

EFFICIENT RADIO RESOURCE MANAGEMENT IN NEXT GENERATION WIRELESS NETWORKS



BY
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Dedication

Dedicated to my lovely wife (Chigozie), son (Orobosa), and daughter (Efe).

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Abstract

The current decade has witnessed a phenomenal growth in mobile wireless communication networks and subscribers. In 2015, mobile wireless devices and connections were reported to have grown to about 7.9 billion, exceeding human population. The explosive growth in mobile wireless communication network subscribers has created a huge demand for wireless network capacity, ubiquitous wireless network coverage, and enhanced Quality of Service (QoS). These demands have led to several challenging problems for wireless communication networks operators and designers.

The Next Generation Wireless Networks (NGWNs) will support high mobility communications, such as communication in high-speed rails. Mobile users in such high mobility environment demand reliable QoS, however, such users are plagued with a poor signal-to-noise ratio, due to the high vehicular penetration loss, increased transmission outage and handover information overhead, leading to poor QoS provisioning for the networks' mobile users. Providing a reliable QoS for high mobility users remains one of the unique challenges for NGWNs.

The increased wireless network capacity and coverage of NGWNs means that mobile communication users at the cell-edge should have enhanced network performance. However, due to path loss (path attenuation), interference, and radio background noise, mobile communication users at the cell-edge can experience relatively poor transmission channel qualities and subsequently forced to transmit at a low bit transmission rate, even when the wireless communication networks can support high bit transmission rate.

Furthermore, the NGWNs are envisioned to be Heterogeneous Wireless Networks (HWNs). The NGWNs are going to be the integration platform of diverse homogeneous wireless communication networks for a convergent wireless communication network. The HWNs support single and multiple calls (group calls), simultaneously. Decision making is an integral core of radio resource management. One crucial decision making in HWNs is network selection. Network selection addresses the problem of how to select the best available access network for a given network user connection. For the integrated platform of HWNs to be truly seamless and efficient, a robust and stable wireless access network selection algorithm is needed.

To meet these challenges for the different mobile wireless communication network users, the NGWNs will have to provide a great leap in wireless network capacity, coverage, QoS, and radio resource utilization. Moving wireless communication networks (mobile hotspots) have been proposed as a solution to providing reliable QoS to high mobility users. In this thesis, an Adaptive Thinning Mobility Aware (ATMA) Call Admission Control (CAC) algorithm for improving the QoS and radio resource utilization of the mobile hotspot networks, which are of critical importance for communicating nodes in moving wireless networks is proposed. The performance of proposed ATMA CAC scheme is investigated and compare it with the traditional CAC scheme. The ATMA scheme exploits the mobility events in the high-speed mobility communication environment and the calls (new and handoff calls) generation pattern to enhance the QoS (new call blocking and handoff call dropping probabilities) of the mobile users. The numbers of new and handoff calls in wireless communication networks are dynamic random processes that can be effectively modeled by the Continuous

Time Markov Chain (CTMC) process. An analytical framework of the proposed scheme is developed using the Markov chain process. The network performance metrics, namely new call blocking probability, handoff call dropping probability, and radio resource utilization are evaluated, under low, medium, and high handoff calls arrival traffic rate conditions. The simulation results demonstrate significant improvements in new call blocking probability, handoff dropping probability, and radio resource utilization, for low, medium, and high new call arrival traffic rate conditions .

Recent research studies have proposed several techniques to improve the network capacity of cell-edge users. The Buffered Cooperative Communication (BCC) scheme is proposed to address this problem. An analytical framework is developed, based on the Markov chain process, to investigate the network performance of BCC and compared with Non-Buffered Cooperative Communication (NBCC) scheme. In the network performance evaluations, three important wireless communication networks' metrics, such as the average network throughput, blocking probability, and radio resource utilization are studied. The investigations show that the BCC scheme performs better than the NBCC scheme. Simulation results show the BCC scheme can significantly improve the QoS in terms of blocking probability, resource utilization, and average throughput for the wireless communication networks with cell-edge users.

Finally, the problem of access network selection for single and group calls in HWNs with dynamic multi-criteria is studied. A new access network selection algorithm, based on Multi-Criteria Decision Making (MCDM) is proposed. The accuracy of the proposed algorithm for single and group calls in HWNs with the dynamic criterion is investigated. A similar

investigation is carried out with some traditional MCDM algorithms that have been used for access network selection in HWNs. The simulation results demonstrate that the proposed scheme is efficient and more stable than the traditional MCDM algorithms that are currently used in access network selection.

Acronyms

AAA	Authentication Authorization and Accounting
ABC	Always Best Connected
ACK/NACK	ACKnowledgement/Negative-ACKnowledgement
AF	Amplify-and-Forward
AHP	Analytic Hierarchy Process
AMC	Adaptive Modulation Coding
AMPS	Advanced Mobile Phone Service
AP	Access Point
ATMA	Adaptive Thinning Mobility Aware
BCC	Buffered Cooperative Communication
BER	Bit Error Rate
BPSK	Binary Phase Shift Keying
BS	Base Station
CA	Carrier Aggregation
CAC	Call Admission Control
CF	Compress-and-Forward
CN	Core Network
CoMP	Cooperative Multipoint
CQI	Channel Quality Indicator
CR	Consistency Ratio
CSI	Channel State Information
CTMC	Continuous Time Markov Chain
DeNBs	Donor-evolved Node Base stations
DF	Decode-and-Forward
EDGE	Enhanced Data Rate for GSM Evolution
ELECTRE	Elimination Et Choix Traduisant la Realite
EPC	Evolved Packet Core
ETSI	European Telecommunication Standard Institute
E-UTRAN	Evolve Universal Terrestrial Radio Access Networks
FDMA	Frequency Division Multiple Access
FM	Frequency Modulation
FSK	Frequency Shift Keying

GA	Genetic Algorithm
GMSK	Gaussian Minimum Shift Keying
GPRS	General Packet Radio Service
GRA	Grey Relational Analysis
GSM	Global System for Mobile communication
H	High
HARQ	Hybrid Automatic Repeat reQuest
HSDPA	High-Speed Data Packet Access
HSRCS	High-Speed Rail Coaches
HWNs	Heterogeneous Wireless Networks
ICI	Inter-Cell-Interference
IMSI	International Mobile Subscriber Identity
IP	Internet Protocol
JRRM	Joint Radio Resource Management
L	Low
LTE	The Long Term Evolution
LTE-A	Long Term Evolution Advanced
M	Medium
MAC	Medium Access Control
MAHO	Mobile-Assisted Handover
MCDM	Multi-Criteria Decision Making
MCGDM	Multi-Criteria Group-Decision
MCHO	Mobile-Controlled Handover
MeNB	Mobile Evolved Node base station
MH	Medium High
MoH	Mobile Hotspot
MIMO	Multiple Input Multiple Output
ML	Medium Low
MME	Mobility Management Entity
MMSE	Minimum-Mean-Square-Error
MN	Mobile Node
MRC	Maximum Ratio Combination
MRN	Mobile Relay Node
MTU	Maximum Transmission Unit
MULTIMOORA	MULTIpliative Multi-Objective Optimization Ratio Analysis
NAHO	Network-Assisted Handover
NBCC	Non-Buffered Cooperative Communication
NCHO	Network-Controlled Handover
NE	Nash Equilibrium
NGWNs	Next Generation Wireless Networks
NMAT	Non-Mobility-Aware Thinning
OFDMA	Orthogonal Frequency Multiple Access
PBCH	Physical Broadcast Channel

PCRF	Policy Control and Charging Rules Function
PDN-GW	Packet Data Network Gateway
PoA	Point of Attachment
PRACH	Physical Random Access Channel
PUCCH	Physical Uplink Control Channel
PUSCH	Physical Uplink Shared Channel
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RATs	Radio Access Technologies
RB	Resource Block
RRM	Radio Resource Management
RSS	Received Signal Strength
SAW	Simple Additive Weighting
SC-OFDMA	Single Carrier Orthogonal Frequency Multiple Access
SER	Symbol Error Rate
S-GW	Serving Gate Way
SIM	Subscriber Identity Module
SINR	Signal-to-Interference-to-Noise Ratio
SNR	Signal-to-Noise Ratio
SOR	Successive Over-Relaxation
TDMA	Time Division Multiple Access
TFN	Triangle Fuzzy Numbers
TOPSIS	Technique for Order Preference by Similarity to Ideal Solutions
UE	User Equipment
UMTS	Universal Mobile Telecommunications System
VHO	Vertical Handover
VIKOR	VlseKriterijumska Optimizacija I Kompromisno
VoIP	Voice over Internet Protocol
VH	Very High
VL	Very Low
VPL	Vehicular Penetration Loss
WCDMA	Wideband Code Division Multiple Access
WiFi	Wireless Fidelity
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Networks
3GPP	Third Generation Partnership Project

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Chapter 1

Introduction

1.1 General Introduction

This present decade has witnessed a monumental growth in mobile wireless networks and subscribers. In 2015, mobile wireless device connections were reported to have grown to about 7.9 billion [1]. The explosive growth can be attributed to some crucial developments. These developments include an increase in the production of cheaper smart-phones/internet-access devices supporting application demanding higher data rate and lower wireless network data cost. In addition, the increasing demand for daily online connectivity with friends and families has also contributed to the explosive growth. This unprecedented growth has created a huge demand for wireless network capacity, ubiquitous wireless network coverage, and enhanced Quality of Service (QoS).

The Next Generation Wireless Networks (NGWNs) will support mobile communication users operating in diverse wireless communication environments, such as in high vehicular

speed environment and cellular network cell-edge zone, with improved network capacity and QoS. To meet these challenges, NGWNs will have to provide a great leap in wireless network capacity, coverage, and QoS. Different enabling technologies for cell network capacity and cell-edge user equipment (UE) terminals throughput enhancement have been proposed. These techniques include Multiple-Input Multiple-Output (MIMO) antenna, Cooperative Multi-Point (CoMP) Transmission and Reception, Carrier Aggregation (CA), and Cooperative Communication through cooperative relaying [2-8].

The NGWNs are going to be convergent wireless networks, where the diverse homogeneous wireless networks are seamlessly integrated together [9, 10]. Exploiting the features mentioned above to providing the increased network capacity and improved QoS are some major challenges for wireless communication network designers and operators. The NGWNs will utilize heterogeneous wireless networks, where different Radio Access Technologies (RATs) will co-exist. Some of these RATs will include the Wireless Local Area Networks (WLAN), Universal Mobile Telecommunications System (UMTS), and Long Term Evolution Advanced (LTE-A) networks.

Apart from the potential increase in networks capacity offered by NGWNs, there is the need to avoid network congestion through efficient network congestion control mechanisms. Networks congestion control mechanism employs Call Admission Control (CAC) and load balancing control. These are vital cores of wireless Radio Resource Management (RRM) schemes [11]. The CAC influences the QoS provisioning in a wireless network in terms of new call blocking probability, handoff call dropping probability, transmission rate, and packet

delay [12]. CAC can guarantee the signal quality in interference-limited wireless networks while increasing the radio channel utilization [13].

High vehicular speed UE terminals can suffer from low Signal-to-Noise Ratio (SNR) and QoS degradation in the fixed macro-cellular wireless networks. Mobile Hotspots (MoH) wireless (i.e, moving wireless) network has been proposed as the enabling technology platform to resolving such higher network capacity and improved QoS demand from high-speed vehicular communication users [14, 15]. Mobile hotspots, which is of enormous interest to the Third Generation Partnership Project (3GPP) for the future 5G networks have attracted a lot of academic and industrial research interests [15]. The deployment of mobile hotspots in the high-speed vehicular environment can resolve the UE's communication signal-to-noise ratio and QoS problems. Mobile Hotspots networks can deliver up to 1Gigabit per second (Gbps) data rate to mobile UEs at millimeter waveband [16]. In addition, mobile hotspots will offer mobile users improved access to wireless communication operators' networks. It will enhance QoS for the mobile communication users and reduce handovers and control signaling overheads in the wireless networks [17].

The unique characteristics of moving wireless networks carry some challenges that traditional CAC frameworks are not designed to handle. The demands require an adaptive call admission control framework. The adaptive CAC framework should consider the period when the moving networks transit between the mobile phase and stationary phase events. It should improve the utilization of the radio resource blocks assigned to the moving networks and the QoS within the moving networks.

Recently, network designers and operators have been considering the adoption of cooperative communication as a standard feature to improving the poor network performance of communicating nodes at cell-edge zone [18–20]. Wireless communication networks suffer from reduced data rates at the cell-edge zones. The reduced data rate can be attributed naturally, to the lower signal and higher signal interference levels that are prevalent within the cell-edge zone [21].

The use of Orthogonal Frequency Division Multiplexing (OFDM), MIMO, and advanced error correction techniques enhance wireless networks throughput. However, they do not adequately mitigate against poor network performance at cell-edge zones [22]. The cooperative communication technique is a fundamentally simple idea, which is being investigated currently as an exciting solution for improved network throughput and cell-edge coverage performances [22].

In cooperative communication, a node with better direct channel quality links to the macro base-station can be made to serve as a cooperative relay node for any neighboring node with poor direct channel quality links to the macro base-station [23, 24]. The ability of nodes with good channels to serve as relay nodes and help other nodes with poor channels to improve their data rate transmission is the defining feature of cooperative communication.

Cooperative communication can be used to extend cellular network coverage and enhance cell-edge UEs' throughput [18, 20]. In addition, it can help to reduce the transmission power of cell-edge UE. The reduced transmission power is due to the relatively shorter communication distance between the cell-edge UE and the serving cooperative relay node

compared to the longer communication distance of the direct transmission between the cell-edge UE and base station. Cooperative communication, consequently, prolongs the battery lifetime of the communication device. This technique can also offer an immense benefit for devices with stringent power capacity, such as in remote sensor network devices.

The Heterogeneous Wireless Networks (HWNs) are considered as an indisputable core for the convergent of existing communication technologies for NGWNs. The HWNs will be Ultra-Dense Networks (UDN) comprising of various cell types (e.g., macro-cell, micro-cell, pico-cell, etc.) and different RATs (e.g., Global System for Mobile communication (GSM), LTE-A, IEEE 802.11, etc.) for NGWNs. Three types of handoffs will exist in NGWNs: intra-cell, inter-cell, and Multi-RATs handoffs [25].

Decision making represents the fundamental core of RRM in HWNs [26]. The two main decision making in HWNs are access network selection and bandwidth allocation decision making. Access network selection decision making tackles the problem of how to select the best available access network for a given network user connection, while bandwidth allocation decision making resolves the issue of how to allocate bandwidth from different networks in the HWN to a given network user [26]. Bandwidth allocation decision can also be referred to as joint radio resource management decisions. This is the allocation of bandwidth provided simultaneously by different networks to users [26].

One of the main problems for the present and next generation HWNs is access network selection and part of this research work is focused on access network selection problem. The access network selection provides a flawless and proficient handoff scheme, which enhances the roaming experience of UEs from one wireless system to another [27]. The HWNs will

offer higher network capacity, network coverage, and diverse wireless network resources for the network users and more revenue for the network operators. They will also support single and multiple calls (group call) applications. For the benefits of HWNs to be fully exploited, efficient and stable RATs selection schemes are needed. These schemes provide optimal RAT selection for UEs. Also, efficient and stable RATs selection schemes enhance seamless connections for the users and better capacity utilization for the network operators. Handoff management is an important kernel of RRM in HWNs [11]. Hence, HWNs have received immense interest from Third Generation Partnership Project's standardization work [28, 29].

With the adoption of the higher capacity and QoS enhancing technologies mentioned in this chapter, future wireless communication networks show an immense potential. The future wireless network should satisfy the increasing network capacity demand and improve UEs' QoS in different challenging wireless network environments. These wireless network environments include high vehicular speed network user environment and cellular network cell-edge zones.

The main focus of this thesis is to investigate the impact some of these higher network capacity enabling techniques have on the QoS performance metrics (new call blocking probability and handoff call dropping probability), radio resource utilization of the wireless network and average network throughput performance, and in addition to providing an efficient and more stable scheme for RATs selection for the proposed HWNs in the NGWNS.

In the remainder of this chapter, the motivations for this research, research questions, the research objectives, contributions, research scope and the outline of the thesis organization are presented.

1.2 Motivations

Network capacity and QoS enhancing technologies will provide the potential for meeting the ever-growing mobile wireless communication subscribers demands in vehicular high-speed environment and wireless communication cell-edge zones. The following factors are the motivations for the study carried out and reported in this thesis:

- MoH networks deployment has attracted the attention of wireless network providers. The MoH networks provide solution that enhances the UEs' QoS in high mobile environments like high-speed coaches and buses. Therefore, the radio resource management through CAC of mobile hotspot networks need to be investigated further. The investigation should provide ways to reduce the call blocking probability, handoff call dropping probability, and improve the radio resource channel utilization of the moving wireless networks.
- Cooperative communication through the use of cooperating relay nodes is a major framework that has been supported by the LTE-A and the proposed 5G standard for 2020 and beyond. Cooperative communication aims to improve UEs' data rates in the cellular wireless communication networks. Nevertheless, performance gains of such networks in terms of the average throughput, call blocking probability need to be studied. In addition, the influence of cooperative communication on radio resource utilization still requires further investigation.
- The mobile user will be inundated with the diverse radio resources and wireless network services of the individual homogeneous wireless networks as NGWNs converge to

HWNs. The NGWNs will support single and group call services. The mobile users demand to be always connected to the best service network at all times while enjoying services offered by the wireless network service operators. Therefore, wireless network service operators require an efficient and stable RATs selection scheme for the efficient allocation and utilization of the available wireless access networks resources.

1.3 Research Questions

In this thesis, the following research questions are examined:

- What are the unique features of moving wireless hotspot networks that can be exploited by call admission control algorithm to enhance QoS (call blocking probability and handoff call dropping probability) for the users?
- How can call admission control algorithm be designed to enhance the quality of service for communication users and radio resource utilization in MoH networks environment?
- What are the performance gains offered by buffered cooperative communication to wireless networks with cell-edge users in next generation wireless networks?
- What network performance metric investigated is influenced/enhanced the most or least by the proposed buffered cooperative communication?
- How can a more efficient and stable access network selection decision making be performed for single and group calls in the next generation wireless network with dynamic multi-criteria?

1.4 Research Objectives

Next generation wireless networks need efficient radio resource utilization and QoS provisioning. These require design and implementation of efficient radio resource management schemes. Efficient radio resource management for next generation wireless network can be achieved through the design of efficient and robust call admission control algorithms and access network selection schemes.

The primary objectives of this research are to develop effective call admission control schemes for mobile hotspots, provide an analytical framework for the buffered cooperative communication wireless networks and propose a new network selection algorithm based on Multi-Criteria Decision Making (MCDM) for heterogeneous wireless networks with dynamic criteria. The specific objectives of the thesis are to:

- Review current existing related work on mobile hotspots networks, wireless communication relay networks, and wireless access networks selection.
- Design an adaptive call admission control scheme to enhance QoS provisioning and radio resource utilization for mobile hotspots networks, and evaluate its performance.
- Develop a buffered cooperative communication framework, which increases wireless network capacity, QoS and radio resource utilization for next generation wireless networks, and evaluate its performance.
- Develop a new access network selection mechanism based on MCDM algorithm and evaluate its performance. The presented access network algorithm aims to provide

accurate and stable access network selection decisions for single and multiple (group) calls in HWNs with dynamic criteria.

1.5 Research Contributions

The research work documented in this thesis has produced new contributions in the area of wireless radio resource management. Some of these contributions are already documented in the author's peer-reviewed publications as outlined at the end of this section, under the Peer-Reviewed International Journal and Conference Publications. The key contributions of this research are summarized as follows:

1. The first contribution is the presentation of a comprehensive and critical review of some prevailing techniques for wireless radio resource management. The review provides a background information for research in wireless MoH networks, cooperative communication networks, and handover management process in heterogeneous wireless networks and MCDM techniques for access network selection. The end result of the critical review is the discussion on the open research challenges that need to be addressed to enhance the radio resource management in next generation wireless networks.
2. A wireless radio resource management scheme based on adaptive thinning and mobility aware (ATMA) call admission control scheme for MoH networks is developed in Chapter 3. This scheme adaptively exploits the calls (new call and handoff call) generation pattern and the mobile phase and stationary phase events of the MoH

networks to mitigate against the low QoS provisioning for mobile users in MoH networks. The numbers of new calls, handoff calls, the mobile phase and stationary phase events in MoH networks are dynamic random processes that can be effectively modeled by the Continuous Time Markov Chain (CTMC) process. Based on Markov chain process, an analytical framework is developed for the performance evaluation of the ATMA scheme in comparison with non-adaptive thinning non-mobility aware call admission control scheme. The analytical model is used to evaluate the impact of new call arrival traffic rate for low, medium, and high handoff call arrival rate on the QoS (new call block and handoff call dropping probabilities) and radio resource utilization of the MoH networks. Simulations are conducted using MATLAB software to evaluate the performance of the ATMA scheme using the networks performance metrics: new call blocking probability, handoff call dropping probability, and radio resource utilization.

3. A wireless radio resource capacity enhancing scheme based on buffered cooperative communication (BCC) for wireless networks with cell-edge user equipment (UE) terminals is developed in Chapter 4. The BCC scheme improves the average throughput, data blocking probability, and radio resource utilization by opportunistically engaging cell-center UEs, with good transmission channel qualities, in cooperative communication and buffering the UEs data request within the networks. An analytical model is developed for the performance evaluation of the BCC scheme in comparison with Non-buffered cooperative communication scheme (NBCC). The

analytical model is used to evaluate the effect of the UEs' packet arrival rate, cell-center zone index, and cell-center UE cooperative communication index on the average networks' throughput, QoS (data blocking probability), and radio resource utilization of the networks. Simulation results show that the proposed BCC scheme reduces data blocking probability while improving the average throughput and radio resource utilization.

4. A wireless radio resource management technique based on a new multi-criteria decision making MULTIpliative Multi-Objective Optimization Ratio Analysis (MULTIMOORA), for access network selection in heterogeneous wireless networks is developed in Chapter 5. A comparative study of the new proposed multi-criteria decision making scheme with some traditionally used MCDM algorithms (Simple Additive Weighting (SAW), Grey Relational Analysis (GRA), Technique for Order Preference by Similarity to Ideal Solutions (TOPSIS), and VlseKriterijumska Optimizacija I Kompromisno (VIKOR)) in HWNs for access network selection decision making is conducted. In the simulations, influence of the weight of importance/priority of network service applications (voice call, file-download, and video-streaming) for single and group calls is considered. Furthermore, the simulation study of the impact of dynamic criteria on the decision making of access network selection algorithm is carried out. Simulation results show that MULTIMOORA provides an efficient/accurate and stable access network selection/ranking decisions for both single and group calls in HWNs, under various heterogeneity conditions.

The author's research papers publications from this research work are listed below:

Peer-Reviewed International Journal Publications

1. E. Obayiuwana and O.E. Falowo, "Network Selection in Heterogeneous Wireless Networks using Multi-Criteria Decision-Making Algorithms: a Review" Springer Journal of Wireless Networks (WINE), pages: 1-33, Vol. 22, Issue 6. 07, June 2016.
2. E. Obayiuwana and O.E. Falowo, "The Impact of Selection-Criteria Dynamics on Network Selection for Group Calls in Heterogeneous Wireless Networks" *Submitted to the Springer Journal of Network and Systems Management, 2016.*

Peer-Reviewed International Conference Publications

3. E. Obayiuwana and O.E. Falowo, "Adaptive Mobility Aware Call Admission Control For Mobile Hotspot Networks", Proceedings of 27th Annual IEEE International Symposium on Personal Indoor and Mobile Radio Communication, pages: 2419-2424, 4-7, September 2016, Valencia, Spain.
4. E. Obayiuwana and O.E. Falowo, "The Impact of Dynamic Criteria on Access Network Selection for Group Calls", Proceedings of the Southern Africa Telecommunication Networks and Applications Conference (SATNAC), pages 1-6, 4-7 September 2016, Fancourt George, Western Cape, South Africa.
5. E. Obayiuwana and O.E. Falowo, "A new network selection algorithm for group calls over heterogeneous wireless networks with dynamic multi-criteria", Proceedings of 13th IEEE Annual Consumer Communications & Networking Conference (CCNC) pages:491-494, 9-12 January 2016, Planet Hollywood Resort and Casino, Las Vegas, U.S.A.

6. E. Obayiuwana and O.E. Falowo, “A multimode approach to the access network selection process in heterogeneous wireless networks”, Proceedings of 12th IEEE AFRICON, pages:1-5, 1417 September 2015, UNECA Conference Center, Addis Ababa.

1.6 Scope of Research

In this research, the focus is on improving the radio resource management and enhancing radio resource utilization and QoS provisioning in next generation wireless networks. The scope of this work covers mobile hotspots, cooperative communication, and access network selection for next generation wireless networks.

1.7 Thesis Outline

The remainder of this thesis is organized into six chapters, and they are outlined as follows. A comprehensive overview of the background topics related to this thesis is provided in Chapter 2. Chapter 3 investigates the QoS provisioning for moving hotspot networks. The discussion in Chapter 3 exploits the knowledge of new and handoff calls generation pattern and the mobility events of the mobile hotspot networks. The chapter presents an adaptive call admission control scheme to enhance the QoS and radio resource utilization of the MoH networks. An analytical framework for adaptive call admission control scheme using Markov chains process is developed. The balanced (steady-state) equations are derived from the

Markov chains analysis and solved using the Successive Over-Relaxation (SOR) iterative algorithm technique.

Chapter 4 investigates the performance of buffered cooperative communication for a cell-center and edge zones UEs. An analytical framework to model the wireless network system based on Markov chain analysis is developed. The steady-state equations for the network are derived. The Successive Over-Relaxation (SOR) technique, a class of an iterative numerical algorithm, is applied to obtain the solutions of the derived steady-state equations. The performance benefit of the buffered cooperative communication is studied via stimulation results. The networks performance metrics are average throughput, packet blocking probability, and networks radio resource utilization. The effect of varying queue buffer size on the performance gains is investigated. A study of the impact of packet arrival traffic rate, the UEs' willingness to serve as cooperative relay and variation of cell-edge zones on the performance metrics of the networks model is carried.

In Chapter 5, the performance on a new MCDM technique: MULTIMOORA for handoff decision making in HWNs is evaluated. The network ranking performance of MULTIMOORA for voice, file-download, and video-streaming calls are investigated against some well-known MCDM algorithms in HWNs. These MCDM algorithms are SAW, GRA, TOPSIS, and VIKOR in HWNs. The efficiency and stability of TOPSIS and MULTIMOORA algorithms are investigated for handoff decision making for group calls in HWNs with dynamic criteria.

Finally, Chapter 6 summarizes and concludes the work in this thesis and outlines areas for future study.

Chapter 2

Background

This chapter presents the background materials that are related to the work in this thesis. It is organized as follows. An overview of the evolution of wireless cellular networks is presented in Section 2.1. The LTE/LTE-A architecture, and radio resource management for moving wireless networks and cooperative communication are presented in Sections 2.2 and 2.3, respectively. Handover management in HWNs is discussed in Section 2.4. Finally, Multi-Criteria Decision Making (MCDM) methods in HWNs are presented in Section 2.5.

2.1 The Evolution of Wireless Cellular Networks

As modern information technology development skyrockets, the demands and consumption of wireless communication radio resources have risen astronomically. Since the first commercial cellular phone concept by Advanced Mobile Phone Service (AMPS) Inc. in the United States of America, in October 1983, the wireless radio resource landscape has never been the same. The introduction of AMPS heralded the beginning of the First Generation (1G) wireless

networks. In 1G wireless networks, two separate analog frequency channels are employed: uplink frequency channel and downlink frequency channel. The base station uses the uplink frequency channel for communicating with mobile stations. The downlink frequency channel is used for mobile stations to base station communications. The uplink and downlink channel communications are also referred to forward communication and reverse communication, respectively.

The wireless communication networks use the cellular concept to provide service coverage to a given geographical area. The cellular concept divides the communication service coverage area into cells while employing a subset of the radio frequency channel in the cells. The cellular concept allows for the reuse of the same subset of frequency channels in some other cell areas that are of reasonable geographical distances apart from other given cell area, without causing co-channel interference that is above the acceptable limit to one another [30].

As the mobile station moves across the adjacent cells, a technique known as handoff is used to transfer the mobile station from its current communication cell to its next/target communication cell seamlessly, with no communication outage. Figure 2.1 highlights the growth of cellular wireless communication in terms of the peak throughput and estimated mobile subscribers from its 1G to the projected Fifth Generation (5G) roll-out for 2020 [31].

The first generation cellular network was designed for only voice communication. Frequency Modulation (FM) and Frequency Shift Keying (FSK) modulation are used for the modulation of transmitted messages. The baseband voice signal is modulated using FM

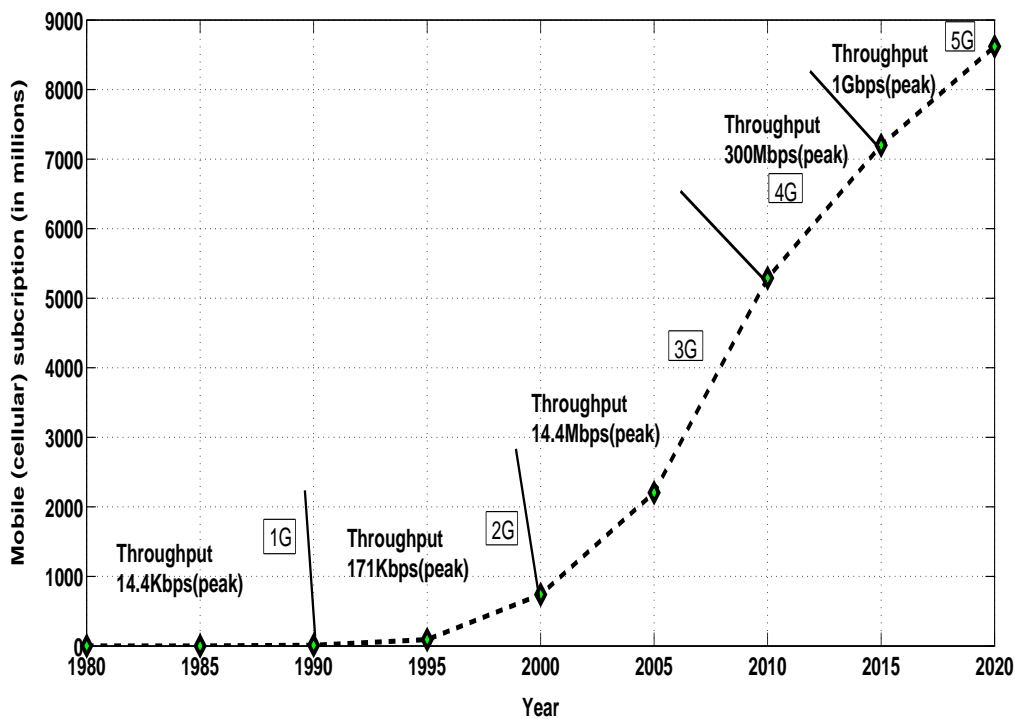


Figure 2.1: The evolution of wireless cellular communication networks.

technique, and the control channel signal is modulated using FSK method. A radio channel bandwidth of 30 kilo-Hertz (kHz) is assigned to the analog signal [33].

In the 1980s, the European Telecommunication Standard Institute (ETSI) promoted the development of the Second Generation (2G) cellular wireless communication widely known as Global System for Mobile Communications (GSM). While the first generation was based on analog voice communication, the 2G was mainly built for the digitized voice signal, using digital technology [34]. The digital channel employs the Gaussian Minimum Shift Keying (GMSK) to modulate the carriers. Frequency Division Multiple Access (FDMA) and Time Division Multiple Access (TDMA) are employed on circuit switching for voice and data transmissions [35].

GSM created a great boom in the growth of mobile wireless subscription around the globe. The network subscribers were identified and accepted into the cellular network with the help of their unique user interface tag: Subscriber Identity Module (SIM) card. The SIM card contains an International Mobile Subscriber Identity (IMSI), authentication key and location area identity. The SIM card was often a storage for Short Message Service (SMS): an advanced form of the pager system. The GSM technology allows mobile subscribers to be able to go with their mobile devices across regions of different GSM service providers and maintain communication. This GSM capability was revolutionary, and it is referred to as roaming technology. The ability to roaming was very attractive to mobile phone subscribers and indeed made GSM a global success.

After a short while, the GSM network service operators began to notice the sharp rise in the demand and usage for SMS data facilities within their networks. This led to the developmental upgrade of the 2G networks with such technologies like the General Packet Radio Service (GPRS)[36] and Enhanced Data rate for GSM Evolution (EDGE) . This technological upgrade of 2G, which is often referred to 2.5G, provided higher data rate transfer of up to 380kilo-bits per second (kbps) on cellular GSM network, for Web browsing and file transfer applications[36].

The rapid growth of the Internet created the further impetus for higher data rate and Internet Protocol (IP) based network services. The 3rd Generation Partnership Project (3GPP) produced a standardized architecture for the Third Generation (3G) wireless cellular network known as the UMTS. The 3G is based on packet switching. The wireless network architecture provided support for the increased speed of data traffic with improved QoS.

The 3GPP proposed new air interface for UMTS called Wideband Code Division Multiple Access (WCDMA). The UMTS mobile user is called user equipment (UE). The WCDMA allows UEs to share the same radio spectrum while using different orthogonal codes. The standardized 3GPP architecture had the capacity to integrate existing generations of wireless cellular networks. This capability means that UMTS can exist heterogeneously with the legacy GSM networks. This allows the heterogeneous networks to share a common (packet and circuit switching) Core Network (CN), user information account and database while maintaining separate network access base stations that could also be co-located together.

The 3G network was more data-centric than the voice-centric network. The upgrade of 3G to 3.5G with the High-Speed Data Packet Access (HSDPA) further enhanced the wireless network performance. The LTE network was designed and marketed as the Fourth Generation (4G) wireless networks under the 3GPP Release 8 [37]. The need to meet the subscribers' demand for higher data rate, improved QoS and with the design of a low complexity packet-optimized network were some of the major motivations behind the introduction of 4G networks.

The 4G allows for the use of some new technological innovations, such as Multi-Input Multiple-Output (MIMO) antenna, CoMP transmission, CA and Cooperative Relay Transmission [38]. These possible 4G advances opened up a whole new multi-service platform for broadband wireless access and improved user mobility support experiences. It integrates different wireless communication technologies, such as GSM, GPRS, EDGE, HSDPA, Wireless Fidelity (Wi-Fi), etc. The LTE uses the Orthogonal Frequency Division Multiple Access (OFDMA) and the Single Carrier OFDMA (SC-OFDMA) for its DownLink

(DL) channel and UpLink (UL) channel, respectively. The 3GPP Release 10 introduced an upgrade to the LTE networks, which is termed the Long Term Evolution Advanced (LTE-A) Networks. Further releases before or on the projected year 2020 are expected to herald the dawn of the 5G cellular networks with the much-anticipated data throughput rate of over 1Gbps.

2.2 LTE/LTE-A Architecture and Radio Resource Management for Moving Wireless Networks

Moving wireless networks or Mobile Hotspot networks will increasingly get deployed in speed vehicular environment in the NGWNS, as more high-mobility users request diverse network broadband services, such as video-streaming, online-gaming, web-streaming on the go within the network. The MoH network is a small scale wireless cellular network with a low-powered Mobile Evolved Node Base-station (MeNB). The MeNB can also be regarded as an enhanced Layer 3 relay with a unique physical cell identification [39].

A group of high mobility mobile users can encounter higher frequency of handovers and higher Vehicular Penetration Loss (VPL), without the MoH networks. This situation can lead to increased connection failure, handover, control signaling overheads, and call blocking and dropping probabilities [40–43]. Some of the features of MoH network that make it very attractive to both industry and academic researchers include:

- Improved vehicular-indoor coverage: The transmissions and receptions of the mobile group nodes in an indoor vehicular environment usually suffer from high VPL [43]. This

makes the signal from the macrocell Base-Station (BS) to become weak and difficult to detect in these environments. However, with MoH networks the VPL is substantially reduced and the network coverage enhanced, due to the application of indoor and outdoor mounted antennas of the MeNB of MoH networks [42–44]. The link between the MoH’s outdoor antenna and macro-cell base station serves as the wireless backhaul link (U_n), while the link between MoH’s indoor antenna and mobile group nodes serves as the access link (U_u).

- Reduced handover and control signaling overheads: MoH networks can perform an aggregate handover of the mobile group of communicating nodes between macrocells. This group handover aggregation function of MoH helps to reduce the handover and controlling signaling and better radio resource utilization within the entire network, unlike if the base station were to execute individual handover progress for each of the mobile nodes [45].
- Reduced transmission power: The deployment of MoH networks, allows mobile group nodes to enjoy better channel gains, less shadowing and better Line-of-Sight (LoS) due to the closer proximity or shorter distance range of the access point to the mobile group nodes. Hence, the vehicular UE nodes can transmit their messages with less transmission power compared with the baseline case of when the vehicular group UE devices are served directly by macro-cell’s eNB [14].

- Improved QoS satisfaction: Mobile hotspot networks serve a relatively smaller number of users compared to macrocells. More resource can be assigned to the relatively smaller number of users, thereby leading to improved QoS for the mobile group nodes.

An example of LTE-A network architecture that supports MoH's MeNB is shown in Figure 2.2. The LTE-A system can be subdivided into two major parts: the Evolved Packet Core (EPC) and the Evolve Universal Terrestrial Radio Access Networks (E-UTRAN). These together are referred to as the LTE-A System Architecture Evolution (SAE). The EPC and E-UTRAN are also referred to as the core networks and radio access networks, respectively.

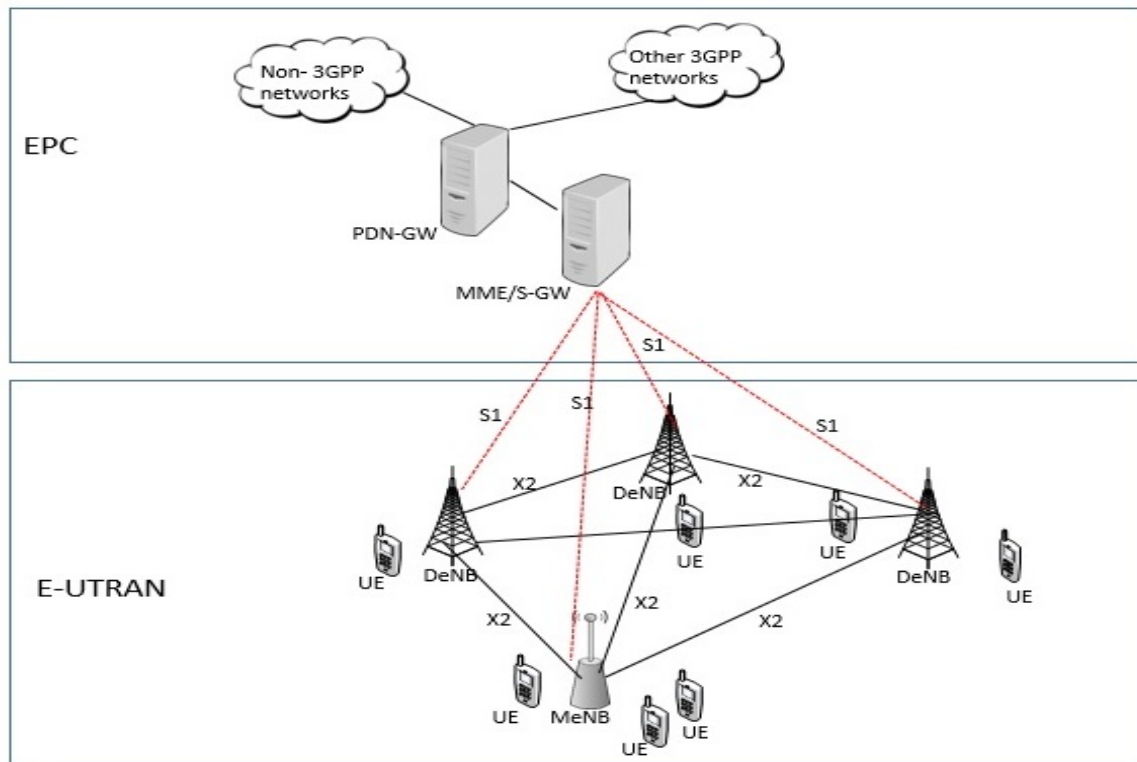


Figure 2.2: LTE-A system architecture evolution with MeNB [46].

The EPC consists of the Serving Gateway (S-GW), Mobility Management Entity (MME) and Packet Data Network Gateway (PDN-GW) [47]. It helps the UEs in the Macro and

MoH networks to connect to other non-3GPP networks (WLAN, Worldwide Interoperability for Microwave Access (WiMAX), the Internet, etc.) and other 3GPP networks (2G, 2.5G, UMTS, etc.) through the PDN-GW. In Figure 2.2, the E-UTRAN consists of the Donor-eNBs (DeNBs), MeNB and UE terminals. The UEs access the DeNBs or MeNB using the wireless backhaul interface link. The MeNB of the MoH is attached to the DeNB of the macro-cell. The DeNBs can see the MeNB as a cell extension.

The MME/S-GW of MoH network can be embedded in the DeNBs of the macro-cells as in alternative 2 (proxy S1/X2) architecture or decoupled from the DeNBs and placed separately in the CN as in alternative 1 (mobile relay full layer 3) architecture [46]. The DeNBs and MeNBs in the E-UTRAN communicate among themselves using the X2 interface, while the DeNBs and MeNBs communicate with MME/S-GW in the core network using the S1 interface. The S-GW serves as the termination interface between the EPC network and E-UTRAN and manages the user-plane mobility.

The S-GW provides the local mobility anchor functionality, as UEs move between DeNBs or DeNB and MeNB within the E-UTRAN. It also maintains the data paths between DeNBs/MeNBs and the PDN-GW. The MME is the critical control node of the LTE-A architecture. The MME is involved in UE's radio bear activation and deactivation, control plane signaling, paging, tracking, roaming, and handovers. It supports the Authentication, Authorization, and Accounting (AAA) procedures of UEs in the networks [47]. The PDN-GW is the termination point for the packet data interface for UEs. It provides connectivity anchor for UEs with other 3GPP and non-3GPP networks, like the internet. The PDN-GW ensures network operator policy and charging compliance, packet filtration, deep packet

inspection (lawful inspection) of UEs' data traffic and QoS enhancement according to the Policy Control and charging Rules Function (PCRF). PDN-GW also performs UE's IP address allocation

The DeNBs and MeNBs in the E-UTRAN perform the RRM and control signaling functions and they help manage the DL and UL transmissions of UEs. The core enabling air-interface technology of LTE-A systems is OFDMA [48]. The adoption of the OFDMA air interface helps to mitigate against intra-cell interference and radio frequency selective fading. The spectral efficiency is increased, due to the orthogonality that exists between OFDMA sub-carriers. The OFDMA based macro-cell networks with deployed mobile MoH allow the radio channel bandwidth to be divided into radio resources known as physical Resource Blocks (RBs). The radio resources are scheduled both in time and frequency domains. As shown in Figure 2.3, the LTE-A transmission is divided into frames, with a frame having a duration length of 10ms. The frame is further divided into ten subframes of the equal time length of 1ms. Each subframe consists of two slots of the same time duration of 0.5ms per slot [49]. Hence, there are twenty slots per radio frame. Each slot consists of 7 OFDMA symbols. Each sub-frame interval is referred to as Transmission Time Interval (TTI) in the time domain. The total available bandwidth is divided into 12 successive equally spaced sub-carriers of 180 kHz per sub-carrier, in the frequency domain [50].

The RB is the smallest radio resource unit that can be allocated to UEs. One RB is defined as $12 \text{ sub-carriers} \times 0.5\text{ms}$, while one resource element is defined as one sub-carrier \times one symbol. Different scheduling algorithms, such as round robin, proportional fairness, logarithmic rule are employed.

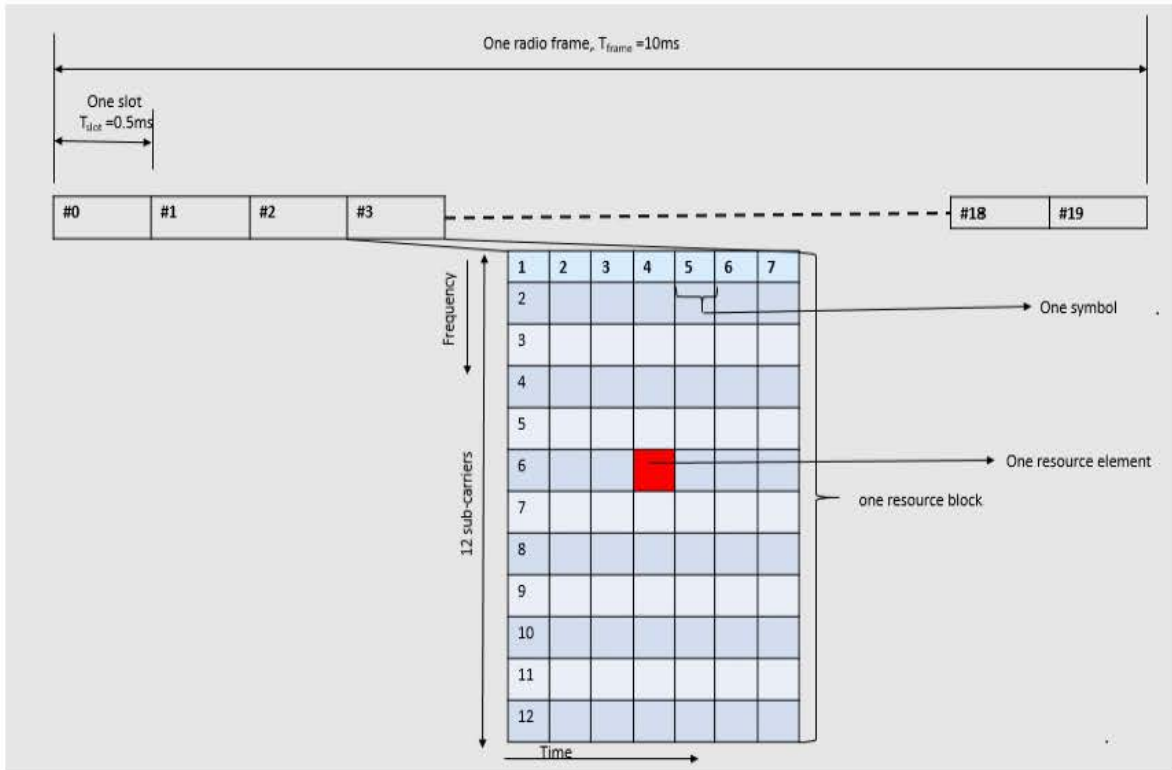


Figure 2.3: LTE/LTE-A radio frame [51].

In LTE, channels are defined for users' data and control signals in UL and DL transmissions. The channels are divided into three groups: physical, transport and logical channels. The physical channels are used to transport users' data and control signal information, the transport channels serve as information transfer bridge between the Medium Access Control (MAC) and higher layers above the MAC layer, while the logical channels are used to provide services within the MAC layer [52]. For reliable detection, control signals are usually modulated using a more redundant modulation scheme, such as Binary Phase Shift Keying (BPSK) and Quadrature Phase Shift Keying (QPSK). The physical channels for downlink transmission are:

- Physical Broadcast Channel (PBCH) conveys the Master Information Block (MIB).

- The Physical Control Format Indicator Channel (PCFICH) is used to carry the control frame indicator and the number of OFDMA symbols used for the control channel transmission. It specifies the length of the control information in a subframe [53].
- Physical Downlink Shared Channel (PDSCH) carries the users' data, network paging, and system information messages.
- Physical Downlink Control Channel (PDCCH) carries the scheduling assignment and other link adaptation control information for the DL and UL for a given DeNB/MeNB to UE connection. It contains the control information required for coherent data detection and demodulation at the UEs.
- Physical Hybrid-ARQ Indicator Channel (PHICH) is used to convey the Hybrid Automatic Repeat reQuest (HARQ), ACKnowledge (ACK)/Negative-ACKnowledge (NACK). This process confirms to the UEs if the DeNB or MeNB has correctly detected and demodulated sent UEs data that are conveyed on the PUSCH or not.

The physical channels for uplink transmission are:

- Physical Uplink Control Channel (PUCCH) is used to convey the Channel Quality Indicator (CQI) information, the HARQ ACK/NAK, uplink scheduling information, and the MIMO feedback (Rank Indicator, RI).
- Physical Uplink Shared Channel (PUSCH) carries both users' data and control data information. PUSCH supports a range of modulation schemes, such as QPSK, 16-Quadrature Amplitude Modulation (QAM), and 64-QAM.

- Physical Random Access Channel (PRACH) is used to carry random access preambles. The PRACH helps to achieve uplink synchronization between the UEs' and MeNB or DeNB.

The RRM provides the resource allocation/partitioning functionality among the DeNBs of the macrocells and MeNBs of MoH cells, link adaptation, packet scheduling, CAC, and handover management for the LTE-A networks [49].

1. The RRM should efficiently allocate the RBs among the DeNBs and MeNBs. The resource partitioning allocation between the backhaul link (DeNB-MeNB), the access link (MeNB-UE) and the direct link (DeNB-UE), should be done in such a way that mitigates any interference in the wireless networks, taking into account resource demand, and number of users within the Evolved Node Base-stations' (eNBs) cells [11]. A Cluster-Based Resource Allocation (CBRA) algorithm has been proposed to enhance radio RBs allocation among DeNB of macrocell and MeNB of MoH cells using time interval dependent graph coloring technique [54].
2. Packet Scheduling at the MAC layer must be done efficiently to satisfy the required stringent delay constraints of different network applications. Packet scheduling can be implemented in time and frequency domains. The support of the stringent QoS (e.g., delay and jitter) requirements can be performed by the time domain scheduler, while the radio channel aware scheduling can be done by the frequency domain scheduler using Channel State Information (CSI) [11, 55]. Also, packet scheduling fairness factor among the UEs is an important metric that RRM has to control. Different

packet scheduling algorithms, such as proportional fairness, logarithmic rule, sequential scheduling (round robin), random scheduling have been proposed [56, 57].

3. The CAC plays an important role in meeting users QoS requirement and ensuring the efficient utilization of radio resources within the wireless networks. The CAC in a given DeNB or MeNB can help to decide which user is accepted into networks or rejected from the networks. The CAC decision can be based on the required QoS, the source of the network calls (i.e., whether the call is a new call from within the cell of the DeNB/MeNB or a handoff call from nearby DeNB/MeNB cell), and the availability of radio resources within the wireless networks. The CAC helps to ensure QoS provisioning in terms of new call blocking and handoff call dropping probabilities; CAC contributes to guaranteeing QoS satisfaction of calls admitted into the wireless networks.
4. Link adaptation is enabled by the CSI feedback from UEs, regarding the channel state qualities, as measured by the CQI. The Link adaptation is implemented through Adaptive Modulation and Coding (AMC) and power control. With CSI feedback information, DeNB/MeNB can determine the appropriate AMC or Modulation and Coding Scheme (MCS), as well as the transmission power level that should be assigned to the UE [53]. DeNB/MeNB can achieve adaptive transmission rates control for UEs, based on the accurate reports from CQI of the instantaneous channel state quality of the communication links. The AMC, channel dependent scheduling, and power control are driven by CQI reporting [53]. Usually, lower channel quality links are assigned

lower MCS (with low spectral efficiency, such as QPSK) and higher transmission power level, while higher channel quality links are assigned higher MCS (with high spectral efficiency, such as 64-QAM) and lower transmission power level. To preserve energy, the RRM entity can exploit link adaption technique by allocating more resources to higher quality channels and fewer resources to lower quality channels. However, due to the relatively small physical size of MoH networks and the proximity of UEs to the MeNBs, most UEs have relatively good channel link qualities and link adaptation is not a major controlling resource management factor for such small cell networks.

2.3 Cooperative Communication

In the cellular wireless communication system, the network throughput capacity is not uniformly distributed across its entire coverage areas. Due to the better SNR and closer proximity of the UEs in the cell-center zone to the DeNB than the UEs in the cell-edge zone, the UEs in the cell-center zone can achieve much higher average throughput than the UEs in the cell-edge zone [42].

In Figure 2.4, the UEs can experience independent channel fading and varying level of SNR. The UEs at the cell-edge, generally, have low SNR, due to distance-dependant path-loss [58, 59]. Multi-path channel fading for example can create a communication situation that allows a given transmission channel link between UE5 to DeNB (Path I) to be in a deep fade (very high signal attenuation), while the same transmission channel link between DeNB to UE1 and UE1 to UE5 (cooperative communication transmission path) is not in deep fade. This situation can result in network transmission outage and re-transmission

for communication transmission between UE5 and the marco-cell DeNB. The poor network

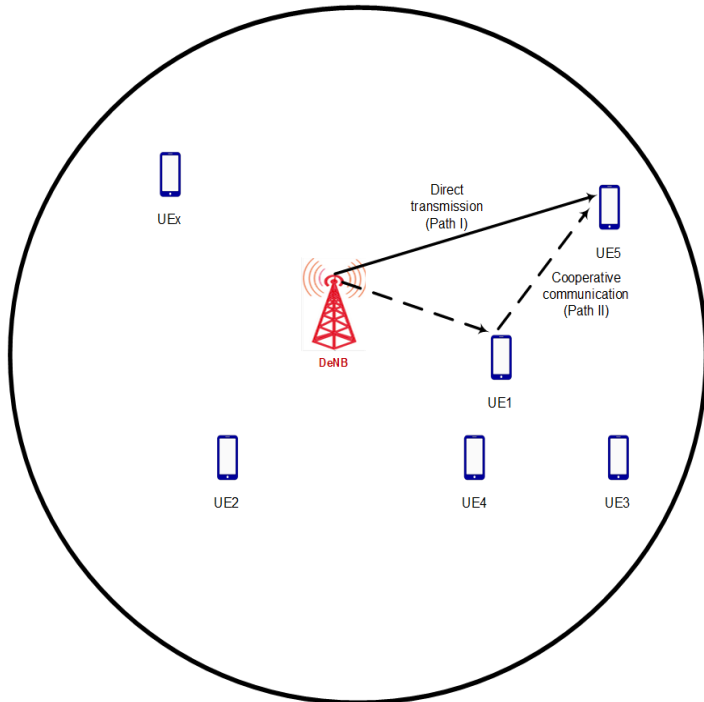


Figure 2.4: A three-node cooperative communication wireless network system.

management leads to link failure, waste of resource, and performance. However, such poor resource management and network performance can be averted, if UE1 is available and willingly to cooperate with UE5 and acts as a relay node for UE5 [60].

Figure 2.4 shows a three-node cooperative communication system that consists of DeNB (source), UE1 (relay), and UE5 (destination). Cooperative communication is a technique that can allow UEs with excellent channel qualities to act as relays and help other UEs (e.g., UEs at cell-edge) with poor channel qualities to relay their messages to their desired transmission destinations. This technique allows UEs to mimic a distributed antenna array system that exploits the spatial diversity of wireless communication channels [61, 62]. Because of the exploited spatial diversity by the cooperative communication system, the UE5

message on the multiple-hop (two-hop) transmission link from source to destination through the relay node (cooperative communication transmission path) can be transmitted using higher order modulation scheme with higher spectral efficiency. Communication transmission outage can occur, only when UEs experience deep fade simultaneous on the channel links. Cooperative communication can exploit link adaptation to improve the throughput of users at the cell-edge zone [11].

Link adaptation is one of the RRM core functions that is used to achieve high user throughput performance in wireless networks. With cooperative communication, higher-order modulation schemes (e.g., 16-QAM and 64-QAM), with higher spectral efficiency can be assigned to cell-edge zone and this can improve the wireless networks' average throughput.

Some of the features of cooperative communication network that makes it very attractive to the industry and academia include:

- Enhanced user throughput capacity: The application of cooperative communication scheme offers alternative transmission paths with better channel capacity gains for UEs. This allows cooperative networks to explore and apply higher MCS that can lead to enhanced network throughput capacity.
- Enhanced cell-edge zone performance: The cooperative transmission technique can help to provide better communication channel paths in cell-edge zone with low SNR and high transmission outage [20]. This technique can significantly improve the SNR and transmission outage performances.

- Lower deployment cost: With UEs serving as cooperative relays, the cost of deployment/installation is reduced compared to deploying/installing additional eNodeBs within the networks [20].
- Reduced power consumption: The implementation of cooperative communication scheme reduces the transmission range for the UEs compared to the direct transmissions to the eNodeBs [20]. The reduced transmission range leads to lower transmission power demands. This advantage is very crucial in prolonging the average battery lifetime and increased talk time for energy limited handheld communication devices.

Cooperative transmission can be divided into two phases. The broadcast phase (phase I) and the coordination phase (phase II). Three primary cooperative communication transmission protocols have been proposed in the literature, they are Amplify-and-Forward (AF), Decode-and-Forward (DF) and Compress-and-Forward (CF) transmission protocols [63, 64]. In the AF Protocol, the UE acting as the relay receives a signal from the source UE in phase I and scales the signal with an amplification factor and transmits the amplified source signal towards the source's desired destination in phase II. Compared to DF and CF, AF has the advantages of low implementation complexity and simplicity [65]. However, in high noise environment the benefits of AF are reduced, due to its equal amplification of the noise and message signals. Other variants/hybrids of cooperative communication transmission protocols, such as Decode-Amplify-and-Forward(DAF) [63] and Hybrid DF/CF [64] exist.

In the DF protocol, the message sent by the source UE is received and decoded in phase I. In phase II; the decoded signal is re-encoded into a new codeword and forwarded to the

destination. DF has the advantage of reducing additive noise; however, in high impulse noise environment there is the possibility that erroneously decoded messages from the source can be forwarded to the destination [66].

In the CF protocol, the relay maps the received signal into a compressed signal space using a compression coding scheme (e.g., Wyner-Ziv), in phase I, then encodes and forwards the compressed signal to the destination. The target uses the direct signal it receives in phase I from the source, as its side information [67].

When the signals from the direct and cooperative transmissions are combined and used at the destination node, this is referred to as diversity combining [68–70]. However, in some wireless network environment direct transmission from the source UE is not feasible, while the destination node only received and decoded the message through cooperative transmission, this process is referred to as without diversity combining. In the next section, the handover management process in HWNs is presented.

2.4 Handover Management in HWNs

Handover management plays an important role in meeting users' QoS requirements and ensuring the efficient utilization of radio resources within the wireless networks. Network operators can exploit handover management process to allow for the seamless transition of the Mobile Nodes (MNs) from one cell to another in order to relieve congestion, balance the load, and satisfy the QoS requirements of network users, while in addition achieving the optimal radio resource utilization within the networks [71, 72]. Handover process is an essential requirement for MN's mobility management. As illustrated in Figure 2.5, a handover

is horizontal handover, when any of the MNs moves from a single Point of Attachment (PoA) to another, within the same RAT (e.g., from AP \iff AP in WLAN, NodeB \iff NodeB in UMTS, or eNodeB \iff eNodeB in LTE) or vertical handover, when any of the MNs moves from a PoA in a given RAT (e.g., eNodeB of LTE) to PoA in a different RAT (e.g., NodeB of UMTS) [73].

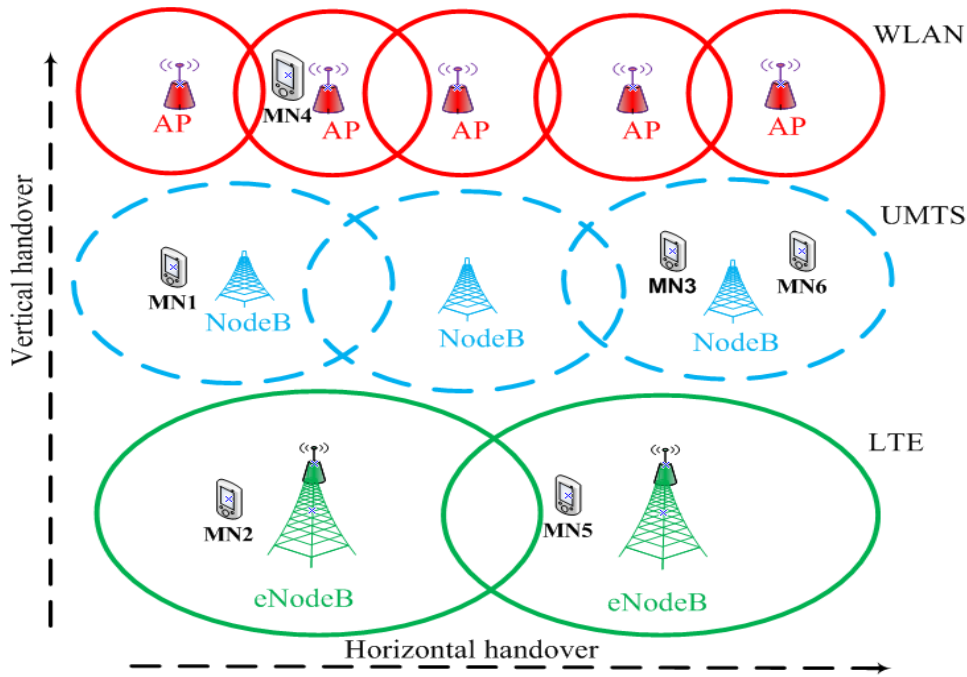


Figure 2.5: The horizontal and vertical handovers [73].

A handover process can occur when MN detects new networks that offer better QoS than its current network's PoA. The dynamic nature of mobile users' service requirements necessitates the implementation of a robust vertical handover management process in HWNs. Moreover, to minimize the ping-pong effect and the handover latency: handover initiation, decision, and execution should be given serious consideration and proper management. The ping-pong handover in HWNs is when two or more subsequent handovers occur between the incumbent and target PoAs. Figure 2.6 is an example of HWNs that comprise of

overlapping LTE-A, WLAN, and UMTS with MNs. An MN equipped with LTE-A, WLAN, and UMTS network interfaces while located within the HWNs should be able to connect with any of the available RATs, such as the DeNB of LTE-A, an Access Point (AP) of WLAN and Node Base-station (NodeB) of UMTS. When the MNs are equipped with message-forwarding capabilities, MN5, for example, could be engaged by the DeNB of the LTE-A networks, as a cooperative forwarding relay node for MN4. This process could occur, if the transmission channel qualities between DeNB to MN5 and MN5 to MN4 are better than the direct transmission channel quality of DeNB to MN4.

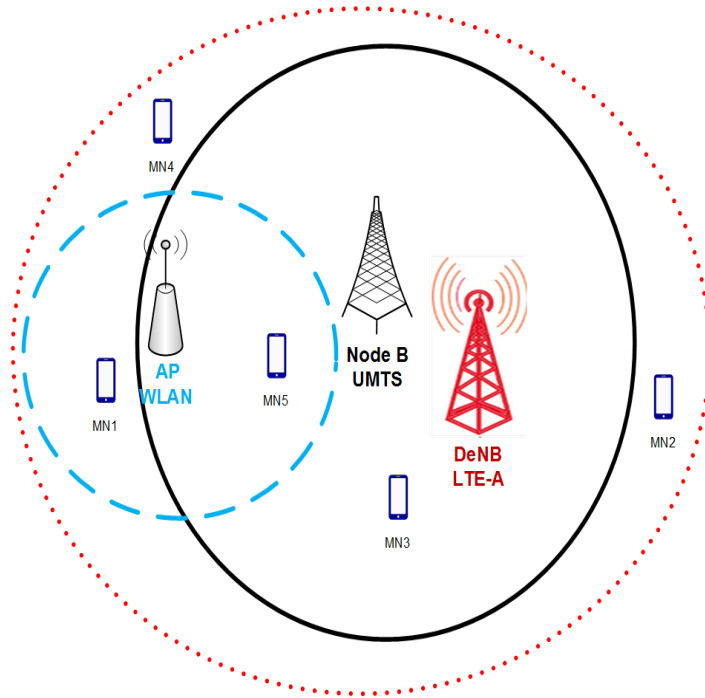


Figure 2.6: An heterogeneous wireless networks.

The RATs are integrated to complement one another in the HWNs. The ETSI has specified loose and tight coupling approaches for integrating WLAN–cellular networks [74]. In the loose coupling system, the external IP network receives the information flows from the dissimilar cases of networks directly, and only signaling information is required

between cellular networks and other complementary networks. With the tight coupling system, complementary networks communicate with the external network (internet networks) through the cellular networks gateway [75].

For homogeneous networks, to maintain physical connection and load balancing; horizontal handover is initiated when the link quality falls below a certain preset threshold. In HWNs, vertical handover is initiated based on complex network criteria and users' preferences, in order to dynamically select the network with the optimal QoS at all times.

In HWNs, the single Received Signal Strength (RSS) or the Signal-to-Interference-to-Noise Ratio (SINR) criterion of the link alone is not an adequate indicator for handover decisions; unlike in homogeneous wireless networks, multiple criteria are required. In most cases, these criteria frequently conflict with one another. Therefore, a trade-off needs to be reached. The criteria need to be combined and appropriately weighted for optimum network selection decision making.

The network selection technique plays a major role in ensuring that the QoS requirements in HWNs are maintained [76]. Considering that HWNs consist of integrated homogeneous networks with different range values of RATs' parameters, it would be logical to create a level playing field for comparing these parameters. The level playing field can be achieved by transforming the several network parameters and user preferences to the same range of values, e.g., $[0, 1]$, via a normalization process. An efficiently designed network selection scheme can ensure optimum network connection while balancing the trade-offs that exist among the network conditions, user preferences, and service applications; and consequently providing a minimal amount of network handoffs.

A network selection algorithm can be initiated, whenever a new network alternative is sensed, or when the requested service class changes. Connecting low mobile speed MNs to access network with smaller coverage area and high mobile speed MNs to access network with larger coverage area can reduce any unnecessary handoffs and handover signaling overheads [77].

In executing vertical handover, seamlessness and automation are two significant challenges that must be tackled, to achieve Always Best Connected (ABC) for the network users [78]. The vertical handover procedure can be categorized as a hard or soft handover. Handover is said to be hard if the MN is connected only to one PoA at a time, during the handover from one PoA to another. This process is also referred to as a break-before-make handover. The hard handover requires less coordination between the incumbent and the target PoAs and hence less control signaling overheads from the handover management unit's point-of-view. Therefore, it is fast to initiate and easy to execute by the handover management unit. A hard handover process could make the MNs experience glitches in network connectivity, or yield some form of degraded QoS when moving from one wireless network cell to another. A ping-pong effect could also occur between the incumbent and the target PoAs, whenever MNs move transiently around the wireless network cell-edge [79].

Handover is considered a soft handover if the MN creates a connection to the target PoA before the release from the previous PoA, during the handover period in the HWNs. This process is also referred to as make-before-break handover. The soft handover is more complicated than the hard handover. It requires more coordination and signaling overhead information between the incumbent and the target PoAs. Therefore, soft handover

is relatively slower to initiate and execute compared to the hard handover process. This situation presents a challenge for the handover management unit.

To achieve a seamless handover connection, the handover process needs to be transparent to the MNs, without MNs perceiving any service degradation during the handover process; as the MNs transit from one wireless network to another. Hence, the handover process must be fast and smooth, with minimal handover latency and packet loss.

The control of handover decision making is usually classified into Network-Controlled Handover (NCHO), Mobile-Controlled Handover (MCHO), Network-Assisted Handover (NAHO), and Mobile-Assisted Handover (MAHO) [78]. The handover decision involves measuring and gathering of the information necessary for the handover. The handover decision-management mechanism can either be located in the network entity or the mobile entity. If the network entity has the total control of the handover decision management mechanism, it is referred to as an NCHO; such handover is deemed network-centric. The NCHO can balance the overall network load; since the decision point is located in the network within the service area; and this allows the NCHO to exploit, more accurately, the knowledge of the network's conditions [80]. It is required in an NCHO, that all the wireless networks' nodes be cooperatively involved. The wireless network users' co-operation is essential. Some important drawbacks of the network-centric approach are the increase in overall network complexity, handover latency, signaling overhead, and the probability of a single point of network failure [81].

An alternative approach to the network-centric handover approach is the user-centric handover approach [82]. If the MN entity has the total control of the handover decision-management mechanism, it is referred to as an MCHO. In a user-centric framework, the network selection algorithms are implemented at the users' MNs [83, 84]. This method offers the distributive control of the handover management process. It has a low overall network and implementation complexities, with reduced handover latency. Unlike the network-centric framework, it generates low signaling overhead, and it is scalable. The MNs can discover accessible network interfaces of several wireless networks based on the regular broadcast services of the various active networks. However, user-centric handover networks can be plagued by instability, if they are not adequately implemented.

Hybrid handover management control functionality exists in HWNs, if the data measured and gathered by the network entity are shared with MN to assist the MN in making and managing/controlling its handover decision, such handover procedure is referred to as NAHO [85]. Also, when the information measured and gathered by the mobile terminals is shared with the network entity for the network's managing and controlling handover decisions, the handover process is referred to as MAHO [86]. Having an efficient handover management process is vital for the seamless integration of the diverse RATs in the HWNs. Figure 2.7 shows the integral blocks of the handover management unit.

2.4.1 Handover information gathering

The handover information gathering unit serves as a repository and a network discovery system for newly available networks. It gathers, manages, and evaluates the changes in the

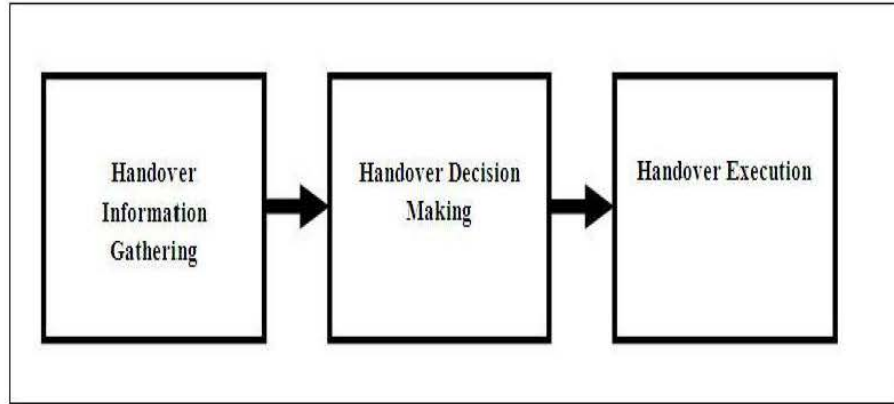


Figure 2.7: The integral units of the handover management process.

collected handover information, to make decisions on whether to initiate a handover process or not. The QoS information (e.g., required bandwidth and the minimum delay), terminal device information (e.g., battery power level and MN's speed), network information (e.g., network security level and network load), and users' contextual information (e.g., users' locations and users' preferences) are stored and managed here. The contextual information is the user-associated information that is used to define the state of a user entity or a system in a given situation [87]. When a handover event is triggered, the vital information required for handover decision is consequently forwarded to the handover decision unit. The handover event is usually triggered when the evaluation of the collected key parameters indicates a need for such a handover.

2.4.2 Handover decision making

The handover decision making is the heart of the handover management process. It is also referred to as the network selector. This unit helps to decide whether the MN should remain connected to its existing network or switch to a more suitable network. In the case of

switching MNs over to another network, this unit selects the most appropriate network for the MNs, from the set of available network alternatives by using a MCDM algorithm and taking into account the criteria necessary for handover decision making. The output of a handover decision unit is then passed on to the handover execution unit.

2.4.3 Handover execution

The handover execution ensures smooth session transition and the transfer of user's contextual information from the incumbent network to the target network. The transition is done while avoiding any possible degradation in the QoS of the ongoing calls. The handover execution also helps to facilitate the authentication and authorization of MNs into the target network. The next section presents some of the popular MCDM methods used in HWNs and the mathematical implementations.

2.5 MCDM Methods in HWNs

The Vertical Handover (VHO) decision problem in HWNs involves complex and often-conflicting multi-criteria, which can be modeled as MCDM problems. An MCDM is an advanced tool of optimization research technique for resolving multiple and conflicting criteria decision making problems. The MCDM methods offer HWNs designers a decision making tool that considers all the criteria of the decision problem, using a robust, explicit, rational, and efficient decision making process for wireless access network selection.

MCDM schemes, such as Simple Additive Weighting (SAW) [88], GRA [89], Technique for Order Preference by Similarity to Ideal Solutions (TOPSIS) [90], and VlseKriterijumska Optimizacija I Kompromisno (VIKOR) [91] are very popular and are being utilized in HWNs. There are other types of algorithms that have been employed to resolve the problem network selection in HWNs that can be found in the literature, such as utility functions [92], game theory [93], and genetic algorithms [94]. However, there are some significant drawbacks in the application of these algorithms, with respect to the application of MCDM algorithms in access network selection in HWNs.

The utility theory-based algorithm requires the use of different utility functions for each mobile user, network criterion, and network alternative [95]. Utility function-based algorithms become cumbersome to apply; as the size of the HWNs and the mobile users scale up. Another drawback of the utility function-based algorithm is the very restrictive assumptions on users' preferences. These restrictive assumptions on users' preferences make the resulting utility function-based network selection model simple but not adequate; while less restrictive assumptions on users' preferences make the resulting network selection model more suitable but also more complicated [96].

Some significant limitations of the game theory-based decision model for network selection in HWNs are the assumptions that the players (mobile users or network operators) are rational and would act mutually for the benefit of one another [97, 98]. However, these are not always the case, as players can act selfishly to increase their payoffs/utilities to the detriment of the overall HWNs' performance. Also due to the iterative solutions of game theory-based decision making, the models for network selection decision problems in HWNs,

achieving convergence solution that leads to Nash Equilibrium (NE) from different players can be computationally time-consuming. Also, the NE decision from the game theory can sometimes not be the Pareto-optimum (best optimum).

The Genetic Algorithm (GA) technique for network selection decision making is an iterative evolutionary optimization search method. It emulates the principles of biological natural selection and genetics to accomplish the natural choice of the the survival of the fittest [99]. In HWNs, the GA encodes the decision variables of network selection decision problems into a finite string of some elements to form a set. This finite string is referred to as the chromosome set, and its number values are called alleles. Iterative optimization search is conducted by using mathematical operations that mimic natural biological processes (mutation, crossover, reproduction, and selection) and fitness test function evaluation to obtain a more desirable chromosome set or decision solution. The GA relies on the size of the decision variables (population size) of network selection problems. The population size is a crucial factor that affects the scalability and performance of genetic algorithms. A small population size could lead to premature convergence and hence produce poor network selection decisions; while large population sizes could result in increased consumption of the critical processing/computational time or resources in the HWNs. This situation can present a weak point in the application of GA for network selection decision making in HWNs. The MCDM techniques are investigated in this thesis.

2.5.1 MCDM algorithms

An MCDM is a technique for achieving optimal decision making in multi-criteria decision making problems. The MCDM analysis is a well-known field of decision making method and a branch of operational research. It is a robust decision making tool that offers a flexible method that can handle a broad range of complex decision variables and thus provide useful insight for the decision-maker in arriving at the best decision [100]. An MCDM problem can be mathematically defined by using a decision matrix problem, $\mathbf{D}(M \times N)$:

$$\mathbf{D} = \begin{matrix} & \begin{matrix} C_1 & C_2 & \cdots & C_j & \cdots & C_N \end{matrix} \\ \begin{matrix} A_1 \\ A_2 \\ \vdots \\ A_i \\ \vdots \\ A_M \end{matrix} & \begin{bmatrix} x_{1,1} & x_{1,2} & \cdots & x_{1,j} & \cdots & x_{1,N} \\ x_{2,1} & x_{2,2} & \cdots & x_{2,j} & \cdots & x_{2,N} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{i,1} & x_{i,2} & \cdots & x_{i,j} & \cdots & x_{i,N} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{M,1} & x_{M,2} & \cdots & x_{M,j} & \cdots & x_{M,N} \end{bmatrix} \end{matrix}, \quad (2.1)$$

and the network criteria weight \mathbf{W}

$$\mathbf{W} = \{w_1, w_2, w_3, \cdots, w_j, \cdots, w_N\}. \quad (2.2)$$

The $\{A_1, A_2, A_3, \cdots, A_i, \cdots, A_M\}$ denotes the set of M available access networks alternatives, from which the decision-maker can choose while $\{C_1, C_2, C_3, \cdots, C_j, \cdots, C_N\}$ denotes the set of N criteria on which each access network alternative performance is evaluated. The

$x_{i,j}$ indicates the performance rating of the i^{th} access network alternative, with respect to the j^{th} criterion of the decision matrix, \mathbf{D} . M and N are the total number of access network alternatives and criteria, respectively. W is the weight vector of importance of the criteria; and w_j is the weight of importance of the j^{th} criterion. The value of w_j indicates how important the contribution of the j^{th} criterion is in achieving the desired goal of selecting the best alternative, by the decision maker. The goal of the defined MCDM matrix problem is to determine and select the best access alternative from the list of alternatives presented. The solution to the defined decision making problem can be obtained by MCDM techniques.

Some MCDM techniques have been proposed for making network selection decisions in the literature [101–109]. The following sub-sections give an extensive review of the currently proposed MCDM schemes and their application to access network–selection problems in HWNs.

Simple Additive Weighting

The Simple Additive Weighting (SAW) is an MCDM technique that is based on the weighted average. It allows the determination of the score of each alternative by mathematical multiplicative operations of the normalized alternative criteria with the relative weights of importance, as indicated by the decision-makers. SAW is also referred to as the weighted-linear combination. It is one of the simplest MCDM algorithms [110]. In SAW, the ranking of each alternative is the total weight of that alternative, as determined by the weighted value of the normalized criteria of that alternative, which is also the weighted average of the network criteria.

The weighted average of the i^{th} alternative from the total number of M alternatives is determined by multiplying the normalized decision-matrix element ($r_{i,j}$) of the i^{th} alternative with respect to the j^{th} criterion by the corresponding criterion weight of importance w_j , as assigned by the network decision-makers. The $r_{i,j}$ is defined as the normalized performance score of the i^{th} alternative with respect to the j^{th} criterion in the normalized decision matrix. When summation of the weighted products of all the criteria for each network alternative is performed, the network alternative with the largest weight product performance score is ranked as the best network. The computation of SAW ranking procedure comprises the following steps:

1. Given a decision matrix problem, \mathbf{D} as shown in Equation (2.1), where $\{A_1, A_2, A_3, \dots, A_i, \dots, A_M\}$ is the set of M alternatives, $\{C_1, C_2, C_3, \dots, C_j, \dots, C_N\}$ is the set of N criteria and entry, $x_{i,j}$ indicates performance score of the i^{th} alternative with respect to the j^{th} criterion. If the larger the value of a criterion the better, then such criterion is referred to as benefit criterion. Calculate the normalized decision-matrix element, $r_{i,j}$ for the benefit criteria as follows:

$$r_{i,j} = \frac{x_{i,j}}{x_j^{max}}, \quad i = 1, 2, 3, \dots, M, \quad j = 1, 2, 3, \dots, N. \quad (2.3)$$

Similarly, if the smaller the value of a criterion the better, then such criterion is referred to as cost criterion. Calculate the normalized decision-matrix element, $r_{i,j}$ for the cost

criteria as follows:

$$r_{i,j} = \frac{x_j^{min}}{x_{i,j}}, \quad i = 1, 2, 3, \dots, M, \quad j = 1, 2, 3, \dots, N, \quad (2.4)$$

where x_j^{max} and x_j^{min} are the maximum and minimum entries of the j^{th} column in D , respectively.

2. Obtain the assigned weight, w_j of each criterion in the network.
3. Compute each SAW rank index, A_{SAW}^i of the i^{th} alternative using Equation (2.5):

$$A_{SAW}^i = \sum_{j=1}^N w_j r_{i,j}. \quad (2.5)$$

4. Finally, obtain the highest ranked SAW ranking index, A_{SAW}^* , which corresponds to the best/optimum access network alternative for the multi-criteria decision problem by using the formula:

$$A_{SAW}^* = \arg \max_{i \in M} \sum_{j=1}^N w_j r_{i,j}. \quad (2.6)$$

SAW has been extensively applied in making network-selection decisions. For example, in [101], N. Singh *et al.* have proposed SAW algorithm for making vertical handoff decisions in 4G wireless networks, due to its simplicity.

Technique for Order Preference by Similarity to Ideal Solutions

The Technique for Order Preference by Similarity to Ideal Solutions (TOPSIS) is an MCDM technique that exploits the idea of finding the alternative that is closest to the positive

ideal solution and furthest from the negative ideal solution. The TOPSIS idea was first presented by Yoon and Hwang in [111]. TOPSIS is a very popular MCDM technique. The multi-criteria decision matrix raw-data inputs require Euclidean normalization. The TOPSIS ranking solution to the access network selection problem is carried out by using the following steps:

1. Construct a decision-matrix problem, \mathbf{D} and the set of criteria weight, \mathbf{W} as defined in Equation 2.1 and Equation 2.2, respectively,

where $w_1, w_2, w_3, \dots, w_j, \dots, w_N$ is the weight of the criterion $1, 2, 3, \dots, j, \dots, N$, respectively.

2. Using the Euclidean normalization, the normalized element, $r_{i,j}$ of the i^{th} alternative with respect to the j^{th} criterion is given by:

$$r_{i,j} = \frac{x_{i,j}}{\sqrt{\sum_{i=1}^M x_{i,j}^2}}. \quad (2.7)$$

3. Calculate the weighted normalized decision matrix element, $v_{i,j}$ of the i^{th} alternative with respect to the j^{th} criterion as follows:

$$v_{i,j} = w_j r_{i,j}, \quad (2.8)$$

where

$$\sum_{i=1}^N w_j = 1. \quad (2.9)$$

4. Define the Positive Ideal Solution (PIS), $V,^+$ and the Negative Ideal Solution (NIS), $V,^-$ as follows:

$$V^+ = \{(\max_i v_{i,j} | j \in J), (\min_i v_{i,j} | j \in J')\} = \{v_1^+, v_2^+, v_3^+, \dots, v_j^+, \dots, v_N^+\}, \quad (2.10)$$

and

$$V^- = \{(\min_i v_{i,j} | j \in J), (\max_i v_{i,j} | j \in J')\} = \{v_1^-, v_2^-, v_3^-, \dots, v_j^-, \dots, v_N^-\}, \quad (2.11)$$

respectively. J is associated with the benefit criteria and J' is associated with the cost criteria.

5. For each i^{th} access network alternative, compute the Euclidean distance separation measure from the PIS, $S,^+$ and the Euclidean distance separation measure from the NIS, $S,^-$ respectively as:

$$S_i^+ = \sqrt{\sum_{j=1}^N (v_j^+ - v_{i,j})^2}, \quad i = 1, 2, 3, \dots, M, \quad (2.12)$$

and

$$S_i^- = \sqrt{\sum_{j=1}^N (v_j^- - v_{i,j})^2}, \quad i = 1, 2, 3, \dots, M. \quad (2.13)$$

6. Finally, compute the closeness to the ideal solution, C_i for the i^{th} access network alternative as follows:

$$C_i = \frac{S_i^-}{(S_i^+ + S_i^-)}, \quad i = 1, 2, 3, \dots, M. \quad (2.14)$$

The highest value of C_i is the closest access network alternative to the ideal solution, and it is subsequently ranked as the best access network alternative.

The TOPSIS method is widely adopted in the literature to rank and select network alternatives. However, it suffers from ranking abnormality. A robust MCDM algorithm ensures that the best alternative ranking order is unaltered or unchanged when a low-ranked alternative is removed or added to the set of available alternatives. Hence, when an algorithm suffers from the ranking abnormality problem, the ranking order is not stable. This process can make the network selection decision inefficient [112].

VlseKriterijumska Optimizacija I Kompromisno

The VlseKriterijumska Optimizacija I Kompromisno (VIKOR) is developed based on the concept of a compromised solution. VIKOR determines the preference-ranking index of the individual alternative, with multiple confliction criteria. VIKOR was first proposed in [113]. The ranking index of VIKOR is derived from considering both the maximum-group utility and the minimum individual regret of the opponent. Given the decision-data matrix of entry, $x_{i,j}$, where $x_{i,j}$ is the performance score of the i^{th} alternative with respect to the j^{th} criterion, and $f_{i,j}$ the normalized score of the i^{th} alternative with respect to the j^{th} criterion, with $i = 1, 2, 3, \dots, M$ alternatives and $j = 1, 2, 3, \dots, N$ criteria, the P-norm, L_p , can be defined [114] as:

$$L_{p,i} = \left\{ \sum_{j=1}^N \left[w_j \frac{(f_j^* - f_{i,j})}{(f_j^* - f_j^-)} \right]^p \right\}^{\frac{1}{p}}, \quad 1 \leq p \leq \infty, \quad i = 1, 2, 3, \dots, M. \quad (2.15)$$

However in the VIKOR scheme, the 1-norm $L_{1,i}$ is used to formulate its ranking measure.

The VIKOR can be implemented in the following steps:

1. The decision matrix is normalized using the Euclidean norm:

$$f_{i,j} = \frac{x_{i,j}}{\sqrt{\sum_{i=1}^M x_{i,j}^2}}, \quad i = 1, 2, 3, \dots, M, \quad j = 1, 2, 3, \dots, N. \quad (2.16)$$

2. Compute the best, f_j^* , and the worst, f_j^- , values of all the criteria, for $i = 1, 2, 3, \dots, M$,

as:

$$f_j^* = \begin{cases} \max_i f_{i,j}, & i = 1, 2, 3, \dots, M, \text{ for benefit criteria,} \\ \min_i f_{i,j}, & i = 1, 2, 3, \dots, M, \text{ for cost criteria,} \end{cases} \quad (2.17)$$

and

$$f_j^- = \begin{cases} \min_i f_{i,j}, & i = 1, 2, 3, \dots, M, \text{ for benefit criteria,} \\ \max_i f_{i,j}, & i = 1, 2, 3, \dots, M, \text{ for cost criteria.} \end{cases} \quad (2.18)$$

3. Compute the utility, S_i , for alternative $i = 1, 2, 3, \dots, M$ as:

$$S_i = \sum_{j=1}^N \left[\frac{(f_j^* - f_{i,j})w_j}{(f_j^* - f_j^-)} \right], \quad (2.19)$$

and the regret measure, R_i , for alternative $i = 1, 2, 3, \dots, M$ as:

$$R_i = \max_j \left[\frac{(f_j^* - f_{i,j})w_j}{(f_j^* - f_j^-)} \right], \quad (2.20)$$

where w_j is the weight of the j^{th} criterion.

4. Calculate the ranking index value, Q_i , for the i^{th} alternative using:

$$Q_i = \lambda \frac{(S_i - S^*)}{S^- - S^*} + (1 - \lambda) \frac{(R_i - R^*)}{R^- - R^*}, \quad (2.21)$$

where $S^- = \max_i S_i$, $S^* = \min_i S_i$, $R^- = \max_i R_i$ and $R^* = \min_i R_i$. S^* is the maximum majority rule index, R^* is the minimum individual regret of the opponent index and, λ is the weight for the strategy of maximum group utility; and it is usually assigned a value of 0.5; and $(1 - \lambda)$ is the weight of the individual regret.

5. For alternative ranking, sort Q_i , S_i and R_i in descending order, a proposed solution of the compromised alternative $Q^{[1]}$ is ranked the best as the minimum Q_i , if condition 1 and condition 2 are satisfied:

(a) Condition 1: Acceptable advantage; $Q^{[2]} - Q^{[1]} \geq \frac{1}{N-1}$, where $Q^{[2]}$ is the second-best ranked position of the ranking order of Q_i and N is the number of criteria considered.

(b) Condition 2: Acceptable stability in decision making: The alternative $Q^{[1]}$ is the best ranked by S , or/and R . This compromise solution is stable and could be attained within a decision making processes through; voting by majority rule (when $\lambda > 0.5$), voting by consensus (when $\lambda = 0.5$), or voting by veto (when $\lambda < 0.5$). If one of the conditions is not satisfied, then a set of compromised solutions is proposed, which is made up of:

i. Alternative $Q^{[1]}$ and $Q^{[2]}$, if only condition 2 is not satisfied or,

- ii. Alternative $Q^{[1]}, Q^{[2]}, Q^{[3]}, \dots, Q^{[K]}$, if condition 1 is not satisfied; $Q^{[K]}$ is determined by $Q^{[K]} - Q^{[1]} < \frac{1}{N-1}$, for maximum K .

Grey Relational Analysis

The Grey Relational Analysis (GRA) is an MCDM technique that explores the grey system theory for analyzing the relationship between a reference and a comparative series. GRA was first proposed in [115]. The comparative series is generated from all the performance values of each alternative. The comparative sequence process is analogous to the normalization process. This process helps to eliminate errors of scale in decision making that can occur as a result of comparing criteria of relatively different dimensional units or scales and diverse ranges.

The comparative series of all the alternatives are compared with the defined reference sequence to produce grey relational grade coefficients for the compared alternatives. The alternative with the highest Grey relational grade factor from the comparison between itself and the reference series is ranked as the best alternative. A $y_{i,j}$ can be defined as the performance score of the i^{th} alternative with respect to the j^{th} criterion. Hence, $Y_i = \{y_{i,1}, y_{i,2}, \dots, y_{i,j}, \dots, y_{i,N}\}$ are the performance scores of the i^{th} alternative with respect to all the criteria. Given M alternatives and N criteria, GRA can be used to select the best alternative from the set of alternatives with multiple criteria, by executing the following steps below:

1. Generate the comparative series $X_i = \{x_{i,1}, x_{i,2}, \dots, x_{i,j}, \dots, x_{i,N}\}$ from the original raw data performance score Y_i of the i^{th} alternative with $x_{i,j}$ the comparative

performance score of the i^{th} alternative with respect to the j^{th} criterion and similarly for all the alternatives. If the criterion is a benefit criterion, then the comparative sequence elements are defined as:

$$x_{i,j} = \frac{y_{i,j} - \min\{y_{i,j}\}}{\max\{y_{i,j}\} - \min\{y_{i,j}\}}, \text{ for } i = 1, 2, 3, \dots, M, j = 1, 2, 3, \dots, N. \quad (2.22)$$

If the criterion is a cost criterion, the comparative sequence elements are defined as:

$$x_{i,j} = \frac{\max\{y_{i,j}\} - y_{i,j}}{\max\{y_{i,j}\} - \min\{y_{i,j}\}}, \text{ for } i = 1, 2, 3, \dots, M, j = 1, 2, 3, \dots, N, \quad (2.23)$$

while if the criterion is the closer to the nominal value y_j^* , the better then the comparative sequence element are defined as:

$$x_{i,j} = 1 - \frac{|y_{i,j} - y_j^*|}{\max\{\max\{y_{i,j}\} - y_j^*, y_j^* - \min\{y_{i,j}\}\}}, \text{ for } i = 1, 2, 3, \dots, M, j = 1, 2, 3, \dots, N. \quad (2.24)$$

2. The range of the comparative sequence obtained from step 1 is $[0, 1]$. The closer alternative value of the comparative sequence is equal to 1 for the all criteria; the more the alternative is desired. In fact, the ideal alternative has its comparative sequence as:

$$X_0 = \{x_{0,1}, x_{0,2}, \dots, x_{0,j}, \dots, x_{0,N}\} = \{1, 1, 1, \dots, 1\}, \quad (2.25)$$

unfortunately, such ideal alternative may not exist in the problem being analyzed. The ideal alternative is defined as the reference alternative against which the performances of the comparative sequences are measured and ranked.

3. Compute the grey relational coefficient, to determine how close is a given comparative score $x_{i,j}$ of a given i^{th} alternative to the reference score $x_{0,j}$ for the j^{th} criterion using:

$$\eta(x_{0,j}, x_{i,j}) = \frac{\Delta_{min} + \Phi \Delta_{max}}{\Delta_{i,j} + \Phi \Delta_{max}}, \text{ for } i = 1, 2, 3, \dots, M, j = 1, 2, 3, \dots, N, \quad (2.26)$$

where $\Delta_{i,j} = |x_{0,j} - x_{i,j}|$, $\Delta_{min} = \min\{\Delta_{i,j}\}$, $\Delta_{max} = \max\{\Delta_{i,j}\}$ and Φ is the distinguishing coefficient with $\Phi \in [0, 1]$. The range of grey relational coefficient $\eta(x_{0,j}, x_{i,j})$ can be varied for the values of distinguishing coefficient Φ as in Equation (2.26), but the ranking order of the alternatives for a given problem is unaltered with any variations in Φ . For most decision problems, Φ is usually assigned a value of 0.5.

4. Finally, compute the aggregate grey relational coefficient $\Psi(X_0, X_i)$ of the i^{th} alternative as:

$$\Psi(X_0, X_i) = \sum_{j=1}^N \eta(x_{0,j}, x_{i,j}) w_j, \text{ for } i = 1, 2, 3, \dots, M. \quad (2.27)$$

The $\Psi(X_0, X_i)$ represents the correlation between the reference sequence and the comparative sequence of the i^{th} alternative, w_j is the weight of the j^{th} criterion and

$$\sum_{j=1}^N w_j = 1. \quad (2.28)$$

The GRA measures the degree of closeness of the comparative sequence to the reference sequence; hence, the best available access network alternative is the closest alternative to the reference sequence.

2.6 Chapter Summary

In this chapter, an overview of the evolution of wireless cellular networks is presented. The growth of wireless mobile user subscribers and network data demands are highlighted along with the generations of mobile wireless communication networks. The LTE/LTE-A architecture and radio resource management for moving wireless/Mobile Hotspots networks are introduced. The significance of MeNB in MoH networks is highlighted. The concept of cooperative communication is outlined and its contributions to network capacity/ throughput enhancement, especially in cell-edge users networks are discussed. Handover management HWNs is outlined, while the three handover functionalities, namely, handover information gathering, decision making, and execution are carefully explained. Finally, an review of some the popular MCDM algorithms in HWNs for access network selection for handoff calls is carried out. The details mathematical implementations of these reviewed MCDM algorithms are presented, using common mathematical notations.

Chapter 3

Call Admission Control for Moving Wireless Networks

3.1 Introduction

An increasing number of mobile users demand improved QoS and networks connectivity in some challenging mobile environments, such as when the mobile users are inside an indoor high-speed moving environment: High-Speed Rail Coaches (HSRCs), buses, trams, etc. [116]. One of the main problems for UEs in an indoor moving environment is the relative low SNR experience. This is due to the high vehicular penetration loss [42, 117]. A group of individual UE terminals connected to the DeNB inside an indoor high-speed moving environment could easily generate a surge of handover signaling information overheads at the DeNB when they individually request handover from a DeNB to another; as several UEs are requesting

handovers at almost the same time. This surge in signaling information overheads could lead to inefficient resource management and network performance degradation.

A solution to this challenge of UEs in an indoor moving high-speed environment is the use of Mobile/MoH networks [118]. Recently, several network designers have been experimenting with the idea of deploying MoH networks to address the problem of low QoS and high handover overhead of mobile group nodes in high mobility terminal/high mobility environments [17, 42]. MoH network can be implemented in the form of mobile picocell or mobile femtocell networks. In MoH networks, the UEs are connected to the MeNB while the MeNB is attached to the DeNB as a single interface link. The DeNB deals with the MeNB handover as a single handover request; with less handover signaling overheads generated, unlike when the UEs attached to the MeNB were connected directly to the DeNB.

A mobile hotspot based on LTE-A network can be considered as a small moving wireless cell network. The mobile hotspot is a small scale wireless cellular network with a low-powered MeNB [17, 119]. The current 3GPP release-13 and Fifth-Generation (5G) network offer support for MoH. MoH is based on a standard cellular network system (e.g., UMTS, WiMAX, LTE-A). MoH networks support has become an attractive feature for NGWNS. MoH network can be installed on HRSCs, trams, buses, etc.

The MeNB can also be regarded as an enhanced Layer 3 mobile relay, which has a unique physical cell identification [39]. The MeNB serves as the PoA for the mobile nodes' access to the core network of the wireless network operator. The MeNB connects to the DeNB of the LTE-A through a wireless backhaul link. The MeNB apart from serving as a connecting node between the DeNB and the mobile group nodes, it can perform more complex functionality,

such as radio resource management (call admission control and resource scheduling), within the moving wireless networks [119]. The mobile hotspot can perform handover operations for mobile group nodes on its PoA [42]. Due to the relatively short communication range between the MeNB and the mobile group nodes compared to the long distance direct transmission between the mobile group nodes and DeNB, the battery life of the associated mobile group nodes can be prolonged [17].

A UE in an MoH network environment demands excellent wireless communication access and services. Communication networks that support MoH should offer diverse and quality multimedia services, such as web-browsing, video-streaming, online-gaming, etc. to its UEs. MoH has tremendous applications in military surveillance and disaster-relief management.

Furthermore, with the advantages of advance MIMO, CA, and CoMP techniques in LTE-A networks, MoH can deliver up to 100 MHz bandwidth for a better QoS experience for UEs [120]. MoH can offer a host of advantages. These include reduced UEs transmission power, reduced signaling overheads, and better channel-quality conditions [121].

The unique characteristics of moving wireless networks exhibit some challenges that traditional call admission control frameworks are not designed to handle. The demands require an adaptive call admission control framework: from when the access point of the moving wireless station becomes stationary, just like the traditional DeNBs, and when the access point of the moving wireless network transits into moving access point. The adaptive call admission control framework should always aim at maximizing the utilization of the radio resource blocks assigned to the moving networks and enhancing the QoS of users inside the moving networks. The CAC algorithm is an essential part of RRM. The CAC regulates

network congestion and ensures the pre-defined level of QoS for on-going calls through the acceptance or rejection of service requests. Network congestion leads to an undesirable increase in handoff call dropping and new call blocking probabilities. The probability of handoff call being dropped is defined as the dropping probability. The likelihood of a new call being blocked is defined as blocking probability. Any increase in these probabilities leads to the deterioration of QoS in the networks.

For better QoS experience, traditional CAC algorithms reserve a certain amount of resource for handoff calls, since network users feel much worse if their ongoing calls are disrupted/terminated abruptly by the network service providers. Traditional CAC algorithm implemented in MoH would reserve more wireless resources for handoff calls than new calls. This action is usually a logical thing to do when the MeNB is stationary. New and handoff calls are generated and offered to the stationary MoH by incoming and outgoing UEs, respectively. For example, an HSRC with MoH at its terminal station would experience new calls from the domicile UEs in the HSRC, while it experiences handoff calls from the UEs that want to board the HSRC at the terminal stations (i.e., going from the macro-cell's going DeNB to the HSRC's MeNB). However, it is a waste of resources to reserve wireless network resources for handoff calls when the HSRC is out of its terminal station and is moving, since no handoff call can be generated except new calls.

Wireless resource reservations for handoff calls when HSRC is mobile could lead to inefficient physical RBs utilization. In this work, an RB utilization is defined as the ratio of the occupied RB for calls to the total RB capacity of the MoH network. All resource blocks should be made available for new calls when an HSRC is mobile. Traditional CACs are not

mobility aware. Traditional CAC schemes have been implemented for macrocells and fixed hotspot [122–125]. The MoH’s CAC algorithm needs to take full advantage of the benefits of moving networks and enhance the QoS of UEs in the MoH. The main challenges in the design of an efficient CAC scheme are improving the QoS provisioning for each class of calls (new and handoff calls) and enhancing the system resource block utilization in MoH. These issues comprise the motivations for this work.

In this chapter, the problem of enhancing QoS for wireless MoH based cellular network is addressed. An Adaptive Thinning Mobility Aware (ATMA) CAC is proposed. The ATMAC CAC exploits the calls generation pattern and the mobile phase and stationary phase events of the moving wireless networks to enhance the new call blocking probability, handoff call dropping probability and channel resource block utilization. Using the Markov chain process, a framework to investigate the effect of varying new call traffic loads; for high, medium, and low handoff call traffic rates on new call blocking probability, handoff call dropping probability and RB utilization of our proposed scheme for MoH is developed. The RB refers to the smallest resource unit used for the transmission of data.

To the best of our knowledge, this is the first research work to utilize the ATMA CAC scheme to address QoS provisioning problems for MoH. The followings are the main contributions of this chapter:

- A comprehensive review of related work is presented.
- A new CAC scheme for MoH that can improve the new call blocking probability, handoff call dropping probability, and radio resource utilization is proposed.

- A framework based on Markov chain analysis to investigate the performance of the proposed scheme is developed.
- The steady-state probability of the proposed scheme is derived and the new call blocking probability, handoff call dropping probability, and radio resource utilization are obtained.

Our work provides an insight into the benefits of using ATMA CAC to improve the QoS compared to the traditional Non-Mobility-Aware Thinning (NMAT) CAC for MoH. The NMAT CAC policy is chosen to evaluate the performance benefits of using ATMA against the use of a non-mobility aware CAC scheme that is implemented in traditional network cell, such as macrocell, microcell, and picocell networks.

Our simulation results show that our proposed ATMA achieved a significant reduction in new call blocking probability, handoff call dropping probability, and improved resource block utilization, while outperforming the traditional NMAT CAC scheme for QoS provisioning and radio resource utilization. The ATMA scheme can be used to design a new CAC strategy for MoH.

The rest of this chapter is organized as follows: in Section 3.2, a review of the related work is presented; Section 3.3 introduces the system model of our proposed scheme; Section 3.4 presents the analysis of the proposed scheme; and finally, the simulation results and conclusion of this chapter are given in Section 3.5 and Section 3.6, respectively.

3.2 Related Work

In this section the related work on moving wireless networks is provided. W. Li *et al.* in [126] investigate the capacity and handover performance gain of mobile relay node over non-mobile relay node for the high-speed railway system in LTE-A networks with mobile group nodes. The introduction of mobile relay node increases the throughput by 24.12% for UEs in the high-speed rail system and with an overall system throughput gain of more than 16.53%; while the radio-link failure ratio is significantly decreased compared to the high-speed rail system with non-mobile relay node.

In [46], the authors investigate two possible candidate architectures for mobile relays in LTE: (i) Alternative 1 (Full-Layer 3 (L3) relay) and (ii) Alternative 2 (Proxy S1/X2). In alternative 1, the Serving Gateway (S-GW)/Packet Gateway (P-GW) entity serving the relay is separated from the DeNB, and the relay is transparent to the DeNB. In alternative 2, S-GW/P-GW functionality serving the relay is embedded in the DeNB, and the relay (S1/X2) interfaces are terminated in the DeNB. The architecture alternative 1 has more benefits than the alternative 2, for mobile-relay changing of its backhaul link (Un interface) from Source-DeNB to Target-DeNB. The study concludes that alternative 1 is therefore more suitable for MeNB handling. Alternative 1 is selected as the baseline architecture for MeNB networks.

J. Sanchez *et al.* analyzed the impact of LTE-A in-band and out-band access architectures for MeNB in HSRC scenarios in [127]. Out-band access is reported to give more network throughput. However, its implementation is more expensive and complicated. In-band access implementation requires less bandwidth resource to setup; however, group

nodes experience increased network delay due to the time gap required for switching from transmission to receptions. Moreover, the Physical Downlink Control Channel (PDCCH) imposes further constraints on the in-band access architecture.

Y. Kim *et al.* in [128] propose a CAC scheme based on guard-band reservation with prioritized handoff queue in Wi-Fi networks. The handoff call dropping probability results show better performance than those of cut-off and non-priority schemes; as the queue size increases. However, the performance of new call probability obtained from the proposed scheme is heavily sacrificed to improve the performance of handoff call dropping probability. Moreover, the QoS and security of the Wi-Fi access are not guaranteed.

To reduce the connection blocking probability and the handover dropping probability, the authors in [129] propose a Predictive Group Handover (PGHO) with a channel borrowing scheme. It uses the location and direction information of the mobile group to predict the target BS and pre-inform the target BS about the group-connection information. The pre-informed target BS utilizes this information to reserve the necessary RBs for the group. However, this predictive scheme can lead to low network RB utilization due to unnecessarily holding down and non-release of scarce resources.

In [121] the concept of a group leader MN is proposed for a moving WiMAX networks for a troop of soldiers in a military warfare environment. The group leader MN integrates the ranging request from the MNs in the group into an individual group leader request to the BS. This situation helps to reduce any possible collision of ranging requests at the BS, and it mitigates against contention of a back-off. The group leader can serve as a local BS and support local communication within the troops when the attached BS and target BS are

out of coverage range for the mobile group nodes. QoS parameters, such as latency, jitter, packet-delivery ratio and throughput, for Voice over Internet Protocol (VoIP) applications are enhanced for moving wireless networks with group leader MN than moving wireless network with non-group leader MN scheme. However, the QoS degrades as the size of the MNs in the group increases. The issue of handoff calls dropping from MNs from different group leaders' cells is not addressed here.

MoH networks in HSRC travels at high velocity and the handover procedures are frequent. This can incur substantial handover information overheads and lengthened handover time. To mitigate against this effect of increasing handover time and significant handover information overheads, M. Pan *et al.* in [130] propose an enhanced handover scheme, which comprises enhanced measurement and group in network handover procedures. The enhanced measurement procedure accelerates the measurement procedure when the MeNB detects that the train is moving close to some neighboring DeNBs. The results show that the proposed scheme can effectively reduce mobile relays' handover time and overhead information.

MoH networks users can enjoy improved QoS, lower transmission power, and enhanced channel quality gains. However, due to the relatively small capacity and mobility of MoH compared to the fixed macro-cells, MoH could quickly get swamped by a resource-demand surge from a large number of UEs that could appear within its vicinity [131]. This could lead to sudden network congestion and QoS degradation. QoS provisioning for UEs in MoH networks is important and a challenging issue. Effective CAC algorithm is vital for MoH networks. The CAC helps to admit and regulate network traffic into the MoH networks. To

be able to provide the guaranteed QoS for UEs, admitted calls traffic need to be monitored efficiently. Two types of handoffs are encountered in MoH. Type 1 handoffs: this comprises handover calls from macrocell's DeNB to MeNB, and Type 2 handoff: this includes handover calls from MeNB to macrocell's DeNB. In this work, the focus is on Type 1 handoffs.

The above review highlights the benefits and challenges of moving wireless networks. In the next section, the system model for the ATMA CAC scheme is introduced. The ATMA scheme enhances QoS provisioning by improving the new call blocking probability, handoff call dropping probability, and radio resource utilization.

3.3 System Model

Moving wireless are going to become a standard feature in the NGWNs. The CAC scheme plays a vital role in the QoS provisioning and radio resource utilization in wireless networks. To improve QoS in traditional wireless network, the CAC reserves radio resources for the prioritized handoff calls. The unique mobility characteristics of moving wireless networks, affect the generation of prioritized handoff calls. The applications of traditional wireless networks CAC algorithms, which are not mobility aware, to MoH networks have produced poor QoS provisioning and radio resource utilization performance. Hence, new and effective CAC algorithms for MoH networks are required.

This study considers an MoH network with MeNB mounted on an HSRC. To reduce Vehicular Penetration Loss (VPL), the MeNB is equipped with indoor and outdoor antennas [42, 132]. The UEs can access the MeNB through the indoor-mounted antenna, using radio access link (Uu) interface; while the MeNB can access the DeNB of the macrocell through

its outdoor mounted antenna, using wireless backhaul link (Un) interface [133]. MeNBs in LTE-A networks are given layer 3 classification [134]. This means that MeNB can handle MoH's network control signaling, resource scheduling, routing of user-plane data towards the serving gateway, mobility configuring, and scheduling of attached UEs. MoH networks greatly enhances the communication quality of vehicular UEs.

The MoH network is operated on open access policy by the network provider. Open access policy applies to situation where the service provider placed the cell in a hotspot, and all subscribed users can connect to it. The HSRC commutes on its routes through various terminal stations. The system model for the HSRC with MoH networks is shown in Figure 3.1. At the terminal station (stop event), UEs can get off/on the HSRC. The MoH is supported by LTE-A networks [135]. It has the capability to carry out independently, UEs' RB allocation, scheduling, and calls admission control functionalities. A given capacity of RB is allocated to MoH by DeNB. The HSRC goes through two-sequence of mobility events: zero mobility (stationary) event at terminal station, as shown system model in Figure 3.1 (a) and non-zero mobility (mobile) event at non-terminal station, as shown in Figure 3.1 (b). In Figure 3.1, calls from UE1, UE3, UE5, and UE6 are the handoff calls generated from the DeNB to the MeNB at the terminal station, while calls from UE2 and UE4 are the existing new calls generated within the MoH networks.

The MoH can perform handoff call admission control for calls from the DeNB into the MeNB. The handoff calls can be accepted into the MoH network, if there are RBs available to serve them; otherwise, the handoff calls are dropped.

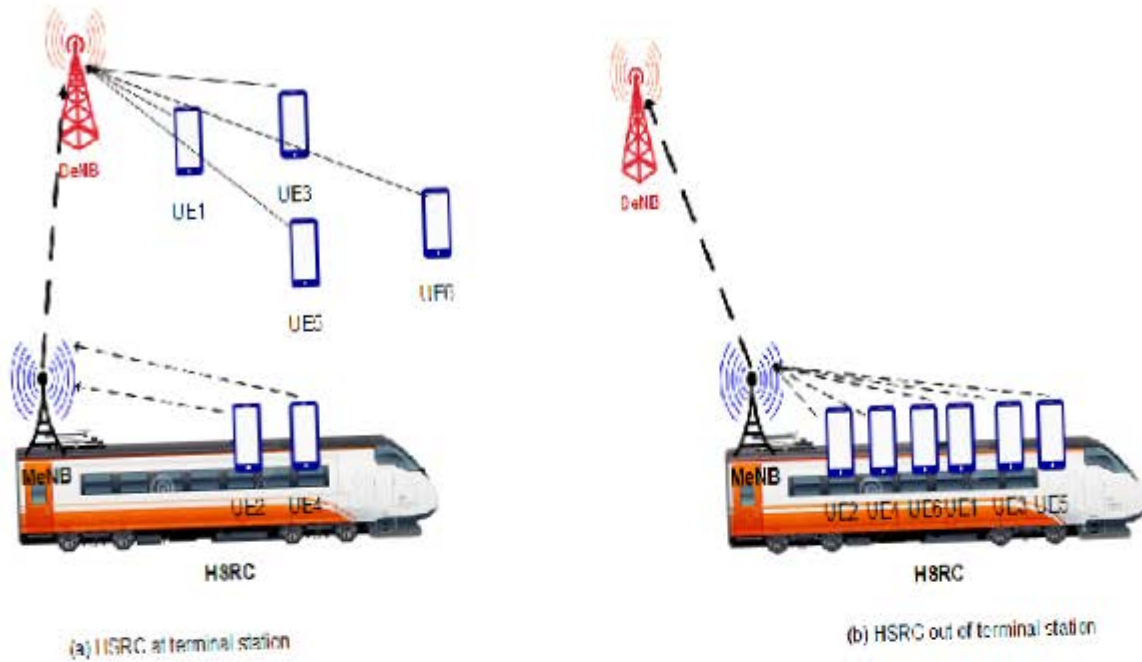


Figure 3.1: HSRC in and out of the terminal station.

New calls are accepted by the MoH with a certain probability as long as there are sufficient resources to support them; otherwise, the new call is blocked. The probability of the acceptance of a new call depends on the amount of available RB(s). If a call request is accepted, an RB is released for the call.

In the HSRC's moving event, handoff calls are not generated. Therefore, handoff calls are not accepted by MoH; as HSRC commuters are not physically allowed to jump into a moving HSRC. In HSRC's mobile event, it would lead to low resource utilization and poor QoS provisioning to thin-out new calls and to allow some priority for handoff calls that are not generated during the mobile event. Consequently, a new call is accepted with certainty, as long as there is sufficient resource to support it. The ATMA CAC scheme exploits the concept of thinning of new calls at the MoH. The thinning of new calls is adaptively

implemented to take full advantage of HSRC's mobility and calls (new and handoff calls) generation pattern.

3.4 Numerical Analysis

In this section, the notations, numerical analysis of the ATMA CAC scheme, and assumptions made in the numerical analysis are presented.

3.4.1 Notations

The following conventional notations are used, the bold face \mathbf{S} denotes the state space of ATMA CAC scheme. x is used to denote the mobility events of the HSRC. y indicates the number of ongoing calls in the HSRC. The summary of the rest notation symbols used are shown in Table 3.1.

3.4.2 The ATMA Analysis

In this section, the numerical analysis of ATMA CAC scheme for MoH networks is presented. The two dimensional (2D) Markov chain process for ATMA CAC scheme is given in Figure 3.2. The state space is defined as:

$$\mathbf{S} = \{(x, y) | x \in \{0, 1\}, 0 \leq y \leq T\}, \quad (3.1)$$

Table 3.1: Summary of important symbols.

Symbol	Description
T	Resource capacity of the MoH networks
$\mu_{h,s}$	Call life-time of handoff call at terminal station
$\mu_{n,s}$	Call life-time of new call at terminal station
$\mu_{n,m}$	Call lifetime of new call at out of terminal station
μ_s	Call life-time at terminal station
μ_m	Call life-time at out of terminal station
$\lambda_{h,s}$	Handoff call arrival rate at the terminal station
$\lambda_{n,s}$	New call arrival rate at terminal station
$\lambda_{n,m}$	New call arrival rate at out of terminal station
λ_h	Handoff call arrival rate
λ_n	New call arrival rate
ϕ_s	The transition rate from mobile event to stop event
ϕ_m	The transition rate from stop event to mobile event
$P_{x,y}$	Steady state probability of state (x, y)
β_y	Probability that a new call will admitted, given that there is y on going call(s)
w	Successive over-relaxation factor
P_B^{ATMA}	New call blocking probability of ATMA
P_D^{ATMA}	Handoff call dropping probability of ATMA
η^{ATMA}	RB utilization of ATMA

where x indicates the mobility events of HSRC ($x = 0$, when HSRC is stationary; $x = 1$, when HSRC is moving), y indicates the number of ongoing calls (new and handoff calls) in the HSRC; T is the capacity of the MoH of the HSRC.

When the HSRC is at the terminal station, $x = 0$ and $y < T$ handoff calls are accepted with certainty while new calls are accepted with a probability. When HSRC is outside the terminal station $x = 1$ and with $y < T$, only new calls are accepted, with certainty. This is so because, with HSRC out of terminal stations, no handoff call can be generated, but only new calls. Hence, there is no available handoff call to compete with the generated new calls for network access admission and available network resource utilization, therefore under this HSRC's mobility condition, new calls are admitted with certainty provided $y < T$.

CAC scheme in Figure 3.2, the steady state probability, $P_{x,y}$ of state (x, y) can be derived from the balance equations. The β_y is defined as the probability that the new call will be admitted, given that there is y ongoing call(s).

For the HSRC in the stationary event, $x = 0$, for $y = 0$, then the balance equation gives:

$$[\beta_y \lambda_n + \lambda_h + \phi_s] P_{x,y} = (y + 1) \mu_s P_{x,y+1} + \phi_m P_{1,y}. \quad (3.2)$$

For $0 < y < T$, then the balance equation is expressed as:

$$\begin{aligned} [\beta_y \lambda_n + \lambda_h + y \mu_s + \phi_s] P_{x,y} &= (\beta_y \lambda_n + \lambda_h) P_{x,y-1} \\ &+ (y + 1) \mu_s P_{x,y+1} + \phi_m P_{1,y}. \end{aligned} \quad (3.3)$$

For $y = T$, then the balance equation is defined as:

$$[T \mu_s + \phi_s] P_{x,y} = (\beta_y \lambda_n + \lambda_h) P_{x,y-1} + \phi_m P_{1,y}. \quad (3.4)$$

For the HSRC in the mobile event, $x = 1$, for $y = 0$, then the balance equation is obtained as:

$$[\lambda_n + \phi_m] P_{x,y} = (y + 1) \mu_m P_{x,y+1} + \phi_s P_{0,y}. \quad (3.5)$$

For $0 < y < T$, then the balance equation gives

$$\begin{aligned} [\lambda_n + y \mu_m + \phi_m] P_{x,y} &= \lambda_n P_{x,y-1} + (y + 1) \mu_m P_{x,y+1} \\ &+ \phi_s P_{0,y}. \end{aligned} \quad (3.6)$$

For $y = T$, then the balance equation is as follows:

$$[T\mu_m + \phi_m]P_{x,y} = \lambda_n P_{x,y-1} + \phi_s P_{0,y}, \quad (3.7)$$

where $\lambda_{h,s} = \lambda_h$, $\lambda_{n,s} = \lambda_{n,m} = \lambda_n$, $\mu_{h,s} = \mu_{n,s} = \mu_s$, and $\mu_{n,m} = \mu_m$.

The steady state probability, $P_{x,y}$ is computed from Equations (3.2)-(3.7), numerically. The successive over-relaxation (SOR) technique [136], which is an iterative algorithm, is used to obtain the steady state probability, $P_{x,y}$. The right choice of the over-successive relaxation factor, w helps to speed up the convergence rate of the iterative solution process for $P_{x,y}$, where $w \in (0, 2)$ [137]. The right choice of w can not to be determined a priori [138, 139]; however, a new and better choice of w can be estimated within the course of the iteration process by updating w as w' , at every i^{th} ($i > 2$) iteration step. The right choice estimated w is given as:

$$w' = \frac{2}{1 + \sqrt{1 - a^2}}, \text{ with} \quad (3.8)$$

$$a = \frac{e + w - 1}{w\sqrt{e}} \text{ and} \quad (3.9)$$

$$e = \frac{\|P_{x,y}^i - P_{x,y}^{i-1}\|}{\|P_{x,y}^{i-1} - P_{x,y}^{i-2}\|}. \quad (3.10)$$

The operator $\|\bullet\|$ is defined as the absolute-value norm on one dimensional vector space, and i denotes the i^{th} iteration step of the SOR iteration process.

The new call blocking probability P_B^{ATMA} , handoff call dropping probability P_D^{ATMA} , and RB utilization η^{ATMA} of ATMA scheme are obtained from $P_{x,y}$. The new call blocking

probability, P_B^{ATMA} is derived as:

$$P_B^{ATMA} = \sum_{y=0}^T (1 - \beta_y) P_{0,y} + P_{1,T}. \quad (3.11)$$

The hand-off dropping probability [128], P_D^{ATMA} is obtained as:

$$P_D^{ATMA} = \frac{P_{0,T}}{\sum_{y=0}^T P_{0,y}}. \quad (3.12)$$

The RB utilization, η^{ATMA} can be evaluated as:

$$\eta^{ATMA} = \frac{1}{T} \sum_{x=0}^1 \sum_{y=0}^T y P_{x,y}. \quad (3.13)$$

3.4.3 Assumptions

The MoH networks CAC scheme improves the QoS of UEs and ensures efficient radio resource management by dynamically controlling calls onboard the HSRC. An MoH network with an effective maximum uplink throughput of 18 Mbps is considered. Also a voice application call system, where a voice call is encoded at 128 kilo-bits per second (kbps) is considered. The MoH resource capacity is T units, with $T = 140$ (18Mbps/128kbps). A unit RB that supports an encoded voice call at 128 kbps is assumed. It is assumed that the MeNB performs the RRM of the MoH networks. In this simulation, β_y is considered to be a uniform random distribution, $\beta_y \in (0, 1)$ and sorted in descending order with increasing magnitude of y . The rest of the simulation parameters are given in Table 3.2.

Table 3.2: Simulation parameters.

Parameter	Value
λ_h	[25, 15, 5] calls/min
λ_n	varied between 5 and 35 calls/min
μ_s	0.2 calls/min
μ_m	0.08333 calls/min
ϕ_s	0.07692 min
ϕ_m	0.07692 min
w	0.98

3.5 Results and Discussion

In this section, the performance results of the ATMA scheme are obtained and compared against the NMAT scheme using MATLAB simulation tool. For better understanding and analysis of the results, the calls (new and handoff calls) arrival rates are classified into: low ($0 < \lambda_h, \lambda_n, \leq 10$ calls/min), medium ($10 < \lambda_h, \lambda_n, \leq 20$ calls/min), and high ($\lambda_h, \lambda_n, \geq 20$ calls/min) traffic rates. The wireless networks performance metrics: new call blocking probability, handoff call dropping probability, and radio resource utilization as a function of new call arrival rate; for handoff call arrival rate, $\lambda_h = 25, 15,$ and 5 calls/min are presented in Figure 3.3–Figure 3.11.

Figure 3.3, Figure 3.4, and Figure 3.5 show the new call blocking probability as a function new call arrival rate; for handoff call arrival rate $\lambda_h = 25, 15,$ and 5 calls/min or high, medium, and low handoff calls traffic rates, respectively. At high handoff traffic rate as depicted in Figure 3.3, it can be observed that the new call blocking probability for ATMA and NMAT schemes increases as the new call arrival rate increases. This is due to the fact that, as the new call traffic in the MoH network increases more resource is being consumed, while the probability of any incoming new call finding a larger percentage of the RBs in the

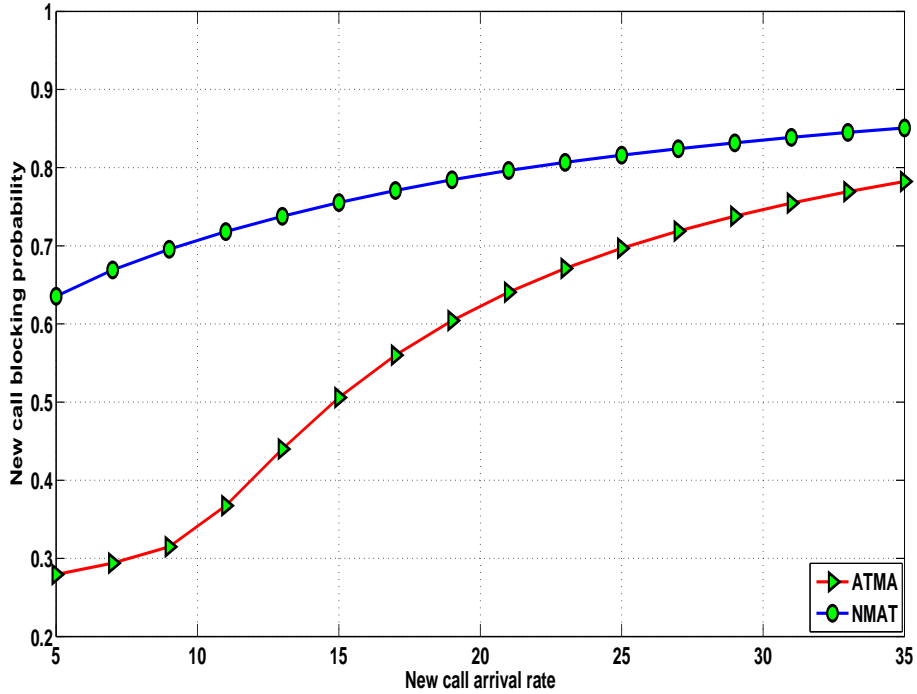


Figure 3.3: New call blocking probability as a function of new call arrival rate; for $\lambda_h =$ high traffic rate (25 calls/min).

MoH network occupied increases. The ATMA scheme provides a lower and better new call blocking probability performance than NMAT scheme. This is due to the ATMA scheme adaptively exploiting the mobility stages of HRSC and calls (new and handoff calls) generation pattern to enhance its new call blocking probability, unlike NMAT’s scheme.

When HSRC is in the terminal station and handoff calls (prioritized calls) are being generated from the DeNB to the MeNB in the MoH networks, the ATMA scheme accepts new calls into the network, with a probability of acceptance, until the MoH networks’ resource capacity is filled. However, when the HRSC is out of the terminal station and with no prioritized handoff calls being generated, all the resources in the MoH network are released to the incoming new calls with certainty. This is unlike in the NMAT scheme, where scarce

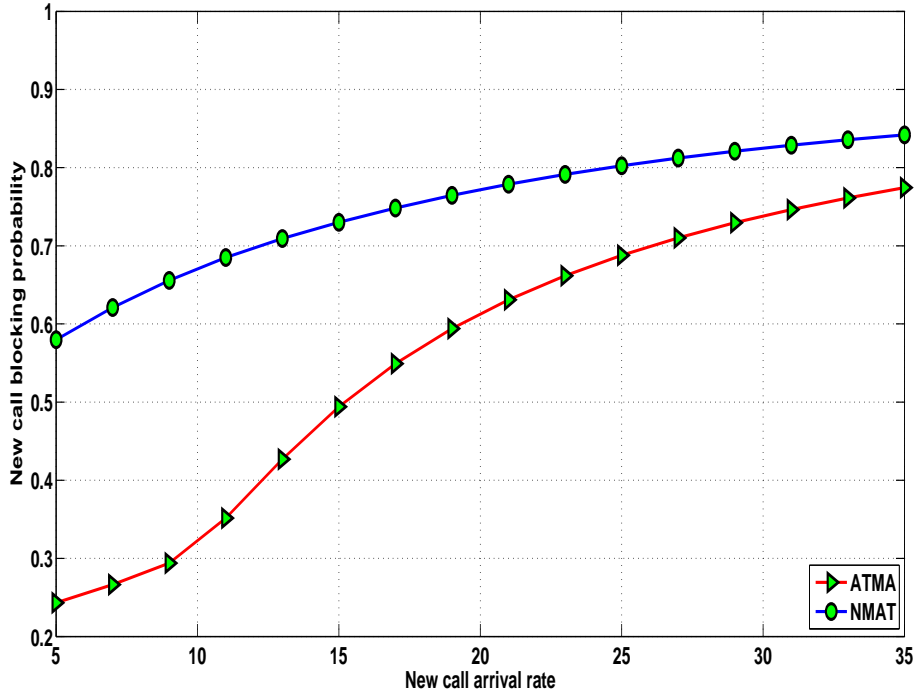


Figure 3.4: New call blocking probability as a function of new call arrival rate; for $\lambda_h =$ medium traffic rate (15 calls/min).

radio resources will be reserved for the prioritized handoff calls, even when the HSRC is out of the terminal station and the prioritized handoff calls are no longer being generated from the DeNB to MeNB. This contributes greatly to the relatively poor performance of NMAT’s new call blocking probability in comparison to ATMA’s new call blocking probability performance as in seen in Figure 3.3.

A similar trend of the result in Figure 3.3 can be seen with results in Figure 3.4 and 3.5; for medium and low prioritized handoff call traffic rates, respectively. The new call blocking probability of ATMA always outperforms the NMAT’s as can be observed as the handoff call traffic rate vary from high to low through Figure 3.3- 3.5. As the prioritized handoff call traffic rate decreases from high to low, through Figure 3.3-3.5, the probability

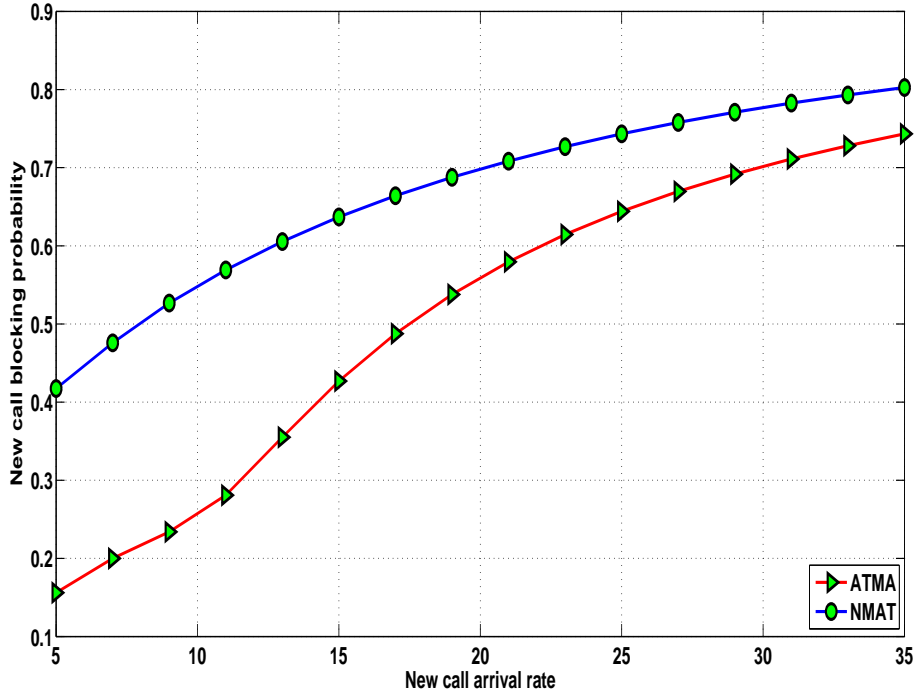


Figure 3.5: New call blocking probability as a function of new call arrival rate; for $\lambda_h =$ low traffic rate (5 calls/min).

of the non-prioritized new calls traffic getting blocked with respect to each scheme (ATMA or NMAT), decreases at the same percentage; at $\lambda_n = 25$ calls/min. This shows that as less prioritized handoff calls are generated more non-prioritized new calls can be admitted into the MoH networks.

Figure 3.6, Figure 3.7, and Figure 3.8 present the handoff call dropping probability as a function of new call arrival rate; for handoff call traffic arrival rates at high, medium, and low, respectively. The handoff call dropping probabilities for ATMA and NMAT are shown in Figure 3.6. As seen in Figure 3.6 the handoff calls dropping probability increases as the new call arrival rate increases. This is so because, as the new call arrival rate increases

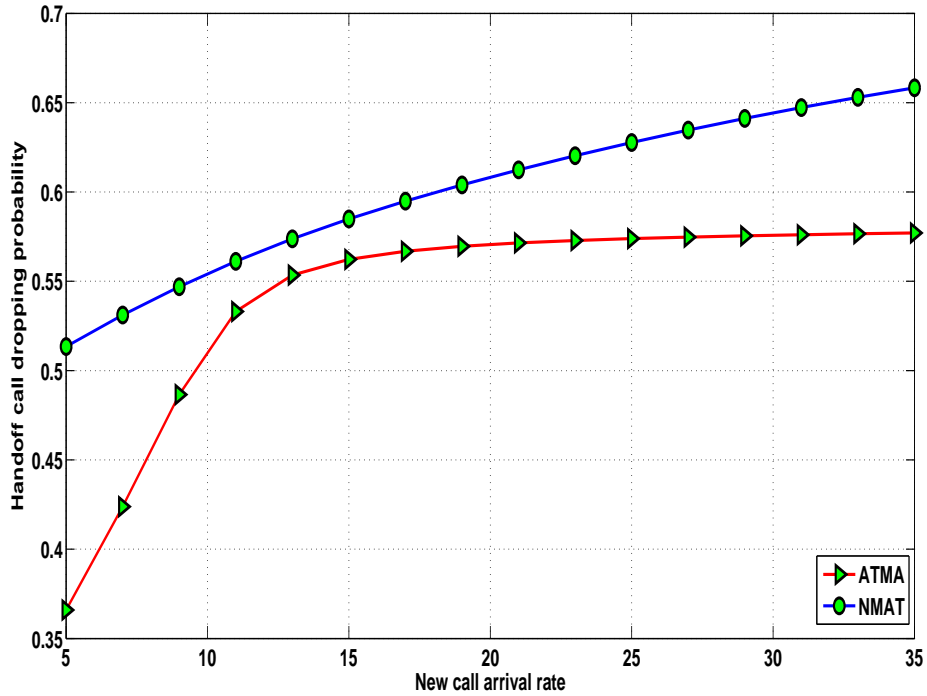


Figure 3.6: Handoff call dropping probability as a function of new call arrival rate; for $\lambda_h =$ high traffic rate (25 calls/min).

relatively to the constant handoff call arrival rate, the probability that an arriving handoff call from the DeNB into the MeNB of the HRSC finding all the RB occupied increases. It can be observed that ATMA’s handoff call dropping probability outperformed NMAT’s handoff call dropping probability. Since mobile users are more sensitive to degradation in handoff calls than new calls, when the HSRC is at the terminal station, the ATMA’s scheme gently smoothed/thinned-out the incoming new calls when both new calls and the prioritized handoff calls are being generated, even when the MoH networks resources are just initially getting being consumed. This action allows ATMA’s handoff call dropping probability performance to be more enhanced or lowered than NMAT’s as shown in Figure 3.6.

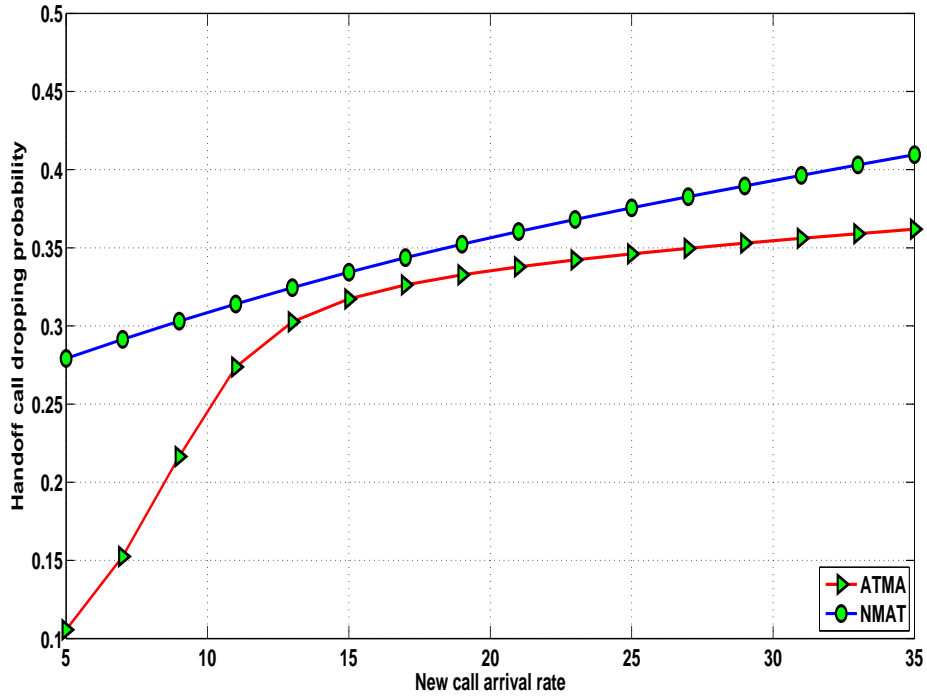


Figure 3.7: Handoff call dropping probability as a function of new call arrival rate; for $\lambda_h =$ medium traffic rate (15 calls/min).

When HRSC is out of terminal station and with no handoff calls generated from the DeNB to the MeNB, ATMA scheme allows new calls into the network with certainty as long as there is an available resource in the network. However, the acceptance of new calls with certainty when HRSC is out of terminal station does not degrade the handoff call dropping probability performance of ATMA scheme, since no prioritized handoff calls are generated into the MoH networks, from the DeNB. Although unlike in the ATMA's scheme, the NMAT will reserve radio resource for the prioritized handoff calls, however, this does not contribute to the improvement of NMAT's handoff call dropping probability performance, since no prioritized handoff calls are being generated at this mobile stage event of HSRC. As reiterated earlier, regarding QoS performance, mobile users are more sensitive to deterioration or increase in

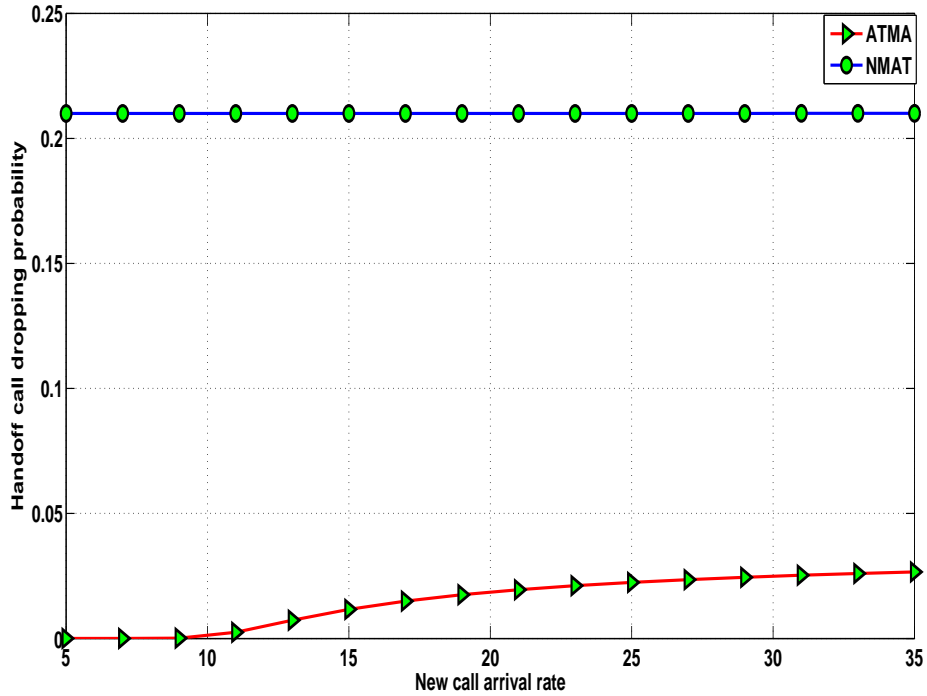


Figure 3.8: Handoff call dropping probability as a function of new call arrival rate; for $\lambda_h =$ low traffic rate (5 calls/min).

handoff call dropping probability than new call blocking probability. Hence, a well designed and implemented CAC scheme in MoH should ensure that handoff call dropping probability is effectively regulated. The ATMA CAC scheme controls the degradation of the handoff call dropping probability as the new call arrival rate increases beyond $\lambda_n = 15$ calls/min, by keeping handoff call dropping probability saturated just below 0.58, unlike the traditional NMAT CAC scheme implemented in MoH as shown in Figure 3.6.

Identical results trend corresponding to those in Figure 3.6 are displayed in Figure 3.7 and Figure 3.8 for medium and low handoff call traffic rate, respectively. The prioritized handoff dropping probability of ATMA always outperforms that of NMAT's, irrespective of the traffic rate variation (i.e., high-low) of prioritized handoff calls as observed from Figure 3.6

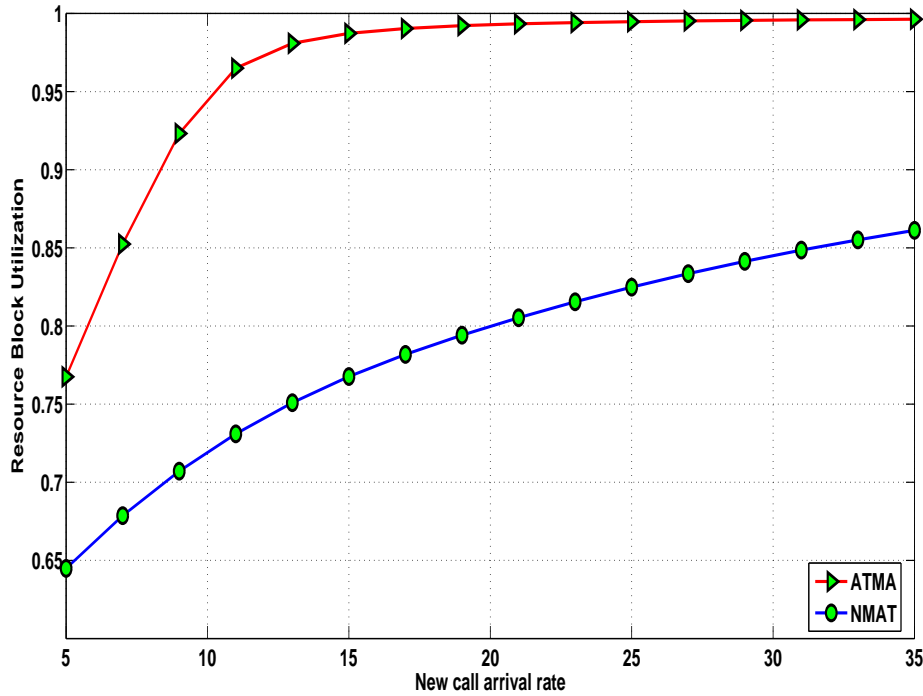


Figure 3.9: Resource block utilization as a function of new call arrival rate; for $\lambda_h =$ high traffic rate (25 calls/min).

to Figure 3.8. Also, as seen from Figure 3.6 through Figure 3.8, the percentage performance of the probability of the prioritized handoff call of ATMA scheme getting dropped decreases by about 34% over the decrease of NMAT’s scheme for new call medium traffic rate. This means that the chances of the prioritized handoff calls getting admitted into the MoH networks increases, for lower generated handoff call traffic rates from the DeNB to MeNB.

Figure 3.9, Figure 3.10, and Figure 3.11 show the results of radio resource utilization as a function of new call arrival rate; for handoff call traffic arrival rates at high, medium, and low, respectively. Depicted in Figure 3.9, is the radio resource block utilization performance of ATMA and NMAT schemes as a function of the new call arrival rate. The results show an increase in radio resource block utilization, as the new call arrival increases. However,

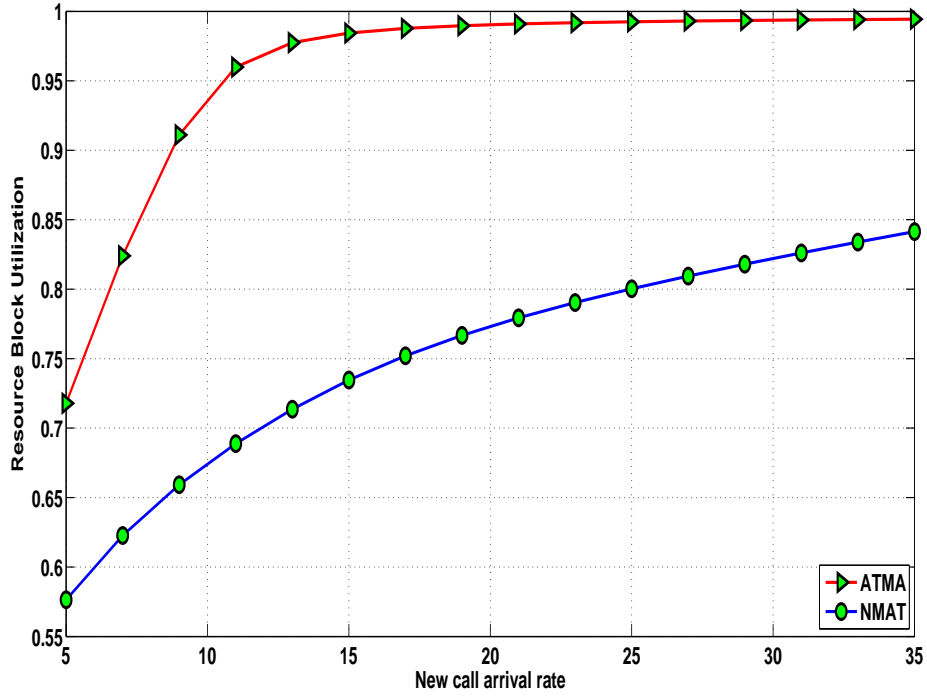


Figure 3.10: Resource block utilization as a function of new call arrival rate; for $\lambda_h =$ medium traffic rate (15 calls/min).

the ATMA scheme shows a higher increase in RB utilization than the NMAT scheme. This is so because the ATMA scheme is mobility aware. It does not reserve the scarce radio resources for prioritized handoff calls, when prioritized handoff calls are not begin generated, it however, allows the generated new calls within the MoH networks to have unlimited access the to the utilization of the available MoH networks' radio resources. The unconditional reservation of MoH networks' resources to the prioritized handoff calls, when handoff calls are not generated/available leads to the poor performance of radio RB utilization of NMAT's scheme as seen in Figure 3.9. The NMAT RB utilization at new call arrival rate $\lambda_n = 15$ calls/min for ATMA is 99%; while NMAT is 77%. In Figure 3.9, it can be observed that the ATMA scheme produces a steady increasing RB utilization performance gain over the

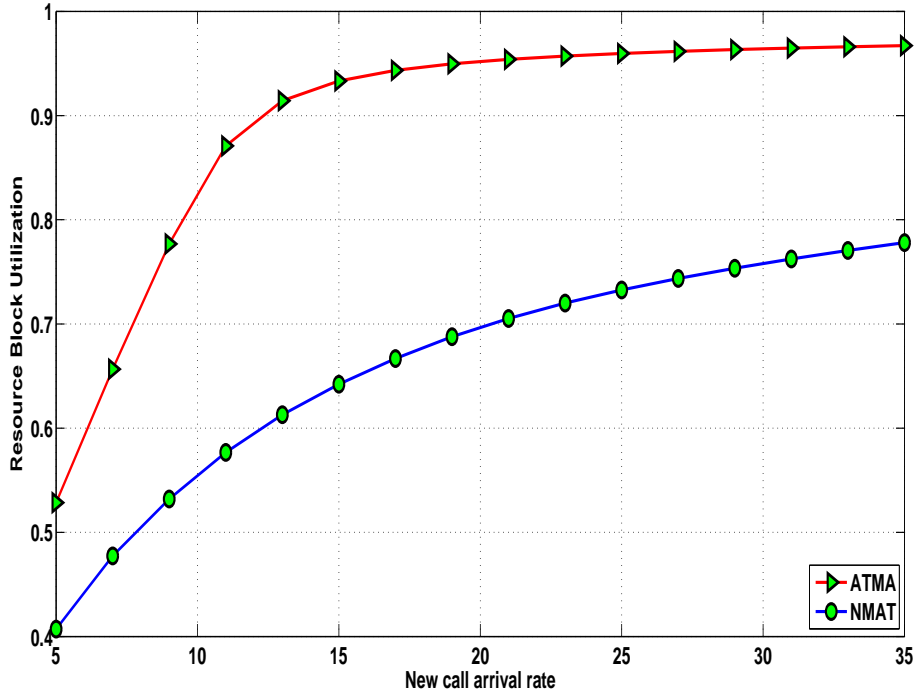


Figure 3.11: Resource block utilization as a function of new call arrival rate; for $\lambda_h =$ low traffic rate (5 calls/min).

NMAT scheme, before ATMA’s RB utilization saturation level is reached. At ATMA’s RB utilization saturation level, a performance gain of not less than 13% over NMAT’s RB utilization performance is always achieved from Figure 3.9.

Similar result performance can be observed in Figure 3.10 and Figure 3.11 for handoff call at medium and low traffic rates, respectively. The resource block utilization performance of ATMA is always higher/better than that of NMAT’s, at any variation of handoff traffic rate as seen in Figure 3.9 to 3.11. At new call arrival rate of, $\lambda_n = 15$ calls/min as depicted in Figure 3.9 to Figure 3.11 the radio resource block utilization decreases as the handoff call traffic rate goes from high to low. The percentage of radio resource utilization performance at this new call traffic are about 5% and 17% decrease for ATMA and NMAT schemes,

respectively, for the variation of prioritized handoff calls from high to low traffic rate. This means that the systems resource utilization decrease with decreasing handoff call traffic rate, moreover, the NMAT resource utilization performance decreases much faster than ATMA with about 12% (i.e., 17% – 5%).

3.6 Chapter Summary

In this chapter, the problem of enhancing QoS and radio resource utilization for MoH in LTE-A based cellular network is investigated. A novel ATMA CAC scheme for MoH networks is proposed. The scheme adaptively exploits the calls generation pattern and smoothly throttles out the new calls, depending on the mobility event of the HSRC. The simulation results obtained from ATMA CAC scheme showed improved RB utilization, with lower new call and handoff call dropping probabilities performance than the NMAT CAC's scheme for various prioritized handoff traffic rates. The ATMA scheme can easily be used to design CAC strategy for MoH networks.

Chapter 4

Wireless Networks Performance

Enhancement through Buffered

Cooperative Communications

4.1 Introduction

Meeting the data rate and QoS demands by UE terminals within the coverage zone of cellular wireless communication networks have created a significant challenge to cellular network designers and operators. The UEs at the cell-edge experience reduced transmission rates and QoS provisioning from the network, due to the relative poor channel qualities created by the increased path loss (path attenuation), noise, and interference from the neighboring cells. Several innovative techniques, such as MIMO antenna, CA and Cooperative Communications (CC) have been proposed to address this major challenge [48, 50]. Efforts are currently

being made to include these innovations as standard features in the next generation wireless networks.

The MIMO antenna scheme is a powerful technique that uses more than one antenna at either or both the radio transmitter and receiver nodes for signal transmission and reception, respectively [50]. It exploits the multipath/spatial diversity that exists between the radio transmitter and receiver to deliver higher SNR communication signal at the receiver. The higher SNR reduces the Bit Error Rate (BER), minimizes the probability of data re-transmission, and signal outage in wireless networks, but the adoption of MIMO technique creates a higher implementation complexity and cost, most particularly in the receiver nodes. The physical size limitation of the UEs creates an undue physical constraint to MIMO implementation at the receiver nodes.

Carrier Aggregation (CA) technique is another promising scheme that has tremendous potential to improve network throughput and QoS provisioning for UEs. The CA, as proposed for LTE/LTE-A, allows the aggregation of multiple carriers from the available bandwidths for data transmission [50]. The individual aggregate carrier is also referred to as the component carrier. The component carrier can have a bandwidth of 1.4 MHz, 3 MHz, 5 MHz, 10 MHz, 15 MHz, or 20 MHz [20, 140]. A different number of component carriers can be used for uplink and downlink transmissions in LTE/LTE-A. The maximum component carrier or bandwidth that can be employed in either link is limited to five component carriers or 100 MHz [20, 141]. Nevertheless, the ever-increasing problem of spectrum scarcity limits the full exploitation of the benefits of CA technique.

The cooperative communication method is yet another very interesting technique that provides higher bit-rate and enhanced QoS to for UEs. Cooperative communication allows available UEs to be cooperatively engaged as relays. A UE node with good channel links between the transmitter and the receiver node can serve as a cooperative relay between the transmitter and receiver node. The cooperative relay helps to reduce the communication link failure rate and outage probability while improving the average transmission rate of transmitter to receiver nodes. The cooperative UEs can act as virtual antenna [142] or a form of distributed MIMO antenna [143], thereby mimicking the MIMO antenna scheme, without the increased implementation complexity of MIMO antenna. Furthermore, unlike the traditional network relay, cooperative communication has the advantages of lower implementation cost and deployment flexibility [67].

In this chapter, the problems of enhancing the throughput, QoS, and radio resource utilization enhancement on LTE-A networks with cell-edge UEs are addressed. A Buffered Cooperative Communication (BCC) framework that exploits the transmission channel qualities using link adaptation to enhance the average throughput, QoS, and radio resource utilization in the wireless cellular networks is proposed. A framework, using Markov chain analysis to investigate the effect of the queue buffer size on the average throughput, data blocking probability, and radio resource utilization: under varying network load traffic, UE cooperative relay index, and cell-center zone of the wireless networks is developed.

To the best of our knowledge, this is the first research work to utilize the BCC scheme to address the problems of throughput and QoS provisioning for UEs in the wireless networks. The followings are the main contributions of this chapter:

- A comprehensive review of the related work is presented.
- A BCC scheme that can improve the average transmission rate/throughput, data blocking probability, and radio resource utilization performance for wireless networks with cell-edge UEs is proposed.
- Using Markov chain process, an analytical framework is developed to investigate the performance of the proposed BCC scheme.
- The steady state probability is derived and the average throughput, data blocking probability, and radio resource utilization performance metrics for the proposed BCC scheme are obtained.

This work provides a framework to investigate the performance of the BBC scheme for improving the UEs' bit transmission rate and QoS compared to Non-Buffered Cooperative Communication (NBCC) scheme in wireless networks. The simulation results show that the proposed BCC scheme achieves a significant improvement in the average bit-rate transmission, data blocking probability, and radio resource utilization for wireless communication networks compared to the NBCC scheme.

The rest of the chapter is organized as follows: a review of the related work is presented in Section 4.2, Section 4.3 gives the system model of the proposed scheme, in Section 4.4, the analysis of the proposed scheme is presented, Section 4.5 provides the results and discussion, while Section 4.6 finally concludes the chapter.

4.2 Related Work

In this section, the relevant related work on cooperative communication in wireless communication networks is presented. There has been growing research interest in the analysis and performance evaluation of the application cooperative communication in wireless networks. In [67], a survey of cooperative communication schemes and their advantages in improving system capacity in LTE-A network systems is presented. The discussion in [67] shows that cooperative communication provides both network and capacity extension for LTE-A network. Furthermore, it leads to significant improvement in system spectrum efficiency and performance of LTE-A networks.

In [144], P. Krishna *et al.* study the performance evaluation of cooperative relay-assisted transmission model in LTE system using multiple cooperative relays. Single Carrier Orthogonal Frequency Division Multiple Access (SC-OFDMA) and OFDMA are employed for uplink communication and downlink communication, respectively. The cooperative relay nodes use a Decode and Forward scheme for data forwarding. Its system performance is measured in terms of Symbol Error Rate (SER) for varying levels of SNR. The simulation results obtained, showed a better performance for cooperative relay-assisted transmission (two-hops) than direct transmission (one hop), but the author fails to highlight the need for synchronization of the multiple cooperative relay transmission to avoid transmission collisions in the system model.

A. Abdallah *et al.* [143] study relay techniques (cooperative and non-cooperative) for LTE-A networks. The relay characteristics and channel model are created using the WINNER II. The relay transmission scheme performance is described in terms of BER. The

study in [143] employs the adaptive modulation and coding schemes of QPSK and 16-QAM on the communication channel links. The simulation results show that the transmission power levels on the links influence the performance of the relay techniques. By increasing transmission power levels on both direct and relayed transmission links, this could improve the BER and outage probability for cell-edge UEs. Nevertheless, this could lead to the generation of an unacceptable level of inter-cell-interference; hence a possible degradation in the overall wireless network system performance.

The LTE-A standard supports Type I in-band cooperative relays that use a two-hop DF relaying mode. Time division multiplex configuration is applied to the relay reception and access transmission links. Any misalignment in the sub-frame configuration of the relays could lead to cooperating relay-to-relay interference. A. B. Saleh [145] propose a divide and conquer approach to address the problem of relay-to-relay interference. The scheme in [145] exploits the localized nature of relay-to-relay interference to isolate and group the interfering relay nodes and hence performs sub-frame synchronization/alignment within the interfering grouped relay nodes.

Unequal bit reliability within each QAM symbols could lead to the sub-optimal performance of DF relaying scheme [146]. Y. Meng *et al.* in [146] propose the application bit remapping/rearrangement technique at the relay node to improve the bit reliability; and therefore, it enhances the performance of the cooperative relaying system. The proposed scheme achieves a substantial performance gain over the traditional DF relaying scheme without remapping/rearrangement technique in terms of BLock Error Rate (BLER).

In the work done in [147], P. Lin *et al.* propose an Opportunistic Driven Multiple Access (ODMA) scheme for downlink transmission in UMTS networks. The scheme is proposed to enhance the average transmission rate for UEs in the low bit transmission rate zone. The average transmission rate, data blocking probability, and resource channel utilization are used to measure the performance of ODMA and non-ODMA networks. Simulation results show that ODMA outperforms the non-ODMA networks. However, the authors reported slight QoS degradation in terms of blocking probability of networks.

To improve the UpLink (UL) spectrum efficiency and maximize the throughput of the cooperative communication aided LTE-A system, X. Zhang *et al.* [148] propose an optimal power allocation scheme for the sub-carriers at the UE and DF relay nodes. The achievable capacity of the UL SC-OFDMA system is derived using the Zero-Forcing (ZF) equalization and Minimum-Mean-Square-Error (MMSE) equalization at the relay node and eNodeB. The simulation results show a considerable improvement in system throughput. However, a joint optimization of power and sub-carrier allocations can deliver further improvement in spectrum efficiency for the proposed scheme.

To the best of our knowledge, there is no existing study on the performance gains of cooperative communication in LTE-A networks in terms of transmission throughput, channel resource utilization, and of data blocking probability (QoS). Furthermore, scheme on how to improve these performance metrics need to be proposed and analyzed. A performance evaluation analysis of these gains is required, hence, this is the primary aim of the study of this chapter.

4.3 System Model

This study considered a wireless networks with both cell-center and cell-edge UEs as shown in Figure 4.1. Based on the geographical distances/locations of the UEs from the DeNB, as shown in 4.1, the cell is divided into cell-center zone ($0 < \text{cell-center zone} \leq r$) and cell-edge zone ($r < \text{cell-edge zone} \leq R$), where r and R are the radii of inner circle and outer circle, respectively. The UEs in the cell-center zone are referred to cell-center UEs (UE5, UE3, and UEx), while the UEs in the cell-edge zone are referred to as cell-edge UEs (UE1, UE2, and UE4). The UEs within the cell-center zone are more likely to have excellent channel qualities and high SNR due to their relative proximity to the DeNB. This increases the chances of high data transmission rate and more resource allocation to UEs at the cell-center zone. The UEs at the cell-edge are more likely to experience poor channel quality due to their larger path-loss and interference. This network situation increases the likelihood of low data transmission rates, communication transmission outage and re-transmission, and less resource allocations for the UEs at the cell-edge zone.

This situation can lead to low average data transmission rate for the entire networks and hence poor wireless resource utilization for the networks. The LTE-A system supports link adaptation on wireless communication channels. Link adaptation allows the dynamic rate transmission using Adaptive Modulation and Coding (AMC) scheme based on the CQI's feedback. Before each transmission cycle, the DeNB broadcasts a known pilot signal within the networks. All the UEs within the DeNB's coverage area decode it and generate a list of CQI, which is sent as CQI's feedback to the DeNB.

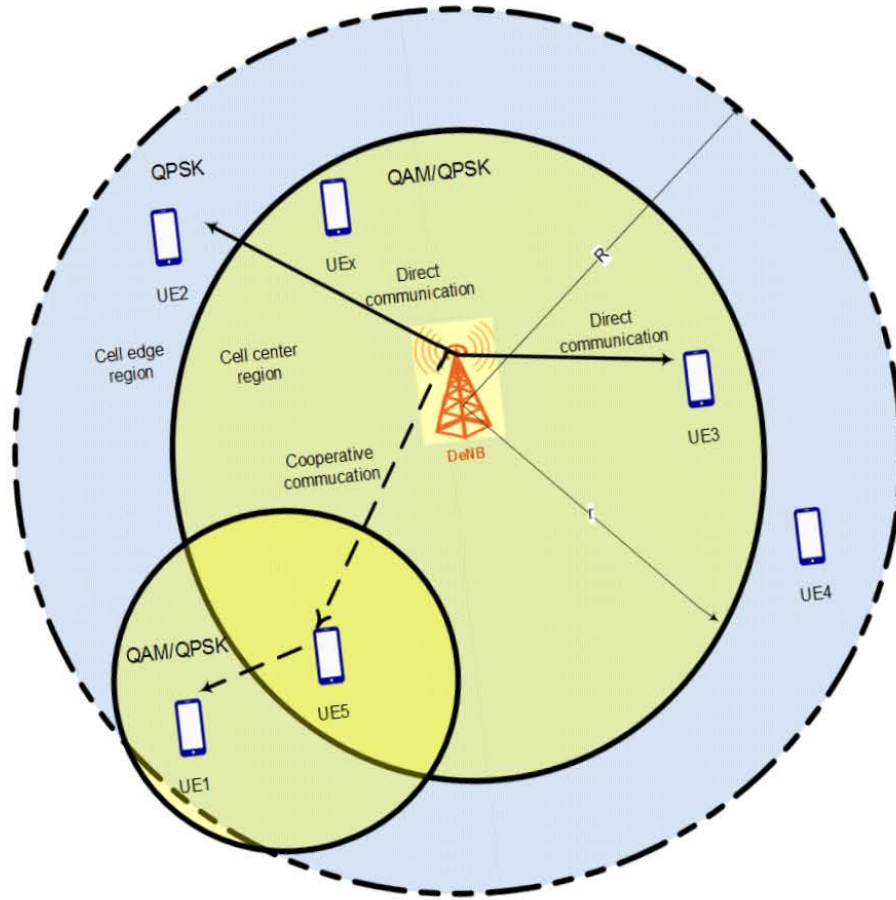


Figure 4.1: Buffered cooperative communication networks.

The OFDMA technology is a multiple access interface for LTE-A cellular networks. The DeNB in LTE-A assigns orthogonal OFDMA sub-carrier channels to UEs for transmission and reception. The use of orthogonal sub-carrier channels mitigates against intra-cell interference and improves network throughput performance. The LTE-A network offers huge transmission rate over its coverage area. LTE-A can provide downlink and uplink peak data rates of 3 Giga-bits per second (Gbps) and 1.5 Gbps, respectively [24]. OFDMA supports a set of variable rates of 6Mbps, 9Mbps, 12Mbps, 18Mbps, 24Mbps, 48Mbps, and 54Mbps. The LTE-A system can apply higher modulation schemes (16-QAM and 64-QAM)

on the good channel to achieve a reliably higher transmission rate [149]. For sub-carrier channels with poor channel quality and high noise level, the LTE-A system can apply lower modulation scheme (such as QPSK) to ensure a resilient/reliable data transmission; however at a relatively lower transmission rate [149]. The data transmission rate enhancement for cell-edge UEs will significantly improve the average data throughput and QoS of the networks. To achieve this objective, a buffered cooperative communication scheme based on LTE-A networks where UEs are buffered and cell-center UEs are opportunistically exploited to serve as cooperative relay communication nodes for other UEs within the cell-edge zone is proposed.

The wireless network of the proposed BCC system model in Figure 4.1 can support a amount of T data bit rate and has a finite buffer queue size of Q . Each UE in the cell network is required to register with the cell's DeNB and regularly send its CQI feedback to the DeNB. The DeNB can use the CQI feedback to map the UEs' distribution within the cell-center and cell-edge zones. UEs within the cell-edge (UE1, UE2, and UE4) will report low CQI feedback, while UEs in the cell-center (UE5, UE3, and UEx) will report high CQI feedback. Due to distance-dependant path-loss (path attenuation), UEs in the cell-edge zone experience relatively poor channel link to the DeNB compared to UEs in the cell-center zone. The UEs within the cell-center that have excellent channel link between the UE in the cell-edge, and the DeNB can assist cell-edge UEs with cooperative communication. In the network system model scenario is shown in Figure 4.1, the UE5 can serve as a cooperative relay node between UE1 and DeNB, also, UE3 can act as a cooperative relay node between

UE4 and the DeNB, while the UEx can act as cooperative relay node between UE2 and the DeNB. This increases the data transmission rate.

For UEs in the cell-edge requesting high data rate transmission, the UE sends its cell-edge identification (ID) and a sounding reference signal on a common Physical Broadcast Channel (PBCH). Neighboring UEs in the cell-center and the DeNB can measure the SNR of the sounding reference signals from the cell-edge UE to determine if the SNR of the sounding reference signal is equal or greater than the network preset threshold (τ). If the SNR of the sounding reference signal of the cell-edge UE as measured by the neighboring cell-center UEs is $\geq \tau$ and there is a cell-center UE that is willing to assist the cell-edge UE in cooperative communication, then the cooperative cell-center UE broadcast its cell-center ID and the cell-edge UE's ID to the DeNB, else no information is broadcast from the cell-center UEs to the DeNB.

The flowchart for the call admission control of UEs at the cell-edge zone for the BCC system is shown in Figure 4.2. When the DeNB receives the high data request from the cell-edge, one of the five possible events will occur:

- Cell-edge event 1: if the residual channel resource can support the high data rate transmission request by the cell-edge UE, and there is a willing cell-center UE to assist the cell-edge UE with cooperative communication and the buffer queue is empty, then the DeNB instructs the UEs to use a higher order modulation. The DeNB releases two high bit rate channels. One of the channels for high data rate transmission from the DeNB to the cooperating cell-center UE node and the other for high data rate transmission from the cooperating cell-center UE to the cell-edge UE.

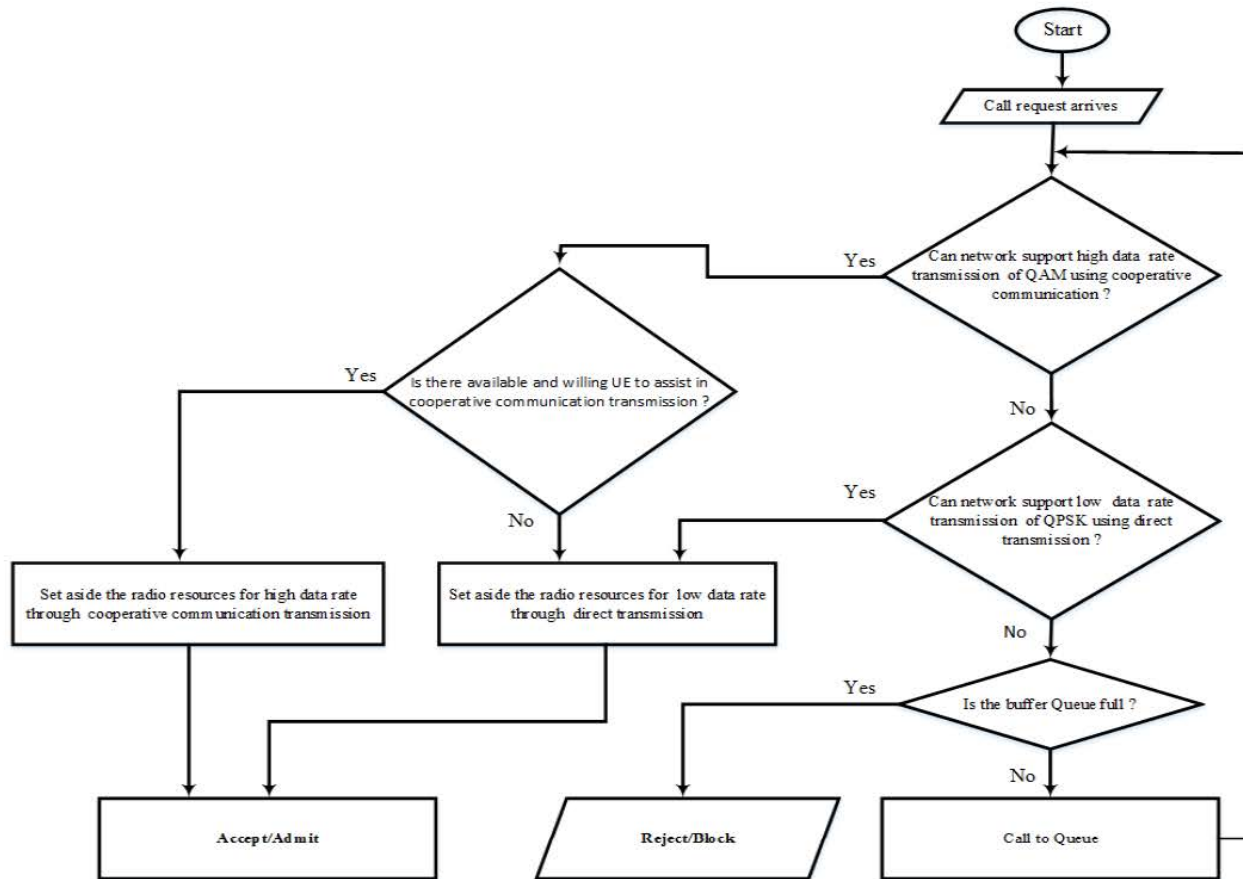


Figure 4.2: The flowchart of call admission control for UEs at the cell-edge zone for BCC system model.

- Cell-edge event 2: if the residual channel resource can support the high data rate transmission request by the cell-edge UE, and there is no willing cell-center UE to assist the cell-edge UE with cooperative communication and the buffer queue is empty, then the DeNB instructs the cell-edge UE to use low order modulation scheme such as QPSK. The DeNB releases the one low bit rate channel to the cell-edge UE for direct transmission.
- Cell-edge event 3: if the residual channel resource can only support low data rate transmission and the buffer queue is empty, then the DeNB instructs the cell-edge UE

to use low order modulation scheme (QPSK). The DeNB releases the one low bit rate channel to the cell-edge UE for direct transmission.

- Cell-edge event 4: if all the transmission channel resources are used and the buffer queue is not filled, then the cell-edge UE's request is queued in the buffer and served when any transmission channel resource is released.
- Cell-edge event 5: else if the buffer queue is filled, then the cell-edge UE's data transmission is blocked or dropped.

The flowchart for the call admission control of UEs at the cell-center zone for the BCC system is shown in Figure 4.3. For UEs in the cell-center zone requesting high data rate transmission from the DeNB, at the DeNB one of the four possible events will occur:

- Cell-center event 1: if the residual channel resource can support the high data rate transmission request and the buffer queue is empty, then the DeNB instructs the cell-center UE to use a high order modulation scheme such as QAM. The DeNB releases one high bit rate channel resource for direct transmission between the cell-center UE and DeNB.
- Cell-center event 2: if the residual channel resource can only support low data rate transmission and the buffer queue is empty, then the DeNB instructs the cell-center UE to use a low AMC scheme (QPSK). The DeNB releases one low bit rate channel for direct transmission between the DeNB and the cell-center UE.

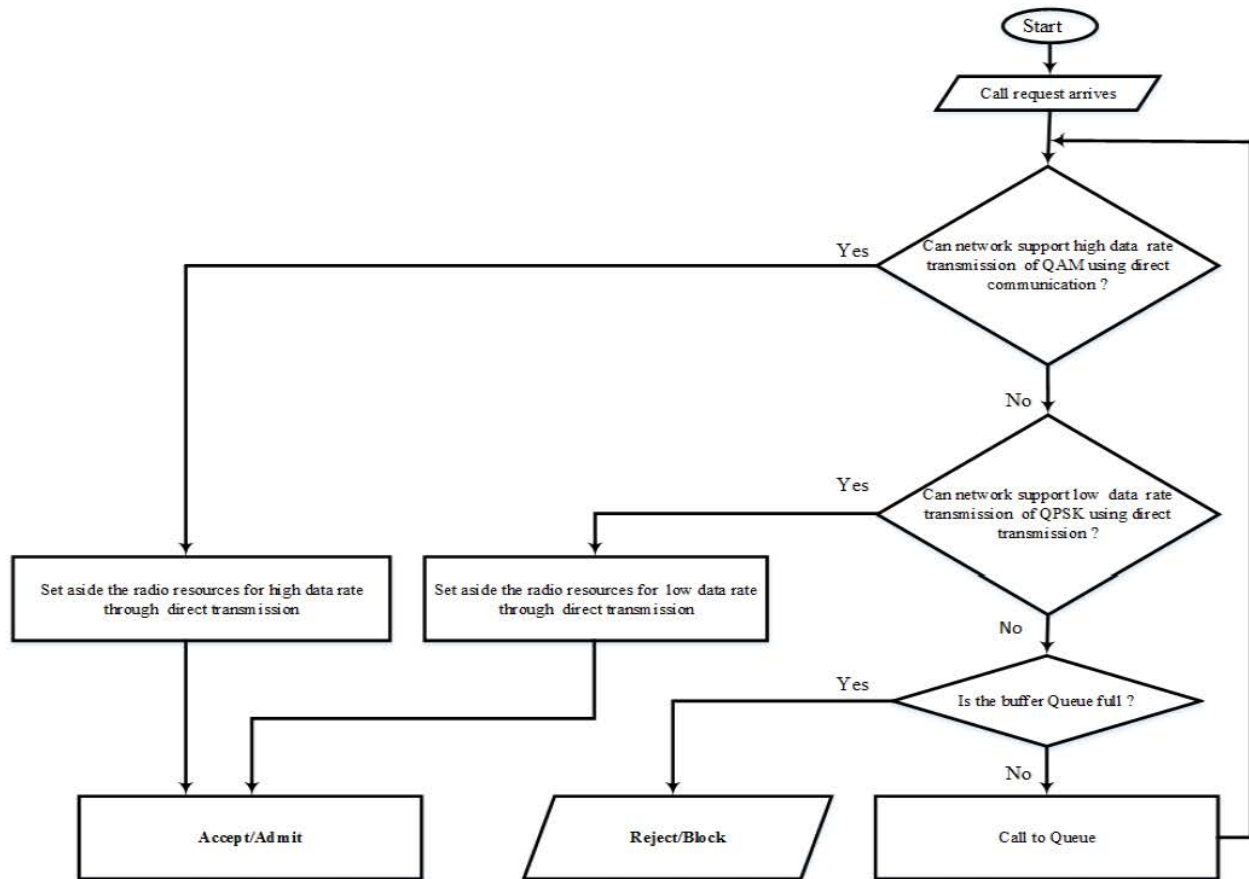


Figure 4.3: The flowchart for the call admission control of UEs at the cell-center zone for the BCC system model.

- Cell-center event 3: if all the transmission channel resources are used and the buffer queue is not filled, then the cell-center UE's request is queued in the buffer and served when any transmission channel resource is released.
- Cell-center event 4: else if the buffer queue is filled, then the cell-center UE's data transmission is dropped or blocked.

In the next section, the analysis of the framework of the BCC model is developed using Markov chain technique.

4.4 Numerical Analysis

In this section, the description of some of the necessary notations used, the relevant underlining assumptions, and the numerical analysis of the propose BCC scheme are provided.

4.4.1 Notation

The notation T denotes maximum bit rate capacity of the network and ϑ denotes the cell-center zone index. A summary of the important notations used in this chapter is shown in Table 4.1.

4.4.2 Assumptions

For the purpose of problem simplification, a circular network cell coverage with a DeNB located at its center is assumed. The cell is divided into two concentric cell (inner and outer concentric cell zones). The inner concentric cell coverage is referred to as the cell-center zone, and the outer concentric cell zone is referred to as the cell-edge zone. UEs are uniformly distributed over the cell-center and cell-edge zones coverage of the networks. A downlink transmission with no combination of both direct and cooperative communication transmissions is considered, hence no Maximum Ratio Combination (MRC) at the receivers. The UEs are uniformly distributed within the wireless network coverage.

Table 4.1: Summary of important symbols.

Symbol	Description
T_M	Bit rate achieved with QAM AMC scheme
T_K	Bit rate achieved with QPSK AMC scheme
R	Random variable
μ	The inverse mean packet size of exponential distribution of the random variable R .
ζ	Cell-edge zone index
λ	Data packet arrival rate from the entire networks
λ_C	Data packet arrival rate from the cell-center zone
λ_E	Data packet arrival rate from the cell-edge zone
Q	The buffer queue size
β_{cc}	The cooperative relay index of the cell-center UE.
β_{ncc}	The non-cooperative relay index of the cell-center UE.
\mathbf{S}	The Markov state space
\mathbf{S}_A	The active Markov state space
\mathbf{S}_B	The blocked Markov state space
\mathbf{S}_Q	The queued Markov state space
\mathbf{S}_{NQ}	The non-queued Markov state space
x	The number of data transmitted with QAM modulation scheme in direct transmission
y	The number of data transmitted with QPSK modulation scheme in direct transmission
z	The number of data transmitted with QAM modulation scheme using CC
q	The number of data in the buffer queue
$P_{x,y,z,q}$	The steady state probability of the network state (x, y, z, q)
P_A	The probability of the active states
P_B^{BCC}	The packet blocking probability of the BCC network
Υ_{av}^{BCC}	The average throughput of the BCC network
η^{BCC}	Radio resource utilization of BCC network

4.4.3 The BCC Analysis

In this section, the numerical analysis of the proposed BCC scheme, using Markov chain technique is presented. The performance of the BCC model is evaluated based on the average throughput, data blocking probability, and resource channel utilization as the performance metrics. For the system model presented in Figure 4.1. The cell-center zone (ϑ) and cell-edge

zone (ζ) indices are defined as:

$$\vartheta = \frac{r^2}{R^2} \quad \text{and} \quad (4.1)$$

$$\zeta = 1 - \frac{r^2}{R^2}. \quad (4.2)$$

The data packet arrival of UEs in the cell is assumed to follow a Poisson distribution, with data packet arrival rate, λ . Hence, the data packet arrival rate from the cell-center is:

$$\lambda_C = \lambda \times \vartheta, \quad (4.3)$$

while the data packet arrival rate from the cell-edge is

$$\lambda_E = \lambda \times \zeta. \quad (4.4)$$

Let T_M and T_K be the data rate achieved by using QAM and QPSK, respectively. Let the size of data packet from the UEs in the cellular network be denoted by the random variable R , with an exponential distribution of mean packet size $\frac{1}{\mu}$. Therefore, the transmission times required to transmit the random variable, R using QAM and QPSK modulation schemes are $\frac{R}{T_M}$ and $\frac{R}{T_K}$, respectively. The random transmission times of QAM and QPSK symbols also follow an exponential distribution with mean $\frac{1}{\mu T_M}$ and $\frac{1}{\mu T_K}$, respectively. For LTE-A system a Maximum Transmission Unit (MTU) data packet size of 10kBytes is reported [150].

The UEs in the cell-edge can not always be guaranteed of access to high data rate transmission through cooperative communication, even when there is enough available radio channel resource to support it. The probability that the cell-center UE will assist the cell-edge UE in cooperative communication depends on the availability of cell-center UEs and their readiness to act as relays. A cell-center UE that is running low on battery power will be most likely unwilling to serve as a cooperative relay for any cell-edge UE. Let β_{cc} and β_{ncc}

denote the cell-center UE's cooperative and non-cooperative relay indice, respectively.

$$\beta_{cc} + \beta_{ncc} = 1. \quad (4.5)$$

A possible method that can be used to influence β_{cc} is for the DeNB to assign a token to a cell-center UE, each time it willingly engage in cooperative communication. The UE's priority increases as it acquires more tokens from the DeNB. The increased UE's priority enables the UE to receive greater consideration during DeNB resource scheduling decisions.

Let the state (x, y, z, q) denote a scenario within the BCC wireless networks system model. x and y indicate the number of data transmitted in direct transmission using QAM and QPSK modulation schemes, respectively. z is the number of data transmitted during cooperative communication using QAM. The q is the size of the buffered data. The Markov state space, \mathbf{S} for BCC scheme is defined as:

$$\mathbf{S} = \{(x, y, z, q) | (q = 0, 0 \leq xT_M + yT_K + 2zT_M \leq T) \cup (0 < q \leq Q, xT_M + yT_K + 2zT_M = T)\}, \quad (4.6)$$

where $0 \leq x \leq \lfloor \frac{T}{T_M} \rfloor$, $0 \leq y \leq \lfloor \frac{T}{T_K} \rfloor$, $0 \leq z \leq \lfloor \frac{T}{2T_M} \rfloor$, $0 \leq q \leq Q$, and $(xT_M + yT_K + 2zT_M)$ are the transmission rates for the network at the network state (x, y, z, q) . From the Markov chain analysis of the BCC scheme in Figure 4.4 through 4.7, the steady state probability $P_{(x,y,z,q)}$ can be derived from the transitions through all possible states.

Transition through states $(x - 1, y, z, q) \Leftrightarrow (x, y, z, q)$ and $(x, y, z, q) \Leftrightarrow (x + 1, y, z, q)$ created by using QAM in direct transmission of data

The cell-center event 1 is a direct transmission of data using QAM, when the network can support high data rate transmission. This transmission only occurs if the conditions; $[(x - 1)T_M + yT_K + 2zT_M] \leq (T - T_M)$, $(y, z) \geq 0$, $x > 0$, $q \neq 0$] and $[(xT_M + yT_K + 2zT_M) \leq$

$(T - T_M), (x, y, z) \geq 0, q \neq 0]$ are satisfied, where $(T - T_M)$ is the transmission rate of the network, when the network supports a high data rate using QAM for direct transmission. If the network is either in state $(x - 1, y, z, q)$ or state (x, y, z, q) , then the network state makes a forward transition at the rate of λ_C to state (x, y, z, q) or state $(x + 1, y, z, q)$, respectively.

After the completion of data transmission, the network state makes a backward transition from the state (x, y, z, q) or state $(x + 1, y, z, q)$ to state $(x - 1, y, z, q)$ at the rate of $x\mu T_M$ or state (x, y, z, q) at the rate of $(x + 1)\mu T_M$, respectively. The network state transition diagram is shown in Figure 4.4.

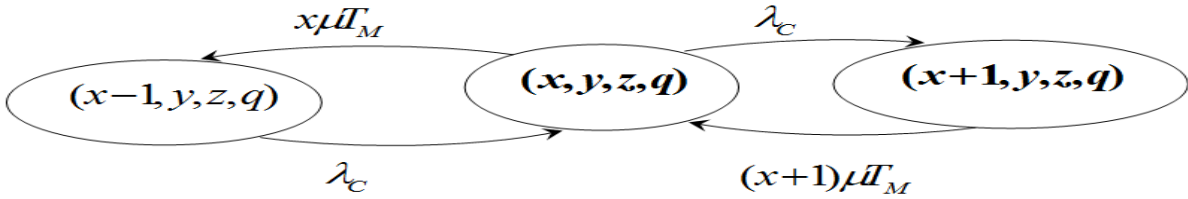


Figure 4.4: The network state transitions for $(x - 1, y, z, q) \Leftrightarrow (x, y, z, q)$ and $(x, y, z, q) \Leftrightarrow (x + 1, y, z, q)$.

The balance equation for this event is derived from the network state transition diagram as:

$$[\lambda_C + x\mu T_M]P_{(x,y,z,q)} = \lambda_C P_{(x-1,y,z,q)} + (x + 1)\mu T_M P_{(x+1,y,z,q)}. \quad (4.7)$$

Transition through states $(x, y - 1, z, q) \Leftrightarrow (x, y, z, q)$ and $(x, y, z, q) \Leftrightarrow (x, y + 1, z, q)$ created by using QPSK in direct transmission of data

The network state transition created in the process of direct transmission of data using QPSK AMC scheme can occur under the following network cell events: cell-center event 2, cell-edge events 2, and 3.

- The cell-center event 2 is a direct transmission of data using QPSK coding for cell-center UE demanding high data rate transmission, when the network only has the resource to support QPSK data rate. This transmission occurs if the conditions; $[(T - T_M) < (xT_M + (y - 1)T_K + 2zT_M) \leq (T - T_K), (x, z) \leq 0, y > 0, q \neq 0]$ and $[(T - T_M) < (xT_M + yT_K + 2zT_M) \leq (T - T_K), (x, y, z) \geq 0, q \neq 0]$ are satisfied, where $(T - T_K)$ is the network transmission rate, when the network supports a low data rate using QPSK for direct transmission. If the network is either in state $(x, y - 1, z, q)$ or state (x, y, z, q) , then the network state makes a forward transition at the rate of λ_C to state (x, y, z, q) or state $(x, y + 1, z, q)$.
- The cell-edge event 2 is a direct transmission of data that occurs when there is enough channel resource to support cell-edge UE's high data rate request using QAM; however, when there is no available or willing cooperative cell-center UE node to assist with cooperative communication. This transmission occurs if the conditions; $[(xT_M + (y - 1)T_K + 2zT_M) \leq (T - 2T_M), (x, z) \leq 0, y > 0, q \neq 0]$ and $[(xT_M + yT_K + 2zT_M) \leq (T - 2T_M), (x, y, z) \geq 0, q \neq 0]$ are satisfied. The term $(T - 2T_M)$ is the network transmission rate and if a high data rate using cooperative communication transmission is to be supported by the network. If the network is either in state $(x, y - 1, z, q)$ or state (x, y, z, q) , then the network state makes a forward transition to state (x, y, z, q) or state $(x, y + 1, z, q)$, respectively at rate $\lambda_E \beta_{ncc}$.
- The cell-edge event 3 is a direct transmission of data that occurs when the network only have a enough resource to support QPSK rate. This transmission occurs if the

conditions; $[(T - 2T_M) < (xT_M + (y - 1)T_K + 2zT_M) \leq (T - T_K), (x, z) \geq 0, y > 0, q \neq 0]$ and $[(T - 2T_M) < (xT_M + yT_K + 2zT_M) \leq (T - T_K), (x, y, z) \geq 0, q \neq 0]$ are satisfied. If the network is either in state $(x, y - 1, z, q)$ or state (x, y, z, q) , then the network state makes a forward transition to state (x, y, z, q) or state $(x, y + 1, z, q)$, respectively at rate λ_E .

After completing the data transmission, the network state makes a backward transition from the state (x, y, z, q) or state $(x, y + 1, z, q)$ to state $(x, y - 1, z, q)$ at the rate of $y\mu T_K$ or state (x, y, z, q) at the rate of $(y + 1)\mu T_K$, respectively. The network state transition diagram is shown in Figure 4.5.

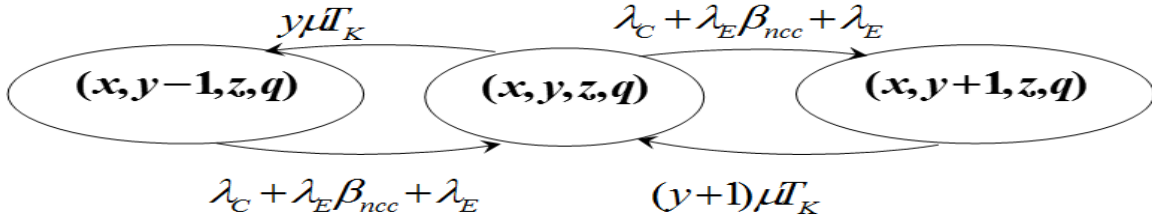


Figure 4.5: The network state transitions for $(x, y - 1, z, q) \Leftrightarrow (x, y, z, q)$ and $(x, y, z, q) \Leftrightarrow (x, y + 1, z, q)$.

The balance equation for these events is obtained from the network state transition diagram as:

$$[\lambda_C + \lambda_E\beta_{cc} + \lambda_E + y\mu T_K]P_{(x,y,z,q)} = [\lambda_C + \beta_{cc}\lambda_E + \lambda_E]P_{(x,y-1,z,q)} + (y+1)\mu T_K P_{(x,y+1,z,q)}. \quad (4.8)$$

Transition through states $(x, y, z - 1, q) \Leftrightarrow (x, y, z, q)$ and $(x, y, z, q) \Leftrightarrow (x, y, z + 1, q)$ created by using QAM in cooperative communication transmission of data

The cell-edge event 1 is a cooperative communication transmission of data using QAM, when the network can support high data rate transmission, and there is an available and willing cell-center UE to assist in the cooperative relaying of cell-edge UE's data at high bit rate. This transmission only occurs if the conditions; $[(T_M + yT_K + 2(z - 1)T_M) \leq (T - 2T_M), (x, y) \geq 0, z > 0, q \neq 0]$ and $[(xT_M + yT_K + 2zT_M) \leq (T - 2T_M), (x, y, z) \geq 0, q \neq 0]$ are satisfied. If the network is either in state $(x, y, z - 1, q)$ or state (x, y, z, q) , then the network state makes a forward transition to state (x, y, z, q) or state $(x, y, z + 1, q)$, respectively at rate $\lambda_E \beta_{cc}$.

After the completion of the data transmission, the network state makes a backward transition from the state (x, y, z, q) or state $(x, y, z + 1, q)$ to state $(x, y, z - 1, q)$ at the rate of $z\mu T_M$ or state (x, y, z, q) at the rate of $(z + 1)\mu T_M$, respectively. The network state transition diagram is shown in Figure 4.6.

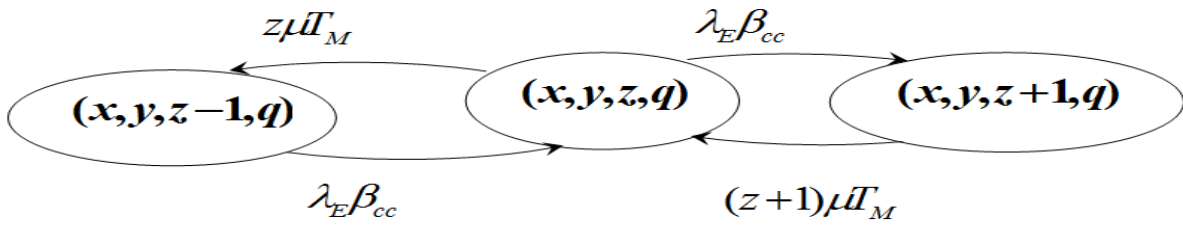


Figure 4.6: The network state transitions for $(x, y, z - 1, q) \Leftrightarrow (x, y, z, q)$ and $(x, y, z, q) \Leftrightarrow (x, y, z + 1, q)$.

The balance equation for this event is defined from the network state transition diagram as:

$$[\lambda_E \beta_{ncc} + z \mu T_M] P_{(x,y,z,q)} = \lambda_E \beta_{ncc} P_{(x,y,z-1,q)} + (z+1) \mu T_M P_{(x,y,z+1,q)}. \quad (4.9)$$

Transition through states $(x, y, z, q-1) \Leftrightarrow (x, y, z, q)$ and $(x, y, z, q) \Leftrightarrow (x, y, z, q+1)$ created by buffering of data

The network state can transit into, within and out of the buffer queue. The network state transition occur under the three following concurrent conditions; when the network is currently supporting total data transmission rate capacity T , there is data transmission request from the UEs within the network cell's coverage zone (cell-center and cell-edge zones) and while the buffer queue is not filled. The cell-center event 3 and cell-edge event 4 generate these network state transitions. These transitions satisfy the conditions; $[(T_M + yT_K + 2zT_M = T), (x, y, z) \geq 0, q > 0]$ and $[(xT_M + yT_K + 2zT_M = T), (x, y, z) \geq 0, (0 \leq q < Q)]$. If the network is either in state $(x, y, z, q-1)$ or (x, y, z, q) , then the network state makes a forward transition to state (x, y, z, q) or $(x, y, z, q+1)$, respectively at the rate $\lambda(\lambda_C + \lambda_E)$.

After the completion of the data transmission, a queued data transmission request is pulled from the buffer queue and served on by the DeNB. Hence, the network sate makes a backward transition from the state (x, y, z, q) or $(x, y, z, q+1)$ to state $(x, y, z, q-1)$ or (x, y, z, q) , respectively at the rate of $(xT_M + yT_K + zT_M) \mu T_M$. The network state transition diagram is shown in Figure 4.7.

The balance equation for this event is given from the network state transition diagram as:

$$[\lambda + (xT_M + yT_K + zT_M) \mu] P_{(x,y,z,q)} = \lambda P_{(x,y,z,q-1)} + (xT_M + yT_K + zT_M) \mu P_{(x,y,z,q+1)}. \quad (4.10)$$

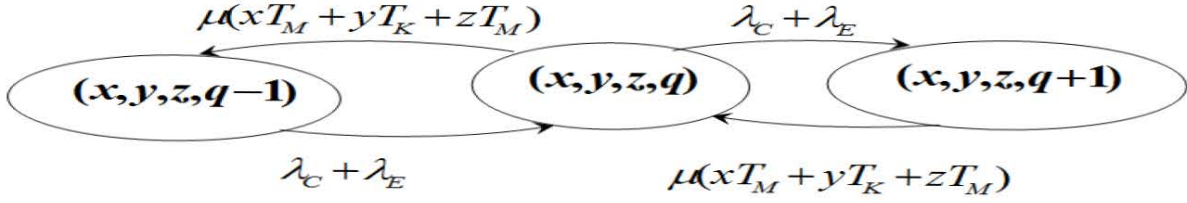


Figure 4.7: The network state transitions for $(x, y, z, q - 1) \Leftrightarrow (x, y, z, q)$ and $(x, y, z, q) \Leftrightarrow (x, y, z, q + 1)$.

The steady state probability, $P_{x,y,z,q}$ solution is obtained from the Equations (4.7)-(4.10), using the Successive Over-Relaxation (SOR) technique. The SOR is a popular iterative numerical method [136]. The over-successive relaxation factor, w controls the speed of convergence of the solution for $P_{(x,y,z,q)}$, where $w \in (0, 2)$. The w is estimated as stated in Section 3.4.2.

The wireless network performance metrics: average throughput, blocking probability, and radio resource channel utilization are used to evaluate the performance of the BCC scheme. These performance metrics are derived from the steady state probability obtained from the numerical iterative solution of the balance state equations. To obtain the blocking probability, the blocked data state space, \mathbf{S}_B with data block state $(x^*, y^*, z^*, q^*) \in \mathbf{S}_B$ is defined, such that $\mathbf{S}_B \in (\mathbf{S} | xT_M + yT_K + 2zT_M = T, q = Q)$. Hence, the data blocking probability P_B^{BCC} is calculated as:

$$P_B^{BCC} = \sum_{(x^*, y^*, z^*, q^*) \in \mathbf{S}_B} P_{(x^*, y^*, z^*, q^*)}. \quad (4.11)$$

To evaluate the average throughput of the network, the active state space, \mathbf{S}_A of the network, with active state $(\tilde{x}, \tilde{y}, \tilde{z}, \tilde{q}) \in \mathbf{S}_A$ is defined, such that $\mathbf{S}_A \in (\mathbf{S} - (0, 0, 0, 0))$. The active states probability, P_A is obtained, where $P_A = 1 - P_{(0,0,0,0)}$.

Therefore, the average throughput, Υ_{av}^{BCC} is obtained as:

$$\Upsilon_{av}^{BCC} = \frac{1}{P_A} \sum_{(\tilde{x}, \tilde{y}, \tilde{z}, \tilde{q}) \in \mathbf{S}_A} \frac{(\tilde{x}T_M + \tilde{y}T_K + 2\tilde{z}T_M)P_{(\tilde{x}, \tilde{y}, \tilde{z}, \tilde{q})}}{(\tilde{x} + \tilde{y} + \tilde{z})}. \quad (4.12)$$

To compute the radio resource utilization, the non-queued state space, \mathbf{S}_{NQ} , with non-queued state $(\dot{x}, \dot{y}, \dot{z}, \dot{q}) \in \mathbf{S}_{NQ}$ is defined, such that $\mathbf{S}_{NQ} \in (\mathbf{S} | xT_M + yT_K + 2zT_M \leq T, q \not\leq 0)$. Also, the queued state space \mathbf{S}_Q , with queued state $(\ddot{x}, \ddot{y}, \ddot{z}, \ddot{q}) \in \mathbf{S}_Q$ is defined, such that $\mathbf{S}_Q \in (\mathbf{S} | xT_M + yT_K + 2zT_M = T, 0 < q \leq Q)$. Therefore, the radio resource utilization, η^{BCC} is derived as:

$$\eta^{BCC} = \frac{1}{T} \sum_{(\dot{x}, \dot{y}, \dot{z}, \dot{q}) \in \mathbf{S}_{NQ}} (\dot{x}T_M + \dot{y}T_K + 2\dot{z}T_M)P_{(\dot{x}, \dot{y}, \dot{z}, \dot{q})} + \sum_{(\ddot{x}, \ddot{y}, \ddot{z}, \ddot{q}) \in \mathbf{S}_Q} P_{(\ddot{x}, \ddot{y}, \ddot{z}, \ddot{q})}. \quad (4.13)$$

In Section 4.5, the performance of our proposed BCC scheme is evaluated and compared with the NBCC scheme.

4.5 Results and Discussion

As highlighted in the previous sections, different network variables can affect the wireless network system performance. Some of such network variables include the data packet arrival rate (λ), cell-center zone index (ϑ), and cell-center UE cooperative relay index (β_{cc}). The effect of each of these network variables on the networks' performance metrics, for a given

buffer queue size are investigated. In this simulations, both the buffer queue size and the packet arrival rate, λ are normalized with the average packet size $\frac{1}{\mu}$. The normalized packet arrival rate is varied from 40/sec to 60/sec. The β_{cc} is varied from 0 to 1. The rest of the simulation parameters are given in Table 4.2.

Table 4.2: Simulation parameters.

Parameter	Value
T	1 Gbps
T_M	54 Mbps (64-QAM, 3/4 convolution code)
T_K	12 Mbps (QPSK, 1/2 convolution code)
Q	(5, 15)
ϑ	varied between 0.1 and 0.9
$\frac{1}{\mu}$	390 Bytes
w	0.93

4.5.1 Impact of packet arrival rate (λ) on the performance metrics

In Figures 4.8-4.10, the effect of varying packet arrival rate (λ) on the system performance metrics is studied. In this investigation, $\vartheta = 0.20$ and $\beta_{cc} = 0.85$. In Figure 4.8, the BCC scheme provides higher average throughput than NBCC, as it allows the DeNB more opportunity of assigning increasing data rates to more UEs. Hence, the average throughput of BCC outperforms that of NBCC for increasing value of Q . With increasing λ , there is a relative higher and increasing number of UEs at cell-edge zone than the UEs at cell-center zone. The cell-edge zone delivers relatively lesser average throughput/UE/radio channel resources compared to the cell-center zone, hence, the average throughput decreases with increasing values of cell-edge UEs for both schemes.

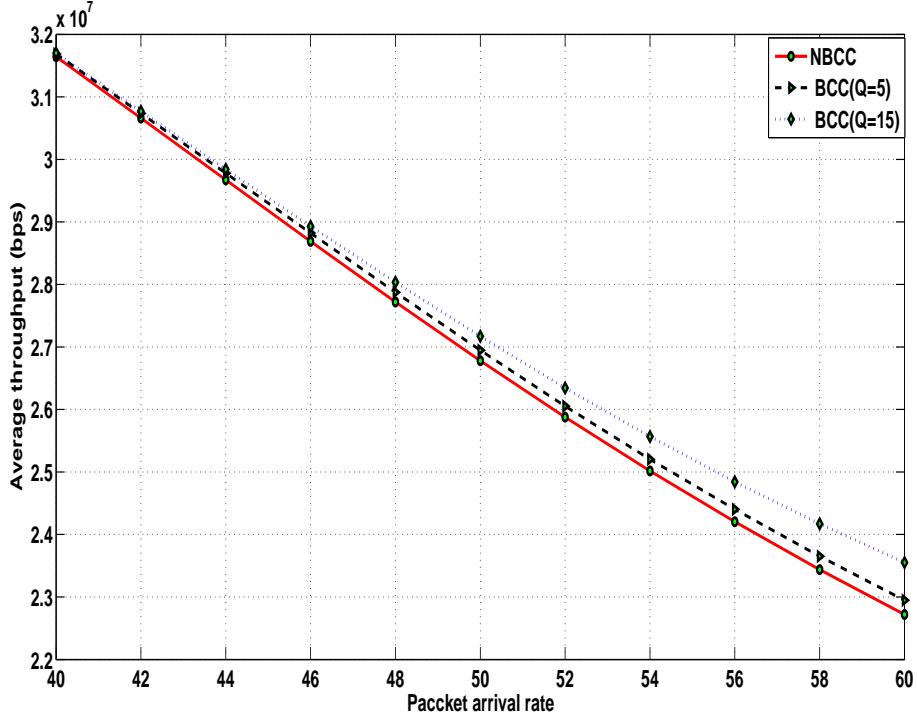


Figure 4.8: Average throughput as a function of packet arrival rate (λ).

Figure 4.9 presents the blocking probability performance, our proposed BCC scheme outperformed the blocking probability performance of the NBCC scheme, since some of the packets can be admitted and made to wait in the buffer without these packets being dropped or blocked. The performance gap of BCC over NBCC is higher at lower λ , this is due to the fact that BCC scheme allows more UEs to be admitted into the network, hence, allowing them opportunity to access and utilize the relatively higher amount of unassigned radio resources at a lower λ . The blocking probability of the network increases monotonously with λ , this is due to the fact that as the number of UEs increases, more radio resources are used up/depleted. This increases the probability of UEs' data packet being blocked. The radio resource utilization result is presented in Figure 4.10. With increasing λ more

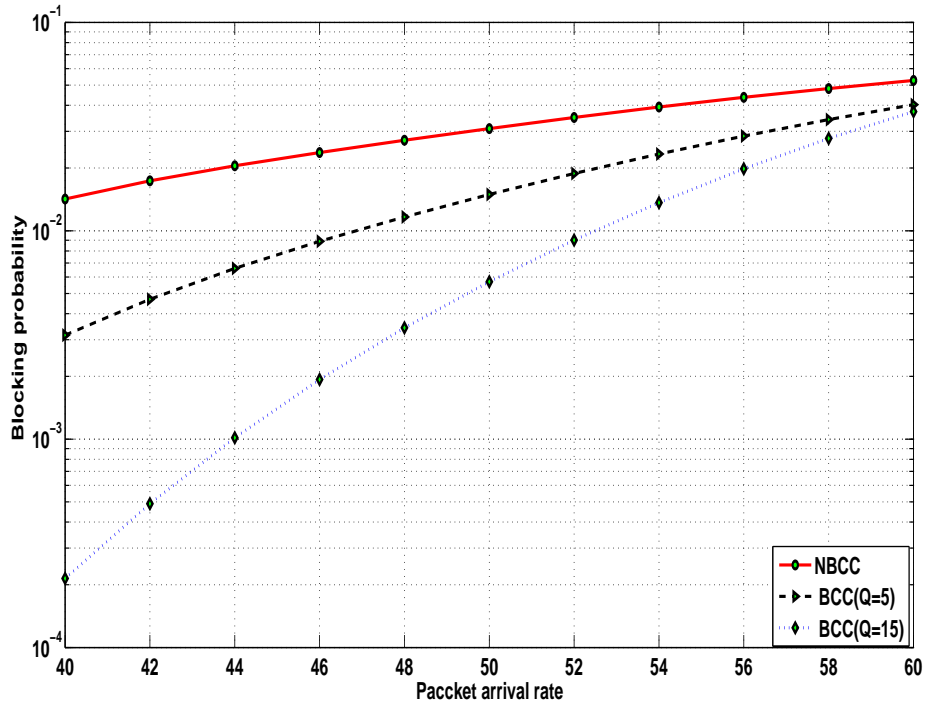


Figure 4.9: Blocking probability as a function of packet arrival rate (λ).

UEs are available to utilize the radio resources. Hence, radio resource utilization increases with the packet arrival rate. The BCC, with increasing Q , provides more UEs access to the radio resource channels than the NBCC. Hence, the proposed BCC enhances radio resource utilization.

For an increasing Q , the maximum performance gain of BCC scheme over NBCC scheme for average throughput is 3.7%, blocking probability is 98.5%, and radio resource utilization is 7.6%. The buffer queue mechanism has a relative tremendous impact on the blocking probability compared to the average throughput and resource utilization parameters. For any UE admitted into the buffer, regardless of whether the UE is assigned a low bit rate using QPSK modulation or a high bit rate using 64-QAM, the the packet request of admitted

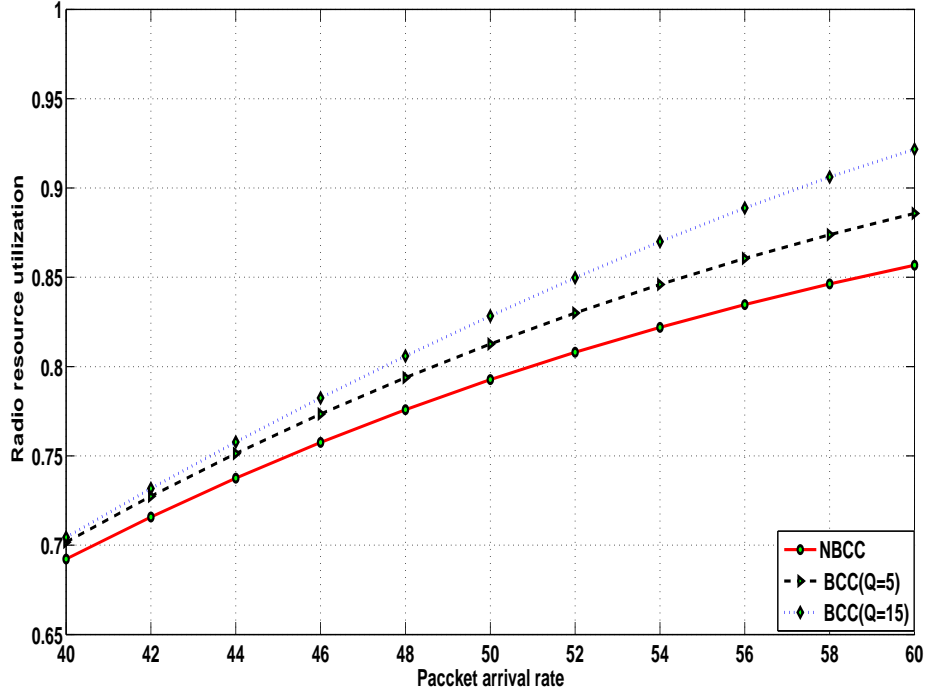


Figure 4.10: Radio resource utilization as a function of packet arrival rate (λ).

buffered UE serves and counts equally as an unblocked call, hence the blocking probability of network is improved buffered UEs, equally. However, the impact of the buffered UE on average throughput and resource utilization parameter is much significant, if high bit rate is assigned to UE. For given cell-center zone index, ϑ , and assuming any given cell-center UE will help cell-edge UE in cooperative communication (i.e., $\beta_{cc} = 1$), the network the relative percentage of UEs that can be assigned high bit rate is about 25% $\left(\frac{\frac{1}{T_M} + \frac{1}{2T_M}}{\frac{1}{T_K} + \frac{1}{T_M} + \frac{1}{2T_M}} \right)$. Hence, about 25% of the buffered UEs will likely provide a relative higher improvement to the average throughput and resource utilization through high bit rate assignment compared to the unbuffered UEs in the NBCC scheme. For the blocking probability, the admitted UEs into the buffer serves as an unblocked call request (significantly reducing the blocking

probability), irrespective whether the UE admitted into the buffer is assigned a low bit rate or a high bit rate, unlike in an unbuffered UE's requests in NBCC scheme.

4.5.2 The impact of cell-center zone index (ϑ) on the Performance metrics

In Figure 4.11 through Figure 4.13, the effect of varying cell-center zone index, ϑ on the network system performance metrics; at $\beta_{cc} = 0.85$ and $\lambda = 60/\text{sec}$ is examined. As depicted in the result in Figure 4.11, increasing the ϑ leads to higher average network throughput. As

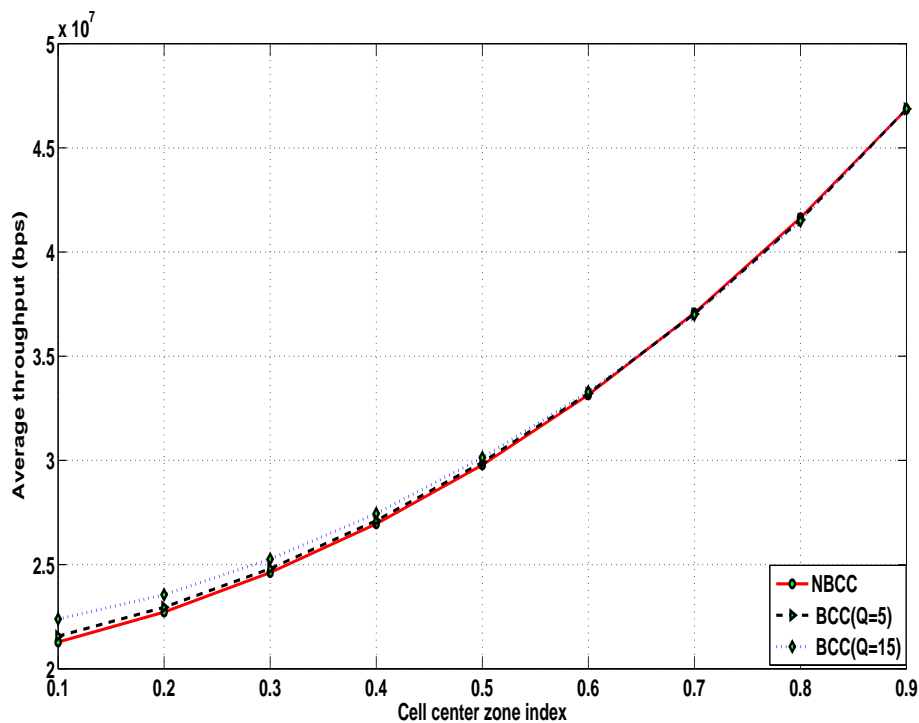


Figure 4.11: Average throughput as a function of cell-center zone index (ϑ).

the ϑ increases, the proportion of UE data packet request from the cell-center zone at the DeNB also increases. Therefore, increased average throughput can be delivered using higher

order AMC in direct transmission. The average throughput of BCC is higher than that of NBCC at low ϑ . At low ϑ , there is a higher proportion of cell-edge UEs in the network. Hence, more cell-edge UEs can be buffered. The buffered cell-edge UEs contribute more to the increasing network's average throughput when they are admitted into the network. However, as ϑ increases the proportion of cell-edge UEs in the buffer decreases, and hence, the contribution of buffered cell-edge UEs to the average network throughput diminishes. A maximum average throughput performance gain of 5.2% is at for $Q = 15$.

As shown in Figure 4.12, as the ϑ increases, the blocking probability decreases. The increasing ϑ increases the chances of more direct transmissions and hence resulting in the consumption of less radio channel resources within the networks. This therefore, increases

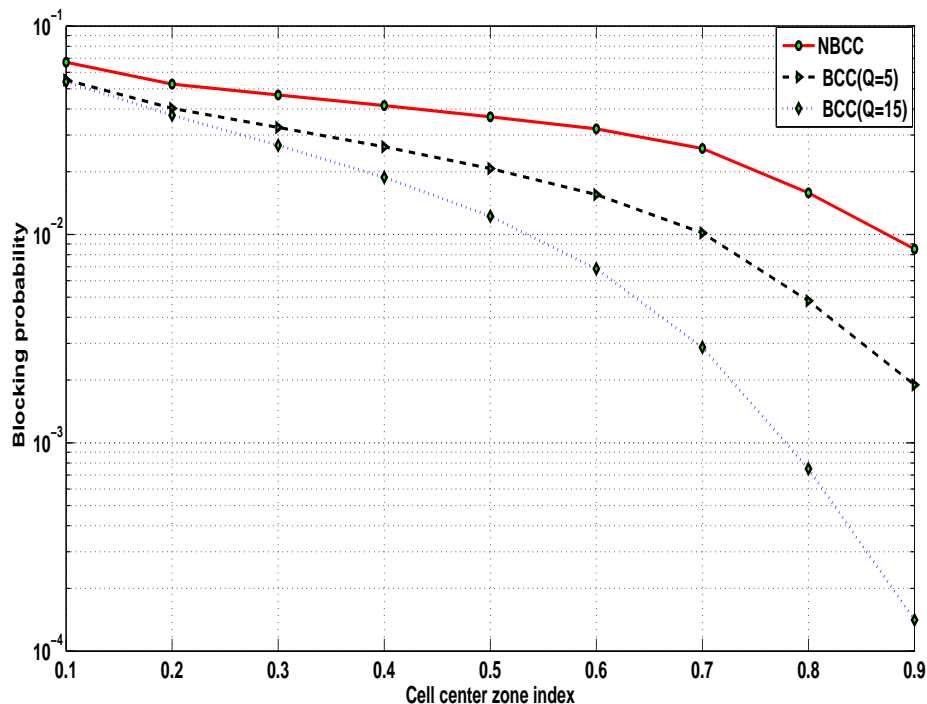


Figure 4.12: Blocking probability as a function of cell-center zone index (ϑ).

the probability of UEs accessing the the unconsumed radio resources. This translates to increasing probability of admission of UEs into the network. Hence, this reduces the blocking probability of the networks. The blocking probability reduces further with increasing buffer queue size. Furthermore, the higher queue size increases the number of packet request that can get admitted into the network and be served. Hence, the blocking probability reduces with increase in buffer queue size.

In Figure 4.13 increasing ϑ reduces the chances of UEs exploiting the cooperative communication and hence leads to lower radio resource channel utilization. However, the

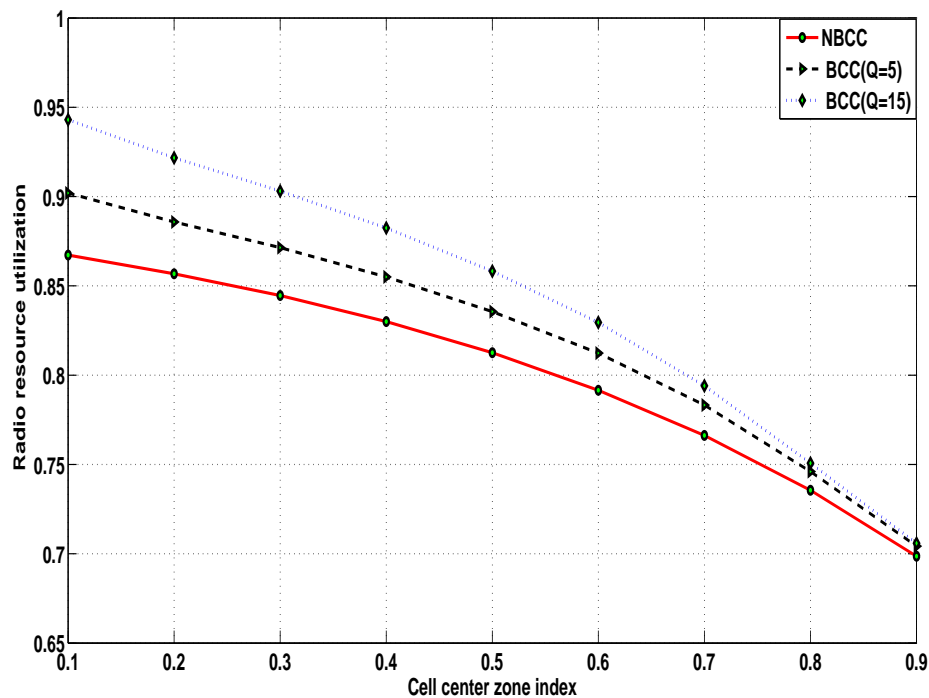


Figure 4.13: Radio resource utilization as a function of cell-center zone index (ϑ).

radio resource utilization of BCC with increasing Q shows increasing out-performance over NBC as at lower ϑ as shown in Figure 4.13. For increasing Q , the maximum performance

gain of BCC scheme over NBCC scheme for average throughput is 5.2%, blocking probability is 98.3%, and radio resource utilization is 8.7%. These results show that the buffering mechanism enhances the QoS (blocking probability), average throughput, and radio resource utilization performance.

4.5.3 The impact of UE cooperative relay index (β_{cc}) on the Performance metrics

Finally in the simulations, the impact of varying UE cooperative relay index (β_{cc}) on the system performance metrics is also investigated. In the investigation $T = 720$ Mbps, $\vartheta = 0.85$, and $\lambda = 60$ /sec. It can be seen from the Figures 4.14, 4.15, and 4.16 the performance

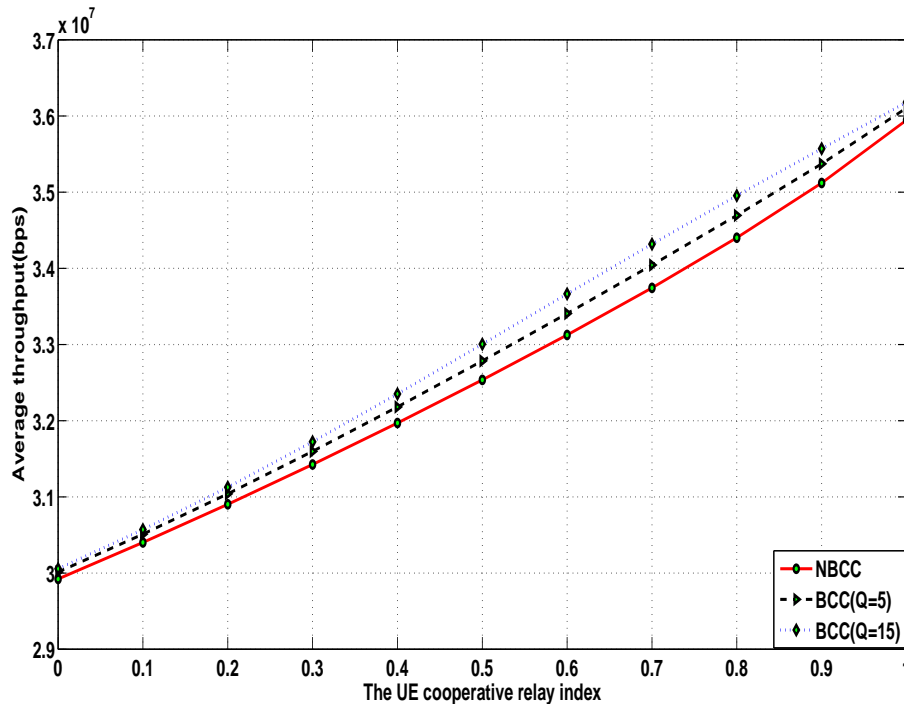


Figure 4.14: Average throughput as a function of UE cooperative relay index (β_{cc}).

results presented show that the proposed BCC outperforms NBCC in terms of the average throughput, blocking probability, and network radio resource utilization. Since, UE's packets are accumulated at the buffer queue, and these packets are dispatched from the buffer as soon as any resource channel is released by the DeNB, the performance improvements are observed for increasing Q and β_{cc} .

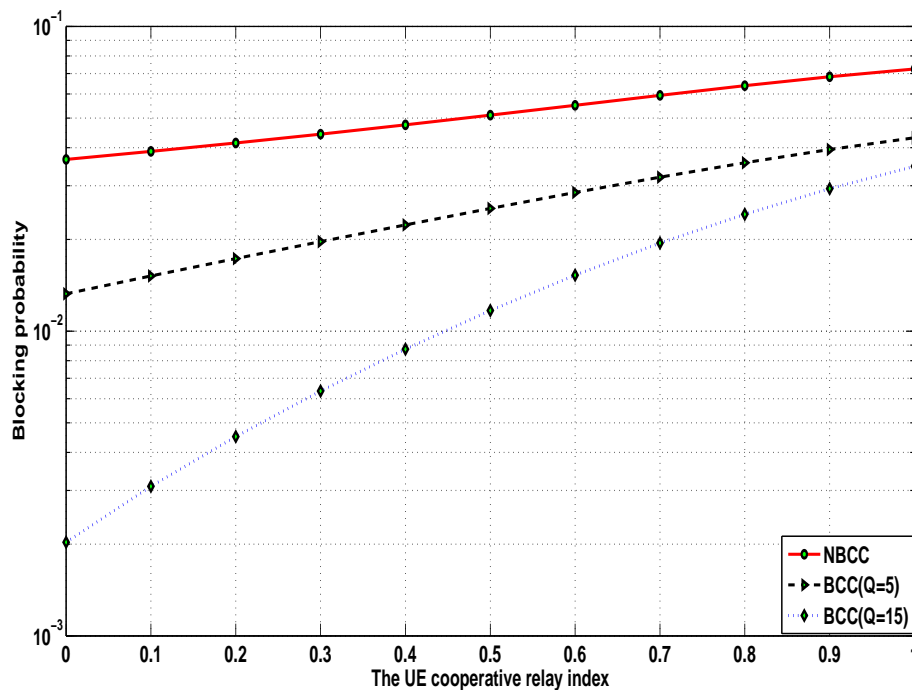


Figure 4.15: Blocking probability as a function of UE cooperative relay index (β_{cc}).

Furthermore, the performance gap of the BCC scheme over the NBCC scheme increases with buffer queue size. In Figure 4.14 and Figure 4.15 as β_{cc} increase, the UEs in the cell-edge are more likely to adopt a high order modulation scheme through cooperative communication for high bit rate. This results to the utilization of more radio resources. Therefore, the average throughput and radio resource utilization increases. In Figure 4.16, an increase

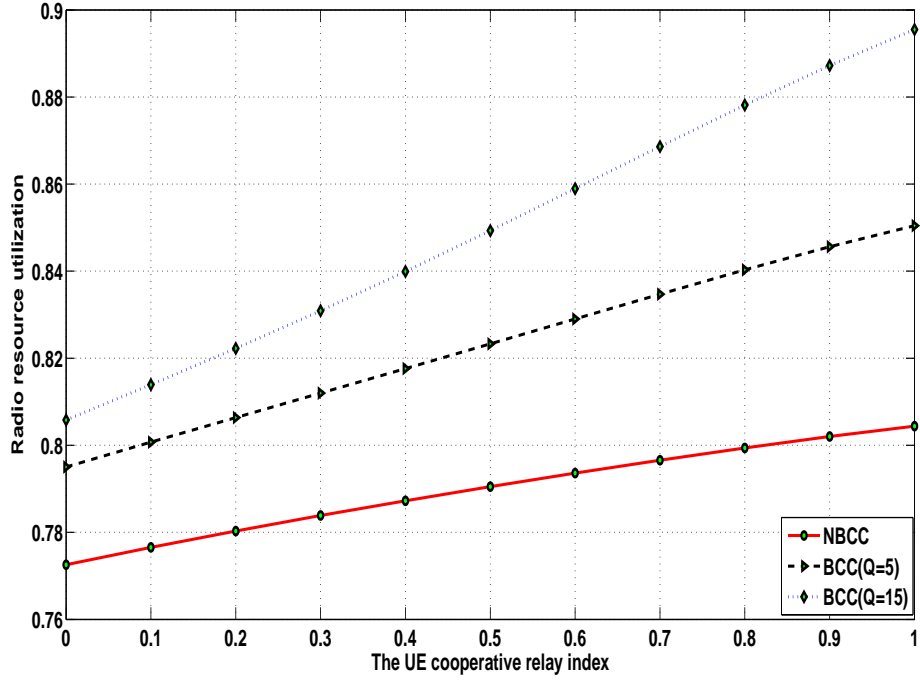


Figure 4.16: Radio resource utilization as a function of UE cooperative relay index (β_{cc}).

in β_{cc} increases the likelihood of using more radio resources. This means that additional radio resources are less available, and new packets are more likely to be blocked; therefore, the blocking probability increases. However, BCC scheme provides more opportunities for UEs to get serviced by waiting in the buffer queue. This enables UEs using the BCC scheme to have lower packet blocking probability than those using the NBCC scheme. A reduced packet blocking probability enhances UEs' QoS. For a maximum Q size of 15, the optimal performance gain of BCC scheme over NBCC scheme for average throughput is 1.7%, blocking probability is 94.5%, and radio resource utilization is 11.3%.

4.6 Conclusion

In this chapter, the network performance enhancement problem for cell-center and cell-edge UEs in the wireless communication networks using BCC scheme is analyzed. An analytical framework for the proposed BCC scheme using Markov chain model is developed. The steady state probability is obtained from the derived balanced equations using an iterative numerical algorithm. From the obtained balance steady state probability, the average throughput, blocking probability, and radio resource utilization parameters for the BCC scheme and compared with the NBCC scheme are investigated. The network analysis variables are packet arrival rates, cell-center zone index, and UE cooperative relay index.

The simulation results revealed that system performance metrics: the average throughput, blocking probability, and radio resource utilization, under our proposed BCC scheme have significant improvements over those under the NBCC scheme. The QoS in terms of blocking probability, is the most enhanced network metric, with a maximum performance gain of 98.5%, the radio resource utilization is improved with a maximum performance gain of 11.3%, and the average throughput is the least enhanced with a maximum performance gain of 5.2% for a buffer queue size of $Q = 15$. The BCC implementation does not require complex modification to UE nodes. Therefore, it can be easily implemented at the DeNB for QoS performance, average throughput, and radio resource utilization enhancement.

Chapter 5

Efficient and Stable Algorithm for Network Selection: a MULTIMOORA Approach

5.1 Introduction

The growth of wireless communication networks has led to global active Subscriber Identification Module (SIM) card connections of over 7.2 billion SIM card connections [151]. The number of access connections to inter-wireless-networks and the demand for wireless application services, like video-streaming, online gaming and trading, Voice over Internet Protocol (VoIP), web-browsing, online instant messaging, etc. have risen astronomically. Effective support of these service applications requires seamless integration of new and existing networks. HWNs with diverse wireless networks, seamlessly integrated

and interconnected together, is the bedrock for the NGWNs [152]. It is essential for communicating MNs in HWNs to switch from one access technology to another in order to take full advantages of the user preferences, network profile configurations, variation in service application, cost, and network performances offered by the diverse wireless networks.

Decision making represents the bedrock of RRM in HWNs. There are two main decision making in HWNs: network selection and bandwidth allocation decision making. In HWNs network selection decision making tackles the problem of how to determine the best available access network for a given network user connection, while bandwidth allocation decision making resolves the issues of how to allocate bandwidth from different networks in the HWNs to a given network user. Bandwidth allocation decision can also be referred to as joint radio resource management (JRRM) decisions. This is the allocation of bandwidth provided concurrently by different networks to users [26].

One of the main crucial problems for the present and next generation HWNs is access network selection. Access network selection process requires a flawless and proficient handoff scheme which enhances the roaming experience of UEs from one wireless system to another [27]. Next-generation multimode MNs have the capability to simultaneously support two or more different classes of calls (group calls) [153]. Group calls comprise multiple independent calls, such as voice, file-download, video-streaming, and online-gaming sessions which are activated and sustained simultaneously while the multimode MN is attached to an access network within the HWNs. Group calls can consist of dual calls, triple calls, quadruple calls, etc. Figure 5.1 shows multimode MNs making different classes of calls in HWNs, moving across point *A* to point *B* at different vehicular speed.

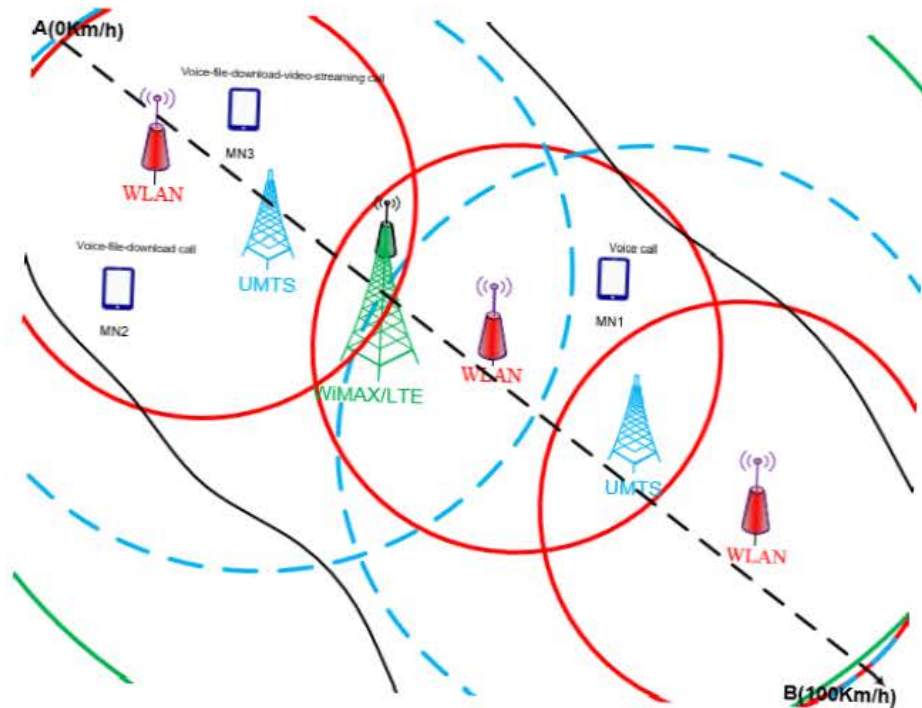


Figure 5.1: Mobile communicating multimode nodes in HWNs.

The HWNs integrates the WLAN, UMTS, LTE, and WiMAX networks together. WLAN has the lowest support for mobility and the least coverage area. LTE supports the highest mobility among the three networks. Each of these networks would support differently, the QoS requirements of a given group call from the MN. Assume that an MN at a given time has initiated a video-streaming while attached to an Access Point/Base Station (AP/BS) within the HWNs and while the initiated video-streaming is ongoing, assume that the MN receives an incoming voice call. The wireless access network should be able to support both calls simultaneously without dropping the existing video-streaming call or blocking the incoming voice call. On the receiver's end, the MN should not perceive any degradation in QoS of the existing/new call throughout the duration of the call sessions.

Achieving these goals for group calls are significant problems in HWNs. The current access network in HWNs may not be able to provide the desired QoS for the group calls, due

to the initiation of a new call(s) concurrently with the existing call(s). It is imperative for the HWNs to be able to execute a fast and seamless Vertical Handover (VHO) of the group calls to different access network within the HWNs that can satisfy the new QoS requirements for the group calls.

VHO process allows such advantages to be realized by allowing fast, smooth, and seamless switching between the different networks with tolerable minimal VHO latency. The provision of fast, smooth, and seamless VHO requires the design of a robust, efficient, and stable VHO scheme. However, the design and implementation of seamless VHO mechanisms is a huge challenge and active area for researchers. Access network selection in NGWNs is inherently a multifaceted problem that requires the consideration of a myriad of parameters for efficient handover decision making. Traditional homogeneous networks handover schemes are based on single criterion parameter and inefficient for handovers in HWNs because of the effect of heterogeneity of networks parameter standards across the HWNs; a single criterion can not efficiently and optimally determine handover process.

VHO decision process in HWNs involves a complex and often conflicting multi-criteria which can be modeled as MCDM problems. MCDM tool is a branch of optimization research technique that is well developed for resolving multi-criteria decision problems. VHO decisions for group calls can be modeled as Multi-Criteria Group-Decision Making (MCGDM) problems. The MCGDM is a logical extension of MCDM. MCDM is an advanced tool of optimization research technique for resolving multiple and often conflicting criteria decision problems. A lot of MCDM schemes, such as Simple Additive Weighting (SAW), Multiplicative Exponent Weighting (MEW), Grey Relational Analysis

(GRA), Analytic Hierarchy Process (AHP), Elimination Et Choix Traduisant la Realite (ELECTRE), Technique for Order Preference by Similarity to Ideal Solutions (TOPSIS), and VlseKriterijumska Optimizacija I Kompromisno (VIKOR) have been utilized in HWNs [91, 107, 154, 155].

Recently, there has been a significant research interest for the search and the application of new and powerful MCDM algorithms to VHO implementation in HWNs. In this chapter, a new access network selection scheme that uses MULTiplicative-form with Multi-Objective Optimization Ratio Analysis (MULTIMOORA) for making access network selection decisions for VHO single and group calls in HWNs is proposed.

The following are the main contributions of this paper:

- A comprehensive review of current network selection algorithms in HWNs is presented.
- The use of a new MCDM based algorithm: MULTIMOORA for access network selection decision making for single and group calls in the NGWNs is proposed.
- The effectiveness/accuracy of the ranking decision of MULTIMOORA, in comparison with several MCDM ranking algorithms (SAW, MEW, Grey GRA, TOPSIS, and VIKOR) that are traditionally utilized for best target access network selection in the HWNs, for single calls is investigated.
- For group calls in HWNs with dynamic criteria, the ranking decision stability performance of best-performing MCDM algorithms (MULTIMOORA and TOPSIS) as obtained from single calls is investigated.

To the best of our knowledge, this is the first research work to apply MULTIMOORA to address the problem of access network selection in HWNs. Our work provides a new dimension and a realistic approach to wireless-access network-selection problems in HWNs.

The rest of this chapter is organized as follows: in Section 5.2, a review of the related work is presented. Section 5.3 gives the introduction to the proposed MULTIMOORA scheme while Section 5.4 introduces the multi-criteria group decision-making problem. In Section 5.5 the case study of the application of MULTIMOORA to access network selection is carried out. Section 5.6 presents the results and discussion on the comparisons of MULTIMOORA to the traditional popular SAW, GRA, TOPSIS, and VIKOR schemes. Finally, Section 5.7 concludes the chapter.

5.2 Related Work

In this section, an overview of the recent work on VHO for HWNs using MCDM algorithms is provided. In [156], a semi and fully distributed network selection schemes based on SAW are investigated for HWNs. The authors show that the proposed SAW scheme outperforms the simple IEEE802.11 preferred strategy in terms of handover latency. In [157], the performances of VIKOR scheme for VHO decisions are compared with SAW and TOPSIS. TOPSIS scheme is observed to have similar performances with VIKOR. However, the impact of criteria weights on the decisions of MCDM schemes is not considered in the investigations.

In HWNs, network selection is influenced by the requested service indicated by the user. The application of ELECTRE in network selection in HWNs environment is studied in [106] while considering three services: VoIP, streaming, and web-browsing.

How to correctly assign weight to the different criteria that control handover decisions and to determine their relative importance has always been a challenging task in deciding handoffs in HWNs [158]. Some well-exploited weighting techniques in the literature include Entropy and AHP methods [159]. O. Markaki, *et al.* in [107] study the problem of access network selection between GPRS and WLAN. An access network selection scheme that integrated AHP and GRA is proposed. The weights of the network QoS are assigned using AHP; while the GPRS and WLAN are ranked using GRA. In [91], a comparative study of the performance of SAW, MEW, ELECTRE, TOPSIS, GRA, and VIKOR for the execution of VHO decisions for voice and data connection applications in HWNs is presented. VIKOR is found to give the best performance for a voice connection, while GRA and MEW gave the best performance for data application.

In HWNs, the access network selection for a single call is influenced by the type of calls requested (i.e., voice, video-streaming, file-download, etc.). Thus, for group calls the access network selection decision would be influenced by the interactive combination of the degree of importance (priority) of these independent calls in the group calls. The problem of Radio Access Technology (RAT) selection for group calls in HWNs is investigated in [153]. A modified TOPSIS group-decision-making technique that selects the most suitable RAT for a group of different classes of calls from a multimode MN in HWNs is proposed.

The authors in [160] investigate the effect of the call dynamics on RAT selection in terms of the probability of having the necessary VHO in HWNs that support voice, video-streaming, and file-download calls using the Markov chain model. The results indicate

that the frequency of necessary vertical handoffs in HWNs is significantly affected by call dynamics.

In [161] the author extend the work in [153] by introducing a RAT preference margin, which is a measure of the degree to which the newly preferred RAT is better than the current RAT in reducing the frequency of VHOs for single or group calls.

From the reviewed related works, the following shortcomings are noted:

- Existing works are limited to the problem of VHO for single calls; and hence, they failed to address the VHO for group calls, except for work done in [153, 160, 161].
- Existing works have not taken into consideration the dynamic nature of some network–decision criteria such as MN’s speed, network service price, and network traffic load in their problem formulations.

To address these shortcomings stated above, a multi–criteria access network–selection scheme for making VHO decisions for group calls in HWNs with dynamic multi–criteria is proposed. The proposed scheme uses an MULTIMOORA algorithm to make the network selection decisions for the VHO of group calls. In the following section, MULTIMOORA is introduced.

5.3 Introduction to MULTIMOORA

In this section, the important notations used in this chapter and an introduction to MULTIMOORA are presented.

5.3.1 Notations

The bold face vector, \mathbf{A} is used to denote the set of available access network alternatives, A_i denote the i^{th} available access networks, and M denote the total number of available access networks. The summary of the rest notations used are shown in the Table 5.1.

Table 5.1: Summary of important symbols.

Symbol	Description
\mathbf{C}	Denote the set access network criteria
C_j	The j^{th} criterion of the available access network
N	Total number of access network criteria
$x_{i,j}$	The performance score of the i^{th} alternative w.r.t the j^{th} criterion
$x_{i,j}^*$	Denote the weighted Euclidean normalized performance score of the i^{th} alternative w.r.t. the j^{th} criterion
\mathbf{W}	The set of criteria weight
w_j	The weight of the j^{th} criterion
$\mathbf{D}_{S(G)}$	Denote the single call (group call) decision matrix
y_i	The Ratio rank index of the i^{th} access network alternative
y_i^*	The Reference point rank index of the i^{th} access network alternative
r_j	The reference point of the j^{th} benefit/cost criterion
k	The cardinal value of the benefit criteria
U_i	Multiplicative form rank index of the i^{th} access network alternative
\mathbf{G}	Denote the set of decision group members
DM_l	Denote the l^{th} group decision member
L	Total number of group decision members
β_l	The normalized weight of degree of importance of the l^{th} group decision member
ψ_j	The aggregate group with for the j^{th} criterion

5.3.2 MULTIMOORA

The MULTIMOORA is a new and powerful MCDM technique that combines three ranking approaches namely: ratio system, reference point system, and multiplicative form using the theory of dominance to integrate their outputs into a robust, accurate, and stable ranking of alternatives. The MULTIMOORA is very simple, stable, and accurate when compared to

other MCDM techniques for ranking alternatives [162]. MULTIMOORA was first proposed in [163] by W. Brauers *et al.* in 2010.

An introduction to MULTIMOORA's methodology is given below. Consider that MN1 in Figure 5.1 moves across the HWNs, Let $\mathbf{A} = \{A_1, A_2, \dots, A_i, \dots, A_M\}$ denote the set of M available access network alternatives to MN1, $\mathbf{C} = \{C_1, C_2, \dots, C_j, \dots, C_N\}$ denote set of N access network criteria on which each available alternative performance is being rated; $x_{i,j}$, indicates performance score of the i^{th} alternative with respect to the j^{th} criterion of the decision matrix. The set of weights of the criteria $\mathbf{W} = \{w_1, w_2, \dots, w_j, \dots, w_N\}$ is defined. The w_j is the weight of importance of the j^{th} criterion. The value of w_j indicates how important is the contribution of the j^{th} criterion to achieving the desired goal of selecting the best alternative and $\sum_{j=1}^N w_j = 1$. The handover decision problem can be formulated into a decision matrix (\mathbf{D}) as:

$$\mathbf{D} = \begin{matrix} & \begin{matrix} C_1 & C_2 & \cdots & C_j & \cdots & C_N \end{matrix} \\ \begin{matrix} A_1 \\ A_2 \\ \vdots \\ A_i \\ \vdots \\ A_M \end{matrix} & \begin{bmatrix} x_{1,1} & x_{1,2} & \cdots & x_{1,j} & \cdots & x_{1,N} \\ x_{2,1} & x_{2,2} & \cdots & x_{2,j} & \cdots & x_{2,N} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{i,1} & x_{i,2} & \cdots & x_{i,j} & \cdots & x_{i,N} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{M,1} & x_{M,2} & \cdots & x_{M,j} & \cdots & x_{M,N} \end{bmatrix} \end{matrix} \quad (5.1)$$

The MULTIMOORA solution for access such network selection problem is implemented in the following steps:

The Ratio System

Compute the weighted Euclidean normalized score, $x_{i,j}^*$ for the i^{th} alternative with respect to the j^{th} criterion as:

$$x_{i,j}^* = \frac{w_j \times x_{i,j}}{\sqrt{\sum_{i=1}^M x_{i,j}^2}}. \quad (5.2)$$

If the larger the value of a criterion the better, such criterion is referred to as benefit criterion and the benefit criteria are summed together. Similarly, if the smaller the value of the criterion the better, such criterion is referred to as cost criterion and the cost criteria are summed together. Compute the ratio rank index, y_i for the i^{th} alternative as:

$$y_i = \sum_{j=1}^k x_{i,j}^* - \sum_{j=k+1}^N x_{i,j}^*, \quad (5.3)$$

where k is the cardinal value of the benefit criteria and $(N - k)$ cardinal value of the cost criteria. The higher the ratio rankings index y_i , the higher ratio system ranking of the i^{th} alternative.

The Reference Point System

The reference point, $r_j = \max_i x_{i,j}^* / r_j = \min_i x_{i,j}^*$ is defined for the j^{th} benefit criterion/cost criterion. Compute the reference point ranking index y_i^* for the for the i^{th} alternative using

the Min-Max metric of Tchebycheff in ascending order for the reference point system ranking:

$$y_i^* = \min_i(\max_j(r_j - x_{i,j}^*)). \quad (5.4)$$

The lower the ranking index y_i of the i^{th} alternative, the higher the ranking of the i^{th} alternative in the reference point system.

The Multiplicative Form System

Evaluates the multiplicative form ranking index U_i for the i^{th} alternative as:

$$U_i = \frac{F_i}{B_i}, \quad (5.5)$$

where $F_i = \prod_{j=1}^k x_{i,j}^{w_j}$ for the i^{th} alternative with benefit criteria, $j = 1, 2, 3, \dots, k$ and $B_i = \prod_{j=k+1}^N x_{i,j}^{w_j}$ for the i^{th} alternative with cost criteria, $j = k+1, k+2, k+3, \dots, N$. The higher the multiplicative form ranking index, U_i , the higher the multiplicative form ranking of the i^{th} alternative. The final MULTIMOORA ranking of the i^{th} alternative is based on dominance theory for the ratio, the reference-point, and the multiplication form systems.

Three types of dominance rules exist: *absolute dominance*, *general dominance*, and *overall dominance*. The MULTIMOORA ranking technique provides a ranking score of absolute dominance, $(1, 1, 1)$, for the i^{th} alternative on a given ranked position, if each ranking system ranked the i^{th} alternative as 1, for that given rank position. Given that $w < x < y < z$, the i^{th} alternative with MULTIMOORA score (z, w, w) has general dominance over the m^{th} alternative with MULTIMOORA score (y, x, x) . Consequently, (w, z, w) is generally

dominating (x, y, x) , and (w, w, z) is generally dominating (x, x, y) . The i^{th} alternative with (y, y, y) has overall dominance over the m^{th} alternative with (z, z, z) . The ranking systems of MULTIMOORA are dimensionless. For more interesting reading on the application of dominance theory in the MULTIMOORA technique, readers can see [164]. The following section introduces the multi-criteria group decision-making problem.

5.4 Multi-Criteria Group Decision Making Problem

A Group Decision Making (GDM) problem is defined as a decision situation, where there are two or more experts who are characterized by their preferences/priorities trying to resolve a decision, to achieve a common solution. A decision-making problem that involves several decision-makers considering several criteria is called an MCGDM. A collective group decision is reached based on the aggregated weighting of the individual decision-maker's opinion in the group.

Consider a MCGDM problem with N wireless access network criteria, M wireless access network alternatives, L group decision members (DMs) (e.g., voice, file-download, video-streaming, etc.), $\mathbf{G} = \{DM_1, DM_2, \dots, DM_l, \dots, DM_L\}$ is the set of L group-decision members (group calls), $\mathbf{C} = \{C_1, C_2, \dots, C_j, \dots, C_N\}$ is the set of N access networks criteria, and $\mathbf{A} = \{A_1, A_2, \dots, A_i, \dots, A_M\}$ is the set of M alternatives (wireless access networks).

The group call decision matrix problem, \mathbf{D}_G is defined as:

$$\mathbf{D}_G = \begin{matrix} & \begin{matrix} C_1 & C_2 & \cdots & C_j & \cdots & C_N \end{matrix} \\ \begin{bmatrix} x_{1,1} & x_{1,2} & \cdots & x_{1,j} & \cdots & x_{1,N} \\ x_{2,1} & x_{2,2} & \cdots & x_{2,j} & \cdots & x_{2,N} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{i,1} & x_{i,2} & \cdots & x_{i,j} & \cdots & x_{i,N} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{M,1} & x_{M,2} & \cdots & x_{M,j} & \cdots & x_{M,N} \end{bmatrix} & \begin{matrix} A_1 \\ A_2 \\ \vdots \\ A_i \\ \vdots \\ A_M \end{matrix} \end{matrix} \quad (5.6)$$

The variable, $x_{i,j}$ indicates the performance score of the i^{th} alternative with respect to the j^{th} criterion of the group decision matrix problem. The weight vector of the access networks criteria with respect to group member (DM_l) is given by $\mathbf{W}^l = \{W_1^l, W_2^l, \dots, W_j^l, \dots, W_N^l\}$, $l = 1, 2, \dots, L$, where W_j^l is the weight assigned to the j^{th} criterion by the l^{th} group-decision member. The weight assignment satisfies $0 \leq W_j^l \leq 1$ and $\sum_{j=1}^N W_j^l = 1$. It is assume that group-decision member, DM_l has a normalized degree of importance, β_l , where $0 \leq \beta_l \leq 1$ and $\sum_{j=1}^L \beta_l = 1$.

To achieve a collective decision for the group call, the group member's degree of importance and the weight vector of the access networks criteria must be aggregated to form the aggregate-group criteria weight vector ψ for the the MCGDM problem, where $\psi = \{\psi_1, \psi_2, \dots, \psi_j, \dots, \psi_N\}$. The aggregate group criterion weight ψ_j for the j^{th} criterion is

obtained as:

$$\psi_j = \frac{1}{L} \sum_{l=0}^L \beta_l \times W_j^l, j = 1, 2, 3, \dots, N. \quad (5.7)$$

5.4.1 Proposed access network–selection scheme for group calls

In this section, a GDM methodology based on MULTIMOORA to solve the problem of VHO for group calls is proposed. Consider MNs moving across the HWNs that support L classes of calls as shown in Figure 5.1, with M available access network alternatives and N access network criteria. Let $\mathbf{A} = \{A_1, A_2, \dots, A_i, \dots, A_M\}$ denote the set of M available access network alternatives, $\mathbf{C} = \{C_1, C_2, \dots, C_j, \dots, C_N\}$ denote set of N dynamic and static access network criteria, $\mathbf{G} = \{DM_1, DM_2, \dots, DM_l, \dots, DM_L\}$ denote the set of L group calls (decision makers).

Let $\mathbf{W}^l = \{W_1^l, W_2^l, \dots, W_j^l, \dots, W_N^l\}$ be the assigned weight of importance of the network access criteria by the class of call DM_l . Let $\beta = \{\beta_1, \beta_2, \dots, \beta_l, \dots, \beta_L\}$ be the set degree of importance of the call in L classes of calls.

The problem of obtaining the best access network for the group calls from MNs can be solved by MULTIMOORA using the following steps:

- Construct the VHO group decision problem, \mathbf{D}_G as defined in Equation (5.6).
- Obtain the aggregate group criteria weight vector, Ψ from the criteria weight vector and group member degree of importance using Equation (5.7).

- Compute the weighted Euclidean normalized $x_{i,j}^*$ score for the i^{th} alternative with respect to the j^{th} criterion as:

$$x_{i,j}^* = \frac{\psi_j \times x_{i,j}}{\sqrt{\sum_{i=1}^M x_{i,j}^2}}. \quad (5.8)$$

- Compute the ratio-ranking index, reference point ranking, the multiplicative form ranking index, and apply the dominance to produce the MULTIMOORA ranked results as described in the previous section.

5.4.2 Network criteria and degree of importance of group calls

In HWNs, VHO decisions for group calls are based on static and dynamic criteria. Examples of dynamic criteria are MN's speed, network delay, network service price, and network traffic load; while examples of static criteria are the security level provided for the class of calls, the data rate, etc. Various networks have different dynamic performances under varying speed of the MNs. Some criteria (e.g., data rate) are specified using real numbers, while other criteria (e.g., battery power consumption) are specified using linguistic membership functions. Table 5.2 and Figure 5.2 show a 7-point linguistic membership function terms. The linguistic terms are defined using Triangle Fuzzy Numbers (TFN); a_1 , a_2 , and a_3 , which are the lower, middle, and upper vertex values of the TFN, respectively. The TFNs are consequently converted into their corresponding crisp numbers using the formula [165]:

$$Crispvalue = \frac{1}{6}(a_1 + 4a_2 + a_3). \quad (5.9)$$

Table 5.2: 7-point linguistic terms.

S/N	Membership function	TFN (a_1, a_2, a_3)	Crispvalue
1	Very Low (VL)	(0, 0, 0.2)	0.0333
2	Low (L)	(0.1, 0.2, 0.3)	0.2
3	Medium Low (ML)	(0.3, 0.35, 0.5)	0.3667
4	Medium (M)	(0.4, 0.5, 0.6)	0.5
5	Medium High (MH)	(0.5, 0.65, 0.8)	0.65
6	High (H)	(0.7, 0.8, 0.9)	0.8
7	Very High (VH)	(0.8, 0.9, 1)	0.9

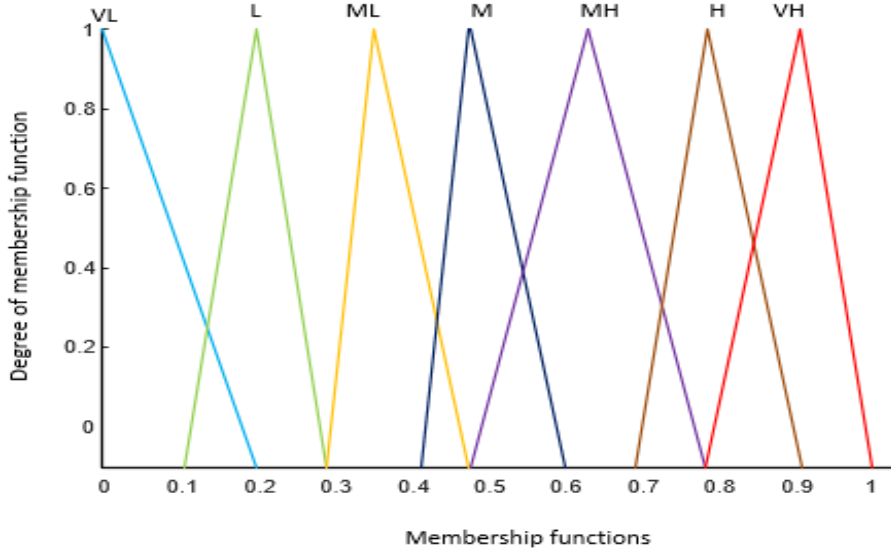


Figure 5.2: Linguistic membership functions.

In this work, the weights of calls in the group calls are specified in their linguistic membership functions, based on the degree of importance of calls to the users. The weights are subsequently converted into their corresponding crisp values. The assigned weight of degree of importance for a particular wireless network criterion shows how important the criterion is to the class of call; while the assigned weight degree of importance to a class of call in a group call shows how important the class of call is in the group call to the users. The weight assignments are done once by the users, and they can always be revised by the users [161].

5.5 Case Study: Application of MULTIMOORA to Access Network Selection

In this section, the application of MULTIMOORA to access network selection for three independent single calls (i.e., voice, file-download, and video-streaming calls) in HWNs and group calls in HWNs with dynamic criteria is examined.

5.5.1 Single calls

In this subsection, via MATLAB simulation, the performance of the proposed MULTIMOORA algorithm on access network selection problem of single calls in an HWNs of WLAN, UMTS, and WiMAX networks for VHO decisions is studied, as shown in Figure 5.3.

Based on the relative simplicity and efficiency, the SAW, GRA, TOPSIS [101], and VIKOR [166] algorithms are studied and compared with the MULTIMOORA algorithm for access networks selection decision problems in HWNs. Three traffic classes: voice, file-downloads, and video-streaming are considered. To enhance the quality of experience of the users within the HWNs, main QoS parameters such as data rate (Mbps) (C_1), packet delays (ms) (C_2), jitter (ms) (C_3), packet loss rate (%) (C_4), network cost (unit/Mbps) (C_5), and network security level (C_6) are considered. The network level of safety is measured in the literature using fuzzy membership functions (e.g., High, Medium, Low, Very Low, etc.). The fuzzy membership functions are converted to their corresponding crisp (numerical) values to allow for subsequent numerical computations. The single call decision matrix

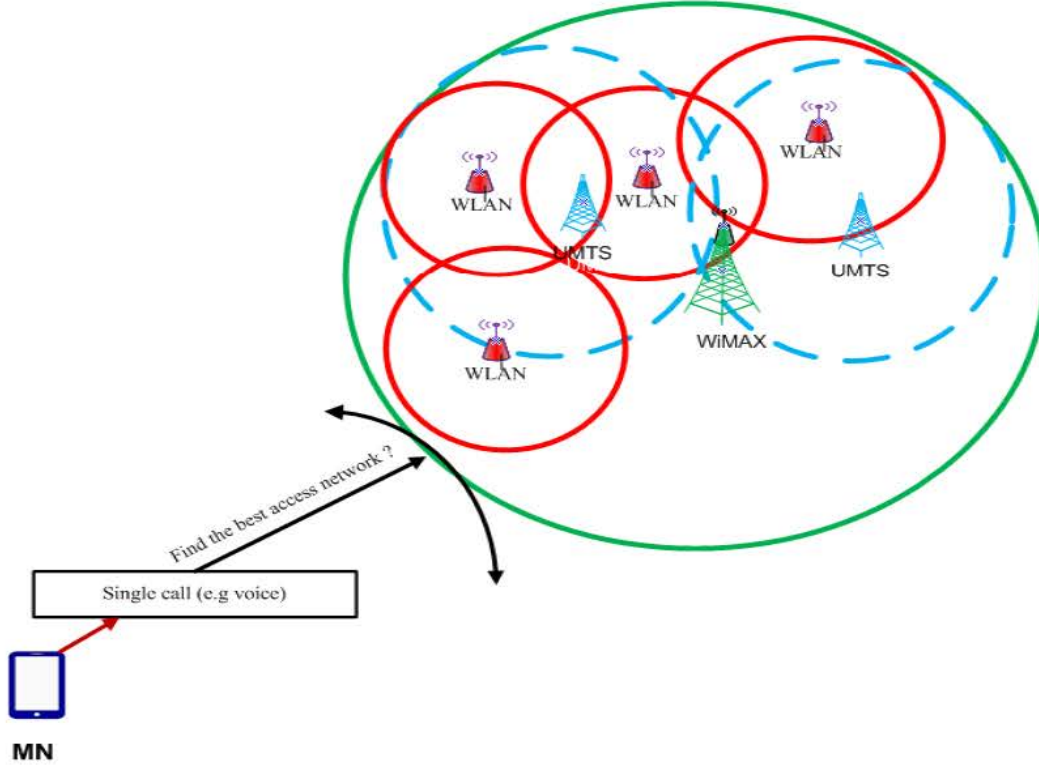


Figure 5.3: Access network selection problem for single calls.

(D_S) is shown in equation (5.10), which contains the performance scores of the three different networks based on the access networks criteria. In Equations (5.10) and (5.11) the $DR, DL, JR, PR, CT,$ and ST represent the data rate, delay, jitter, packet loss rate, cost, and security, respectively.

$$D_S = \begin{matrix} & \begin{matrix} DR & DL & JR & PR & CT & ST \end{matrix} \\ \begin{bmatrix} 54 & 80 & 15 & 0.03 & 20 & 0.283 \\ 7.5 & 30 & 10 & 0.006 & 45 & 0.909 \\ 25 & 50 & 15 & 0.009 & 35 & 0.717 \end{bmatrix} & \begin{matrix} WLAN \\ UMTS \\ WiMAX \end{matrix} \end{matrix} . \quad (5.10)$$

One important issue in network selection is the assignment of suitable weights to different criteria in accordance to the ongoing traffic class of the user. Voice traffic is very sensitive to delay and jitter; file-download traffic is very sensitive to Packet Loss Rate (PLR) and data rate; and while video-streaming traffic is very sensitive to data rate, delay, and jitter.

To ensure consistency of weight determination of criteria, the AHP method [167] is applied in this work to assign weights to the criteria. The single call weight of criteria (\mathbf{W}_S) obtained for voice, file-download, and video-streaming using AHP technique is shown in Equation (5.11). The Vc , Fd , and Vs represents the voice, file-download, and video-streaming applications, respectively.

$$\mathbf{W}_S = \begin{matrix} & \begin{matrix} DR & DL & JR & PR & CT & ST \end{matrix} \\ \begin{bmatrix} 0.065234 & 0.31124 & 0.25908 & 0.03723 & 0.0959 & 0.23132 \\ 0.250873 & 0.04618 & 0.05914 & 0.45589 & 0.075 & 0.11225 \\ 0.34373 & 0.21864 & 0.20208 & 0.0562 & 0.0466 & 0.13273 \end{bmatrix} & \begin{matrix} Vc \\ Fd \\ Vs \end{matrix} \end{matrix} . \quad (5.11)$$

The AHP Consistency Ratio (CR) for voice, file-download, and video-streaming traffic classes are: $CR_{voice} = 0.038$, $CR_{file-download} = 0.057048$, and $CR_{video-streaming} = 0.044027$, respectively. The CRs all satisfied the < 0.1 threshold for good and consistent judgments. For more interesting reading on AHP readers can see [168–170].

5.5.2 Group calls in HWNs with dynamic criteria

In subsection, the performance of the proposed MULTIMOORA algorithm on access network selection problem of group calls in an HWNs of WLAN, UMTS, and LTE networks for VHO decisions is investigated, as shown in Figure 5.4.

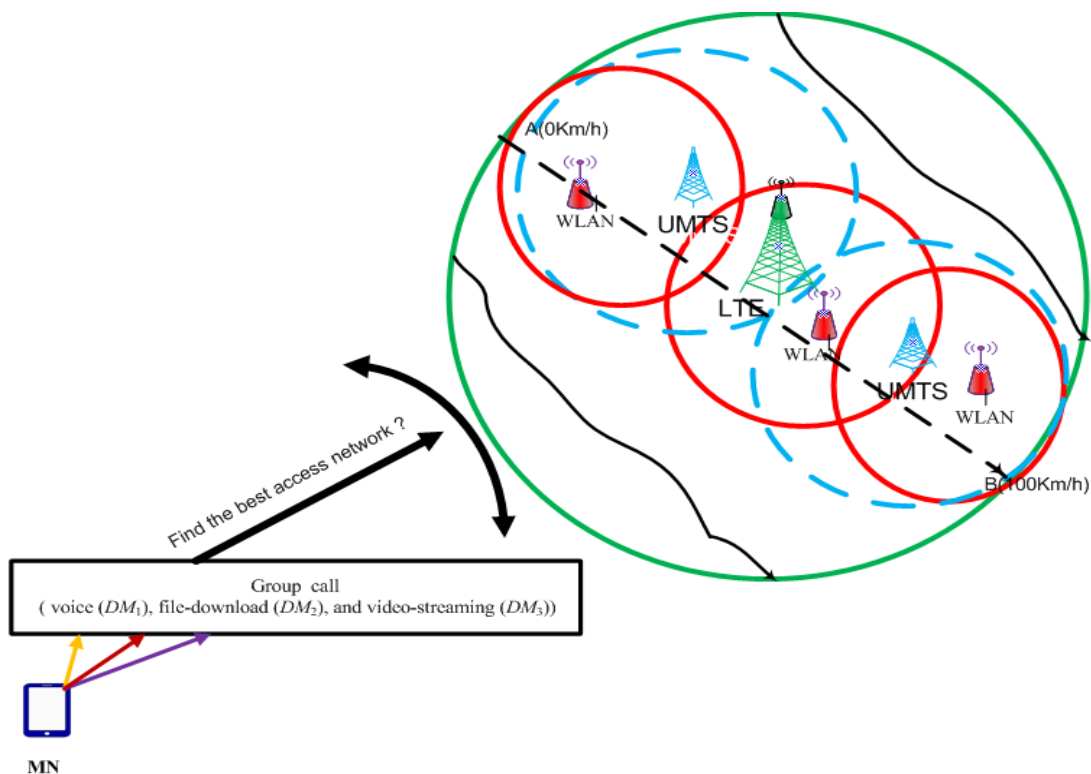


Figure 5.4: Access network selection problem for group calls.

The vertical handoff of group calls for 1000 Multimodal MNs in HWNs that consist of WLAN (A_1), UMTS (A_2), and LTE (A_3) is considered. The three integrated networks are assumed to be available for all calls. HWNs and MNs support a maximum of three classes of calls in a group call. These are voice (DM_1), file-download (DM_2), and video-streaming (DM_3) calls.

- MN's Speed: The mobility criterion performance score for each network is mathematically modeled as a linear function of MN speed, as shown in the equations below:

$$Speed_{WLAN} = VH - \frac{1}{30k}(VH - VL) \times speed, \quad (5.12)$$

$$Speed_{UMTS} = VH - \frac{1}{90k}(VH - VL) \times speed, \quad (5.13)$$

$$Speed_{LTE} = VH - \frac{1}{100k}(VH - VL) \times speed, \quad (5.14)$$

where $k = \frac{26}{27}$.

The mathematical subtraction operation for two linguistic member functions, say VH and VL , is given by:

$$VH - VL = (a_1^{VH} - a_1^{VL}, a_2^{VH} - a_2^{VL}, a_3^{VH} - a_3^{VL}), \quad (5.15)$$

where $a_1^{VH}, a_2^{VH},$ and a_3^{VH} are the lower, middle, and upper vertex values of the membership function VH and $a_1^{VL}, a_2^{VL},$ and a_3^{VL} are the lower, middle, and upper vertex values of the membership function VL .

The benefit criteria are MN's speed, data rate, and security level; while the cost criteria are network delay and network service cost. The weights of the criteria and degree of importance of calls in the group calls used in this proposed algorithm are randomly generated to model practical wireless network operations for different users', group calls and preferences. MATLAB software is utilized for the simulation of the VHO of the group calls.

The group call decision matrix problem, \mathbf{D}_G , is given below as:

$$\mathbf{D}_G = \begin{matrix} & C_1 & C_2 & C_3 & C_4 & C_5 & \\ \left[\begin{array}{l} Speed_{WLAN} \\ Speed_{UMTS} \\ Speed_{LTE} \end{array} \right. & \begin{array}{l} 54 \\ 7.5 \\ 24 \end{array} & \begin{array}{l} ML \\ VH \\ H \end{array} & \begin{array}{l} H \\ VL \\ L \end{array} & \begin{array}{l} Price_{WLAN} \\ Price_{UMTS} \\ Price_{LTE} \end{array} & \begin{array}{l} A_1 \\ A_2 \\ A_3 \end{array} & \end{matrix} . \quad (5.16)$$

Table 5.3 shows the three case studies for different degrees of importance for different classes of calls for triple calls.

Table 5.3: Triple call.

Case	Voice	File-download	Video-streaming
1	H	L	L
2	L	H	L
3	L	L	H

5.5.3 Assumptions

The MNs are assumed to move across the HWNs with uniform acceleration (increasing speed (0–100)km/h. The PV is assumed to vary from 0% – 100%. Five important criteria: MN’s speed (km/h) (C_1), data rate (Mbps) (C_2), security level (C_3), network delay (ms) (C_4), and service price (unit/Mbps) (C_5) are considered for selecting the most feasible network for each group call.

Some of the decision criteria used for VHO in heterogeneous networks are dynamic; while others are static criteria. The MN’s speed, network service price, and network delay are dynamic; and they dynamically affect VHO decision for each network. However, for simplification analysis of this work, the network delay is held constant.

5.6 Results and Discussion

In this section, The results of the application MULTIMOORA to access network selection for three independent single calls (i.e., voice, file-download, and video-streaming calls) in HWNs and group calls in HWNs with dynamic criteria are presented.

5.6.1 Single calls

The performance of MULTIMOORA in term of accuracy is validated by comparing with SAW, GRA, TOPSIS, and VIKOR algorithms for the most popular network traffic such as voice, video-streaming, and file-download traffic classes. In this work, the ranking performance comparison of these algorithms is not investigated under network criteria weight sensitivity or rank reversal (ranking abnormality). Criteria weight sensitivity is the measure of influence, a varying criterion weight has on the ranking outcome on a MCDM algorithm. Rank abnormality is the measure consistency of the ranking decision made by an MCDM algorithm, as the most sub-optimum network alternative(s) is(are) eliminated or removed from the set of available network alternatives in the decision making problem [171].

MULTIMOORA is used to rank and select the optimal network. Comparison results of MULTIMOORA with SAW, GRA, VIKOR, and TOPSIS for optimal network selection for voice, file-download, and video-streaming traffic VHO are shown in Figure 5.5, Figure 5.6, and Figure 5.7, respectively. In Figure 5.5, all the implemented MCDM algorithms produced the same ranking results and selected UMTS as the optimal network for voice traffic. Selection of UMTS as the optimal network is reasonable given that from the decision matrix, UMTS has the relative best rating on delay and jitter, also the weight for delay and

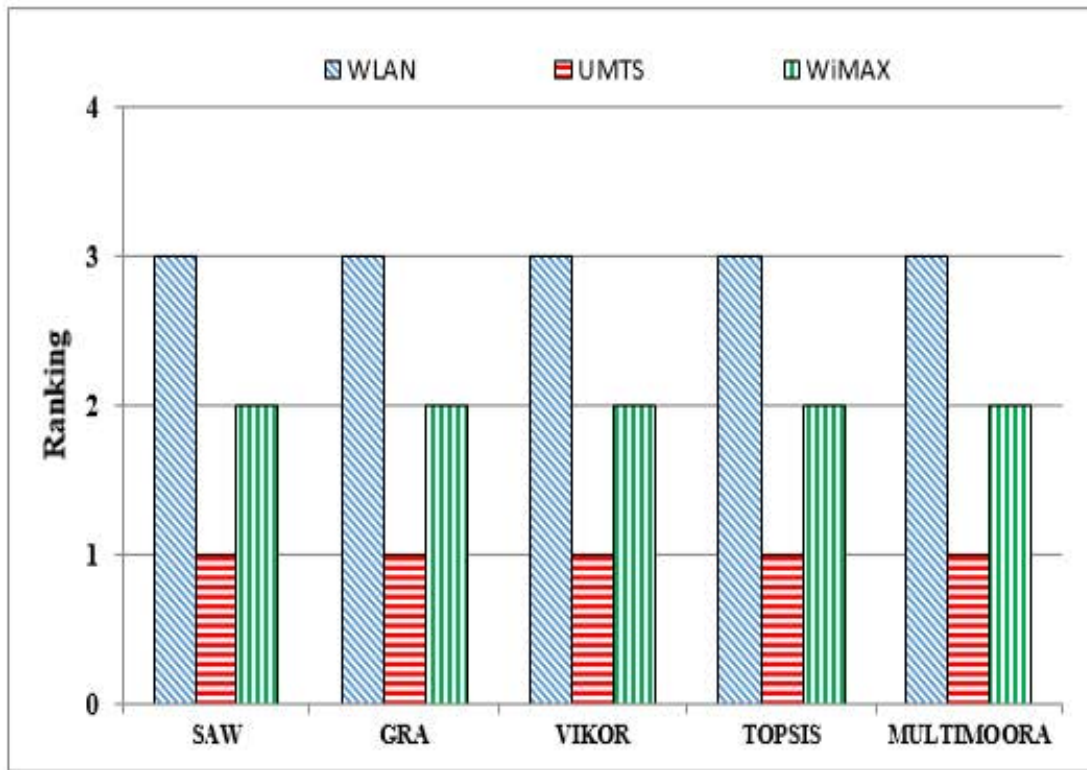


Figure 5.5: Network selection for voice traffic.

jitter are higher than other criteria in the voice weight distribution for voice traffic. The WiMAX is ranked higher than WLAN for voice traffic because of its better delay score rating than WLAN.

In Figure 5.6, although the network criteria performance of the UMTS and WiMAX are almost the same in terms of packet loss rate; however, WiMAX outperforms UMTS in data rate, which is given considerable weight by the file-download traffic weight.

This result produces WiMAX as the best network selection for file-download. MULTIMOORA, TOPSIS, and VIKOR provide the best network selection for the file-download traffic. Unfortunately, SAW and GRA select UMTS networks for file-download traffic and thus failed to take advantage of improved data rate offered by WiMAX network for file-download.

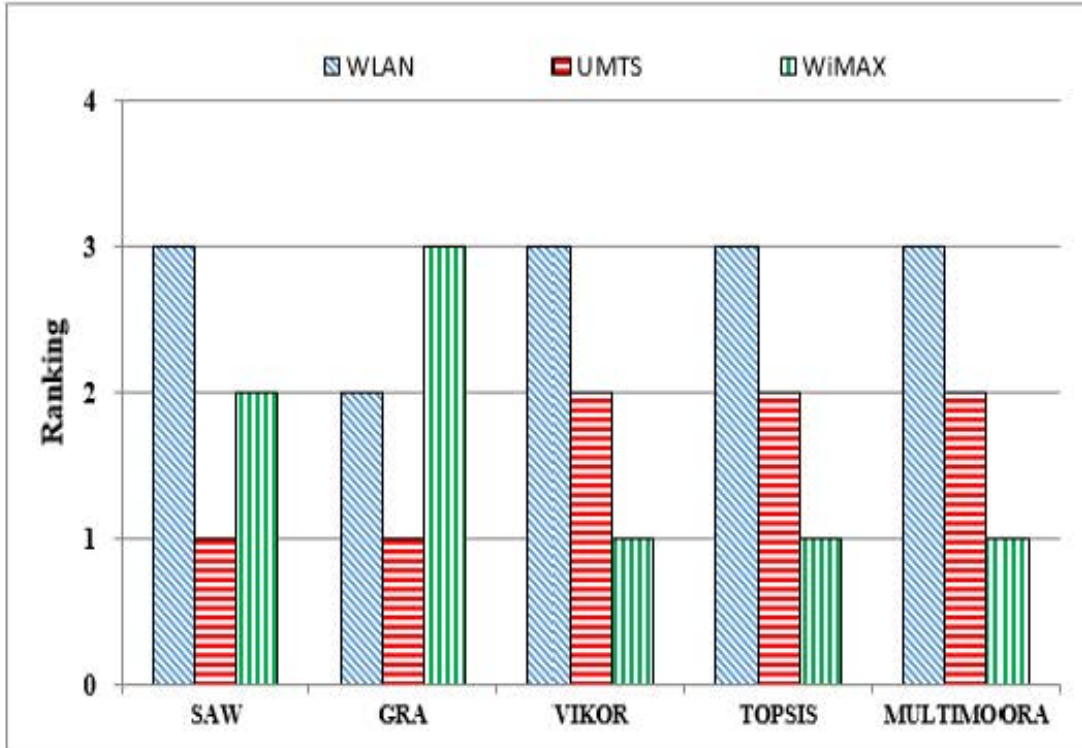


Figure 5.6: Network selection for file-download traffic.

In Figure 5.7, SAW and GRA provide the same UMTS network for video-streaming and same for all other traffic. However, this leads to poor performances for video-streaming, unlike WLAN that is selected by TOPSIS and MULTIMOORA. VIKOR provides WiMAX for video-streaming, which gives better performance on data rate, delay, and jitter than UMTS but performs less than the WLAN chosen by TOPSIS and MULTIMOORA for the video-streaming traffic.

Due to the similar performance of MULTIMOORA and TOPSIS and their out-performance over SAW, GRA, and VIKOR algorithms in terms of accuracy as shown from the simulation results, in the next section, we select and present the comparative performance results of TOPSIS, a well-known MCGDM scheme, against our proposed MULTIMOORA algorithm for triple calls using single and double dynamic criteria.

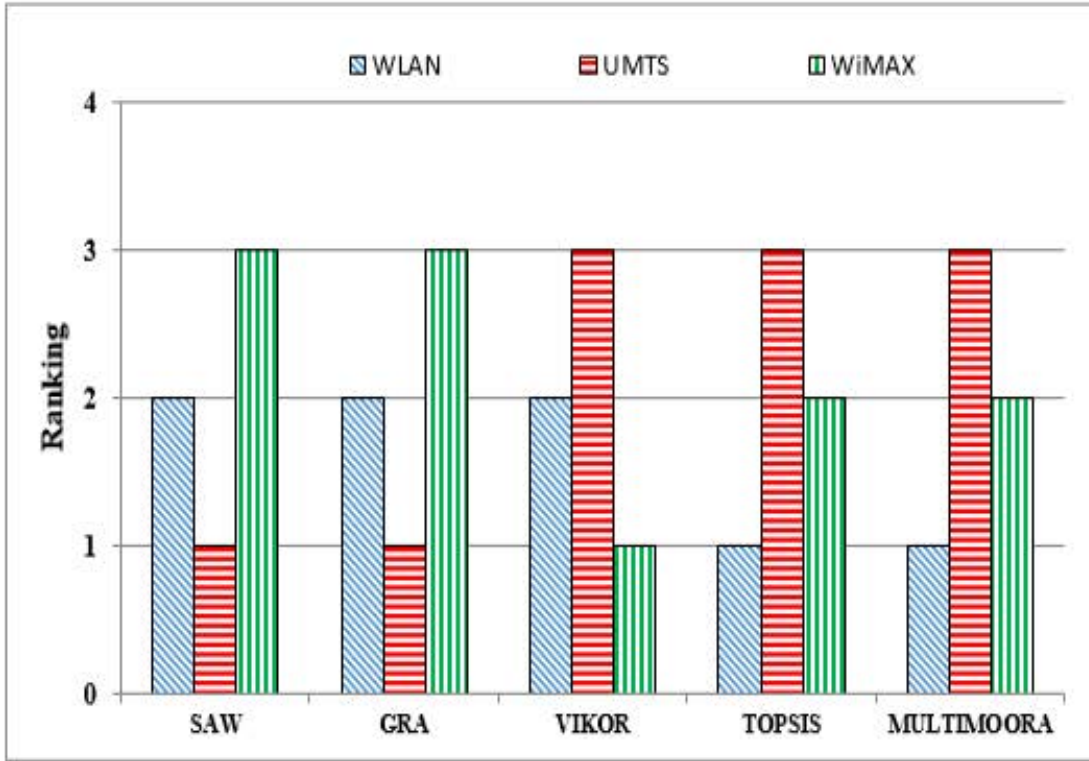


Figure 5.7: Network selection for video-streaming traffic.

5.6.2 Group calls in HWNs with dynamic criterion

In this section, the performance results of the proposed MULTIMOORA algorithm for triple calls using dynamic criterion are presented (Figure 5.8–Figure 5.10). The performance of the MULTIMOORA is validated by comparing it with TOPSIS, a well-known MCGDM algorithm. For better understanding and analysis of the results, the MN’s speed is classified into three categories: low MN speed ($0 \leq \text{MN speed} \leq 30\text{km/h}$), medium MN speed ($30 < \text{MN speed} \leq 60\text{km/h}$), and high MN speed ($60 < \text{MN speed} \leq 100\text{km/h}$). In the legend, TS and MA represent TOPSIS and MULTIMOORA, respectively.

5.6.3 Dynamic criterion: MN speed

In this section, the Cases 1-3 are presented. Case 1: Figure 5.8 shows the result of high priority voice triple call handoffs. At low-speed region, for MN's speed below 20km/h,

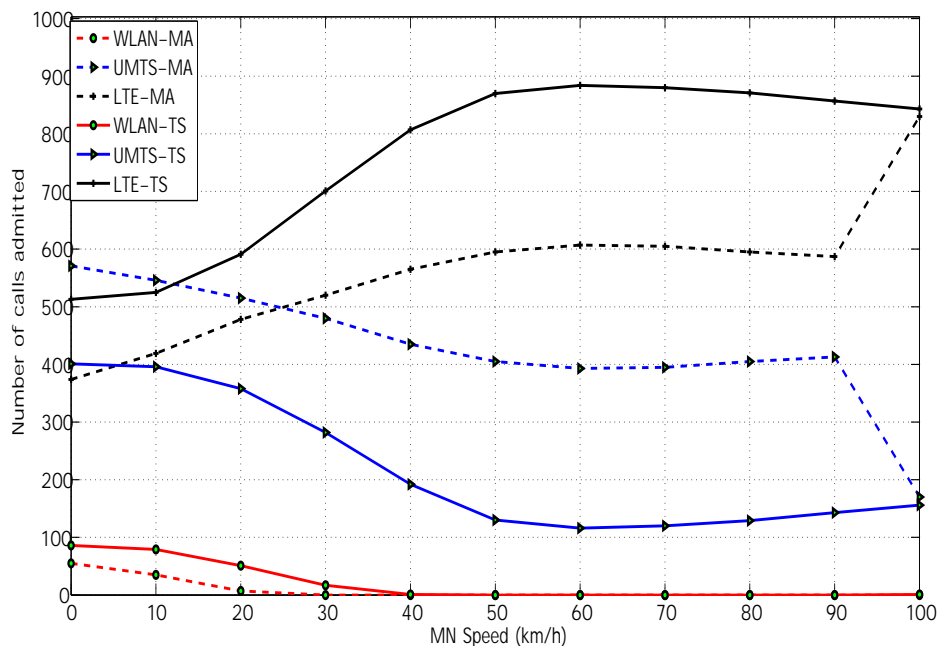


Figure 5.8: High priority voice triple call handoff (voice (H), file-download (L), and video-streaming (L)).

MULTIMOORA scheme selects UMTS network as the best network for the triple call, while switching over its network preference to LTE network at MN's speed above 20km/h. This result shows that at low speed, the relative mobility performance advantage of LTE over UMTS networks is not a major decision factor for VHO decision. TOPSIS scheme prefers the LTE network all through the low-speed region. TOPSIS scheme; however, fails to exploit the benefit of low network delay offered by the UMTS at MN low speed in the HWNs. At medium speed and beyond, both schemes present the LTE network as the best network

alternative. However, there is a decline in preference for LTE network by the TOPSIS scheme, as the MN's speed increases above the medium speed region. This result by the TOPSIS scheme at increasing MN's speed is contradictory. It reveals the relative instability in TOPSIS; however, the MULTIMOORA scheme preference for LTE network above medium speed region is relatively constant and stable.

Case 2: in Figure 5.9, MULTIMOORA scheme handoffs at least 50% of the high priority file-download triple calls to WLAN at any MN's speed below 23km/h, while TOPSIS scheme handoffs at least 50% of the high priority file-download triple calls to WLAN at any MN's speed below 37km/h. At low speed region, TOPSIS's scheme handoffs higher percentage of high priority file-download group calls to WLAN than MULTIMOORA's scheme, hence TOPSIS's scheme exploits the benefits of WLAN more than MULTIMOORA's scheme at low speed region for high priority file-download group calls. At any MN's speed above 37km/h, both schemes show that LTE becomes very competitive and a better alternative than WLAN. However, TOPSIS shows a declining and unstable preference result for LTE networks above medium speed region. In addition at above low speed region, MULTIMOORA's scheme handoffs higher percentage of high priority file-download group calls to LTE than TOPSIS's scheme, hence MULTIMOORA's scheme exploits the benefits of LTE more than TOPSIS's scheme at above low speed region for high priority file-download group calls.

Case 3: in Figure 5.10, MULTIMOORA and TOPSIS schemes handoff atleast 50% of the high priority video-streaming triple calls to WLAN at any MN's speed below 18km/h, at low speed region and at any MN's speed below 36km/h at medium speed region, respectively.

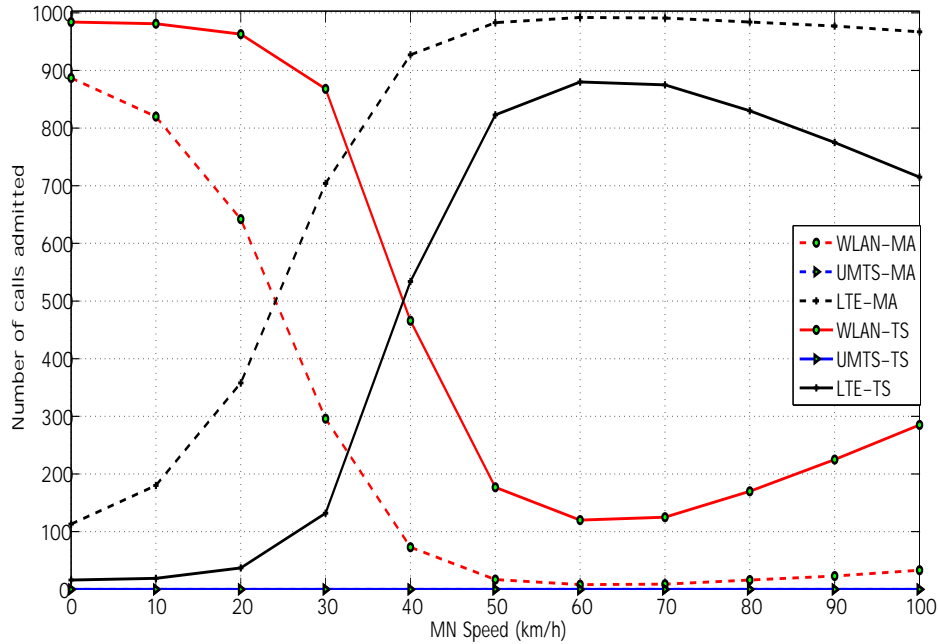


Figure 5.9: High priority file–download triple call handoffs (voice (L), file–download (H), and video–streaming (L)).

At low speed region, TOPSIS’s scheme handoffs higher percentage of high priority video-streaming group calls to WLAN than MULTIMOORA’s scheme, hence TOPSIS’s scheme exploits the benefits of WLAN more than MULTIMOORA’s scheme at low speed region for high priority video-streaming group calls. LTE network clearly outperformed WLAN and UMTS networks at and above medium speed region for both schemes. However, the relative instability of TOPSIS results at high MN speed region is also noticeable. The relative stability of MULTIMOORA comes from the reinforcement and integration of the three decision making techniques of the MULTIMOORA. Furthermore, at above low speed region, MULTIMOORA’s scheme handoffs higher percentage of high priority video-streaming group calls to LTE than TOPSIS’s scheme, hence MULTIMOORA’s scheme exploits the benefits of LTE more than TOPSIS’s scheme at above low speed region for high priority

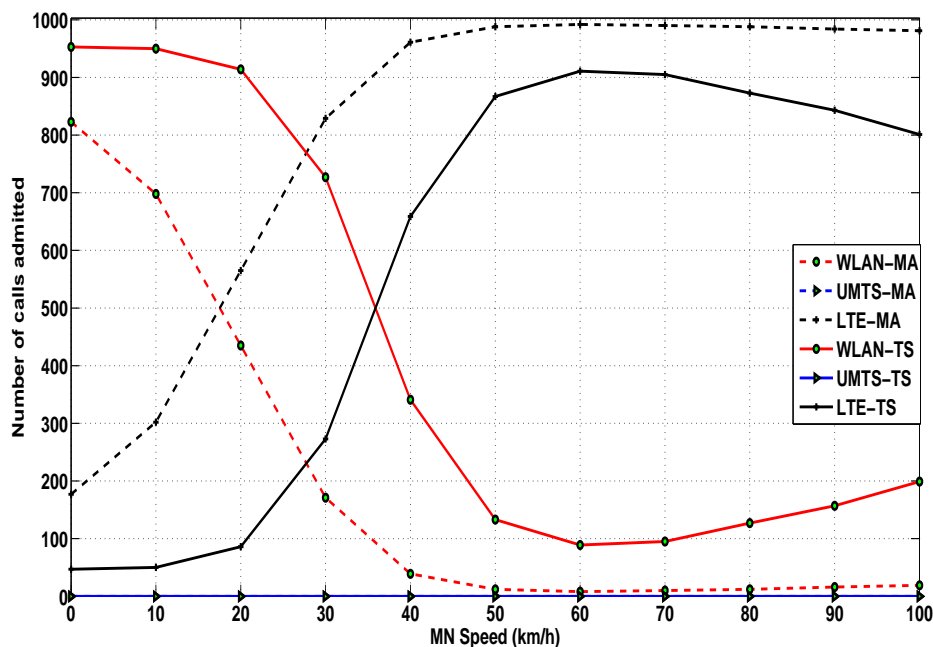


Figure 5.10: High priority video-streaming triple call handoffs (voice (L), file-download (L), and video-streaming (H)).

video-streaming group calls. These results hint on the possibility of producing an improved access network selection algorithm performance through the an hybrid of MULTIMOORA and TOPSIS algorithms.

The impact of the dynamic criteria investigation results clearly showed that the MN's speed heavily influenced the selection of LTE as target network for handoffs, for MNs speed above medium speed region. At above medium speed region, the larger network coverage area of LTE makes it relatively very competitive network for handoffs. This choice ensures lesser frequency of handover; and hence, it reduces the network overhead load.

5.7 Chapter Summary

In this chapter, the problem of access network selection in HWNs is investigated. We proposed the application of a new MCDM algorithm named MULTIMOORA for VHO in HWNs and compared it with some traditionally popular MCDM schemes: SAW, GRA, VIKOR, and TOPSIS. A detailed performance evaluation of the proposed scheme is conducted using different wireless network service application traffic: voice, file-download, and video-streaming.

All the five algorithms are suitable for voice traffic application, and they provide the network that achieves the lowest values of jitter and delay in the HWNs. In file-download traffic VIKOR, TOPSIS, and MULTIMOORA provide the best network solution with PLR and data rate necessary for this file-download. TOPSIS and MULTIMOORA provide the best compromise network solution for video-streaming with the data rate, delay, and jitter metrics. The simulation results demonstrate that MULTIMOORA outperformed SAW, GRA, and VIKOR and showed similar performance with TOPSIS for voice, file-download, and video-streaming application. The accuracy and stability of MULTIMOORA algorithms can be attributed to the complementary contributions of its integrated three ranking system.

MULTIMOORA and TOPSIS emerged as the best-performing MCDM algorithms for single calls, under voice, file-download, and video-streaming conditions. These MCDM (MULTIMOORA and TOPSIS) algorithms are used to investigate access network selection for group calls in HWNs with dynamic criteria. TOPSIS algorithm exploits the benefits of WLAN more than MULTIMOORA algorithm at low speed, while MULTIMOORA algorithm exploits the benefits of LTE more than TOPSIS algorithm at above low speed region for both

high priority file-download and video-streaming group calls. The performance of TOPSIS is seen to be relatively more unstable at the high speed-region, unlike MULTIMOORA's. These findings reveal that an hybrid algorithm between MULTIMOORA and TOPSIS could produce an enhanced access network selection algorithm for NGWNs.

Chapter 6

Conclusion and Future Works

Wireless communication networks designers and operators are faced with the ever-increasing demands for wireless radio network resources and improved QoS provisioning. These challenges are driven by the always best connected (ABC) access network demands through network selection by wireless network users, constant connectivity at anywhere demands by users and the explosive growth of multimedia-hungry devices, such as smartphones, tablets, etc. within the wireless communication networks. Efficient radio resource utilization and QoS provisioning are major issues for wireless communication networks.

In this thesis, the use of MCDM algorithm, call admission control scheme, and cooperative communication techniques to improve the ABC network experience, enhance the radio resource utilization, and QoS provisioning for wireless network users are explored. Section [6.1](#) gives the summaries of thesis's contributions. Finally, Section [6.2](#) highlights some important directions for future work.

6.1 Summary of Contributions

In Chapter 1, an overview of current challenges in radio resource management of wireless communication networks is provided. The chapter introduces the research problems addressed in this research work, the motivations, the research questions, and research objectives. In addition, the research contributions and scope, as well as the outline on the thesis organization are also provided. In Chapter 2, the background topics for the thesis the is presented.

Chapter 3 studied the problem of enhancing QoS for wireless MoH based cellular networks. An ATMA CAC algorithm is proposed. The ATMA CAC exploits the knowledge of the calls generation pattern and moving phase and stationary phase events of the MoH networks to enhance the new call blocking probability, handoff call dropping probability, and channel resource block utilization of the moving wireless networks. The ATMA scheme adaptively smoothens out the new calls, depending on the mobility events of the HSRC. A framework to investigate the effect of varying load traffic on the new call blocking probability, handoff call dropping probability, and resource block utilization of the proposed scheme using Markov chain analysis is developed. The simulation results demonstrated that the ATMA CAC scheme improved resource block utilization; with reduced new call and handoff call dropping probabilities compared to NMAC CAC scheme.

Chapter 4 investigated the problem of throughput and QoS enhancement in wireless cellular networks with cell-edge users. A BCC scheme that opportunistically engage UES in cooperative communication and exploits the transmission channel qualities variation with adaptive modulation coding to enhance the average throughput, QoS, and radio resource

utilization in the cellular wireless networks is proposed. An analytical framework, using Markov chain process to investigate the effect of the queue buffer size on the average throughput, call blocking probability, and radio resource utilization under varying inter-arrival rates (network load), UE cooperative relay and cell-center zone indice of the wireless networks is developed. A platform to investigate the benefit/gain performances of the BCC scheme for improving the network bit-rate transmission, radio resource utilization, and blocking probability of UEs' compared to NBCC scheme is provided. The simulation results showed that the proposed BCC scheme achieved a significant improvement in the average throughput, data blocking probability, and radio resource utilization for wireless communication networks compared to the NBCC scheme.

In Chapter 5, the problem of access network selection for single and group calls in HWNs is investigated. The application of a new MCDM algorithm named MULTIpliative Multi-Objective Optimization Ratio Analysis (MULTIMOORA) for VHO in HWNs and compared it with some traditionally popular MCDM schemes: SAW, GRA, VIKOR, and TOPSIS. A detailed performance evaluation of the proposed scheme was conducted for single calls. The results demonstrate that MULTIMOORA outperformed SAW, GRA, and VIKOR in terms of access network selection for single calls (voice, file-download, and video-streaming), while having similar access network selection performance with TOPSIS for the access network's single call traffic considered.

The access network selection for group calls in HWNs with dynamic criteria investigations demonstrated that TOPSIS algorithm utilizes the benefits of WLAN more than MULTIMOORA algorithm at low speed, while MULTIMOORA algorithm utilizes the benefits

of LTE more than TOPSIS algorithm at above low speed region for both high priority file-download and video-streaming group calls. The performance of TOPSIS is observed to be relatively more unstable at the high speed-region, unlike MULTIMOORA's. The relative stability of MULTIMOORA comes from the reinforcement and integration of the three decision making techniques of the MULTIMOORA. Furthermore from these findings, it can be suggested that an hybrid algorithm between MULTIMOORA and TOPSIS could produce an improved access network selection algorithm for NGWNs.

6.2 Future Work

6.2.1 Handover management in MoH networks

The NGWNs, such as 5G networks are proposed to be ultra-dense heterogeneous wireless communication networks. Handover management in high mobility wireless network systems is still a major challenge that calls for further investigations. The seamless and efficient handover between different MeNBs and RATs remain an open area for future research.

6.2.2 MoH networks traffic load predictions

The wireless environment of practical MoH networks is very dynamic. Some statistical characteristics of the MoH networks, such as new arrival rate, handoff call arrival rates, and call lifetime are time-varying. In MoH wireless network environment where these traffic load parameter values are not well known, the CAC algorithm of such MoH networks could be plagued with inefficient management of the radio resources. An interesting solution to

this problem would be to exploit network traffic load predicting techniques. Predicting techniques, such as Least Squares algorithm, Machine learning algorithm, Grey predictor scheme, would allow the mobile hotspot network to obtain the statistical parameters (call arrival rate and call life time) without prior knowledge. Hence, the investigation into the performance of MoH networks with and without traffic load prediction scheme would be an interesting extension for future work.

6.2.3 Security of BCC

In the BCC scheme, it is possible for malicious relaying UE nodes to attack the network. Some UEs can possibly behave in a malicious manner by intentionally trying to corrupt the communication by sending garbled signal to the destination. This action of malicious relaying UEs can degrade the performance of the network. Considering the effect of malicious of relay UE nodes attack and how to mitigate their actions for ensuring the reliability the networks will be of significant future research importance.

6.2.4 Inter-cell-interference in cellular network communication with BCC deployment

In cellular wireless communication networks, Inter-cell-Interference (ICI) is a predominant problem, especially among cell-edge UEs. ICI problem can significantly degrade the QoS experience of the cell-edge UEs. The effect of the problem of ICI on the QoS experience for edge-cell UEs in wireless cellular networks could be worsen, with the deployment of BCC network scheme, where cell-center UEs are engaged opportunistically as relay nodes.

Therefore, as future work there be would the need to investigate/examine the impact of BCC on ICI management in cellular communication networks, by comparing the ICI performance of cell-edge networks with BCC deployment and with NBCC deployment.

6.2.5 Access network selection

The number of available access network alternatives within HWNs can sometimes fluctuate. One or more RATs can breakdown, and its or their services become unavailable within the HWNS. Sometime more RATs can become activated, thereby increasing the number of available access networks within the HWNs. These variations have been reported to affect the access network selection decisions of MCDM algorithms leading to rank reversal/abnormality. Further work should investigate the rank reversal/abnormality and sensitivity analysis of performance of MULTIMOORA compared to TOPSIS. Also, the interaction of criteria influence using ANP needs to be investigated.

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