced because the decision is context based and according to the availability, the selection is done without waiting for signal quality alone. The mechanisms described in Chapter 4 and 5 described the cases of decision making which involves other parameters than signal, but can facilitate the requirement. Hence, all these lead to minimum delay and better performance is achieved. The findings are described in Figure 6.7.

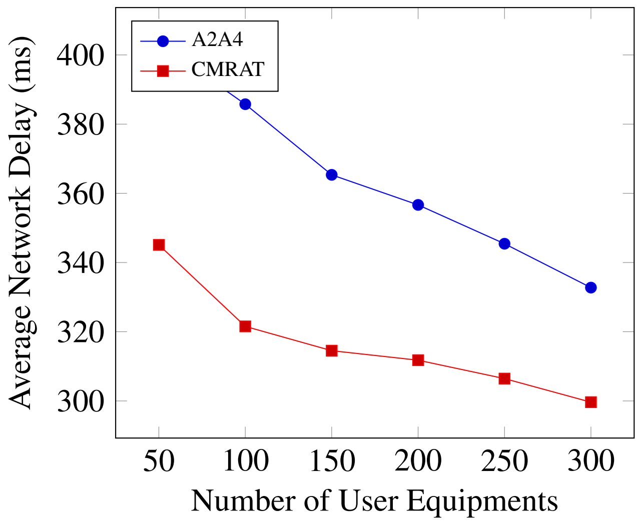

Figure 6.7. The Impact of Varying User Equipments for Average Network Delay

All the above instances showed the performance with varying the devices within the 600 seconds time slice. Now that the devices are fixed to maximum, the described device in shopping mall scenario is 300 equipment devices on the single floor. The time varies from 10 minutes (600 seconds) to 60 minutes (3600seconds), and the performance is observed in terms of all the four metrics for the described case. All the parameters and setup described earlier remain the same. The findings are purely meant for the 300 UE at the time slice of 60 minutes. The approach findings in comparison with the imperative A2A4-RSRQ approach is presented in Figures 6.8 to 6.11.

Figure 6.8 depicts the PDR when the number of devices are increased to 300 and the results are drawn for an hour (3600 seconds or 60 minutes). The findings observed in the varying time intervals the delivery ratio in CMRAT is better compared to the imperative mechanism. This is due to the spontaneous decision variation, according to the criteria requirement and resource availability collaboratively at the context.

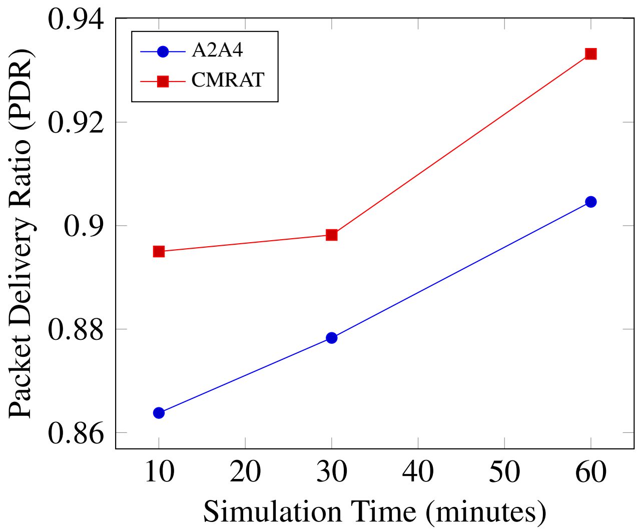

Figure 6.8. The Impact of Varying Time on PDR

Figure 6.9 shows the average rate which the effective data transfer is attained, measured in terms of mega bits per second. The throughput and delay are inter-related, when the network throughput is insufficient, there is a delay also. The findings for the increased UE in the shopping mall scenario shows that the increase in devices will not effect the performance of RAT selection via CMRAT approach. CMRAT still can make the decision with efficient throughput in comparison to the imperative approach. Hence, the context-awareness with multi-criteria is better for UDN heterogeneous environment in RAT selection.

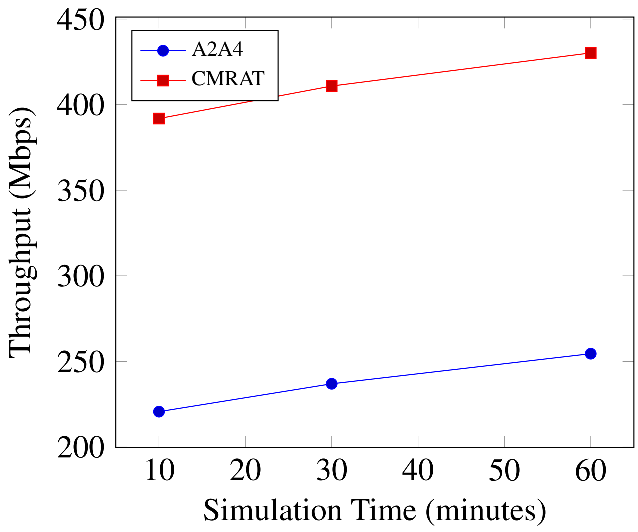

Figure 6.9. The Impact of Varying Time for Throughput

Figure 6.10 illustrates the number of handovers in both the CMRAT and A2A4-RSRQ approaches. The main aim of the CMRAT is to reduce unnecessary handovers in UDN environment. The findings revealed that the CMRAT approach is effective in reducing unnecessary handovers with the increase in the UEs also. The handover is triggered and made only when the current serving RAT is unable to serve the UE requirement. The context-awareness yields better performance than the imperative one, which primarily depends on the received signal quality and power.

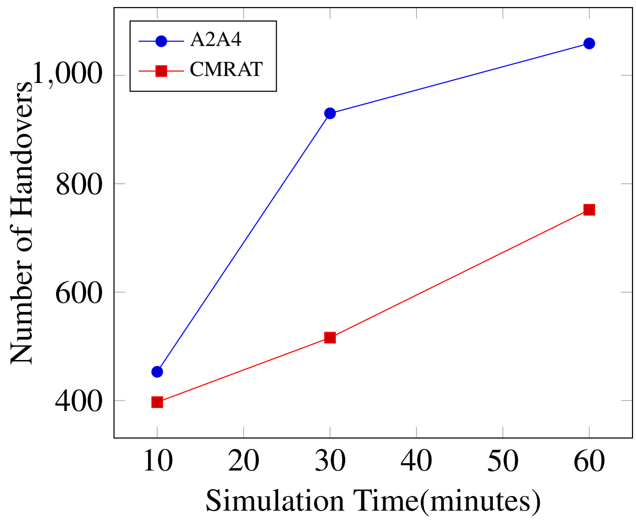

Figure 6.10. The Impact of Varying Time for Handover Event Occurrence

Figure 6.11 outlines the performance of CMRAT for increased UE to 300 and observed for 60 minutes for the performance focusing on the delay metric. The length of the time required to make the RAT selection decision during the the simulation time of a RAT selection is considered for both approaches. The CMRAT performed well, because the handover was triggered only when required and not just with a fall in signal strength or when the UE senses a better signal. The decision was not imperative but the context based. The delay in CMRAT was reduced compared to the A2A4-RSRQ approach.

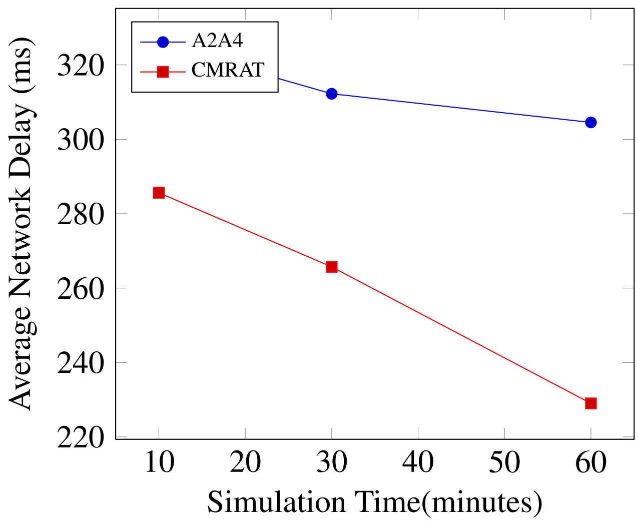

Figure 6.11. The Impact of Varying Time for Average Network Delay

6.3.2 Simulation Using Urban City Scenario

The urban city is another case taken to demonstrate the performance of the CMRAT, where this scenario is UDN with wider area and more number of macro and femto cells present. Also, the UEs are more and scattered more than the shopping mall. The urban city consists of UE movement from building to building, home offices, and across roads in a larger city location. Figure6.12 demonstrates the urban city scenario graphical representation and Table 6.2 describes the simulation parameters for the urban city scenario.

Figure 6.12. Urban City Simulation Scenario

Table 6.2
Simulation Parameters for Urban City Scenario

Environment	The bureaucrat offices like a mini vidhana Soudha System scattered
User Equipments	150-1000 (Number of user Equipments vary with time)
RATs	LTE-A and 802.11n
Number of Wifi Access points	30
Number of (H)eNBs	4 enBs, HenBs- 20
Simulation Time	600-3600s (to capture RAT selection)
UE mobility	0.4m/s, 0.8 m/s, 1.4 m/s (randwalk ranging)
HeNB load	Varying depending on the number of associated UEs (very low, low, medium, high, very high)

6.3.2.1 Performance Evaluation of CMRAT versus A2A4-RSRQ

The performance evaluation of the CMRAT in comparison to the A2A4-RSRQ approach was made. Also, the performance was measured in terms of packet delivery ratio, throughput, number of handovers, and delay. Figure 6.13 to Figure 6.16 present the performance evaluation for urban city scenario for the above mentioned metrics. The detailed network parameters of the simulation are mentioned in Table 6.2.

Unlike to the shopping mall scenario, the urban city scenario illustrates a larger area of UDN with different RATs across a wider range. The shopping mall was confined to a single floor. However the urban city considers a wider area to measure the performance of CMRAT against the traditional A2A4-RSRQ approach. The results are drawn for the varying number of user equipment from 200 to a maximum of 1200 devices at the time interval of 600 seconds.

From the findings it was noticed that even though there was an increase in the number of devices, the CMRAT performed well in terms of both metrics. The packet delivery ratio is comparatively better in context based approach than the link approach. Due, to the priority to the class of traffic, the context approach yields better PDR, consequently the throughput is also improved. The imperative method falls short in both the metrics because it merely considers link quality in the selection process. The results of PDR can been seen in Figure 6.13 and the throughput in Figure 6.14.

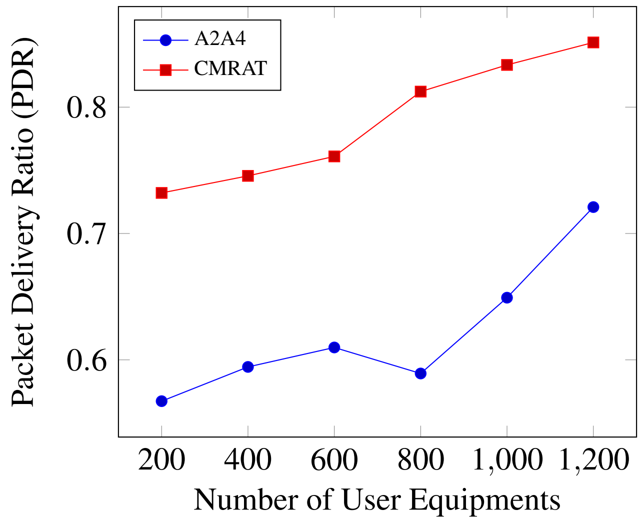

Figure 6.13. The Impact of Varying User Equipments in PDR

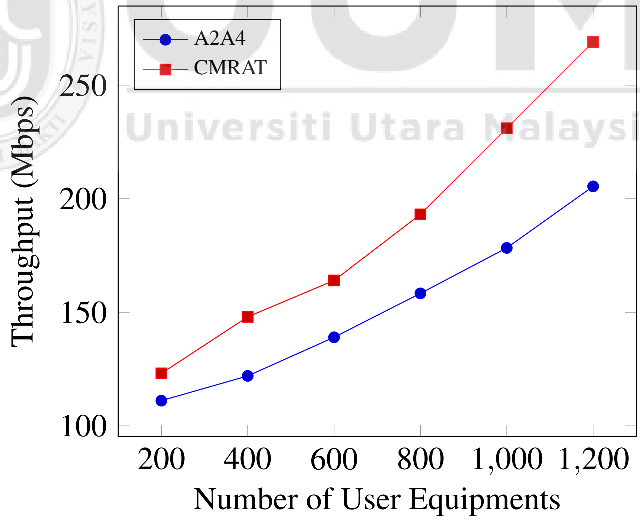

Figure 6.14. The Impact of Varying User Equipments for Throughput

Figure 6.15 reflects the number of handovers in CMRAT and A2A4-RSRQ approaches for UDN in urban city scenario. The number of handovers are less in CMRAT approach than the traditional A2A4-RSRQ event based approach. Hence, the results reiterate the fact that the context based decision is more efficient in RAT selection for the next wireless wave of UDN heterogeneous environment.

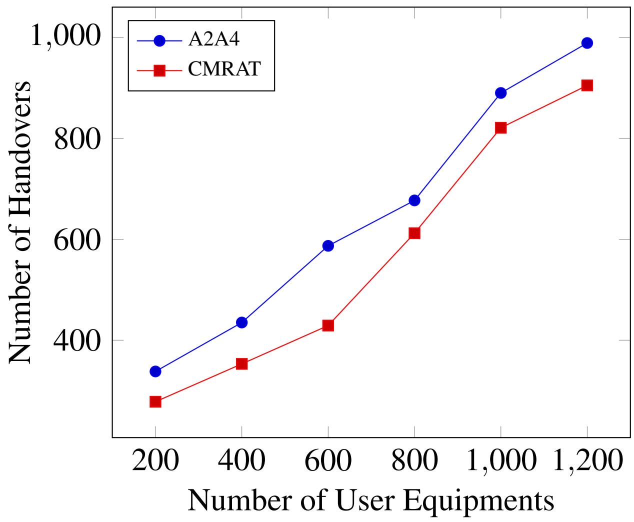

Figure 6.15. The Impact of Varying User Equipments for Handover Event Occurrence

Figure 6.16 shows the average network delay which is calculated for the RAT selection process since the beginning of the simulation to end only. The delay is less compared to the imperative approach because the handovers occur less and it is reduced when the decision is context based. In turn, the throughput also increases.

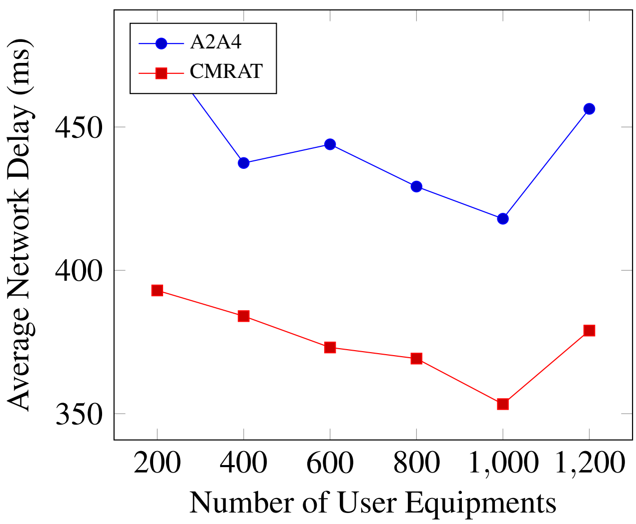

Figure 6.16. The Impact of Varying User Equipments for Average Network Delay

The findings with varying devices and fixed time revealed that the CMRAT is better in all of the four measured metrics. To validate this fact more rigorously, the comparison of the CMRAT and A2A4-RSRQ approaches was made by increasing the number of devices to 1200 and fixing it. The results were drawn at different intervals from 10 minutes to one hour (60 minutes) to observe the performance in this context.

Figure 6.17 shows the result for the new simulation setup with the maximum UE and Maximum time duration of observing the performance. The results stated that the PDR is effective with the increased UE also. The CMRAT out performs the A2A4-RSRQ irrespective of all the constraints and observed contexts.

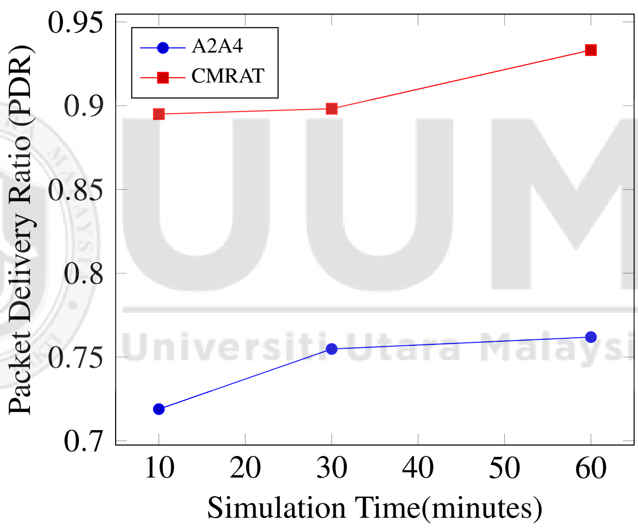

Figure 6.17. The Impact of Varying Time in PDR

The throughput attained for CMRAT in the 60 minute duration of the stated simulation scenario is better, as seen in Figure 6.18. The CMRAT achieved more efficient throughput for the UE than A2A4-RSRQ in the observed execution time.

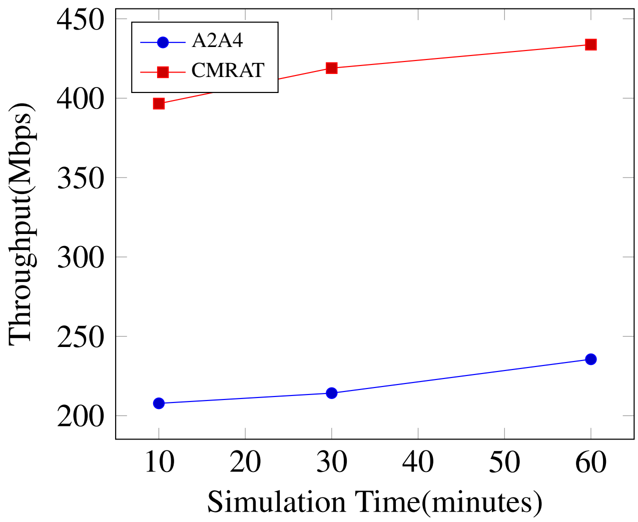

Figure 6.18. The Impact of Varying Time for Throughput

Figures 6.19 and 6.20 show the results for number of handovers and delay respectively. In both the measures, the CMRAT performs more efficiently than the traditional imperative approach. Hence, it can be inferred from all these findings that CMRAT performed well in all scenarios of small cell deployment with the measurements of PDR, throughput, number of handovers, and delay.

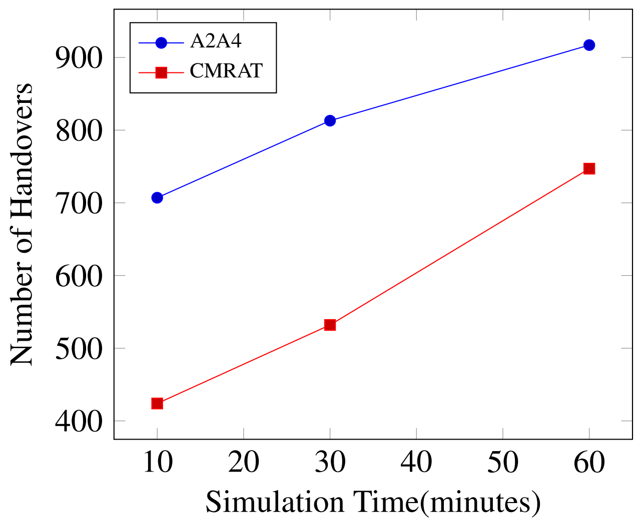

Figure 6.19. The Impact of Varying Time for Handover Event Occurrence

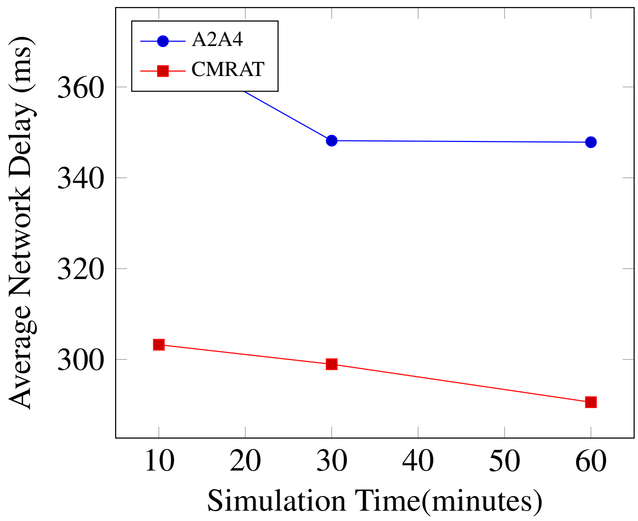

Figure 6.20. The Impact of Varying Time for Average Network Delay

In summarising the findings of both scenarios and the four metrics, the CMRAT performed relatively well in spite of the increase in UEs. In general, the PDR is enhanced by 21.22%, and throughput is better by 42.68%. The number of handovers are reduced by 46.66% and the delay is reduced by 17.19% for the given scenario of shopping mall and urban city configuration by CMRAT as compared to the A2A4-RSRQ approach.

6.4 Summary

This chapter presented an efficient approach for RAT selection in UDN environment. The proposed solution is realistic on how to acquire the necessary contextual information without requiring significant extensions to the network infrastructure. The use of context-aware MADM mechanisms assisted in guiding terminals into unload LTE eNBs, (H)eNBs, or Wi-Fi APs for static or low mobility users, thus improving the efficiency of the overall system.

Performance of the overall system is measured in terms of throughput, packet delivery ratio, number of handover, and delay. The proposed CMRAT performed better compared to the A2A4-RSRQ based approach. The results with varying UE with respect to simulation time in shopping mall and urban city scenarios were also presented.

CHAPTER SEVEN
CONCLUSION AND FUTURE WORKS

This thesis aimed at developing an efficient RAT selection approach for UDN environment, and evaluated its performance extensively via simulation. This chapter provides the conclusion of the research work. It starts with Section 7.1, where the research findings are reviewed and the importance of RAT selection is discussed with possible implementation, and its benefits toward UDN heterogeneous environment. In Section 7.2, the contributions and implications made by this research are highlighted. The limitations of the research are then presented in Section 7.3. Finally, Section 7.4 offers some suggestions for further research studies.

7.1 Review of the Research Findings

The evolution of wireless technology comes with new features to support the exponential growth of 1000X times with new applications in all market segments. Definitely, the evolution resolves many issues relatively inherited from the previous generations, however, new challenges are posed, such as the existence of a heterogeneous environment with extensive deployment of macro and small cell nodes converging to the Ultra Dense Network (UDN). The UDN infrastructure resolves the issue of anytime anywhere service to the UE, but the close deployment of access nodes leads to unnecessary handover that degrades the overall system performance. The challenge is to keep the handover decision in check by selecting RAT based on contextual constraints rather than the traditional imperative constraints.

As mentioned in Chapter 1, the research work presented in this dissertation was motivated by the need for accurate RAT selection in UDN environment of heterogeneous networks to improve the overall performance of the network. The aim of this thesis was to present a Context-aware Multi-criteria based RAT (CMRAT) selection in the UDN environment. The approach should be sensitive to network environment and user preference, and the solution should utilise the available network resources efficiently without extending the infrastructure.

The extensive survey and review made in Chapter 2 aided in establishing the different mechanisms and strategies as part of the decision making process in handing over control from one RAT to another wisely. Knowing the challenges of RAT selection and a strong recommendation from IETF regarding context-awareness, potential mechanisms in this direction were analysed and a new approach to address these issues was formulated based on the literature. This synthesis of literature encouraged and prompted this research effort to introduce CMRAT for UDN environment.

The next level was to form a methodology to accomplish the research plan in a systematic manner. To achieve this objective, the Design Research Methodology (DRM) was adopted. DRM is the framework which fits any sphere of research. The DRM helped the researcher to produce a blueprint in the form of a conceptual model and primary design for implementation covering all the dimensions of research from review to evaluation.

Firstly, context-aware RAT initiation for UDN heterogeneous RAT was introduced in Chapter Four. The initiation mechanism was an integration of MADM theory and context-awareness concept in measuring the need to trigger RAT selection based on the constraints of the context requirement. The analytical model with simulation was also presented and statistical analysis of the theory in triggering the RAT selection with numerous case instances of context was illustrated.

Next, a context-aware RAT decision making mechanism for UDN heterogeneous RAT environment was introduced. The proposed mechanism helped to measure the capability of the available RAT in order to choose a target RAT based on the network rank of each according to the context constraint of requirements. The analytical model with simulation confirmed that the proposed model reduces the number of handovers and is less prone to the ranking abnormality problem.

Finally, the verified and validated mechanisms in RAT selection presented in Chapter 4 and 5 were incorporated into the network simulator. The experimental studies to measure the performance of the approach in different scenarios were carried out. In addition, the traditional approach of RAT selection was chosen to evaluate and accredit the proposed approach. In the end, the simulation results revealed that CMRAT improved the throughput and packet delivery ratio. Also, it reduced the number of handovers and handover delay. The findings have significant implications in providing efficient RAT selection.

In completing the CMRAT performance evaluation, the findings confidently emphasised the fact that the framed objectives of this research, as presented in this thesis, have been well and completely achieved.

7.2 Research Contributions and Implications

The overall contribution of this research was to develop a context-aware RAT selection mechanism for UDN heterogeneous environment. An analytical model was developed for initiation triggering and decision making of the RAT selection to determine the efficient RAT to choose as the target RAT. Furthermore, the analytical model was transformed to measure the performance in a network environment. The specific contributions of this thesis are as follows:

i. A context-aware initiation triggering mechanism in RAT selection of UDN heterogeneous environment based on contextual information of the user and network.

   a. An analytical model for Context-aware Analytical Hierarchy Process (CAHP) mechanism to measure the need for handover initiation based on context repository information was designed.
   b. Furthermore, the CAHP mechanism from mathematical equations was transformed into programmable code using MATLAB and different cases leading to initiation triggering were tested.
   c. The mechanism was verified and validated with the formal method, and the validation was also implicitly done via the mathematical formulation of the mechanism.

ii. A context-aware decision making mechanism to determine the most efficient RAT among the available ones.

   a. An analytical model for Context-aware Technique for Order Preference by Similarity to Ideal Solution (CTOPSIS) mechanism to make network discovery of RAT and determine the best target RAT was designed.
   b. The designed mechanism was transformed from mathematical equations to programmable code in MATLAB to test for different cases.
   c. The model was also tested for sensitivity analysis, as the model is based on operational theory. The sensitivity analysis determined the statistical sensitivity and dynamics of the mechanism in decision making.
   d. Numerous test cases and random runs were performed to check the decision making ability of the mechanism, focusing on ranking abnormality and number of handover issues.
   e. Finally, the mechanism was evaluated and accredited for decision making by comparing the results with parallel approaches.

iii. Performance evaluation of the proposed Context-aware Multi-RAT (CM-RAT) selection approach in UDN heterogeneous environment using Network Simulator-3 (NS-3).

   a. Previously validated analytical mechanisms (CAHP and CTOPSIS) were incorporated forming the complete CMRAT in a network simulator.
   b. CMRAT approach was implemented in two different scenarios, namely shopping mall and urban city, which varies the environment parameters to measure the performance of the approach.
   c. The performance enhancement of CMRAT was compared with the standard A2A4-RSRQ approach to reveal the strengths and weaknesses of the proposed CMRAT in terms of throughput, packet delivery ratio, number of handovers, and average network delay.

7.3 Research Limitations

All though the study was carried out the best way possible to contribute to the research domain, there was a certain scope drawn due to numerous constraints. For this research, the femtocell was considered in decision making, but more types of small cells could have been considered. As of the time during the execution of the simulations, the 802.11ac AP was available only with the physical layer functionality in the NS3. The complete functionality would have aided in implementing it completely as another RAT.

The scenarios considered the limitations for the number of nodes and access points for implementation, which can be scaled to a greater extent. The standard infrastructure and node deployment, and standards for UDN are still evolving to be standardised. Hence, the infrastructure for test cases operator and user deployed nodes were assumed for the simulation purpose.

7.4 Future Research

In this dissertation, the performance of a number of RAT selection approaches had been evaluated in terms of packet delivery ratio, throughput, number of handover, and delay. In the future work, more performance metrics, such as cost and operator's revenue should be evaluated and the performance of more RAT selection approaches should be compared.

The MADM algorithms are usually prone to rank reversal problem, and the mechanism presented in this thesis comparatively reduced this ranking abnormality problem. However, there is still room for improvement for formulating a mechanism which makes the MADM to be rank reversal issue free.

The context repository can evolve with more numbers of criteria pertaining to all stakeholders in the wireless networks for a more realistic form of decision making.

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