

PLANNING AND OPTIMISATION OF 4G/5G MOBILE NETWORKS

AND BEYOND



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Submitted in Partial Fulfilment of the Requirements for the Degree of Doctor of Philosophy in

Data Telecommunications and Networks

2017

## TABLE OF CONTENTS

TABLE OF CONTENTS.....	i
LIST OF TABLES.....	vii
LIST OF FIGURES.....	viii
PUBLICATIONS.....	xii
ABBREVIATIONS.....	xiii
DECLARATION.....	xviii
ACKNOWLEDGEMENT.....	xix
ABSTRACT.....	xx
Chapter One.....	1
INTRODUCTION.....	1
1.0    Introduction.....	1
1.1.1    Evolution of Mobile Communication.....	2
1.1.2    First Generation.....	3
1.1.3    Second Generation.....	3
1.1.4    Third Generation.....	6
1.1.5    Fourth Generation.....	7
1.1.6    Fifth Generation.....	8
1.2    Research Motivation.....	9
1.4    Research Question.....	10

1.5	Contributions to Knowledge and Importance.....	10
1.6	Research Methodology .....	11
1.7	Network Simulation.....	13
1.8	Report Structure.....	16
1.9	Conclusion .....	17
Chapter Two.....		18
LTE/LTE-Advanced Network and the 5G Network Architectures.....		18
2.0	Introduction .....	18
2.1	LTE/LTE-Advanced.....	18
2.2.1	LTE-Advanced Architecture.....	21
2.2.2	Evolved NodeB (eNB).....	22
2.2.3	Mobility Management Entity (MME).....	22
2.2.4	Serving Gateway (S-GW).....	23
2.2.5	Packet Data Network Gateway (P-GW) .....	23
2.3	LTE-Advanced Protocol.....	24
2.5	LTE-Advanced Radio Interface.....	28
2.6	The Fifth Generation (5G) Network.....	31
2.7	The Internet of Things (IoT).....	45
2.8	5G Use Cases.....	47
2.9	Conclusion .....	50
Chapter Three.....		51

RESOURCE ALLOCATION.....	51
3.0 Introduction.....	51
3.1 Resource Allocation in Cellular Networks.....	51
3.2 Quality of Services (QoS) and Bearer Services .....	53
3.3 The Economics of Resource Allocation.....	56
3.4 Resource Allocation Mechanisms in Cellular Networks .....	57
3.4.1 Fairness Based Algorithms .....	57
3.4.2 Delay Based Algorithms .....	58
3.4.3 Throughput Based Algorithms.....	59
3.4.4 Opportunistic Algorithms .....	60
3.4.5 Multiclass Based Algorithm (MBA).....	62
3.4.6 Real Time QoS Guaranteed Algorithm.....	62
3.5 Games with Transferable Utility .....	62
3.6 Market Game and Its Application .....	63
3.7 Shapley Value .....	65
3.8 Owen Multilinear Extension .....	66
3.9 Coalition Formation .....	66
3.10 Control of Coalition Formation.....	68
3.11 Conclusion.....	69
Chapter Four .....	70
COLLABORATIVE RESOURCE ALLOCATION ALGORITHM (CRAA) .....	70

4.0 Introduction .....	70
4.1 Collaborative Resource Allocation Algorithm (CRAA).....	70
4.2 Analytical Model of the System .....	72
4.3 Simulations .....	81
4.4 Performance Evaluation of CRAA .....	84
4.5 CRAA and Relay Networks .....	100
4.6 Conclusion.....	111
Chapter Five.....	112
PLANNING AND OPTIMISATION OF CELLULAR NETWORKS.....	112
5.0 Introduction .....	112
5.1 Network Dimensioning.....	112
5.1.1 Traffic Analysis .....	113
5.1.2 Coverage Estimation.....	115
5.1.3 Capacity Evaluation.....	115
5.2 Site location-allocation using Memetic-Bee Swarm Site Location Allocation Algorithm (MBSSLAA).....	116
5.3 Conclusion.....	135
Chapter Six.....	136
PERFORMANCE EVALUATION OF NETWORK COVERAGE USING MBSSLAA .....	136
6.0 Introduction .....	136
6.1 Simulation.....	136

6.2	Coverage.....	139
6.3	Coverage Analysis.....	140
6.4	Covering a Service Area.....	142
6.5	SINR Distribution.....	144
6.6	Throughput distribution in 5G networks using MBSSLAA.....	152
6.8	Impact of MBSSLAA on 5G Use Cases .....	161
6.9	Conclusion.....	162
Chapter Seven .....		163
CONCLUSION AND FUTURE WORKS .....		163
7.0	Conclusion and the Future.....	163
7.1	CRAA.....	163
7.2	MBSSLAA .....	164
7.3	Research Limitation .....	165
7.4	Future of CRAA.....	166
7.5	Future of MBSSLAA .....	167
7.6	Conclusion.....	167
Reference .....		168
Appendix I .....		184
Numerical and Simulation Data for CRAA .....		184
Appendix II.....		197
Numerical and Simulation Data for CRAA with Relay Network.....		197



## LIST OF TABLES

Table 4. 1: Simulation design parameters .....	83
Table 5. 1: Link utilisation configuration parameters [116] .....	114
Table 6. 1: Design parameters for MBSSLAA .....	137



## LIST OF FIGURES

Figure 1.1 Research Flowchart .....	13
Figure 2. 1: LTE-Advanced Relay Network Architecture .....	21
Figure 2. 2: LTE Advanced Control plane protocol Stack.....	24
Figure 2. 3: LTE-Advanced User Plane Protocol Stack .....	25
Figure 2. 7: An LTE-Advanced Packet being transferred in the DL direction [41].....	26
Figure 2. 8: Further depiction of an IP packet being transferred through the LTE-Advanced Network [41] .....	27
Figure 2. 9: Structure of the OFDMA.....	29
Figure 2. 10: HetNet Architecture.....	30
Figure 2. 11: Evolution of the 5G Network [53].....	33
Figure 2. 12: Generic 5G Network Architecture showing possible deployment of Small Cells [21].....	36
Figure 2. 13: Conceptual Architectural Deployment of the 5G Network [56] .....	37
Figure 2. 14: 5G End-to-End Reference Network Architecture[21].....	38
Figure 2. 15: Decoupled User and Control Planes.....	39
Figure 2. 16: The 5G Hyper Service Cube [57] .....	40
Figure 2. 17: a visualization of the overall 5G network architecture [58, 59] .....	40
Figure 2. 18: Macro Effect on Throughput (Mbps) in 5G [56].....	42
Figure 2. 19: Effect of Small Cell Deployment in 5G Networks [55] .....	43
Figure 3. 1: : LTE-Advanced default bearer [72] .....	54
Figure 3. 2: LTE-Advanced end-to-end bearers services [72].....	55
Figure 3. 3: Differentiated LTE-Advanced bearers and operation level [72].....	55
Figure 4. 1: Standalone flowchart of the proposed CRAA.....	80

Figure 4. 2: Flowchart description of the proposed CRAA as an integral part of the eNB .....	81
Figure 4. 3: Throughput (Mbps) vs. SINR.....	86
Figure 4. 4: CDF vs Throughput (Mbps).....	87
Figure 4. 5: Throughput (Mbps) vs SINR using FTP Traffic .....	88
Figure 4. 6: CDF vs Throughput (Mbps) using FTP Traffic .....	89
Figure 4. 7: Throughput (Mbps) vs. SINR using HTTP Traffic .....	90
Figure 4. 8: CDF vs Throughput (Mbps) using HTTP Traffic .....	91
Figure 4. 9: Throughput (Mbps) vs. SINR using Video Traffic .....	92
Figure 4. 10: CDF vs Throughput (Mbps) using Video Traffic .....	93
Figure 4. 11: Throughput (Mbps) vs SINR using Gaming Traffic .....	95
Figure 4. 12: CDF vs Throughput (Mbps) using Gaming Traffic .....	95
Figure 4. 13: Throughput (Mbps) vs. SINR using VoIP.....	96
Figure 4. 14: CDF vs Throughput (Mbps) using VoIP .....	96
Figure 4. 15: Spectral efficiency vs. SINR .....	98
Figure 4. 16: Fairness Index Measurement.....	100
Figure 4. 17: Throughput (Mbps) vs. SINR in the Relay Network .....	102
Figure 4. 18: CDF vs Throughput (Mbps) in the Relay Network.....	103
Figure 4. 19: Throughput (Mbps) vs. SINR in the Relay Network using FTP Traffic Model ...	103
Figure 4. 20: CDF vs Throughput (Mbps) in the Relay Network using FTP Traffic Model .....	104
Figure 4. 21: Throughput (Mbps) vs. SINR in the Relay Network using HTTP Traffic Model	105
Figure 4. 22: Throughput (Mbps) vs. SINR in the Relay Network using HTTP Traffic Model	105
Figure 4. 23: CDF vs Throughput (Mbps) in the Relay Network using HTTP Traffic Model ..	106
Figure 4. 24: Throughput (Mbps) vs. SINR in the Relay Network using Video Traffic Model	107

Figure 4. 25: Throughput (Mbps) vs SINR in the Relay Network using Gaming Traffic Model .....	108
Figure 4. 26: CDF vs Throughput (Mbps) in the Relay Network using Gaming Traffic Model	108
Figure 4. 27: Throughput (Mbps) vs. SINR in the Relay Network using VoIP Traffic Model..	109
Figure 4. 28: CDF vs Throughput (Mbps) in the Relay Network using VoIP Traffic Model ....	109
Figure 4. 29: Spectral Efficiency (bps/Hz) vs SINR in the Relay Network .....	111
Figure 5. 1: Flowchart of the MBSSLAA.....	131
Figure 5. 2: Illustration of candindate sites from which optimum SeNB location is to be selected .....	132
Figure 5. 3: Optimal site location for SeNB .....	133
Figure 6. 1: Image of Manchester City Centre .....	140
Figure 6. 2: 5G Ultra-Dense network coverage of Manchester City Centre .....	143
Figure 6. 3: SINR distribution for Walfisch-Ikegami (Manchester City).....	145
Figure 6. 4: SINR Distribution for Cost-231-Hata (Manchester).....	146
Figure 6. 5: SINR distribution for Free Space (Manchester).....	147
Figure 6. 6: SINR distribution for Walfisch-Ikegami (Urmston) .....	148
Figure 6. 7: SINR distribution for Cost-231-Hata (Urmston).....	148
Figure 6. 8: SINR distribution for Free Space (Urmston) .....	149
Figure 6. 9: SINR distribution for Walfisch-Ikegami (Birmingham) .....	150
Figure 6. 10: SINR distribution for Cost-231-Hata (Birmingham) .....	150
Figure 6. 11: SINR distribution for Free Space (Birmingham) .....	151
Figure 6. 12: Throughput distribution using Walfisch-Ikegami (Manchester).....	155
Figure 6. 13: Throughput distribution using Cost 231 Hata (Manchester).....	156
Figure 6. 14: Throughput Distribution using Free space (Manchester).....	156

Figure 6. 15: Throughput distribution using Walfisch-Ikegami (Urmstun) .....	157
Figure 6. 16: Throughput distribution using Cost 231 Hata (Urmstun) .....	158
Figure 6. 17: Throughput distribution using Free Space (Urmstun).....	158
Figure 6. 18: Throughput distribution using Walfisch-Ikegami (Birmingham) .....	160
Figure 6. 19: Throughput distribution using Cost 231 Hata (Birmingham) .....	160
Figure 6. 20: Throughput distribution using Free Space (Birmingham) .....	161

## PUBLICATIONS

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- [3] E. Onu and O. Alani, "Collaborative algorithm for resource allocation in LTE-Advanced relay networks," in *Communication Systems, Networks & Digital Signal Processing (CSNDSP), 2014 9th International Symposium on*, 2014, pp. 938-942.
- [4] E. Onu and O. Alani, "Planning and Optimization of LTE-Advanced Relay network and Beyond," presented at the Salford Postgraduate Annual Research Conference (SPARC) 2013: theory, practice and impacts, United Kingdom, 2013.
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- [6] E. Onu and O. Alani, "Cellular Network Planning for 4G (LTE-Advanced) Networks," in *The 3rd Computing, Science and Engineering Postgraduate Research Doctoral School Conference*, United Kingdom, 2012.
- [7] E. Onu and O. Alani, "The Future of Resource Allocation: A Collaborative Resource Allocation Algorithm for 4G Networks and Beyond" presented at the Salford Postgraduate Annual Research Conference (SPARC) 2016: theory, practice and impacts, United Kingdom, 2016.

## ABBREVIATIONS

1G	First Generation
2G	Second Generation
3G	Third Generation
3GPP	Third Generation Partnership Project
4G	Fourth Generation
5G	Fifth Generation
5G	Fifth Generation
5GIC	5G Innovation Centre
ACM	Adaptive Coding Modulation
AMPS	Advanced Mobile Phone Systems
AuC	Authentication Centre
BE	Best Effort
bps	Bits Per Second
BSA	Bee Swap Algorithm
BSC	Base Station Controller
BTS	Base Transceiver System
CAPEX	Capital Expenditure
CDMA	Code Division Multiple Access
CRAA	Collaborative Resource Allocation Algorithm
CRE	Cell Range Expansion
CSG	Close Subscriber Group
D2D	Device to Device

DL	Downlink
EDGE	Enhanced Data rates for GSM Evolution
EIR	Equipment Identity Register
eNB	Evolved Node B
EPC	Evolved Packet Core
EPS	Evolved Packet System
ETSI	European Telecommunications Standard Institute
E-UTRAN	Evolved UMTS Terrestrial Radio Network
FMBC	Filtered Bank Multicarrier
F-OFDM	Filtered-OFDM
FP7	Framework Program 7
FTP	File Transfer Protocol
Gbps	Giga Bits Per Second
GGSN	Gateway GPRS Support Node
GPRS	General Packet Radio Service
GSM	Global Systems for Mobile Communications
HetNet	Heterogeneous Network
HLR	Home Locator Register
HoL	Head of Line
HSS	Home Subscriber Server
HTTP	Hypertext Transfer Protocol
Hz	Hertz
ICI	Inter-Carrier Interference
IMT	International Mobile Telecommunications

IoT	Internet of Things
IP	Internet Protocol
IPv4	Internet Protocol Version 4
ISI	Inter Symbol Interference
ITU	International Telecommunications Union
Kbps	Kilo Bit Per Second
Km/h	Kilometre Per Hour
LAN	Local Area Network
LTE	Long Term Evolution
MA	Memetic Algorithm
MBA	Multiclass Based Algorithms
Mbps	Mega Bits Per Second
MBSSLAA	Memetic-Bee-Swarm Site Location Allocation Algorithm
METIS	Mobile and wireless communications Enablers for the Twenty-twenty Information Society
MIMO	Multi Input Multi Output
M-MIMO	Multi MIMO
MSC	Mobile Switching Centre
M-WLDF	Modified Largest Weighted Delay First
NMT	Nordic Mobile Telephones
NP	Non-Deterministic Polynomial-Time
NRT	Non-Real Time
NSS	Network Switching Subsystem
NTT	Nippon Telephone and Telegraph



OFDMA	Orthogonal Frequency Division Multiple Access
OMC	Operation Management Centre
OPEX	Operations Expenditure
PDCP	Packet Data Convergence Protocol
PF	Proportional Fair
P-GW	Packet Gateway
QoS	Quality of Service
RAN	Radio Access Network
RB	Resource Block
RNC	Radio Network Controller
RR	Round Robin
RS	Relay Stations
RT	Real Time
SAE	System Architecture Evolution
SC-FDMA	Single Carrier Frequency Division Multiple Access
SeNB	Small cell eNB
SGSN	Serving GPRS Support Node
S-GW	Service Gateway
SINR	Signal To Interference Plus Noise Ratio
TACS	The United states Communications Systems
TDM	Time Division Multiplexing
TTI	Time To Transmit Interval
TV	Television
UDN	Ultra-Dense Network

UE	User Equipment
UL	Uplink
UMTS	Universal Mobile Telecommunications System
UTRAN	UMTS Terrestrial Radio Network
VLR	Visitor Location Register
VoIP	Voice over IP
VoLTE	Voice over LTE
WCDMA	Wideband Code Division Multiple Access
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless LAN

## DECLARATION

I, **EGENA ONU** declare that this thesis has been composed solely by myself and that it has not been submitted, in whole or in part, in any previous application for a degree. Except where stated otherwise by reference or acknowledgement, the work presented is entirely my own and has been generated by me as the results of my original research.

Signed:.....

Date:.....

## ACKNOWLEDGEMENT

I would like to thank my supervisor, Dr Omar Alani, without whom none of this would have been possible. His amazing vision, deep insights, and relentless pursuit to not only challenge himself, but all those around him, are only surpassed by his genuine care and wish to educate, mentor, and advise his pupils. I feel very privileged to have had the opportunity to learn from, and work with Dr Omar. He not only has always believed in me, he has always been there whenever I have needed advice, from the smallest of technical problems, to the grandest of intellectual questions. For that, I am forever grateful.

I would also like to thank my Ph.D. qualifying and defence committee members: Dr Hamada Alshaer, Professor Nigel Linge, Professor Helen Louise Ackers, Professor David Parson, Dr Martin Hope and Dr Adil Al-Yasiri. Their comments and suggestions have not only been crucial in bringing many aspects of this work to fruition, but they have also helped in my continued endeavours to personal and professional improvement as a researcher.

I am forever grateful to my benevolent and generous siblings who supported me financially and spiritually throughout this PhD journey, especially, my brother Fred Eche Egena. I am also grateful to my brother, Most Rev Fr Nelson Onu for all his support to ensure that this day came to pass. To my friends and extended family, I say thank you for your prayers and encouragements. I especially want to thank Adejoke Oyewole for her enduring patience throughout this period.

I would like to thank all my collaborators and especially my colleagues at the lab throughout the years that have been truly instrumental in many aspects of what is presented here. Among them, I would especially like to thank Chris Eje, Sam Ayeola, Qusay Al-doori, Ahmed Aaloosi, Subanali, Shema, Giza Abubakar, Yahaya Aliyu, Murtala, Rowane Odum and Deji.

## ABSTRACT

As mobile networks continue to evolve, two major problems have always existed that greatly affect the quality of service that users experience. These problems are (1) efficient resource management for users at the edge of the network and those in a network coverage hole. (2) network coverage such that improves the quality of service for users while keeping the cost of deployment very low.

In this study, two novel algorithms (Collaborative Resource Allocation Algorithm and Memetic-Bee-Swarm Site Location-Allocation Algorithm) are proposed to solve these problems. The Collaborative Resource Allocation Algorithm (CRAA) is inspired by lending and welfare system from the field of political economy and developed as a Market Game. The CRAA allows users to collaborate through coalition formation for cell edge users and users with less than the required Signal-to-Noise-plus-Interference-Ratio to transmit at satisfactory Quality of Service, which is a result of the payoff, achieved and distributed using the Shapley value computed using the Owens Multi Linear Extension function. The Memetic-Bee-Swarm Site Location-Allocation Algorithm (MBSSLAA) is inspired by the behaviour of the Memetic algorithm and Bee Swarm Algorithm for site location.

Series of System-level simulations and numerical evaluations were run to evaluate the performance of the algorithms. Numerical evaluation and simulations results show that the Collaborative Resource Allocation Algorithm compared with two popular Long Term Evolution-Advanced algorithms performs higher in comparison when assessed using throughput, spectral efficiency and fairness. Also, results from the simulation of MBSSLAA using realistic network design parameter values show significant higher performance for users in the coverage region of interest and signifies the importance of the ultra-dense small cells network in the future of telecommunications' services to support the Internet of Things.

The results from the proposed algorithms show that following from the existing solutions in the literature; these algorithms give higher performance than existing works done on these problems. On the performance scale, the CRAA achieved an average of 30% improvement on throughput and spectral efficiency for the users of the network. The results also show that the MBSSLAA is capable of reducing the number of small cells in an ultra-dense small cell network while providing the requisite high data coverage. It also indicates that this can be achieved while maintaining high SINR values and throughput for the users, therefore giving them a satisfactory level of quality of service which is a significant requirement in the Fifth Generation network's specification.

## Chapter One

### INTRODUCTION

#### 1.0 Introduction

Mobile broadband and communication represent one of the fast growing markets with Europe alone experiencing a growth of 21 million subscribers between 2009 and 2011 [1] year on year, caused by the continuous increase in human population and advancement in technologies. The increase in mobile communication is facilitated by the development of new operating systems and applications, therefore, allowing more and more people of diverse economic realities to gain more access to portable communications devices, therefore, enabling mobile businesses to bloom [2]. Also, it is important to note that the growth in data traffic is greatly influenced by the continuous growth in human population. Forecasts from the research community indicate that worldwide mobile devices are expected to consume more than 24 exabytes ( $10^{18}$ ) per month by the year 2020 thus; it would represent nine (9) times the size of the capacity of the existing networks. Also, owing to the plethora of ubiquitous mobile applications that continue to drive cellular data, which is the major component of mobile internet [3, 4]. The authors in [5] also agree that the next decade of mobile communications would experience an increment in the volume of data traffic at the magnitude that is a 1000x the existing traffic demand been experience today. The growth in mobile data traffic is also driven by the rapid advancement in the development of a connected vehicular system which further increases the amount of data that need to be supported by existing and future networks [6].

To accommodate the explosion in human population and the resulting traffic demand from connected network devices due to the increase in their numbers, especially mobile devices, the telecommunications industry has gone through a series of evolutionary phases over the last three decades. This chapter discusses the evolutionary stages of mobile communications and their

respective technologies. The discussion on evolution places more emphasis on the 4G and 5G networks, which represent the current stages in mobile communications' evolution.

This Chapter presents brief description of the different generations of standards through which the industry have been through to reach the current trend in the industry. The Chapter further presents the research motivation, research question as well as the contribution to knowledge. The research method is also presented in this chapter.

### **1.1.1 Evolution of Mobile Communication**

Over the last three decades, mobile communication has evolved in different phases of developments supporting various applications, systems' infrastructure, and services. These evolutionary trends are powered by the users' requirements, which continue to change as the system evolves from phase to phase. The number of connected mobile users continues to grow in direct proportion to traffic demand and data usability thus increasing the needs for coverage, speed, affordability and efficiency of the network system. This forces the industry to keep evolving to meet these requirements and demands. The network evolution involves the inclusion, removal or directional change in existing functional parts to enable the evolving technology to support its user needs. Through the last three decades, the mobile communications industry has gone through different phases of evolution, which distinctively introduced different technologies and functional parts in the networks and their architecture. These phases include First, Second, Third and Fourth generations, respectively [7]. The current phase of evolution is the Fifth generations which is currently under standardisation by the industry players and the research communities. The industry and research communities are deeply invested in defining what technologies the 5G network would support; the network architecture, as well as what users' requirements would be met by the network in order to achieve requisite quality of services.



### **1.1.2 First Generation**

The first generation of mobile networks came into play in 1980 [7], which is the preferred date; it, however, dates back to 1979 when Nippon Telephone and Telegraph (NTT) became the world's first mobile phone system, using analogue transmission system for speech service [7-9]. This trend reached Europe two years later where the Nordic Mobile Telephones (NMT) and the Total Access Communication Systems (TACS) became the two big telephone operators. The United States also launched the Advanced Mobile Phone System (AMPS) in 1982 where it offered 832 channels and data speed of 10kbps. The TACS and AMPS are based on the frequency modulation (FM) transmission technique and multiplexed their traffic on the frequency division multiple access (FDMA) system. Operating on the 800MHz to 900MHz frequency range these systems, however, have problems with interoperability but were able to achieve roaming and handover. The disadvantage in interoperability, therefore, necessitated the further improvement and evolution into the second generations of mobile networks.

### **1.1.3 Second Generation**

The second generations (2G) networks ushered in the digital era in mobile communications [7, 9]. There were several changes made in this generation, and its implementation has better success story than any other generations in discourse. Alongside the traditional speech services offered by telephone systems, the 2G offered low bit rate data services. Digitisation in the 2G networks was aided by its ability to use time division multiple access (TDMA) and code division multiple access (CDMA) to transport its traffic. These technologies allowed the 2G to offer higher spectrum efficiency, high data services and quality roaming services.

For standardisation purposes, the European Telecommunications Standard Institute adopted the Global System for Mobile Communications (GSM) as the standard for the 2G networks. This

standard would later undergo different evolutionary trends within the 2G paradigm. The GSM enabled seamless services using international roaming and higher quality of services enabled by TDMA. The United States, however, did not follow the way of Europe and the rest of the world during this generation; there were three tracks in 2G evolution in the United States; these are the North America TDMA Digital Cellular (IS-54), IS-136 and the IS-95, which operated using based on the CDMA. The GSM's system architecture consists of units such as base station subsystem (BSS) with the base transceiver system (BTS) and base station controller (BSC), network switching subsystem (NSS), which is where the mobile switching centre (MSC) is placed. The MSC is further connected to different units, all contained in the NSS; these units are the visitor location register (VLR), home locator register (HLR), authentication centre (AuC), equipment identity register (EIR), and operation management centre (OMC). This system architecture is shown in Figure 1.1. The introduction of the BSCs reduced the loads otherwise placed on the 1G MSC thus enabling the gradual introduction of interoperability in the GSM system.

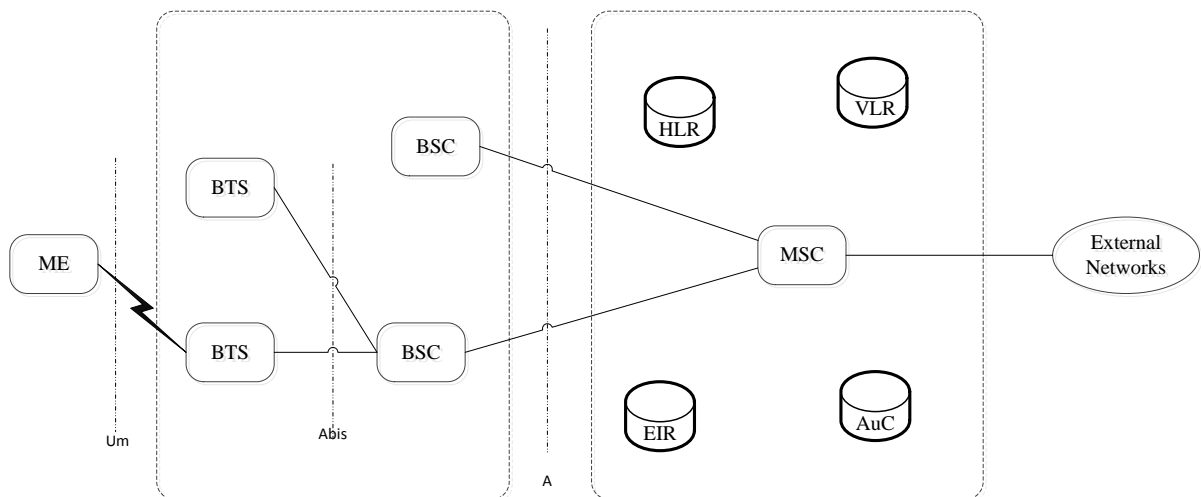


Figure 1.1: GSM network architecture

The GSM technology dominated the 2G standard, enjoying one of the greatest deployment scales in the industry. It allows up to 8 people to share a single 200kHz radio channel by allocating a unique time slot to each of the users sharing the channel [8]. The system was characterised by voice and short message services (SMS) that are limited to 160 characters and offered limited packet data services at low throughput up to 14.4kbps using circuit switched data, which at the time was a significant limitation for required high data transfer services for business users. To overcome this limitation in data services, the research communities and industry experts gradually evolved the system within the paradigm of the 2G to support higher data traffic from connected mobile users and their applications (though these applications were rather primitive at the time). In the course of the evolution, first, was the emergence of the General Packet Radio Services (GPRS) which was necessitated by the increased requirement for sending data traffic on the mobile network. This introduced the Serving GPRS (SGSN) and the gateway GPRS (GGSN) that enabled the network to transport packets on the network's air interface of the GSM. The SGSN and GGSN have been classified into the packet core network system of the GSM. The GPRS system is a major improvement on the 2G system; it is referred to as the 2.5G networks, and offered data speeds of up to 150kbps, therefore enabling wireless access to the internet on the mobile networks. The GPRS system architecture is as shown in Figure 1.2. As a further step in the evolution towards the third generation 3G, the GPRS was further engineered to become the Enhanced Data rates for GSM Evolution (EDGE). The EDGE implemented some level of sophistication in coding methods over the internet thus allowing it to offer users, data rates of up to 384kbps. The EDGE uses the TDMA frame structure, logic channels and carrier bandwidth of 200 kHz.

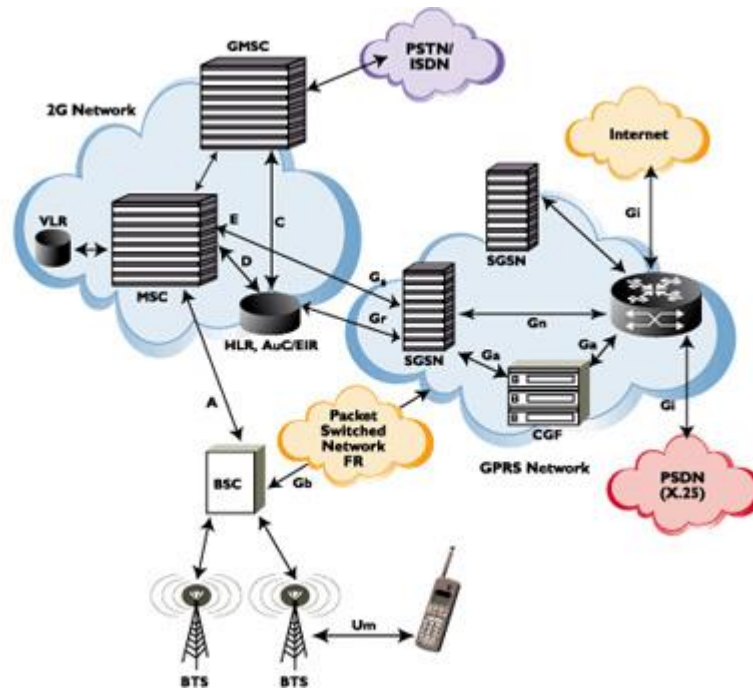


Figure 1.2: GPRS Architecture [10]

### 1.1.4 Third Generation

Because the packet transfer on the EDGE's air interface behaves like some circuit switched call, it was relatively impossible to transmit a high volume of data packet in the system, causing connection inefficiency thus leading to further enhancement of the system to deliver the 3G network systems. During the evolution, several organisations and research institutes as well as operators came together under the International Telecommunications Union (ITU) to form the Third Generation Partnership Project (3GPP/3G) [7]. The 3GPP then adopted the European Telecommunication's Standard Institutes (ETSI) specification: the Universal Mobile Telecommunications System (UMTS) as the 3G standard. The UMTS consist of two domains, the circuit switched, and the packet switched domains respectively in the core network to support voice (circuit-switched) and data (packet-switched) traffic through the network systems. The 3G UMTS is based on the Wideband CDMA (WCDMA) and provide more data rate and efficient services than the previous generations but has its shortfalls as well [9]. Fixing these shortfalls as

it has always been being responsible for the evolution of the next generation networks in which case the fourth generation (4G) network is the next stop [11, 12]. However, this evolution to the 4G came about after a series of improvements have been made to the 3G. These improvements were the High-Speed Downlink Packet Access (HSDPA) and the High-Speed Uplink Packet Access (HSUPA) that later converge to form the High-Speed Packet Access (HSPA) (Theodore et al., 2013) in the 3GPP Release 7. The HSPA enabled the 3G UMTS to operate high-speed data transfer of the 3G network by extending and improving its performance using the WCDMA and was referred to as the 3.5G. This improvement resulted in the ability of the 3G network to support highly improved video and audio capabilities in the [9].

### 1.1.5 Fourth Generation

Through the ITU regulations, as the global regulator for telecommunications worldwide, the 3GPP sets aside the IMT for developments in the 4G network systems. This results from the works already done by the IMT on the IMT2000 standard thereby advancing it to IMT-Advanced, which was accepted by industry players as the 4G network's standard. The IMT-Advanced supports a range of services through mobile and fixed networks that are packet based. The IMT-Advanced standard specification is presented in Table 1.1 [13, 14].

<b>ITEM</b>	<b>IMT-Advanced</b>
Peak Data Rate (DL)	1Gbps
Peak Data Rate (UL)	500Mbps
Spectrum Allocation	>40MHz
Latency (User Plane)	10ms
Latency (Control Plane)	100ms
Peak Spectra Efficiency (DL)	15bps/Hz (4x4)

Peak Spectra Efficiency (UL)	6.75bps/Hz(2x4)
Average Spectra Efficiency (DL)	2.2bps/Hz (4x2)
Average Spectra Efficiency (UL)	1.4bps/Hz (2x4)
Cell-Edge Spectra Efficiency (DL)	0.06bps/Hz (2x4)
Cell-Edge Spectra Efficiency (UL)	0.06bps/Hz (2x4)
Mobility	Up to 350Km/h

Table 1. 1: 4G Specification adapted from [14]

The 4G also supports WLAN interoperability for hot spots, an extension of 2G and 3G, wider cellular coverage, different services and smoother-quicker handoff as well as after some time, provide the total replacement for the 3G network system [15, 16]. It also offers a higher data rate of 50-200Mbps and as well converges with TV broadcast and fixed wireless networks. Due to the space issues in IPv4, 4G implemented the IPv6 on end-to-end [8] or 100Mbps-1Gbps [17, 18] data transmission with a latency of about 5ms [19]. Table 1.1 presents a summary of these characteristics of the 4G network. The 4G's industry standard specification is the Long Term Evolution (LTE)-Advanced, which is further discussed in more details in Chapter Two.

### 1.1.6 Fifth Generation

Having been through several phases of development, the next step in mobile communications is the Fifth Generations (5G). The attentions of the research communities are now very well focused on the 5G network, which is designed to support existing network technologies. Therefore, it is not expected to be a monolithic technology like the previous generations. From the perspective of the research communities and the works from the industry experts, the 5G would be supporting a plethora of applications such as the internet of things (IoT), wearable, augmented reality and immersive gaming. For the network to support a range of complex

requirements, different use cases have been defined, and the network is proposed to operate in the millimetre wave band to unleash high bandwidth with the consequent high throughput that is available in it. These bandwidths are being farmed from used and unused frequencies. The 5G network also looks forward to pioneering cloud-based network management services. Therefore, the possibilities of cloud-based core network services and management are high on the scale.

Given that, historically, there is a 10-year cycle for every generation of mobile communications to fully evolve into commercial deployment for the drawing tables, the industry is now looking forward to the year 2020 for the full deployment of the 5G network and its accompanying technologies. The 5G network and its use cases are further elaborated in Section 2.9 of Chapter Two.

## **1.2 Research Motivation**

The need for data usage has continuously been on the increase since the last two decades especially due to the internet proliferation and innovations and advancements that have been made in the development of smartphones and their applications. This development is accompanied by the constant need to access data networks anywhere anytime and even faster. The 4G shows the high capability of supporting these requirements and the 5G is also being engineered to do even more as the world makes great leaps towards the implementations of the Internet of Things (IoT) which is expected to increase the amount of data traffic on the networks in the magnitudes of 1000x [20]. Mobile data networks have had a great impact on the human society. As society is further, advancing the Internet of Things (IoT), many devices will be connected to the mobile data network. This implies that the IoT will exert far-reaching strains on the capacity of mobile networks. To cope with the traffic demands that would be coming from the increased number of connected devices resulting especially as a consequent response to the IoT, the system would be requiring a more flexible network capacity. This, in the 5G network, is being considered in the

form of “Infinite Capacity” [21]. This approach is intended to focus more on the capacity of the network instead of the speed at which data is transferred. The IoT concept will require a high amount of network resources to achieve high data rate demands of the network users, therefore requiring an efficient resource allocation mechanism that caters for resource needs of connected devices. In addition, in the third world countries where network deployment is still at an extremely low density, the benefits of this advancement have not been fully achieved, and it is closed to be elusive as technologies such as the 3G are still sought after. With the entrance of the 4G network and the industry’s vision locked on the future such as the 5G networks and beyond, which definitely will penetrate these markets, it is important to expand the planning and optimisation framework readily available for network planner for green deployment and optimisations purposes especially in these regions and for optimisation in the developed world.

#### **1.4 Research Question**

How can the 4G/5G Networks and Beyond be Planned and Optimised regarding the network coverage and capacity such that it ensures the users’ contracted quality of service (QoS) is maintained in an overpopulated world that exhibits advancement in technologies, daily? These need to be done such that the provisioned capacity efficiently satisfies the number of users that can be supported with a high data rate and better network coverage in the ever-evolving network’s application and traffic demands and that, the operators’ operation expenditure (OPEX) and capital expenditure (CAPEX) are at their minimum.

#### **1.5 Contributions to Knowledge and Importance**

This research’s contributions to knowledge are:

1. A Collaborative Resource Allocation Algorithm (CRAA), using Market Game as an optimisation technique for resource allocation in OFDMA networks that resulted in



significant improvement in the throughput for users and higher spectral efficiency in the network.

2. A cost-efficient novel heuristic Memetic-Bee-Swarm Site Location-Allocation Algorithm (MBSSLAA), which allocated the small cells to optimal locations that improved high throughput distribution in the coverage area.

#### **The significance of Contributions:**

- i. The CRAA improved the throughput achieved by the users, particularly in the cell-edge, therefore, guaranteeing high quality of experience for users at different points in the network.
- ii. The CRAA ensured higher spectral efficiency in the network. At some point, there are available resources that are not used, by combining these resources to serve the coalition, it becomes usable and helps to increase total QoS.
- iii. The MBSSLAA is a cost-efficient method of deploying a ultra-dense network of small cells in a dense-urban area.
- iv. The MBSSLAA provided high data coverage in the region of interest with a minimal number of small cells.

### **1.6 Research Methodology**

This study employs the scientific research methodology, and the steps taken to complete the research are itemised in this section and further illustrated in Fig 1.1. In using the scientific methodology, analytical model and system level simulations are adopted to verify the results of the proposed algorithms. The methodology follows through an iterative process that includes literature review. The results from the findings have been published to get validations from the research community. Discussions were also held with different scientists in the field as well as

technical experts working in the field. This approach considers the 4G, 5G and Beyond, and the factors that degrade their performance. The processes of the methodology include:

i. Literature review of the LTE-Advanced and 5G Networks

This involves a critical study of the LTE-Advanced system and the 5G Network to acquire an in-depth knowledge by examining different kinds of literature. Various approaches to solving the proposed research question were gathered through the process of literature reviews. These literature covered resource management and network planning for the 4G and previous generations, which were applied to the 4G and 5G small cells in this project.

ii. Research problem

From the study of the literature, it was established that no work had used the approaches proposed in this project so, the research question is formulated in such a way that the proposed algorithms would further go on to answer the question posed from the literature. The algorithms have been published in IEEE and PGNET conferences to give credence to their novelty.

iii. Network Simulation: a series of system-level simulations were run to evaluate the performance of the algorithms. These simulations used real-time mobile network parameters. The simulators used are, the Vienna LTE and the ICS Designer network simulators. Section 1.7 further elucidate the choice of network simulation.

iv. The Vienna LTE system-level simulator [22, 23] was used to simulate the resource allocation algorithm while the site location allocation algorithm was used to overlay the 5G small cell networks over LTE-A network.

v. The algorithms were tested using system-level simulations to evaluate and validate their performance in comparison to the works of the literature.

- vi. Where it was found necessary, amendments were made necessary to optimise the performance of these algorithms by running the simulation over a number of times.
- vii. Having been satisfied with the results from the simulation processes in (v) and (vi), I proceeded to write this report (PhD Thesis).

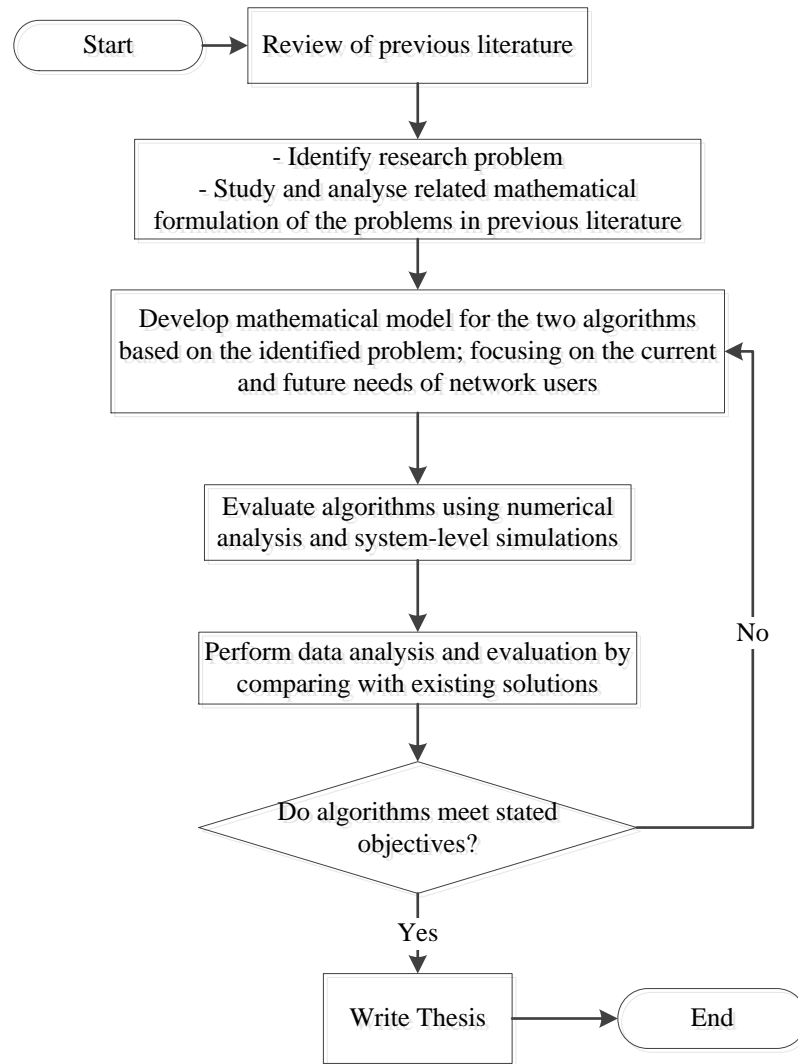


Figure 1.1 Research Flowchart

## 1.7 Network Simulation

Network simulation is a popular method for analysing the performance a network system [24].

Network simulations can be achieved either through analytical modelling or computer simulation

or the combination of both methods [24]. Considering that this project utilised the computer simulation concept, network simulation here focuses on the idea of software for simulating network performance and analysing how this performance helps the network users. Simulation offers the ability to parameterize a system's attribute through modelling to study the system's performance in a controlled manner. Being under control, the modelled system's measurements are made to be nonintrusive and deterministic [25]. Simulation has been used, over time as the means for testing systems performance due to the factors presented by cost, time, specification inaccuracies and errors due to implementation [25]. To accurately measure and test a system's performance, the real system's attributes are abstracted into a mathematical model and run through simulation scenarios that simplify and mimic the actual intention of the system. In the field of telecommunications, for example, two unique types of simulation are used to measure, evaluate and test the performance of new or existing systems. These are; link level simulations and system level simulations. This study used the system level simulation method to evaluate the two proposed algorithms. These simulators are Vienna LTE and ICS Designer. They are further described in Chapters Four and Six, respectively.

System level simulation is very crucial in the study of new and existing mobile network technologies and their performance. It is the most effective means of evaluating the performance and predicting the impact of the network and its technologies [26, 27]. System level simulations help researchers and industry experts to test and optimise their algorithms and procedure pre-deployment. Most importantly, system level simulations allow the investigation and measurement of the impact algorithmic decisions on the performance metrics of the network to ascertain how they affect the users' perceptions of the network, upon deployment [26, 27]. In this regard, system level simulation is the best option when it comes to issues concerning network planning and resource management, considering that these are very important to network

reliability and greatly, general terms; affect the network performance as perceived by the users. In system level simulation, the physical layer of the network is abstracted by simplified models that depict the essential characteristics of the network, thus, resulting in a system with high accuracy and low complexity in implementation which also contributes to reducing the amount of required computational power, in such instances [26].

Scientific researchers depend on mostly software to harness the powers of computing which are ubiquitous in science research domains. Developing this software for them to use for particular research, however, presents very daunting tasks which range from the knowledge of programming to as far as the legal expertise required for licensing such software [28]. This also gives rise to different confusion, therefore, leading institutions set aside technology transfer offices that are capable of handling the complex legal aspect [28]. The intellectual property for a simulator (software, in this case) has to be granted by the owners before it is considered to be a valid research tool for any scientist, which is if the researcher did not create the software. The intellectual properties of a software licence are usually characterised by proprietary and open-source licence [28].

**Proprietary License** – these are commercial packages in which the end users are given a restricted click-through access to achieve the intended results. By such agreement, the users are bound to the intellectual property's owners defined goals and access levels and at such are forbidden from copying, redistributing or creating a derivative of the simulator [28, 29]. Based on such agreements, the researchers are therefore not given permission to access the codes of the software for whatever reason since the agreement rests exclusive rights on the person, people or organisation with the copyright ownership [28, 29].

**Open-Source License** – open-source license, on the other hand, is intended to overcome the restrictions placed on research by the proprietary license owners. These kinds of software give maximum degree of interaction and usability to the users. In open-source software, the users get open, non-discriminatory access to all levels of the software which are grant free thus enabling them to modify the codes [30, 31] such that it suits their research purposes. Researchers using open-source software have the ability to create different derivatives of the software and for redistribution. The advantage here is that this kind of license promotes innovation and further enhancements to the software [28, 30] and comes at no cost to the end users [32]. Some of the major product of open-source licencing come under the different derivatives of the of the GNU agreements [28]. An open-source license fundamentally enables collaboration within the scientific research community thereby allowing for a greater degree of transparency and increases credibility within the scientific community [31] as well as improving productivity in scientific research that especially requires the use of software for data analysis [33]. The Vienna LTE Simulator which was used to evaluate the performance of the CRAA is based on the GNU agreement and also encourages reproducibility which is in tandem with the findings of [31].

## **1.8 Report Structure**

The remainder of this report is arranged in that; Chapter Two presents the literature review of journal articles, conferences papers, white papers and standardisation documents concerning the 4G LTE-Advanced Network, the 5G Network and their accompanying technologies and requirements. Chapter Three discusses resource allocation in a mobile network with the focus on LTE-Advanced as well cooperative game theory and its applications. Chapter Four presents the Collaborative Resource Allocation Algorithm, its implementation performance analysis using LTE-Advanced Network and LTE-Advanced Relay Network. Chapter Five discusses network planning and site location-allocation techniques in comparison with the proposed Memetic-Bee

Swarm Site Location-Allocation Algorithm (MBSSLAA). Chapter Six presents the performance evaluation of the MBSSLAA as simulated in the ICS Designer. Chapter Seven presents the conclusion and future research direction.

## **1.9 Conclusion**

In this Chapter, the concept of network evolution has been elaborated through history. The Chapter also presented the research question, motivation methodology. These indicate the research direction, going forward, as would be seen in the subsequent Chapters.

## **Chapter Two**

### **LTE/LTE-Advanced Network and the 5G Network Architectures**

#### **2.0 Introduction**

As presented in Chapter One, there have been different phases of evolution experiences by the Telecommunications industry before now. This evolution has gone through a period of three decades to allow for fast transfer of data on mobile networks. Top of the trends today are the 4G and 5G networks, which are currently the focus of the industry. In this Chapter, the LTE-Advanced is discussed as the representative of the 4G network. The 5G architectures and use cases are also discussed in order to assess the general impact that the 5G would have on the IoT.

#### **2.1 LTE/LTE-Advanced**

In 2008, the Long Term Evolution (LTE) was established as a work group by the Third Generation Partnership Project (3GPP) and mandated to define the radio access network of the Fourth Generation (4G) Network [7]. The 4G network itself consists of two functional components, the LTE that is otherwise known as the evolved UTRAN (E-UTRAN) and the core network called the Evolved Packet Core (EPC) or System Architecture Evolution (SAE). These two components make up the Evolved Packet System (EPS) [34], which is the technical name but referred to as the LTE for simplicity. It was defined to support a data rate of 50Mbps and 100Mbps for uplink and downlink respectively. These data rates are considered to be very low for 4G support and future networks where offering spectral efficiency of 5b/s/Hz is unacceptable considering the throughput and other performance requirements by future applications that would be supported by the network. This gave rise to the evolution of the LTE-Advanced which is the evolved model of the LTE/SAE; an all-IP centric converged network integrating both fixed and mobile networks based on 3GPP standards with a focus on highly efficient, low latency, packet-optimised and more secure services [35]. LTE/LTE-Advanced use the OFDMA and SC-



FDMA on the downlink and uplink respectively as the access technology to access the radio interface. The OFDMA supports high ubiquitous data rates and high spectral efficiency while the SC-FDMA allows an efficient usage of the UE battery life. The LTE-Advanced architecture adopted the OFDMA radio access technique because of its resilience against multipath delay spread and the higher spectral efficiency, which it offers [7, 34]. Apart from a few differences in the power transmission, the SC-FDMA has almost the same structural unit of transmission with the OFDMA [36]. Table 2.1 describes the performance target for LTE, LTE-Advanced and IMT-Advanced for both uplink and downlink respectively.

<b>Parameters</b>	<b>Transmission Path</b>	<b>Antenna Configuration</b>	<b>LTE (Rel.8)</b>	<b>LTE-Advanced</b>	<b>IMT-Advanced</b>
Peak Data Rate	DL	8x8	300 Mbps	1Gbps	1Gbps
	UL	4x4	75Mbps	500Mbps	
Peak Spectrum Efficiency (bps/Hz)	DL	8x8	15	15	15
	UL	4x4	3.75	15	6.75
Capacity (bps/Hz/cell)	DL	2x2	1.69	2.4	-
		4x2	1.87	2.6	2.2
		4x4	2.67	3.7	-
	UL	1x2	0.74	1.2	-
		2x4	-	2	1.4

Cell-Edge Throughput (bps/Hz/cell/user)	DL	2X2	0.05	0.07	-
		4X2	0.06	0.09	0.06
		4X4	0.08	0.12	-
	UL	1X2	0.024	0.04	-
		2X4	-	0.07	0.03

Table 2. 1: Parameter comparison table

LTE-Advanced is defined as a product of the operators/industry players, which makes its deployment more favourable. It is designed to be backwards compatible with the previous generations of cellular systems. The voice traffic at the earlier stage of the LTE is transmitted as VoIP and fall back to the previous generations is readily available for users in the event of failure. To enable good quality voice communication, research is ongoing on the Voice over LTE (VoLTE) to allow voice to be fully transmitted on the LTE without reasons for fall back thus making every transmission in the network, an IP/packet-based transaction.

The LTE-Advanced, as defined by the 3GPP is a highly flexible radio interface [19]. It supports both frequency-division duplex (FDD) and time division duplex (TDD). The LTE is capable of exploiting a large number of spectrums by operating in a wide range of system bandwidth [19]. These bandwidths include 1.4MHz, 3MHz, 5MHz, 10MHz, 15MHz and 20MHz respectively. Each of the bandwidths carries a specific number of resource blocks and these bandwidths, which can sometimes be combined through carrier aggregation to increase the number of available radio resources in the network, depending on demand and operators' technology.

### 2.2.1 LTE-Advanced Architecture

The LTE-Advanced architecture is a radical evolution of the 3GPP UTRAN representing changes to the 3GPP core network of the UMTS. The LTE is made of single whole system referred to as the Evolved Packet System (EPS). The EPS is further split into two functional components, the radio access network (RAN) which comes as the LTE-Advanced/E-UTRAN and the IP-centric core network which is represented by Evolved Packet Core/System Architecture Evolution (EPC/SAE). Figure 2.1 is the architecture showing the functional components along with the nodes and logical interfaces.

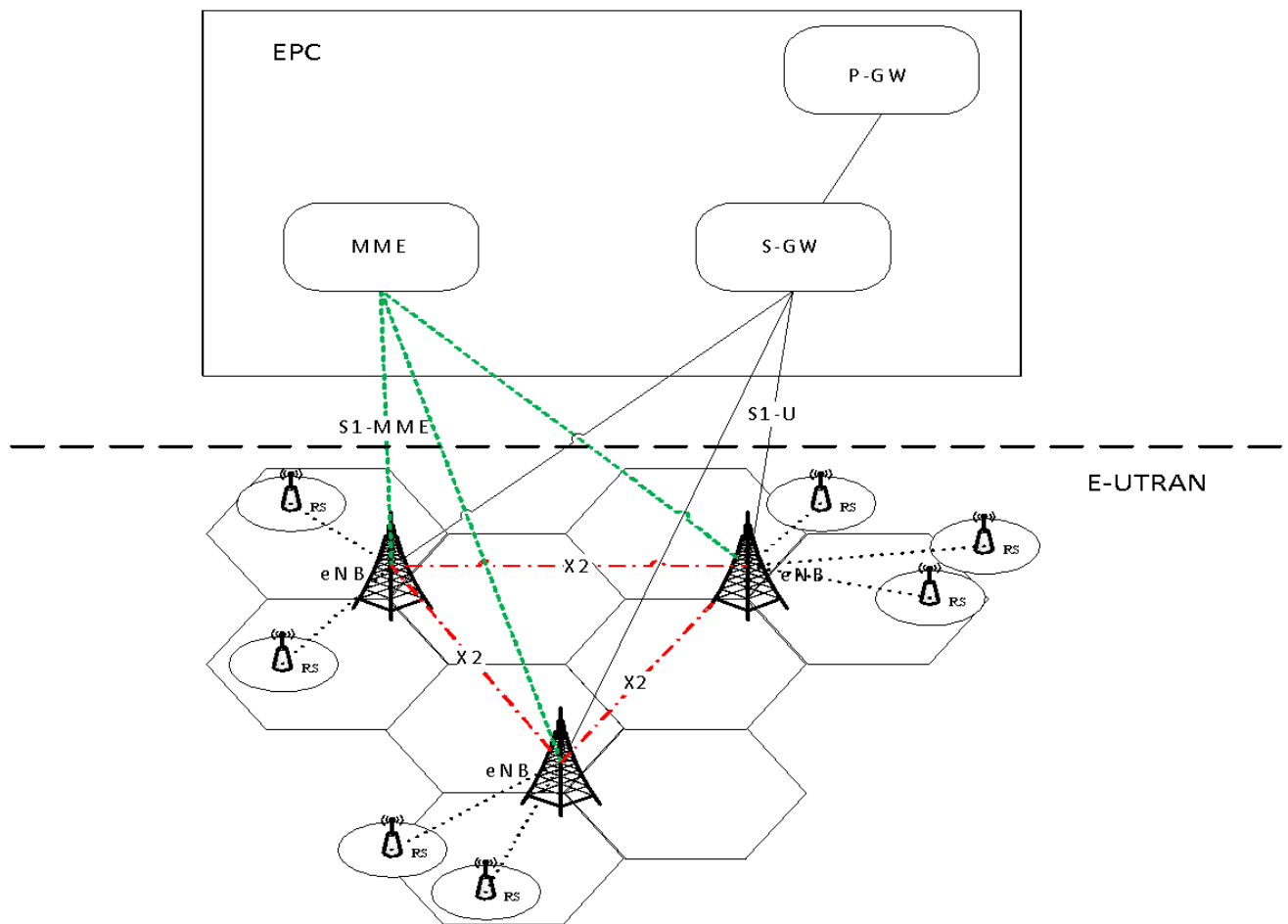


Figure 2. 1: LTE-Advanced Relay Network Architecture

The E-UTRAN comprises intelligent base stations, evolved NodeBs (eNBs). The eNB may serve one or several cells at one time [37] and also combines the base station and the radio network

controller (RNC) of the UMTS as an entity. This means that the eNBs performs radio resource management on its own. The EPC/SAE is an IP-centric system that implies that all transactions are packet-based. It consists of the serving gateway (S-GW), packet data network gateway (P-GW), the mobility management entity, and the home subscriber server (HSS).

### **2.2.2 Evolved NodeB (eNB)**

In the LTE-Advanced specification, the usual 2G BSC and 3G radio network controllers (RNC) were removed from the network architecture to reduce delays due to processing. For replacement, all their functionalities were integrated into one single whole as a function of the eNB. The eNB, therefore, combines all the functions of those network elements in the previous generations, which further contributed to reducing data transmission latency in the network by terminating the layer two protocols in the eNB, and provide for a rather simplified network operation that allows high radio network performance. The eNB supports all legacy procedures that enable transmission and reception through modulation and demodulation, and channel coding and decoding. The eNB is also responsible for radio mobility management, error correction and radio resource control. This unit is referred to as the E-UTRAN and connected to the evolved packet core (EPC) through the S1-U and S1-C interfaces.

### **2.2.3 Mobility Management Entity (MME)**

The MME is homed in the EPC like all other entities as discussed subsequently. The MME terminates the control plane of the network protocol and performs several important tasks in the system architecture of the LTE-Advanced. These tasks include tracking, paging and retransmission for an active and idle user equipment (UEs); location management for idle UEs; session management for UEs; activation and deactivation of bearers; choosing SGW for a UE during initial attach procedure and intra-handover. It is also responsible for authenticating the users towards the home subscriber server. The entity generates and allocates temporary UE

identities (GUTI). It enforces roaming restrictions on users; terminating, ciphering and integrity of protection for non-access stratum (NAS) signalling as well as controlling network interoperability. The MME is connected to the HSS using the S6a interface; it is also connected to S-GW using the S11 interface. In connecting with other MME, they are connected using the S10 interface. The MME directly connects the eNB (E-UTRAN) using the S1-C interface which carries only control information in the network for the UEs.

#### **2.2.4 Serving Gateway (S-GW)**

The S-GW terminates the network's packet data interface towards the E-UTRAN, and for this, a UE is served by a single S-GW per time. The S-GW is the primary mobility anchor for UEs moving within the operator's network and therefore performs handover between neighbouring eNBs and transfers data on the user plane of the network protocol. This unit of the EPC handles the mobility aspect of the system towards 2g/3G. It monitors and maintains context for UEs during their idle states and generates paging request when the data arrive on the downlink for the UE. In the case of lawful interception, the S-GW performs replications for user traffic. The S-GW is connected to the E-UTRAN through the S1-U interface (carrying only data packet for the UE); it connects the billing system (Charging Gateway) through the Gy/Gz interface. The entity also connects the P-GW using the S5/S8 interfaces. The S5 interface is for the bearer user plane while the S8 interface is the control plane. The connection to the P-GW is also similar to the connection to other technologies.

#### **2.2.5 Packet Data Network Gateway (P-GW)**

The P-GW is the gateway, which terminates the interface towards the PDN. A UE may be served by more than one P-GW if the UE is accessing more than one PDN. The P-GW enables inter-technology mobility for UEs between non-3GPP technologies and acts as the entry/exit point for UEs public data networks (PDN) traffic. The unit manages policy enforcement, packet filtration

for UEs, charging support and lawful interception. Among other essential functions of this unit is the allocation of UE IP addresses. The P-GW is connected to the policy and charging rules function (PCRF) using the Gx interface and further connects the entire network to the internet using the SGi interface. As with the S5/S8 interface, the SGi interface also consists of two logical interfaces, one for the bearer user plane and one for the control plane.

### 2.3 LTE-Advanced Protocol

The LTE-Advanced protocol is divided into the control plane, and user plane described in Figures 2.2 and 2.3. The figures show the different interactions from the UE through to the EPC and the interacting interface to the outside world.

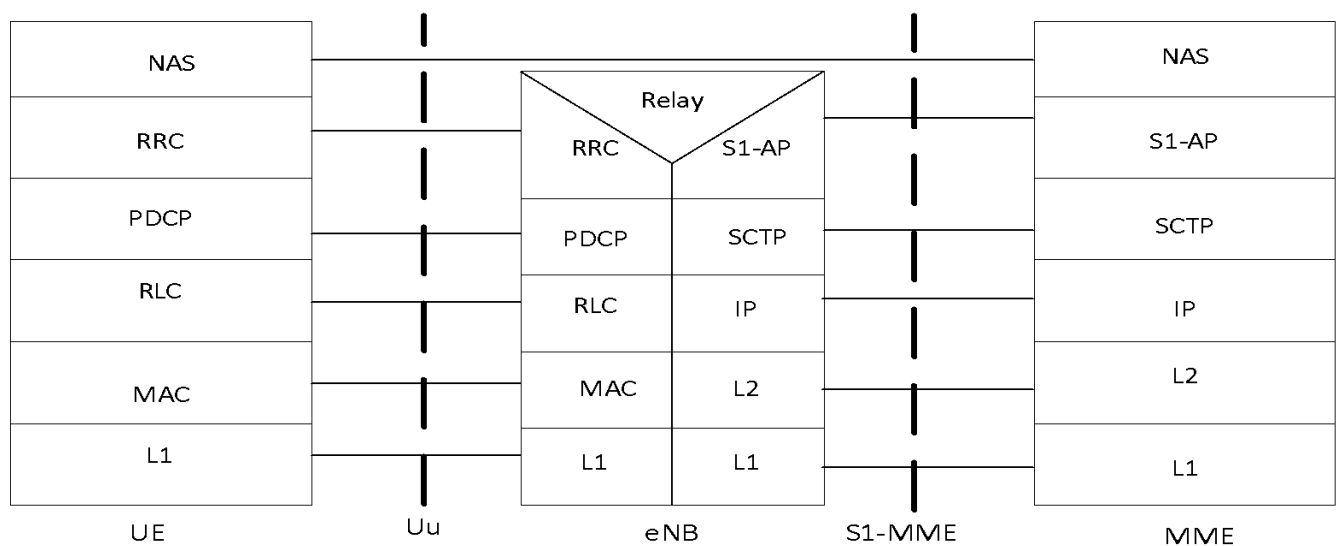


Figure 2. 2: LTE Advanced Control plane protocol Stack

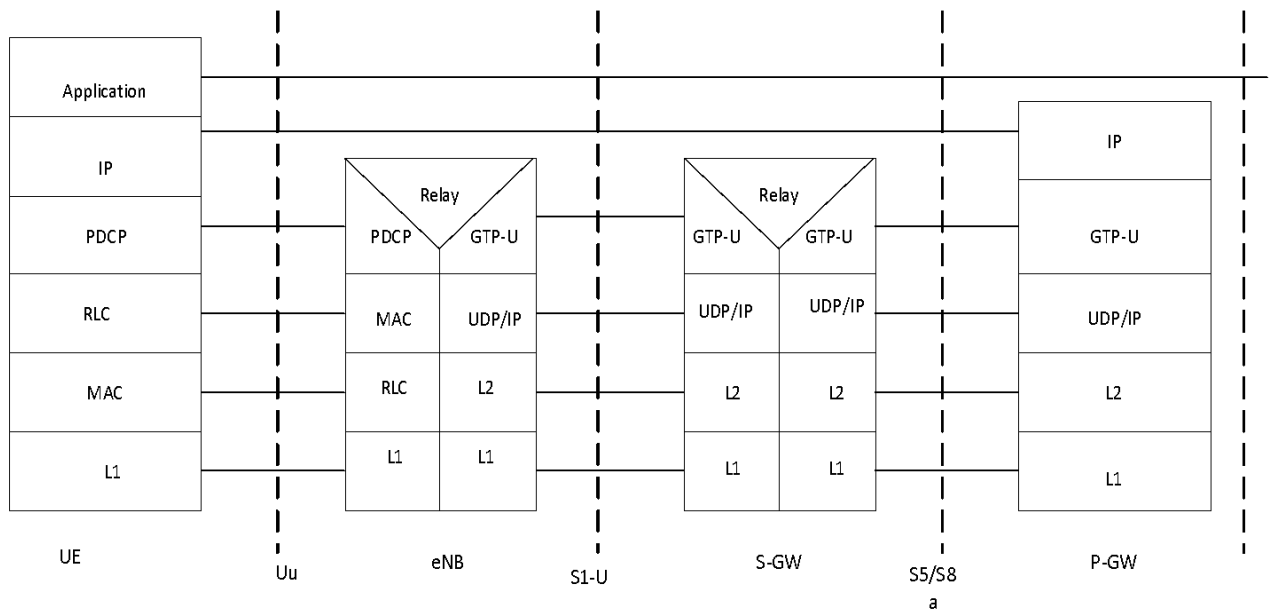


Figure 2. 3: LTE-Advanced User Plane Protocol Stack

#### 2.4.1 Radio Resource Management (RRM)

Radio resource management ensures the efficient use of the available radio resources and provides mechanisms that enable the E-UTRAN to meet radio resource-related requirements that support the efficient transmission and operation of higher layer protocols over the radio interface, such as IP header compression; load sharing and policy management [38]. The RRM performs several fundamental functionalities such as:

- Radio Bearer Control
- Radio Admission Control
- Connection Mobility Control
- Dynamic Resource Allocation and Packet Scheduling
- Inter-cell Interference Coordination
- Load Balancing
- Inter-RAT Radio Resource Management
- Subscriber Profile ID for RAT/Frequency Priority

## 2.4.2 Packet Data Convergence Control Protocol (PDCP)

The PDCP comes in one instance per radio bearer. It performs header compression and decompression for IP data and transfer of both control and user plane data amongst other functions such:

- In-sequence delivery of upper layer PDUs at PDCP re-establishment procedure
- Duplicate detection of lower layer SDUs at PDCP re-establishment procedure
- Retransmission of PDCP SDUs at handover
- Ciphering and deciphering; integrity protection

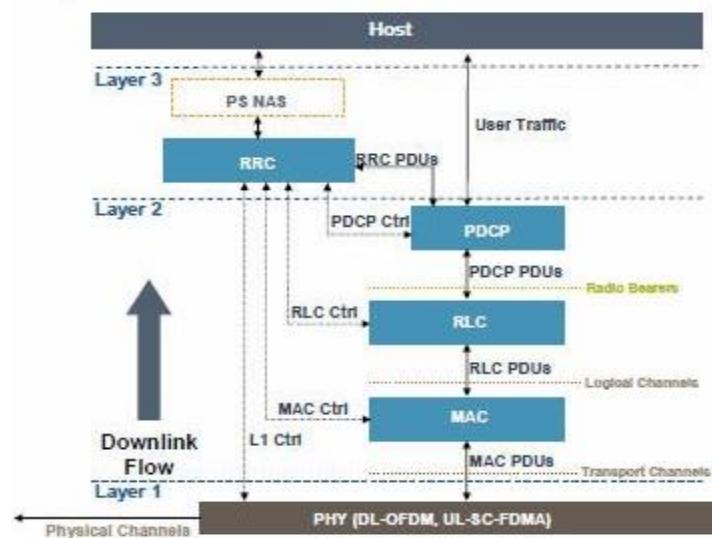


Figure 2. 4: An LTE-Advanced Packet being transferred in the DL direction [41]



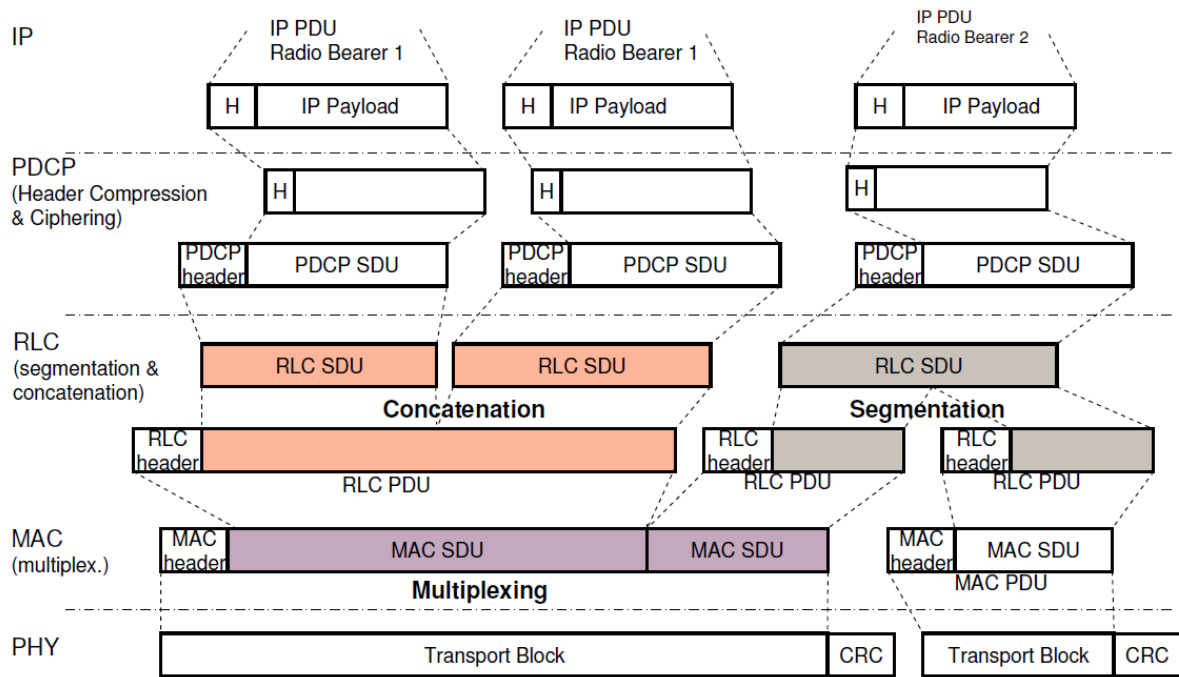


Figure 2. 5: Further depiction of an IP packet being transferred through the LTE-Advanced Network [41]

### 2.4.3 PHY

The physical layer of the LTE-Advanced describes the model upon which the radio access technique of the network operates. It is divided into the uplink and the downlink transmission models respectively. The uplink and downlink transmission models are further granulated into radio frames each with a duration of 10ms. Each of the radio frames is further divided into ten (10) sub-frames each consisting of two slots. The LTE-Advanced radio frame structure is separated into FDD and TDD. In the FDD, the uplink and downlink directions are separated by in the frequency domain; 10 sub-frames are available for uplink and 10 for downlink for every radio frame. The FDD is referred to as the Type 2 frame structure. The physical layer also defines the channels of transmission for the network's radio interface. This layer determines the characteristics of the cellular system concerning peak data rates, latencies and the network coverage [42].

## 2.5 LTE-Advanced Radio Interface

The LTE-Advanced uses the orthogonal frequency division multiple access (OFDMA) technique to access the radio interface due to its robustness and ability to transmit a large amount of data over the air. OFDMA is a version of the orthogonal frequency division multiplexing (OFDM) which is used to transmit data for multi users simultaneously.

The OFDMA works by splitting the radio signal into multiple smaller sub-signals that are then transmitted simultaneously at different frequencies to the receiver. It reduces the amount of crosstalk in signal transmission [12]. The performance of OFDMA system is sensitive to non-perfect frequency synchronisation, which leads to frequency offsets and a consequent degradation in system performance. The OFDMA mitigates the effect of multipath channels through the elimination of inter-symbol interference (ISI). A disadvantage of OFDMA is the system sensitivity to frequency offset between transmitter and receiver caused by local oscillators. This consequently results in the destruction of orthogonality and inter-carrier interference (ICI). The structure of OFDMA as in figure 2.4 consists of subcarriers in the frequency domain and symbols on the time domain, which is used to transmit data. OFDMA exhibits resistance to frequency selective fading by dividing the available bandwidth into many narrow overlapping sub-channels. When used with multi-input-multi-output (MIMO) antenna, OFDMA allows high data throughput, enabling the system to achieve high spectral efficiencies as well as large coverage area that are critical for future wireless networks [44] thus making it an excellent candidate for high-speed broadband [45].

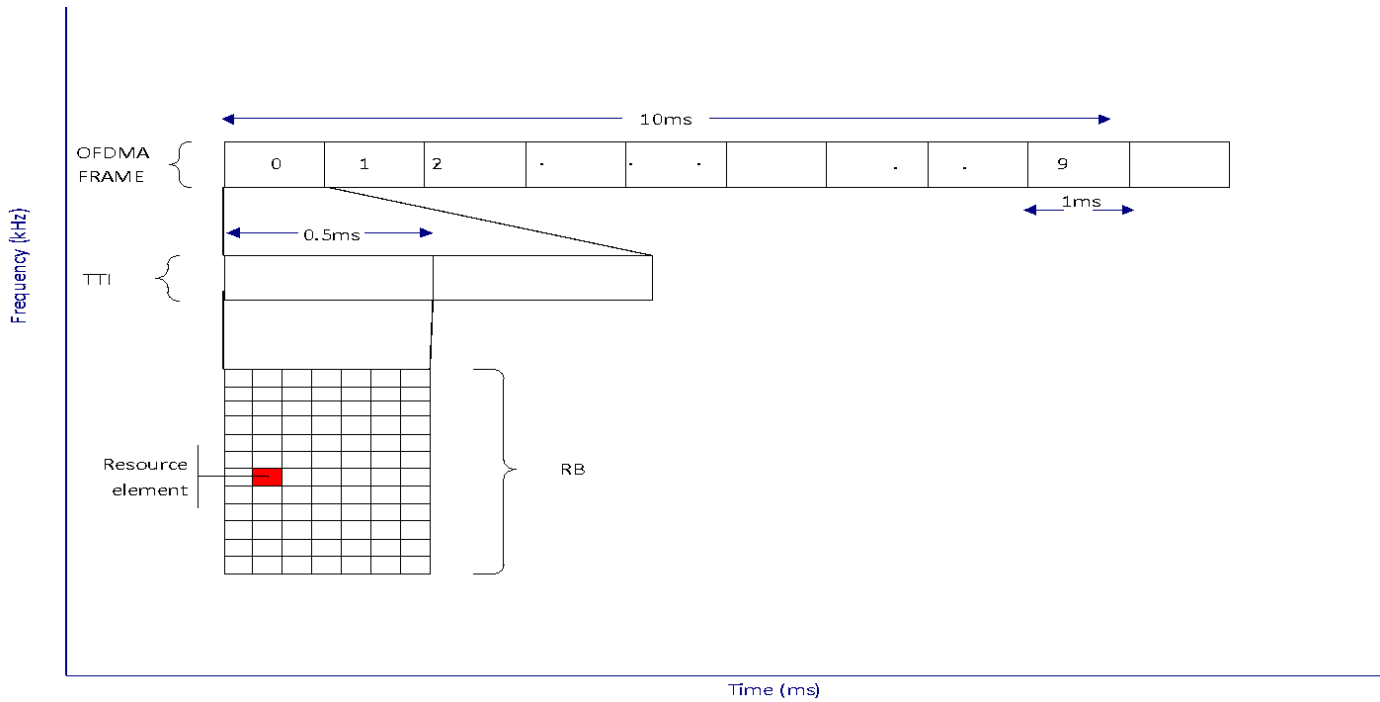


Figure 2. 6: Structure of the OFDMA

### 2.5.1 Heterogeneous Network (HetNet)

HetNet is one of the technologies defined by the 3GPP in the Release 10 to enhance the LTE-Advanced network performance. It involves the deployment of the macro cells along with other smaller cells such as the pico cell, femtocells, remote radio heads and relay stations which appear to the UEs as a different cell spread on the macro as seen in figure 2.5. The objectives of a HetNet is to improve the overall capacity as well as a cost-effective coverage extension and green radio solution by deploying additional network nodes within the local area range such as low powered micro/pico network nodes; home evolved eNBs (HeNB)/close subscriber group (CSG) cells, and relay stations.

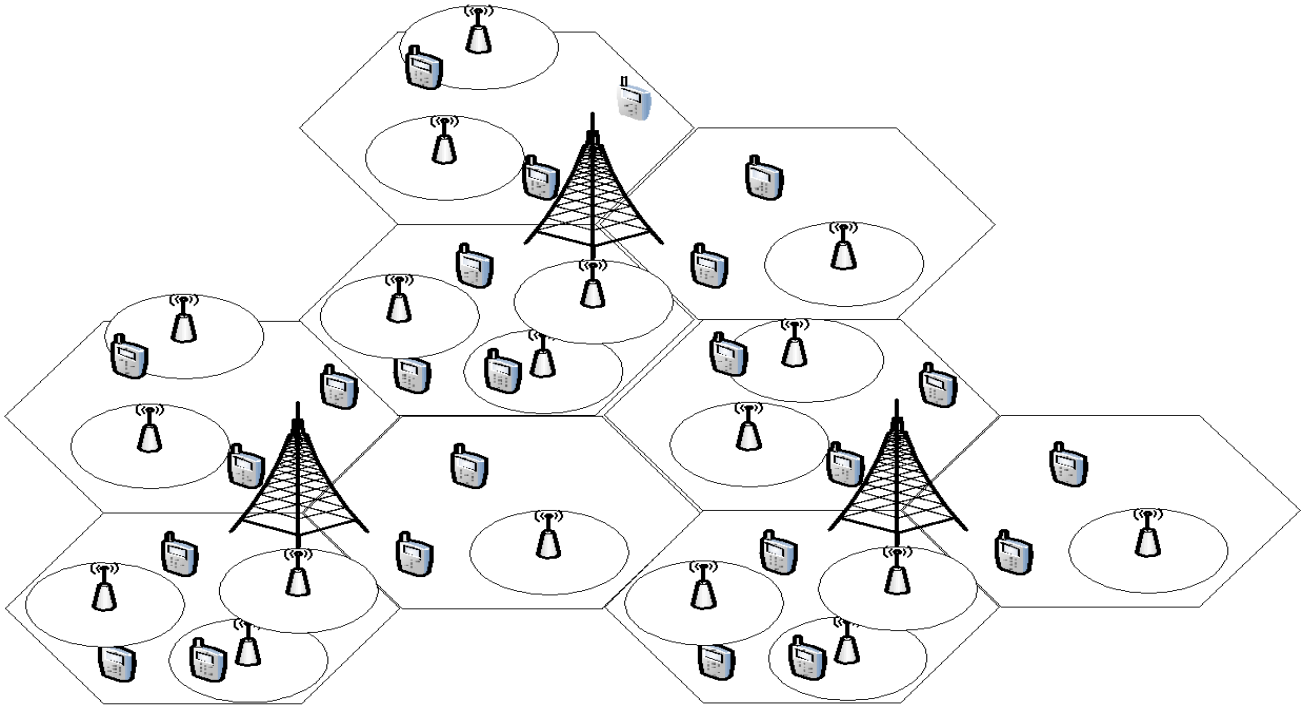


Figure 2. 7: HetNet Architecture

The macro eNB offloads data traffic onto the respective smaller cells covered by the low powered eNBs (Pico, Femto and relay stations) thus providing ubiquitous data transmission for the cell-edge users. To enable the system to make efficient use of the HetNet concept through load balancing, LTE-Advanced HetNet adopts cell range expansion (CRE) techniques where appropriate. CRE is a method for expanding coverage areas [16], and this technique is discussed in section 2.5.6. Some of the barriers in HetNet include cross-tier interference and traffic load variability.

### 2.5.2 Relaying

The cooperative relaying technique has been widely considered as one of the promising solutions to cost-effective delivery of high data rates in the 4G and beyond networks [7]. Layer three relay nodes have full radio resource control functionality and perform IP packet forwarding in the in the network layer and operate essentially as a mini-eNBs. It appears as an independent cell with its cell ID. Layer 3 relaying with in-band wireless backhaul has been adopted in 3GPP LTE-

Advanced standard as a key technique to expand coverage and enhance capacity. Traditionally, UEs are associated with the strongest received signal power or SINR to obtain the best radio service [46]. These feats are further elaborated in this section of the project. Because the RSs do not have any strict operation guidelines on radiation, visual disturbance and planning regulation, installation involves lower OPEX and faster network upgrades when operators aim to improve QoS, increase capacity on demand and extend network coverage [47, 48].

With RSs, the quality of wireless channels can be significantly improved not only by replacing one long distance low-rate link with multiple short-distance high-rate links but also due to the ability to circumvent any obstacles between UEs and eNBs that may impair channel quality. An RS placement jobs may be triggered by

- i. The need to improve wireless network capacity and to extend mobile service coverage.
- ii. The change of wireless network environment.
- iii. Stringent traffic demands.

There are fixed RSs and nomadic RSs. Nomadic RSs are used to mitigate capacity/coverage problems and improve adaptability to traffic demands growth due to special events, emergency response, or newly emerging hot spots that generate large traffic demands [49].

## **2.6 The Fifth Generation (5G) Network**

Leading to the evolution of the 4G Networks, mobile traffic generation was in the order of x1000. This increase in traffic has also been predicted for the 5G [21] which is a continuation of the trends in wireless network evolution over the past three decades through which it strives to meet up with the ever growing traffic demand from the user domain. This sort of dramatic increase in traffic generation is responsible for capacity determination of the network over the last three decades. Authors in [21] reinforced HetNet as one of the reliable techniques to enable

higher performance on the throughput that would support the capacity requirements. This, [21] believe may lead to 3-10 times increment in global spectrum allocation which currently stands at 1,177MHz of IMT spectrum. Their study presents some characteristics for the 5G. These features range from the air interface; cell densification also referred to as the Ultra Dense Network (UDN) in Figure 2.6; and optimal power control to D2D. They, however, did not leave out the fact that this may be an enhancement of the existing LTE-Advanced Network and its accompanying technologies. Although the network standardisation process is still ongoing, both in the research community and among the industry players in collaborations with the governments, some scholars such as [50] have indicated, that the 5G network would likely be operating in the millimetre waves (mmWave) ranging from 3 to 300GHz [51]. It has been asserted that a vast amount of spectrum does exist in these bands. This spectrum is capable of rendering high bandwidth that would consequently provide high network capacity and throughput for the network users [52] that would be making an enormous demand due to the increase in the number of connected devices as well as the different KPI requirements of their applications as would be further elucidated in section 2.9.

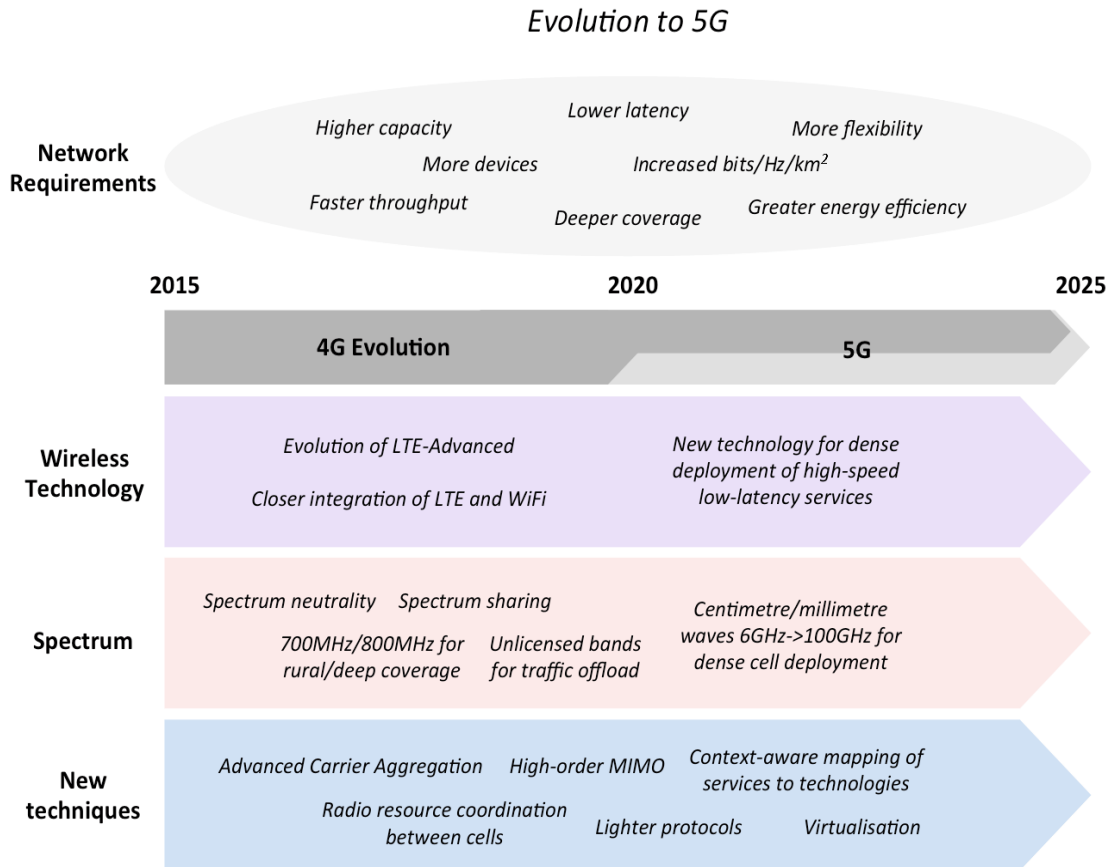


Figure 2. 8: Evolution of the 5G Network [53]

Several technologies are also expected to be realisable with the deployment of the 5G network in the form of the deployment of several kinds of device communications such as the Device-to-Device (D2D), Machine-2-Machine (M2M), and the Internet of Things (IoT). The future of telecommunication, through this generation of network, looks to implement some decade old technological concepts. A research project, partly funded by the EU's Framework Program 7 (FP7), rightly called the Mobile and wireless communications Enablers for the Twenty-twenty Information Society (METIS) [54] is already intensely involved in laying the foundations for 2020 5G and beyond technologies [55]. The focuses of this project for the 5G are:

- Energy, cost, and resource utilisation efficiencies.

- Support for diverse requirements such as payload size, availability, mobility and QoS, and new use cases.
- Scalability on connected devices, densely deployed access points, spectrum usage, energy and cost.

The METIS argues against a total redesign of the existing infrastructure due to the cost of implementation which is in agreement with [21]. Also located in the United Kingdom (UK), there is the 5G Innovation Centre (5GIC) which is developing the 5G infrastructure; bringing together academics and industry players. The 5G Network must strive to reduce latency and increase user's rate simultaneously to satisfy traffic demands that would result from the implementation of the IoT, which is expected to further increase the data density of the internet with its attendant consequence on the network capacity [21, 55]. The traffic expectation, especially as a result of the IoT, also puts more pressure on the required users' experiences in the 5G networks. These expectations focus the network's quality of experience on capacity, coverage and convenience. These aspects of the 5G network are further elucidated as:

#### **i. Capacity**

The capacity of the 5G network is expected to evolve and provide for more user equipment than have been used in any generation. There are scores of developments going on with the IoT, which is expected to put heavy pressure on the network. Satisfying this nature of capacity requires that the network would adopt the *infinite capacity* concept, which is proposed by experts around the world. This concept is perceived on the side of the user in which the user seems to be aware of an infinite network capacity enabling it to send whatever amount of data for its benefit and achieving high throughput; whereas on the network side, this is about flexibility. So far, the capacity of the 5G has attained a consensus of 10Gbps peak data rate for static users, and 1Gbps slow mobile users [21]. This is a massive jump from the 4G LTE-Advanced Network capacity.



## **ii. Coverage**

The 5G network is envisioned to be a great enabler of the IoT and therefore, need to support high-level scalability. This implies strategic deployment policies that support high-performance ubiquity for the network users. One aspect of coverage that is gaining traction is network virtualization, which may remove boundaries from network access. Traditionally, cellular networks are bound within cells that cover a particular location; virtualization, however, would be removing this concept from the radio networks, thus improving the ubiquity of the network. Virtualization, however, does not translate to high coverage so plans to aid high network coverage in the 5G network would include extreme densification of the network through the deployments of a different flavour of small cells.

## **iii. Convenience**

The idea of convenience is a new entrant following on the backs of the IoT. This would determine the quality of experience based on the user of the network: human-to-machine or machine-to-machine. In human-to-machine interaction, the focus would be as usual, the ability to provide ultra-high-speed real-time internet services. This is an enhancement on the existing QoS architecture of the LTE-Advanced Networks where speed and capacity are of greater concern as more and more apps and cloud services continued to be deployed. On the other side, power is an essential consideration for machine-to-machine interaction. This implies development in power saving abilities of devices and better battery life.

### **2.6.1 Architecture**

The architecture of the 5G is still entirely in the conceptual stage, but as already mentioned in the previous section many existing techniques, such as the deployment of the small cells are being renamed as the UDN. The 5G architecture and deployment would not likely go without the incorporation of the 4G network paradigm in it. The architecture also comes with the

consideration of one of its greatest motivations, the Internet of Things (IoT). The Figure 2.12 gives the general view of the 5G network. Figure 2.13 describes the deployment of the network in its true form and promise of platform supports.

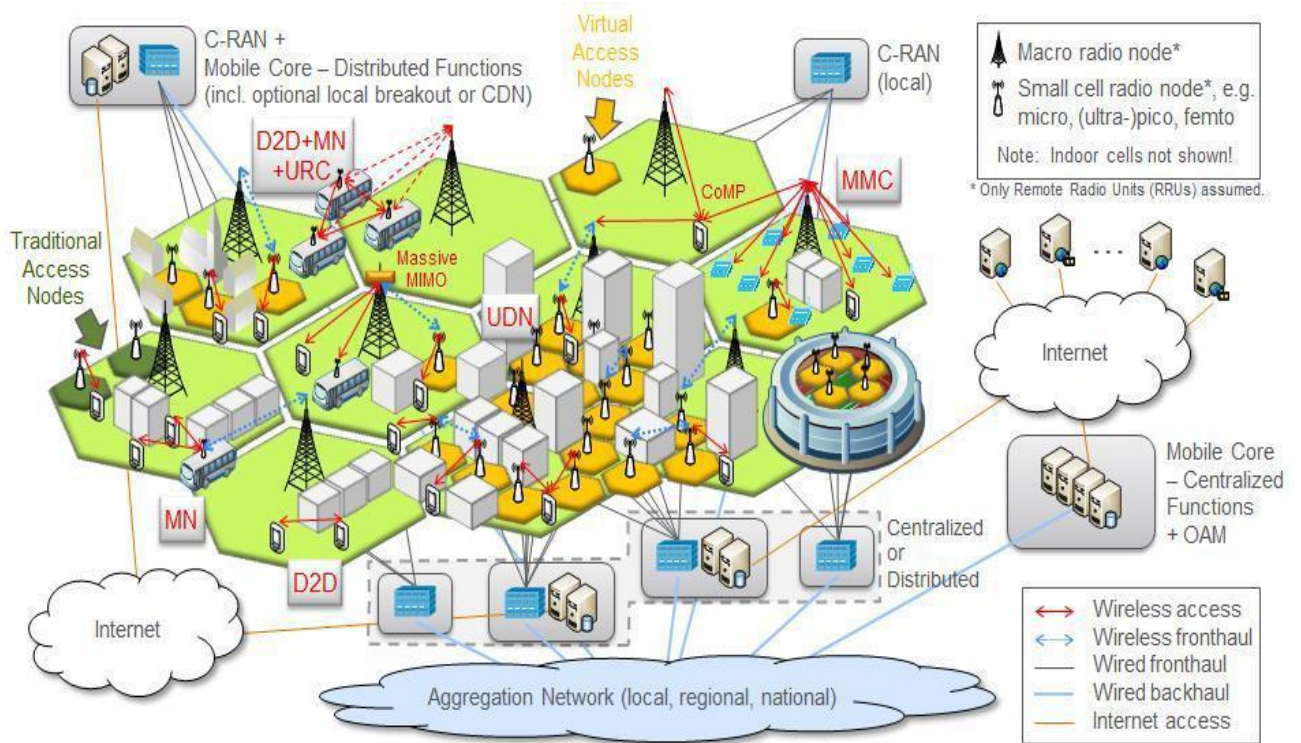


Figure 2. 9: Generic 5G Network Architecture showing possible deployment of Small Cells [21]



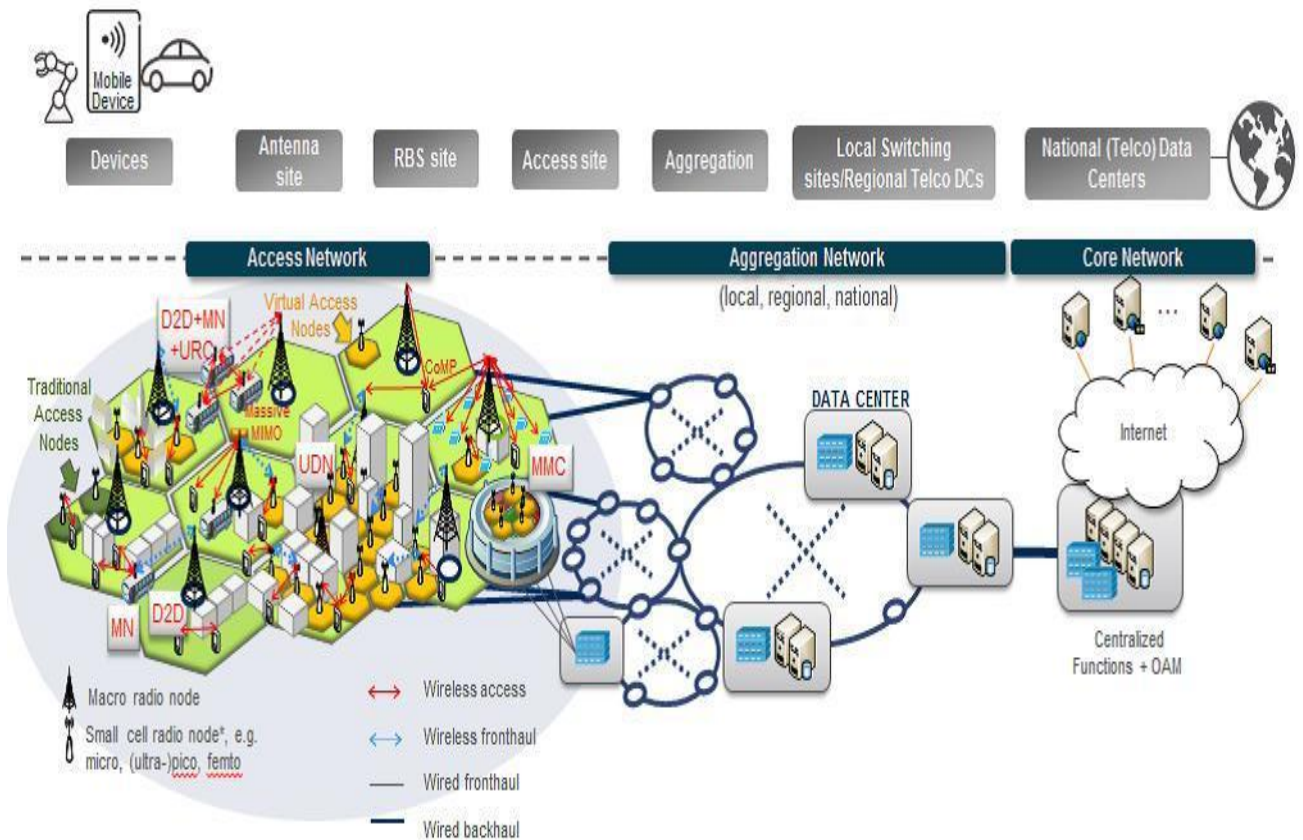


Figure 2. 11: 5G End-to-End Reference Network Architecture[21]

Though there exists a significant difference between the 3G architecture and the 4G architecture that enables the 4G to become an all IP-based network which enabled high-speed mobile broadband network, this is not the same between the 4G and the 5G. There are no such significant differences but rather, improvements that would allow the network to provide high data throughput and low latency and a more efficient service delivery. Also, the 5G network architecture primarily focuses on the development of elements such as [56]:

- i. Network functionalities that can be implemented where and whenever required.
- ii. Separation of the control and data (user) plane as in Figure 2.9.
- iii. Variation of tailored functions that can be used as use cases.
- iv. The development of interfaces between functions instead of between the network entities as in previous generations.

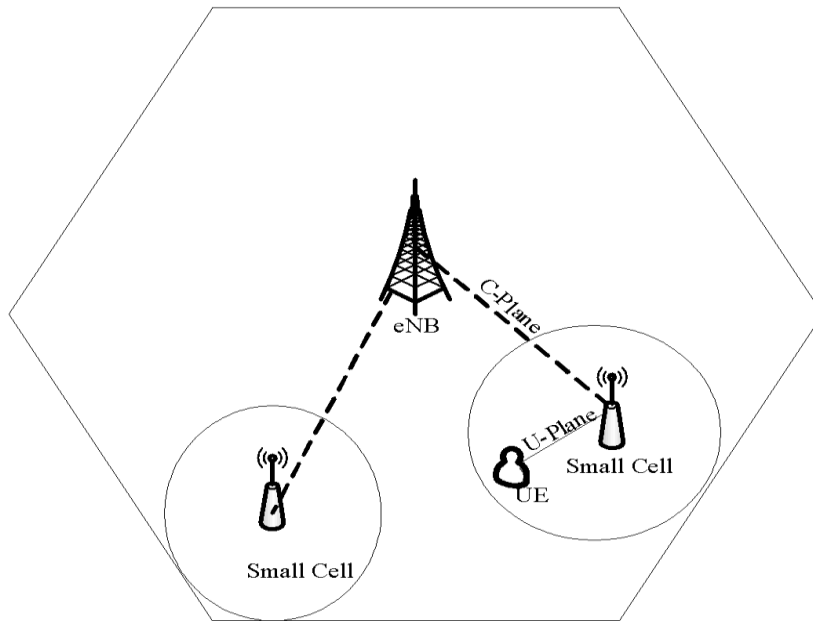


Figure 2. 12: Decoupled User and Control Planes

There are different architectural implementation options in the 5G network; these include M-MIMO, UDN, Multi-RAT and Dynamic-Ran [56]. This project focuses on the UDN implementation of these options.

For services that would be supported by the 5G architecture, the Huawei Technology shows these in a “hyper-service Cube” to emphasise the nature of the society that would be enabled by the network services as illustrated in Figure 2.16. This is an almost all services encompassing architecture that is engineered to provide a never before extreme network service and therefore would require careful planning and optimisation as well as development for it to meet the low latency requirements of its users. The 5G network would entirely transform communications and on its own, drive the internet and its services in such a way that it has not happened in the history of internetworking technologies before now. These services enablers are described by the network use cases in Section 2.9

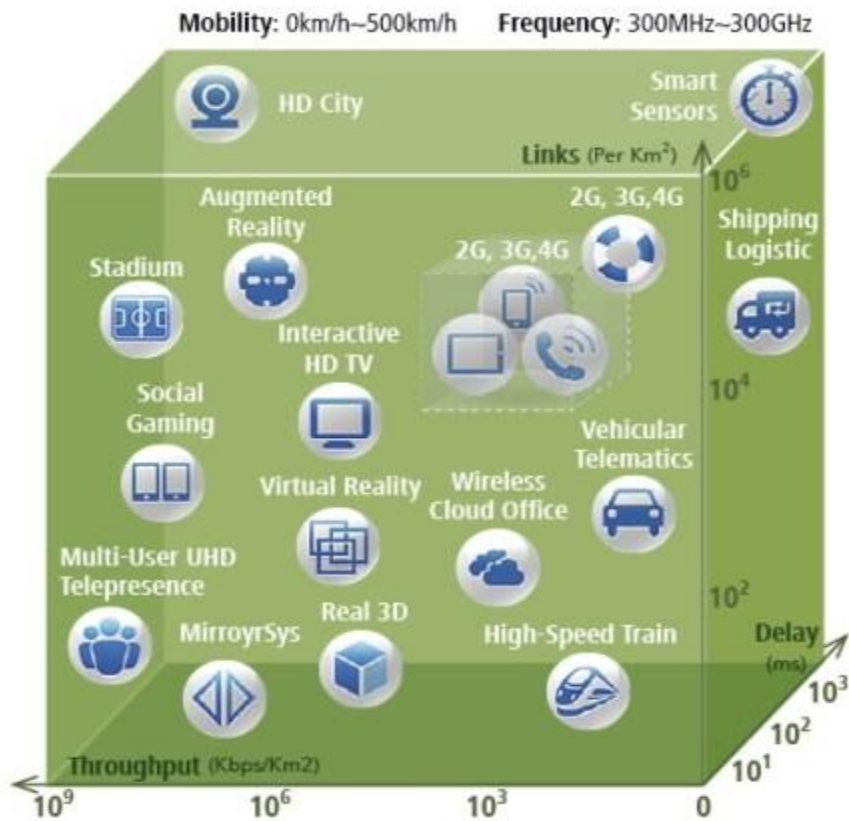


Figure 2. 13: The 5G Hyper Service Cube [57]

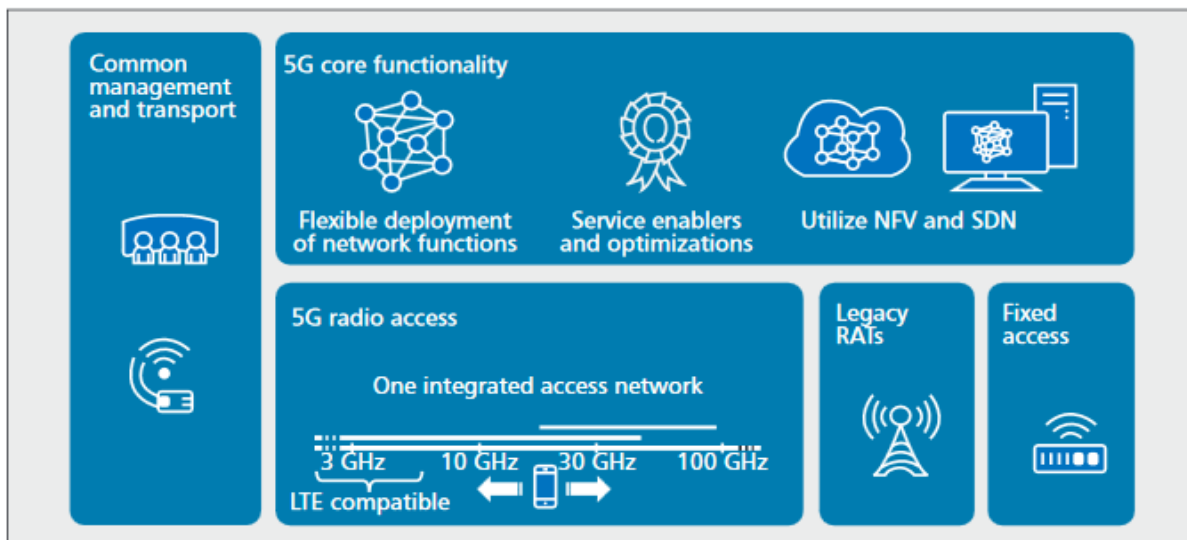


Figure 2. 14: a visualization of the overall 5G network architecture [58, 59]

### **2.6.2 Air Interface**

Because of the growing traffic, it is important to increase the network frequency band. Starting from the World Radio Conference in 2015 to 2019, the International Community is expected to aggregate the spectrums below 6GHz and up to 40GHz for cellular network allocations [60, 61] to meet the long-term traffic demand that would be coming from network users [58]. As already mentioned, capacity is vital to the 5G network; this buttresses the need for further spectrum allocation for the network and would provide more efficient wireless backhauling for operators thus improving the users' perceived network's available capacity which further enforces the notion of infinity.

The network will also introduce a new air interface technology to the telecommunications systems. Though a consensus is yet to be reached on which technique is appropriate, the Filtered-OFDM (F-OFDM) [62-64] and Filter Bank Multicarrier (FBMC) [62, 64, 65] seem to be more favourable to the industry than others are. The discussion here, like in all other literature would focus on the Filter OFDM as the air interface of choice. This is a variation of the OFDM technique. In this technique, a set of data symbols is transmitted through a bank of modulated filters.

### **2.6.3 Small Cells**

The concept of small cells, though not elaborately implied in the LTE-Advanced Network, is a significant aspect of the LTE-Advanced Network through the implementation of relay stations Femtos and Picos. It is well discoursed in the literature as HetNet which covers Pico, Micro, Femtos, Metros and relays stations where most of the technologies, for example, femtos were consumer deployed while the rest are mostly enterprise deployed. The impact of small cells in the 4G was mainly the increase in capacity and coverage which it brought [65]. The 5G is expecting an infinite capacity concept instead of speed. This is where the idea of network

densification, otherwise called the Ultra-Dense Networks (UDN) becomes a great inspiration. In the event of the IoT penetration of the internet community, the deployment of small cells to enhance network capacity is inevitable, however, due to the cost of implementation and deployment, the planning and deployment of such a network are crucial.

Small cells deployment is aimed at improving the network throughput [5, 65, 66]. This theory has already been proved effective through the deployment of RSs and femtos in the LTE/LTE-Advanced networks. This is further justified by the results and predictions of the METIS as seen in the figures 2.9 and 2.10. Figure 2.9 identifies an ordinary network that has no small cells and the throughput distribution through the coverage area. The Figure 2.10, however, describes what is obtainable when there are small cells in the network. The throughput achievable in the total network area seems to increase further and giving perspective to the deployment of UDN to support IoT.

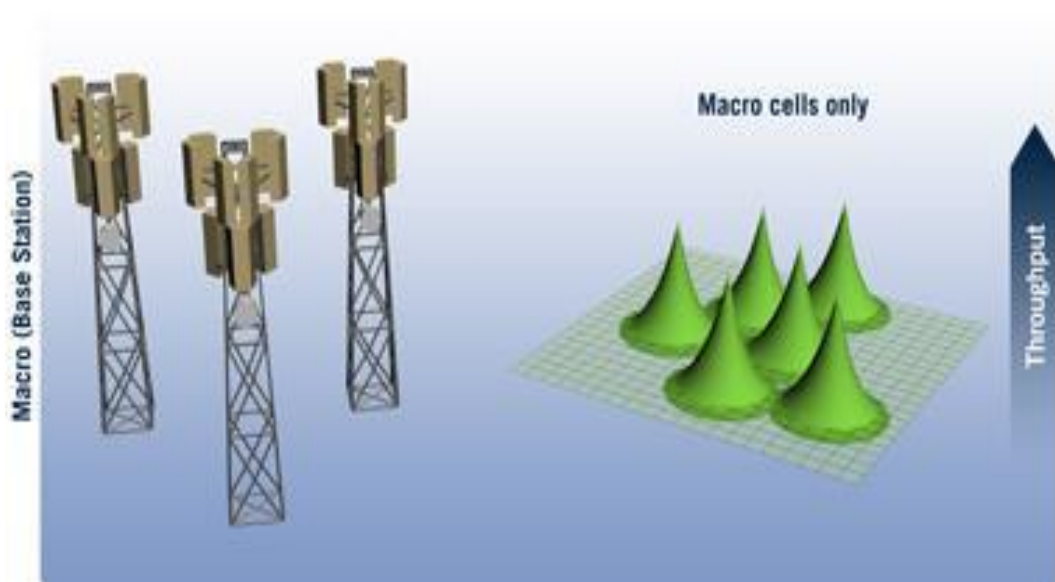


Figure 2. 15: Macro Effect on Throughput (Mbps) in 5G [56]



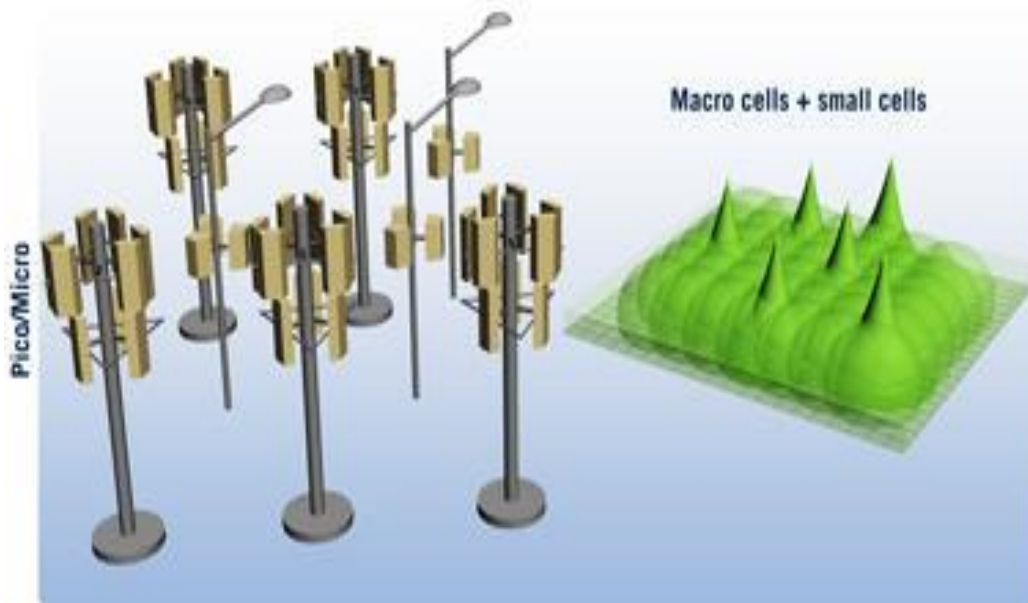


Figure 2. 16: Effect of Small Cell Deployment in 5G Networks [55]

#### 2.6.4 Ultra Dense Network (UDN)

The internet of things is expected to further subject existing telecommunications infrastructure through another round of enormous traffic load. The amount of traffic projected for connected devices will push the existing infrastructures to the edge, therefore, forcing network operators to adopt new techniques to improve their network coverage and provide higher data coverage to users such that would enhance their quality of experience. In LTE-Advanced, this extreme traffic load was handled through femtos and RS which formed small cells within the macro cells.

The authors in [67] projected that in the 5G Networks, system performance gains would be realised using network infrastructure densification on the side of the operators. This is a major attempt to realising the ambitious goal of the next generation networks to enable the 5G networks which is believe to be the result of networks evolution which has seen it moving from focus on transceiver technologies to resource allocation and network management to user-centric and device driving communication. A user-centric and device driven communication would open up more gap hole in coverage and resource allocation techniques. Network densification also

means that future networks would not necessarily be about bandwidth, which was mostly the centre of the previous evolutionary trend. Densification is a disruptive network topology. Therefore, it is envisaged to embody technologies such as small cells, femtos, RSs and WiFis, and also implies that spectral efficiency is not the way to look anymore [5].

UDN is of fundamental difference and importance by offering advantages in proximal communications, which also provides means for critical communications principles. These principles include extreme user-centric, spatial reuse of system bandwidth by partitioning the space to (arbitrarily) small cells up to the point where the traditional notion of the cell is no longer relevant, and each UE is served by one or more serving nodes [65][67]. However, UDN comes with its kind of problem. These problems have a lot to do with resource allocation and serving nodes distribution. The solutions should be in such a way that the resource allocation enables UEs benefit from the importance of UDN. Also, distribution of the serving nodes in the coverage areas needs to consider situations that involve less handover that would consume more radio resources and increase service delays which are quite intolerable for some of the services that would be supported by the network. For resource allocation to be more efficient in the 5G network and looking to amount of connected devices and the future of the internet community; [67] believes that network optimisation has to imbibe cooperative dynamic resource allocation to provide high-level QoS to users.

The authors in [20] understand that UDN is a convergence of old technologies such as MIMO which becomes the massive MIMO concept, RS deployments, femtos and hotspots. All of these technologies have made much progress through the 3G networks. The difference however is, while they are deployed in the previous generations to increase coverage or boost radio signal strength thus improving the network capacity, in this generation, they will be primarily deployed for the purpose of transmission, which increases their chances of stand-alone capability. This

also informs that by all fairness, the UDN is a densification of small cells, RSs, Femtos and MIMOs. Therefore making UDN it a core characteristic of the 5G network and the future of cellular telecommunications. This combination allows it to offer higher throughput to users at an effective low power. Low power implies a longer battery life on the side of the users. Low power demand also further increases the advantages of the UDN for the future.

## **2.7 The Internet of Things (IoT)**

The IoT is rapidly gaining traction and beginning to arouse hope in many industries as the new face of the web and it is quickly gaining grounds across different disciplines [13]. These disciplines include healthcare, finances, transport, and infrastructure management, as the topics of big data, continue to expand to encompass the everyday activities of modern man and how s/he interacts with the surrounding environment. This also means that academics and industry players are turning highly towards the IoT as a hot research topic open to many novel ideas, which are generating a keen interest from all around the world. As mentioned in Section I, one of the biggest enablers of the IoT is the deployment of high-speed internet broadband which renders devices (machines) the ability to communicate with one another at high-speed internet service with excellent quality of service satisfaction. [12]. Considers the IoT to be a novel paradigm in modern wireless telecommunications that will enable the pervasive presence of a variety of *things* or *objects*. Thus, it will be delivering a high impact on the everyday life and behaviour of users of these *things* or *object*; therefore, further extending the borders of the human society using physical entities and virtual components [13].

The main concern of the IoT is about connected devices and how they interact. These devices include everything ranging from households' appliances to offices and the marketplaces. These devices have a broad variety of functionalities that would allow them to function and interact in different ways that they may fit in the social network of machines in place of men. The IoT

would enable massive deployment of wearables, personalised healthcare systems [14], and connected home appliances. There are scores of technologies to be deployed in the IoT which will open up several vulnerabilities in the entire system concerning the security. Authors in [1-3] posit that over the next decade, more than 8 billion devices would be interconnected through the IoT, utilising users' personal, business and sensitive data which may also belong to the government and other National Security. These data will always need to be protected which might give rise to a rather chaotic environment left without proper security coordination especially when the concept of social networking for better good is closely watched.

## **2.8 5G Use Cases**

### **2.8.1 Broadband Everywhere, Anywhere**

The previous years have seen high growth in the number of connectable devices such as tablets, smartphones, wearables and the development of enhanced multimedia applications. These come with the relative consequences of a tremendous increase in the volume of mobile traffic transiting the internet. To handle this level of growth in data traffic, the future network generation (5G) is required to provide extensive network capacity that can accommodate it as well as ensures uniform and seamless connectivity, irrespective of the device/user location [68].

The concept of “Broadband Everywhere, Anywhere” is improved on the existing ubiquitous coverage rendered in the 4G network but in this case, a rather high level of service/coverage would be provided for network users. It would ensure network resource available for all kinds of users (mobile/stationary) irrespective where they are located, whether at an event platform or crowded area. The concept is further tailored to maximise user experience and providing far-reaching QoS. These will be enabled by a radio access network that ensures high data rate, efficiently covering users especially in high-speed trains and also enabling high spectrum efficiency and maximisation of the network capacity. In the 5G network, ubiquitous service provisioning would be experiencing high data transfer rates in such a way that makes communications faster thus further reducing download time. In the reduction of the download time, it is expected that for example, the network would ensure that the download time for an 8GB high definition movie would be around six seconds which is far lower than the seven minutes that is experienced in the 4G network. This speed is evidenced in bandwidth that is being made available to the network. This use case is significant to the development of the network and its technologies. For it to support concepts such as the IoT, there is a need for significant ubiquitous high-speed coverage for the users to experience an infinite presence in the

network and also putting into perspective, the fact that is built around technologies such as the M2M and other network technologies [59, 68]. The ubiquitous broadband realisation would ensure that the network meets the demands of increasingly digital lifestyle, focusing on services with high bandwidth requirements. These services, as already stated, include HD videos, virtual reality and augmented reality.

### **2.8.2 Smart Vehicles, Transport and Infrastructure**

In this use case, the ideas are engineered to enable intelligent application deployment to allow for connection and services for smart infrastructure (management) and ubiquitously connecting bus stops, trucks and cars to the network services. This use case is targeted at industries such as the automotive industries, transport companies, infrastructure and private/government administrations [68, 69]. It enables the large machine-to-machine communications through the development of embedded systems for installation in railways, roads, airports and smart vehicles [68, 69]. The main enablers of this use case network densification, low energy consumption, reduced signalling, low-cost devices, low network resource overhead and sensor devices, which are anticipated for deployment in the 5G network. Some of these applications of the network are sensitive to latency thus requiring a bare minimum for end-to-end latency in communication.

### **2.8.3 Media Everywhere**

Considering the crave to follow different live and recorded TV contents, especially by millennials [70], it is necessary for the 5G network to be engineered in such a way that its coverage allows users to access and follow their programs from anywhere and on their demands. These include access to mobile for in-home, live TV shows, YouTube and Netflix. To achieve this use case, several kinds of literature have worked on enabling technologies such as improved beam forming, massive MIMO, carrier aggregation, and most importantly, the high-frequency

spectrum allocation which is currently being considered for 5G air interface in the specification documents [68, 71].

#### **2.8.4 Critical Control of Remote Devices**

The human society tends to remain safe thus putting safety at both home and workplace on the front burner. Technology, over the last century, has been such that heavy-duty machinery and small-scale devices help to get works done quite efficiently than human labour, for businesses, these also present opportunities for cost cutting. The field of artificial intelligence is a fast growing field and promises to produce, in the next decade, machines that could work by themselves with less human interaction. However, in the meantime, there is the need to control existing machinery remotely. The 5G promise of higher throughput presents such opportunity [59, 69, 71].

This use case presents the opportunity to control heavy machinery in the fields from remote locations to lower risks posed to workers in hazardous environments through wireless links [68]. Its application is mostly intended but not limited to factories, smart grids, remote surgical operations, etc. The major enabler for this use case by the 5g network would be its enhanced radio connection, high service availability and better uplink for high-quality videos.

#### **2.8.5 Interaction Human-IoT**

This use case gives the opportunity for humans to interface with the IoT through augmented reality [68]. This provides the society with some of the most critical technology needs of man. It encompasses gaming, smart everything, child monitoring, smart houses, surveillance, etc. network densification in the 5G network will be of utmost importance for this use case as it will provide for a distributed network of sensor nodes thus enabling a smart society [72].

## **2.9 Conclusion**

In this Chapter Two, some technologies of the LTE network LTE. These technologies are important to the design and implementation of resource allocation schemes. The Chapter also discussed the new 5G technologies and their use cases. In the subsequent Chapters, the contributions of this chapter would be seen as they help to realise the general contributions of the research.



## Chapter Three

### RESOURCE ALLOCATION

#### 3.0 Introduction

This project presents two separate algorithms that work independently to enhance the performance of the mobile network in the 4G Networks and Beyond. These algorithms, as already mentioned in the Chapter One are the CRAA and the MBSSLAA. In this Chapter, the concepts of resource allocation are discussed. The CRAA would build on this concept later in Chapter Four.

#### 3.1 Resource Allocation in Cellular Networks

To allow data flow in telecommunications' networks, different mechanisms interact at various layers of the network protocol stacks to enable connected devices to exchange data between themselves. In wireless networks, this interaction comes in a nontrivial order that leads to data transfer from one point to another [76]. This interaction is accompanied by the traditional behaviour of devices connected in wireless networks in which the devices aggressively compete for available radio resources to satisfy their needs. In a view to enforce some level of fairness in the process of this competition to ensure that every users' need is satisfied, the research communities have over time, designed different kinds of resource allocation methods that allow all connected users have access to the available while ensuring an efficient use of the radio channels which are scarce [77].

In Chapter Two, we have already seen that in the LTE-Advanced network, radio resources which are responsible for carrying data and control information on the air interface are divided in RBs on the frequency domain per time slots. In the previous generation of networks are popularly known as the subchannels [34, 78, 79]. Because of the aggressive nature of connected devices to

satisfy their needs also; coupled with the fact that radio resources are finite in nature, it is therefore commonplace for there to be means by which available resources can be managed so that every device in the network that is accessing some form of data may enjoy a reasonable satisfaction of service delivery which is achieved through resource management. Radio resource management is a system level control of available radio resources to enable network users effectively access available finite radio resource to transfer traffic at defined and satisfactory level of quality of service. In networked communications, resource allocation is essential to enable networks users, and connected devices access the network in a way that satisfies their requirements and demands. However, there is a sharp difference in resource allocation in the wired network and wireless networks; this is the effect of the time variation experienced in the wireless channels. To satisfy user in an environment with this kind variation, experts classified the network into flow types (bearers) which have different attributes that would need to be satisfied by allocating the available radio resources.

In mobile networks, resource allocation is achieved using two different schemes: fixed or dynamic. In fixed resource allocation, radio resources are independently allocated to the connected devices without consideration to the channel conditions of the users' links. This nature of allocation implies that the fixed schemes are not optimal. In dynamic allocation, however, the resources are adaptively allocated to the users based on their channel gains thus resulting in higher performance and give the advantage of multiuser diversity [80]. In consideration of the OFDMA system, the research community has come up with two optimisation techniques to enable the dynamic multi-user resources allocation schemes efficiently utilise available resources. These techniques are the margin adaptive and rate adaptive techniques [80]. The margin adaptive technique ensures that users can transmit their data on a minimum overall

transmits power given as a constraint. While on the other hand, the adaptive rate technique is such that ensures that maximises the users' data rate depending on the total transmit power [80].

In cellular networks, while the bandwidth remains constant and the total capacity remains limited due to the effects of regulation and cost. The number of resources available to users, however, continues to change as more users continue to free up their resources when they are through with their communications. This brings about stiff competitions between users who, naturally are greedy for resources to satisfy their service qualities

### **3.2 Quality of Services (QoS) and Bearer Services**

In the event of evolving applications and their requirements over the last few decades following the internet penetration of the human society, networks needed to be scaled in order to satisfy these applications and their requirements. Bearing this in mind, there arises the need to introduce service differentiation such that different services traffic require clear performance metrics to enable network users to get a better experience while connected to the networks. This gives rise to the idea of QoS which signifies the ability of a network to provide improved service to selected network traffic over various underlying technologies by supporting dedicated bandwidth, improved loss characteristic, avoid or manage congestion, the shape of network traffic and prioritise traffic across the network. These functions are achieved through network configuration that allows for better end-to-end service delivery. This configuration practice includes, but not limited to admission control, to which resource allocation is a primary pointer. Also putting mobile networks in more perspective, QoS is a measure of the capability of the network to provide better services such as good voice quality, strong signal strength, low call blocking and dropping probability, high data rates for multimedia and data applications. The metrics for measuring the QoS include throughput, delay, packet loss rate, packet error rate and reliability.

To further the course of providing better QoS for users, the ETSI further defined the use of service bearers in cellular networks starting on the PLMN backhaul where it was further extended to the radio interfaces as a prelude to the migration towards an all-IP-based cellular network. Bearer Services represent the data services being provided by the network to a connected device. It is essentially used to send and receive data on the end-to-end connection. According to the ETSI framework, it is described by independent attributes grouped into four categories: information, access, internetworking and general. However, moving fast to the 4G and the LTE-Advanced for example, the bearers are further classified into default, and dedicated bearers, which represent NGBR and GBR traffic respectively. These concepts allow the network to provide high performance to users by using different sets of configurations parameters and are pictorially illustrated in Figures 3.1, 3.2 and 3.3. To ensure an end-to-end QoS, the LTE-Advanced, for example, uses the EPS bearer. The EPS bearer consists of three separate bearer types, radio, S1 and S5/S8 bearers respectively. The radio bearer is established between the UE and the eNB and carries the data packets of an EPS bearer between the UE and the eNB; the S1 bearer is established between the eNB and the S-GW, and the S5/S8 bearer connects between the S-GW and the P-GW. For the purpose of this study, the focus is on the radio bearer.

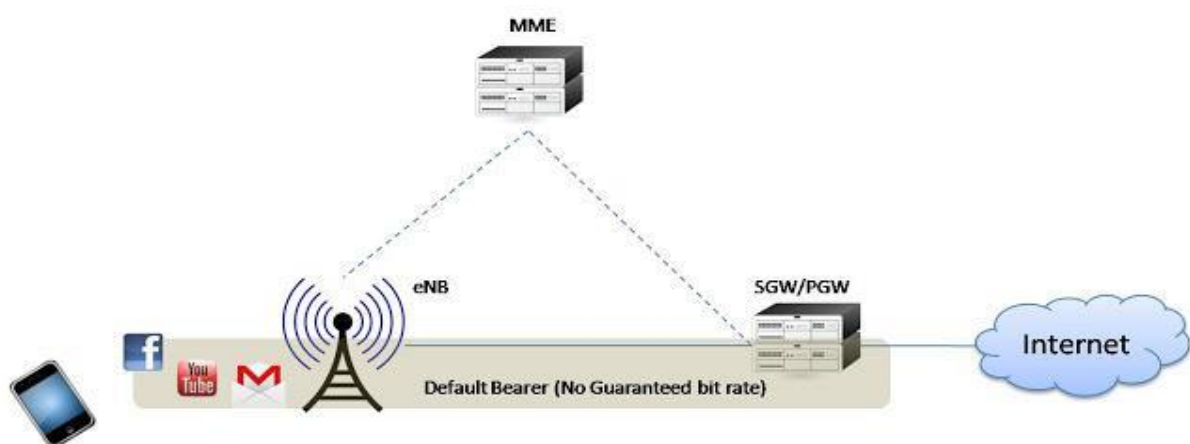


Figure 3. 1: LTE-Advanced default bearer [81]

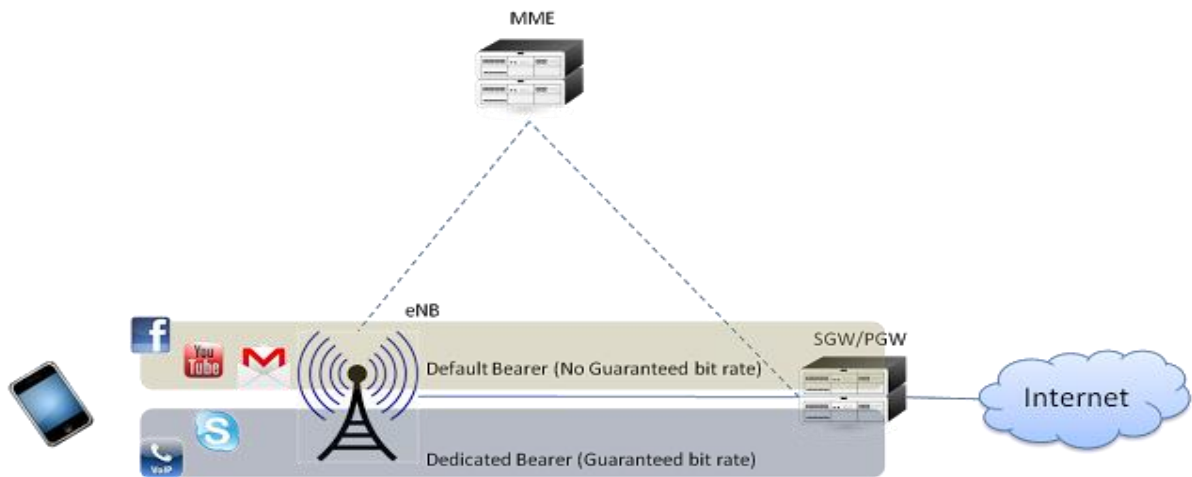


Figure 3. 2: LTE-Advanced end-to-end bearers services [81]

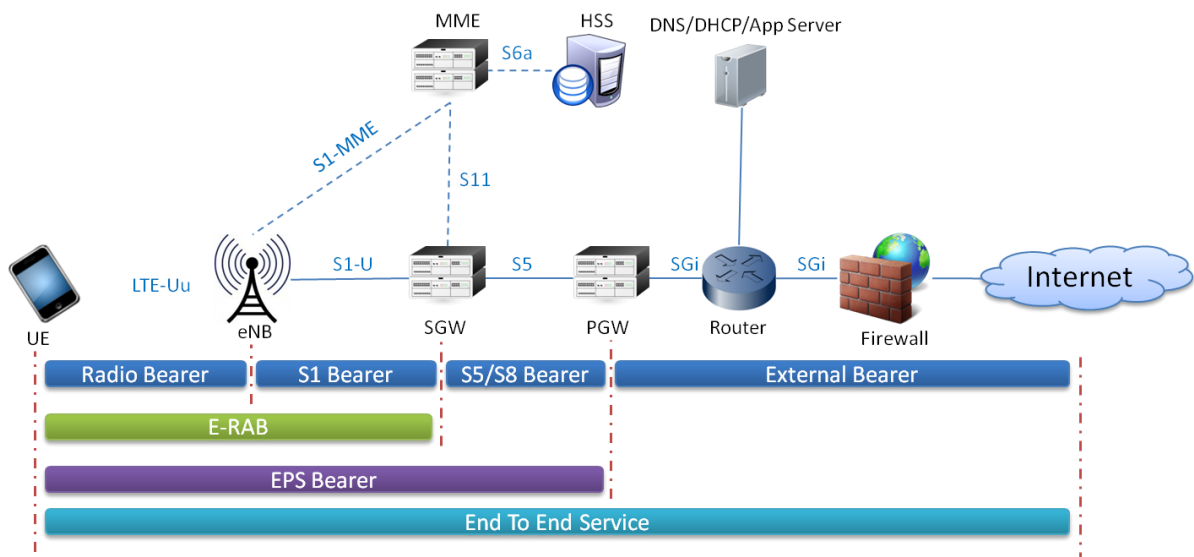


Figure 3. 3: Differentiated LTE-Advanced bearers and operation level [81]

The radio resources are allocated to the bearer which carrier these traffic for UEs through the network. This makes them an important rallying point for collaboration to take place. This is further elaborated in the performance analysis of Chapter Four.

In wired networks, increasing the pipes and number of transmission are some means of improving the quality of service experienced by networks users. This is however not the case in cellular networks. In cellular networks, the QoS improvement strategy includes increasing

capacity by adding more spectrum and improving the spectrum efficiency. Though these are not the best methods to improve the QoS since over-provisioning capacity may eventually affect the cost of bitrates for operators; this is considering that the available radio resources are finite and should rather be efficiently managed to handle the available number of users and their respective application services.

### **3.3 The Economics of Resource Allocation**

The work by [82] describes resources as a scarce commodity if there is not enough supply to meet similar demands. This directly relates to the scenario in cellular networks where the operators pay large sums of money to acquire certain frequency bands (which are then divided into smaller units per transmission time) to transmit users' data. The continuous growth in connected users puts an enormous amount of limit on the capacity available per coverage area (cell) of the operator's networks. Frequency bands are therefore seen as scarce resources that need to be properly managed for efficient utilisation as well as providing adequate services to the users to the best of their satisfaction.

In the fields of economics and political economy, to enable efficient use of scarce resources, trade-offs and choices are well thought and decided such that would benefit every party. The balance between these two is achieved through different resource allocation mechanisms. Sometimes, though efficient, this may not meet some users' demands. Relating this to a coverage area, there are times during the day when there may be more users in the cell than estimated. At such point, the focus is on how to allocate available resources in the cell such that users' QoS requirements are considerably satisfied to achieve higher performance.

The economics of resource allocation in cellular networks is concerned with allocating available resources so that users can be efficiently served per transmission time (TTI). It is concerned with

developing and reusing resource allocation mechanisms. Different mechanisms have been developed over the period of the network evolution; these mechanisms are reviewed in the subsequent sections of this Chapter, and a new mechanism, Collaborative Resource Allocation Algorithm (CRAA) is also proposed.

### **3.4 Resource Allocation Mechanisms in Cellular Networks**

Resource allocation in wireless networks ensures that available scarce radio resources are efficiently and fairly distributed amongst connected user to achieve throughput that very well satisfies applications' QoS demands as they continue to evolve. Different mechanisms of resource allocation have been developed as evidenced in available literature. These mechanisms concentrate on efficiency and fair utilisation of available resources as the core goals while they ensure that certain parameters are considered as constraints to be satisfied. These parameters include:

- i. Fairness
- ii. Delay
- iii. Type of Service
- iv. Channel Condition
- v. Complexity

#### **3.4.1 Fairness Based Algorithms**

The algorithms that implement fairness are none throughput efficient since fairness is treated as equality in the share of available resources. Fairness based algorithms are Round Robin (RR) as discussed in this section; Max-Min Fair and Game Theoretic based algorithms.

##### **❖ Round Robin (RR)**

RR is a well-known resource allocation algorithm that has been in use right from the early days of computing to help operating systems efficiently allocate resources to different users

(applications). This algorithm remains the most considerably cheap form of resource allocation technique in the field of network and systems' resource allocation. During its days of popularity, the algorithm was a fair and efficient technique [83]. Users are allocated resources based on the time in which they occupy the resources in a time-based allocation. It is an inefficient algorithm, seeing that the wireless radio channels suffer several variations in time, RR does not yield high throughput but fair as well as efficient in resource utilizations.

### 3.4.2 Delay Based Algorithms

More applications are constantly deployed that mostly are sensitive to delay to meet their requirements. Delay sensitive multimedia applications require short delays in packet delivery to maintain high QoS in the system. Parameters such as packet delays and Head of Line (HoL) values are considered in allocating resources. Several algorithms have been proposed and developed that are based on this parameter. The Modified Largest Weighted Delay First, (MWLDF) algorithm relies on this parameter, and it is described in this section.

#### ❖ MWLDF

The MWLDF was developed in the 3G network to enable high data rates in CDMA systems for multiple RT services exhibiting different QoS requirements [84]. In doing this, it supports different data streams with varying QoS requirements [84] while accounting for the channel states and packet delays. The algorithm balances weights of the packet delays from exceeding delivery due time below a certain ratio [84, 85] while utilising an adequate knowledge of the channel state, therefore enabling higher throughput performances for users [86, 87]. In the mathematical description of this algorithm, during transmission, for every given TTI  $t$ , a user  $j$  is allowed to transmit its data described in equation (4.1):

$$j = \max_i \frac{\mu_i(t)}{\underline{\mu}_i} W_i(t) \quad (3.1)$$



From equation (4.1);  $\mu_i(t)$  is the data rate of the channel while  $\underline{\mu}_i$  is the mean data rate of the channel whereas  $W_i(t)$  is the head of line (HoL) packet delay. Though the algorithm is focused on real time services, it is however not a good option for non-real time services because in such services, delay is not an important metric of consideration.

### 3.4.3 Throughput Based Algorithms

The throughput based resource allocation algorithms, in their objective functions, allocate resources to improve the user's rate for each flow by finding a balance between an elastic and non-elastic flow. They also look at the type of services then allocate resources using their knowledge of the user's queue length as a major decision maker. The EXP-Rule, Max-Weight and LOG-Rule implementations are based on this principle.

#### ❖ EXP-Rule

This algorithm is a modified version of the Proportional Fair (PF) algorithm as would be seen in 4.2.4. The EXP-Rule algorithm is designed to serve users with high data rate requirements as described in the equation (4.2). For a channel state whose corresponding rate is given as  $\mu_i(t)$ , a  $i$ th user would transmit at TTI  $t$  where the mean rate is given as  $\underline{\mu}_i$ . This relationship is described by the equation (4.2):

$$j = \max_i \exp\left(\frac{a_i W_i(t)}{1 + \sqrt{W}}\right) \frac{\mu_i(t)}{\underline{\mu}_i} \quad (3.2)$$

$a_i$  is the priority value used to characterised the QoS requirement [85].  $a_i = 6/d_i$ ; where  $d_i$  is the maximum delay target for data packets transiting the network [86, 87]. This algorithm guarantees a better QoS over a channel even when a large number of users are involved in the network. The secret is to select a user for high data rate service transmission per TTI. The

decision metrics are the users' queues and the channel state information while it maintains good queue stability without adequate knowledge of the packet arrival and traffic statistics [86, 88].

#### ❖ **Max Weight**

Max Weight algorithm makes allocation algorithm based either on the queue length or on the packet delay. For multi-service supports, the study by [89] reported that the algorithm is well stable in support of multi-level traffic scheduling which makes it an efficient algorithm considering the level of applications that are currently in the markets. The study also finds that the algorithm is not particularly stable when the load on the network increases and it especially does not support dynamic allocation under critical condition. This would present a serious problem for the anticipated Internet of Things (IoT). The plus side of this algorithm is the maximum throughput which it yields to users [90] to RT traffics. Findings by [90] also indicate that the algorithm yields average order-optimal delay thus improving the QoS of the network.

The algorithm implementation follows:

$$j = \max_i q_i \frac{\mu_i(t)}{\underline{\mu}_i} \quad (3.3)$$

As in previous algorithms, parameters remain the same;  $q_i$  is the length of the queue.

#### **3.4.4 Opportunistic Algorithms**

Wireless channels vary in time. This variation in time is exploited by the opportunistic algorithms to decide which subframes (RBs) are allocated to a user. The algorithms have better knowledge of the channel conditions. The user's buffer length is also considered to grant pass to users to transmit their data. Algorithms such as PF, M-LWDF (which was earlier discussed under the delay sensitive based algorithms), EXP/PF, EXP-Rule and LOG-Rule are all variants of the opportunistic scheduling.

#### ❖ **PF**

This algorithm was also implemented in the 3GPP UMTS networks to bring a balance between the total data rate and fair data rate per user. It is a better option for NRT traffics where it considers experienced channel quality and throughput of the past user [84, 87]. This is because the algorithm is developed for Best Effort (BE) service. Therefore, QoS metrics of performance evaluation such as delay, jitter and latency are not considered [86]. Its objective function maximises total network throughput with Fairness as a constraint [84, 86] therefore compromising data rate for users and network capacity [84]. To do this, the algorithm uses previous average throughput as the weighting factor for the expected data rate thus enabling the users in relatively adverse network conditions to be served within a time constraint. The algorithm is implemented as:

$$j = \frac{\mu_i(t)}{\underline{\mu}_i} \quad (3.4)$$

$\mu_i(t)$  is the user's data rate based on the CQI of the user,  $i$  at TTI,  $t$ .  $\underline{\mu}_i(t)$  represents the mean data rate that is supported by the channel.

#### ❖ EXP-PF

The EXP-F rule is a variation of the PF algorithm developed for use in Adaptive Coding Modulation and Time Division Multiplexing (ACM/TDM) systems; the design increases the priority of RT services concerning NRT services [84]. The algorithm uses the PF characteristics to handle NRT services and uses the EXP-Rule function of end-to-end delay to handle the RT services [91]. The algorithm ensures there is fairness and that the bound of tolerable delay is respected. The algorithm implementation is such that for every TTI,  $t$ ,

$$j = \max_i \frac{\mu_i(t)}{\underline{\mu}_i} \exp\left(\frac{a_i W_i(t) - aW}{1 + \sqrt{aW}}\right) \quad (3.5)$$

As in other algorithms,  $\mu_i(t)$  is the  $i$  –  $th$  user’s achievable data rate,  $\underline{\mu}_i$  is the mean rate that can be transmitted on the channel,  $W_i(t)$  represents the HoL packet delay and  $a_i > 0; i = 1, \dots, N$  is the service QoS requirement defined in weights.  $\underline{aW}$  is defined as:

$$\underline{aW} = \frac{1}{N} \sum_i^N a_i W_i(t) \quad (3.5)$$

### 3.4.5 Multiclass Based Algorithm (MBA)

To make allocation decisions, MBAs use considers the service classes that are involved. This implicitly means that RTs and NRTs service classes are the core parameters of the MBAs. For resources to be allocated, the class of service required by the user is first evaluated although the algorithms are developed to enforce a higher level of priority to RT services, they do not, however, neglect the NRTs.

### 3.4.6 Real Time QoS Guaranteed Algorithm

Algorithms developed based on this scheme are such that they guarantee minimum QoS amongst the different services classes. They ensure that those services involving HTTP, FTP, etc. are prioritised in which cases; video streaming and online gaming get more advantages over other services.

## 3.5 Games with Transferable Utility

Games with transferable utility are a class of cooperative game theory consisting of a finite set of players and a characteristic function that distributes payoff amongst the players in the game. Cooperative games focus on the payoff that a player might earn which leads on to the formation of coalition amongst players to maximise their earning. This practice of forming coalitions and demanding for payoffs effectively eliminates focus on the idea of employing strategies by which the game is played. Coalition formation in cooperative games is a rather implicit assumption

which makes it more abstract and accords them the independence to make bids and offers in whatever coalition that benefits them most; therefore, strategies are not model since they are not very important. Instead the earning accruing to the coalition is the major focus. The earnings are what the utility implies, and it is important that this utility is distributed through different means such as the nucleolus, Core and Shapley Value solution concepts. To enable the principles of fairness, this study adopted the Shapley Value solution concept as would be described in Section 3.6.

### **3.6 Market Game and Its Application**

Market Game is a strategic coalitional game with a transferable utility that depicts classical models of an economy in which participating members come along with units that can be traded on which profits are made in the form payoff. These units are expected to be greater or equal to a defined minimum threshold and subject to a certain maximum as expected in this very scheme. Market Games give rise to competitive outcomes where member/participants either lack or possess low market power [92]. In their work, [92] established that in a sufficiently large economy, Market Game mechanisms reliably enables competitive equilibrium allocations. Market Game as an Economic Paradigm provides mechanisms for regulating users' behaviours; enabling the system to scale easily after the initial exchange between members and resources have been established [93]. In the concept of the Market Game, an active user always offers to buy a set of goods which in this case is higher data rate (better performance) and better QoS for users while non-active users present no offer [94] and are considered to be out of the network coverage.

The Market Game was first introduced by Lloyds and Shubik in [95] where it was categorically described as characteristic games with transferable utilities derived from exchange economy. The defined the Market in this Game as an exchange economy where traders have utilities that are

continuous and concave. They further assert that a Market Game with  $n$ -traders forms a closed cone in the space of all  $n$ -person games with side payments. This assertion would later be used through Owen's equation to solve the problem in this Thesis. The literature also further described Market Game as a mathematical model as would be presented in Chapter Four. Participation in the market, which would otherwise be referred to as coalition formation could be in different forms; [95]. Using time as a constraint over various locations, [96] described the Market Game as a cooperative activity involving different players in which there is an exchange in the form of trades where the traders can participate as individual players, commodities or coalitions [95]. The authors in [96] extended the application of the Market Game to include coordinating activities in space centre and scheduling of meetings.

Looking at uncertainty of pricing, which by all means is a common scenario in mobile networks, [97] asserts that prices are non-strategic and determined by invisible hands and models the market such that each trader in this model participates as a state in the market that has two random pairs: bids and offers which form the major elements of trade apart from the participant. Market Games studies the interaction between different individuals to measure the impacts of their behaviour of different variables. This interaction may be in any form but in this thesis, is restricted to between the eNBs and the UEs thus, the variables to be studied because of their interaction are throughput, spectral efficiency and fairness, as would be seen in Chapter Four. The players are allowed to buy/sell (i.e., bid/offer) on which their participation profiles are developed to evaluate their payoff which stands for their return as a coalition member in a strategic game with transferable utility.

Over some time now, the Market Game has evolved into a method used to exercise control over a system consisting of a large number of independent members. Different applications mechanisms have been employed in computing resource allocation, operating system memory

allocation, factory scheduling and manufacturing systems. These feats were achieved using pricings, where the participants are associated with a utility function [93] to determine their payoffs.

### **3.7 Shapley Value**

In cooperative games where coalition formation is the norms, and members of a coalition get to share what comes as a profit or benefit of joining the coalition otherwise known as payoff [98, 99], different solution concepts have been defined over time to enable the sharing process; these are the core, kernel and Shapley solution concepts respectively [99]. Shapley value a solution concept for cooperative games defined by Lloyd Shapley [98]. The advantage of the Shapley value is that it ensures fair distribution of payoff amongst these members and it is unique [99] which makes it an important normative payoff distribution tool in the field of cooperative game and considered very useful in the implementation of the centrality of distribution networks [100]. As evidence in literature, several studies have been done on the computation of the Shapley value; it has been proven to be an NP-Complete problem [98, 99, 101] which conforms to the general problem of resource allocation that is NP-hard in nature and also explains that the Shapley value cannot be determined in polynomial time. In computing the Shapley value, therefore, several approaches have been developed. [98] for example proposed a polynomial method that is based on sampling theory which can be used to estimate the Shapley value where they used sampling as a process or method of drawing a representative or cases from a particular population using statistical inferences where it is deemed impractical to obtain information from individual members of the population [98]. [99, 101] also employed a linear approximation algorithm which was motivated by the complexity of computation. The algorithm is based on randomization and has exhibits time complexity that is linear in the number of the user.

The Shapley value has four distinct properties that ensure it is unique to the user to which allocation is performed. These properties typically referred to as “axioms” are: efficiency, symmetry, dummy and additivity [99, 102, 103]. In computing the Shapley value, literature has revealed that these properties must be satisfied by a game. These properties are established in the System model. The Shapley value also has been established as a rather complex value to determine which has necessitated different methods being developed for the purpose. This study employs the Owen Multilinear Extension [104] to hasten the computation process as well as arriving at realistic values to be allocated to users of the network to realise their QoS needs.

### **3.8 Owen Multilinear Extension**

The Owen Multilinear Equation is an important tool for solving simple coalitional games and used to efficiently compute solution concepts, therefore, making it easy to compute the Shapley’s Value solution concept, which is rather complex to compute.

### **3.9 Coalition Formation**

Coalition formation problems arise when agents need to work together to achieve tasks such as bidding, bulk buying, etc. Different examples of this problem abound in the society, taking various forms. The problem of coalition formation is known to be NP-hard in term of computation. The intractability of the problem arises from the fact that different agents in the coalition may have different goals for joining the coalition which might divide the population of the coalition into a large number of sub-coalitions of common goals to allow the agents get to their individual goals [103, 105]. Coalition formation can be done through mathematical models or heuristic approaches. Agents’ behaviours regarding population and goals are dynamic. To handle these dynamic behaviour changes, agents may choose to remain longer in a particular coalition depending on their status. [106] proposed a general mathematical model that handles multi-agent system with respect to a dynamic system where complex collective behaviours are



observed. The model uses a system of differential equations that describe the dynamics of a multi-agent system; helping collaboration in a group of robots.

The essence of collaboration is in coalition in that collaboration can improve the performance of a multi-agent system bearing in mind that a team can, in most cases, relatively accomplish a task more efficiently than a single agent can. Coalition formation techniques follow either traditional or swarm paradigms. In the traditional paradigm, the coalition is formed and controlled by a central controller with participating deliberative agents. In the swarm paradigm, simple agents are involved with distributed control.

Coalition formation has different reasons for which its a participating member may join however keeping its own goal at heart. In the field of politics, this could be a means to gain power and win an election. In other areas, it could be to work together in achieving efficient outcomes better than some of the individuals in the coalition could achieve alone. In forming a coalition, several factors are considered in other to have an effective coalition structure; these include: information sharing, informing the interested public, mobilising members, and raising money.

In CRAA, the effect of an increase in the number of users on the radio resources is as much as it is in the natural human society where population growth appears to put more pressure and strain on available non-renewable finite resources. In the case of the radio resources, this is more severe since these resources are finitely defined/allocated, and users need to be dynamically allocated as they continue to compete for available resources. These resources are constantly allocated and released per TTI when they finished serving the user to which they are allocated. The effect here is that as the number of active users in the network increases, the amount of available radio resources being used continues to reduce leading up to larger queue and effectively increasing the amount of delay in the network which is not favourable to delay

sensitive applications thus reducing the users' perceived quality of services and its experience of the network.

### **3.10 Control of Coalition Formation**

It is the function of the eNB to add users to the coalition. To ensure this is done, the CRAA looks to the protocol layers of the EUTRAN as integrated in the eNB. The EUTRAN protocol responsible for identifying the user traffic-flow type is the Packet Data Convergence Protocol (PDCP) sub layer. The PDCP layer is a part of the UE and the eNB where it is responsible for sending and receiving packets over the air interface. This sublayer protocol's functions include:

- Header compression and decompression of IP data flows using the Robust Header Compression (ROHC) protocol
- Transfer of data for user and control planes respectively
- Maintenance of PDCP SNs
- In-sequence delivery of upper layer PDUs at the re-establishment of lower layers for radio bearers mapped on RLC AM
- Ciphering and deciphering of user plane data and control plane data
- Integrity protection and integrity verification of control plane data
- Timer based discard
- Duplicate discarding

The PDCP receives PDCP SDUs (PDCP Service Data Units) in the form IP packets from the IP layer and performs a header compression and decompression by essentially removing the IP header from the IP packet and sending it out as a Protocol Data Unit (PDU). Note that the PDCP is responsible for data compression and decompression of IP data flows. By doing this, it detects and stores static fields such as IP addresses and port numbers. By storing port numbers, the

PDCP keeps track of the different traffic flows going through the eNB towards the users of the network since each application packet carries a port number that identifies its application type during compression and decompression. By keeping knowledge of users' bearer streams, location and channel quality through the CQI which provides the users' SINR, the eNB can add users to the appropriate coalitions that would benefit them give them enough throughput to satisfy their traffic demands.

The eNB's control of resource allocation informs the adoption of the tradition paradigm of coalition formation in which the eNB's PDCP sub layer knowledge of the IP packets' port number are taken advantage of to resolve coalition formation by users who share the same traffic type in order for them to pool more resources that enable the network to satisfy their required QoS demands.

### **3.11 Conclusion**

In this Chapter, resource allocation in wireless network was discussed. Different resource allocation schemes were also presented and how they are relevant to this study. The Chapter shows that these existing scheme are efficient in their designs and also that there would be need for them to either be enhanced or dropped entirely in order to be able to handle mobile network traffic in the future generation of networks. The Chapter also discussed Games with transferrable utility. Market Game is also discussed in this Chapter alongside the Shapley value and the Coalition Formation which are fundamental to the resource allocation algorithm to be discussed in the Chapter Four.

## **Chapter Four**

### **COLLABORATIVE RESOURCE ALLOCATION ALGORITHM (CRAA)**

#### **4.0 Introduction**

In Chapter Three, resource allocation has been shown to be of great responsibility in the workings of mobile networks. Efficient allocation of available scarce resource helps to improve the performance of users in the network. Chapter Three presented different schemes of resource allocations that exist in mobile network systems. To further improve on the efficiency of resource allocation, as one of the contributions, this Chapter presents the CRAA. As will be seen subsequently, the CRAA relies on the principles of social welfare to enable the system achieve higher performance both on the side of the users and the operators. This is shown in this Chapter using an analytical model of the CRAA. The performance of the algorithm is further presented and compared with existing works that have been done and investigated in the literature.

#### **4.1 Collaborative Resource Allocation Algorithm (CRAA)**

The CRAA has been necessitated by the ever emerging need for higher data rate requirements due to the increasing deployment of applications (Apps) such as SnapChat, Instagram, Twitter, Music streaming services (Apple Music, Deezer, Spotify, Tidal), video streaming services (Netflix, Flickr, etc.). These applications and services have all changed the way QoS and data transmission are perceived and have continued to place an increasing demand for high data rate as more and more user get connected thus making the request for broadband data traffic grow exponentially [79]. Coupled with the fact that this is happening in the face of governments' regulatory policies on radio resources, operators are therefore bound to exploit other means from those discussed in Chapter Three; by which high data rate traffic demands from the users can be satisfied with some resources in their possession.

To develop the CRAA to meet the requirement for these services' demands; from the available literature, it has been studied that different methods have been developed that closely satisfy these requirements caused by the traffic growth. These methods, however, do not consider the fact that some users' distance from the operators' facilities as the SINR is a function of distance and other factors; also, the existing techniques have mostly been deployed long before the emergence of these new trends in social media services with heavy traffic demands and requirements. To satisfy these, this study proposes the CRAA in which a user whose channel quality is a little below the network's defined threshold can still transmit at considerably better QoS as a result of combined strength of other users in the network through the formation of a coalition of users by applying the Market Game and Shapley Value. This concept is a means of strategically borrowing (pooling) resources to achieve ends meets for users in various needs. In the economic terms of it, it is referred to as coalition formation. Under this strategy, the user's achieved SINR is added to others and the aggregate throughput is calculated for members of the coalition based on the aggregate resource demand for a particular kind of service flow as would be discussed later. The service quality of all users is then improved on the available resources and further allocated fairly using the Shapley Value.

In Section 3.1, it has been shown that dynamic multiuser resource allocation schemes ensure high performance for users of the network. The authors in [107] have shown that the channel state information and transmit power can be adapted at the transmitter to maximise the data rate of users in a time-varying wireless channel OFDMA systems. This goes further to support the reason why the CRAA relies upon the channel state information from users to enter them into coalition with other users with which they can share same bearers. Also, [80] posits that when path loss difference between connected devices is large, the chances are that, the users with the higher average channel gains would be allocated most of the available resources which mean the

users with lower average gains will most likely be unable to transmit their data. While this effect, as seen in the extant literature can, to a greater extent, be resolved through proportional fair allocation strategy, the intention of the CRAA is to ensure that this kind of users can form coalition with users who have higher CSI and are capable of sharing the same bearers so as to enable them to transmit their data efficiently.

## **4.2 Analytical Model of the System**

In using minmax to optimise resource allocation, the minmax problem considers the allocation of multiple resources among competing activities to minimise the largest performance function value associated with any of the activities. “This equals the small value that the other players (users) can force a player to receive, without knowing his actions; equivalently, it value equals the largest value the player (user) can be sure to get when it is aware of the decisions of the others” whilst the “the maxmin value is the largest value a player (user) can be sure to get without knowing the actions of the other user.” The maxmin value also represents the minimum amount of payoff guaranteed the user by entering coalition where it does not know anything concerning the strategic demands of the other players and especially in a situation where it might cause damages to this player (user). In a resource allocation problem of this sort where fairness is a necessary parameter of consideration, maxmin allocation assumes that the resources are allocated to flows in advance, which are the direct opposite of best-effort transmission.

The proposed algorithm is a downlink resource allocation scheme which dynamically allocates available resources to the users to improve their throughput and network spectral efficiency. The algorithm is entirely under the control of the eNBs who do monitor the CSI of connected users since these users do not need to be aware of each other and their requirements but would be constrained to collaborate in order for their neighbours to achieve good throughput that meets their services’ requirements, particularly at the cell edge. We consider the downlink transmission

of the network as the core of our problem. As mentioned in the literature, previous studies have shown that a UE's throughput is a function of the achievable SINR thus making it pivotal in this study. In this section, we present a system of mathematical equations that model the network resource allocation. The model of the problem starts by using the equation (4.6) [108] to calculate the *ith* UE's SINR as:

$$\gamma_i = \frac{P_s K_1 10^{\frac{\sigma_s \cdot 1}{10} \xi}}{d^{\alpha_1} (\sum_1^J P_j + N_{UE})} \quad (4.6)$$

Where  $\gamma_i = SINR$

$P_s$  = Transmission power of the eNB

$P_j$  = Interference power from the eNB<sub>j</sub>

$d$  = Disatnce between UE and eNB

$K_1$  and  $\alpha$  are constant parameters deduced from propagation loss

$$K_1 = 10^{-14.178} * 10^{-\frac{L_{Trans}}{10}}$$

$L_{trans}$  = Penetration loss

$$\alpha_1 = 3.5$$

$N_{UE}$  = UE thermal noise

$\xi$  = Standard normal random variable that models fading

$\sigma_s$  = Standard deviation of shadow fading

The UE's data rate/throughput is defined as

$$C_i = \max_i \min_i \left( z_{ij} * \sum_i^K \frac{B}{N_c} * \log_2(1 + \gamma_i) \right) \quad (4.7)$$

*s. t*

$$C_i \leq C_k \leq C_T \quad \forall i \in K \quad (4.8)$$

$$\sum_i^K u_i \leq \sum_i^K u_K \leq C_T \quad (4.9)$$

$$\sum_i^K C_i \leq C_K \quad (4.10)$$

$$u_i \leq u_K, i = 1 \text{ to } N \forall i \in N \quad (4.11)$$

$$z_{ij} = \begin{cases} 1, & \text{if user } i \text{ is connected to eNB } j \\ 0, & \text{otherwise} \end{cases} \quad i \neq j, \forall i \in K \quad (4.12)$$

$$u_K \leq C_T \quad (4.13)$$

$C_i$  is the  $i$ th user's throughput at given locations in the network.  $B$  is the system bandwidth and  $N_c$  is the number of allocated subchannels.

In Equation (4.7),  $z_{ij} = [0,1]$  is decision variable, which ensures that a user demanding resources from the cell is within service range of this eNB and therefore has the right to be served otherwise, its requests remains invalid as it is shown in (4.12). The constraint in (4.8) ensures that the throughput offered to any one user cannot be more than the aggregate for all users occupying this network at this period and the aggregate throughput for all users of the network cannot be more than the total finite capacity of the cell. The equation (4.9) ensures that the total demand in the cell does not exceed the total allocated service capacity; in the same view, from this constraint, a user's demand cannot exceed the demands of its coalition. The constraint in equation (4.10) also ensures that the rate for any one user is not more than the total rate accruing to all users in a coalition thus avoiding greedy resource allocation where every user tries to ensure it is satisfied at the expense of others. The Equation (4.12) also ensures that the user being served is connected to the serving eNB. While Equation (4.13) ensures that the total



traffic demand coming from all users in the coalition at this TTI does not exceed the total capacity allocated to the cell in order to avoid blocking.

From the equation (4.7), a network user requires throughput,  $C_i$  to enable it transfer its data in one TTI,  $t$ ; supposing that the size of the data to be transferred is  $x'$ . The variable  $\bar{x}'$  is defined as the average size of the data that needs to be transferred over the network with mean traffic load  $p$  where delay factor for packet delivery is given as  $\Delta 1$ . The mean packet arrival rate using the poison distribution is then given as:  $\lambda = \frac{x'}{C_T} * \Delta 1 p$ . Where  $\Delta 1 p = \frac{1}{1-p}$ . Intuitively,  $p$  equals the total file size to be transferred, therefore,  $p$  can then be translated using the mean file size as  $p = \frac{\lambda \bar{x}'}{C_{cT}}$  which represents the mean traffic load that each user puts on the network, either in a coalition or while acting alone. Therefore, the rate requirement for the user to transfer its data over the network for in one period is  $C_i = \frac{x'}{t} * \Delta 1 p$ .

At every Transmission Time Interval (TTI), there is a total of  $K$  users occupying the network. The available radio resources would be shared amongst these users, depending of course, on their demands. A user would therefore bid  $u$  portion of the available cell capacity,  $C_T$  at every  $t$ ; that is  $C_T$ . During  $t$ , in a cell with  $K$  users, the  $i$ th user would therefore demand  $u_i$  which would receive a service rate of [93]:

$$v_i = \left( \frac{u_i}{\sum_{k=1}^K u_k} \right) * C_T \quad (4.14)$$

From(4.8),  $u_i$  is the  $i$ th user's demand for which the rate  $v_i$  is required to satisfy the users' demands. From (4.7) and (4.14);

$$v_i = \left( \frac{C_i}{\sum_{k=1}^K C_k} \right) * C_T \quad (4.15)$$

Where  $C_k$  is the sum total of throughput for all users in the coalition. The price to be paid per unit resource for this demand is given as:

$$\frac{(\sum_{i=1}^K C_k)}{C_T} \quad (4.16)$$

The price to be paid for this demand to be rendered is in effect the UE's required SINR,  $\gamma'$  as identified in the user's CQI. For a  $i$ th user to transmit, it is required that  $\gamma'_i \leq \gamma_i$ .

$$\gamma'_i = \frac{P_s * G_{T_x} * G_{R_x}}{\zeta_{T_x} * \zeta_{R_x} * G_{R_x} * l_p} \quad (4.17)$$

Where  $G_{T_x}$  is the transmitter gains,  $G_{R_x}$  is the receiver gains,  $\zeta_{T_x}$  is the transmitter losses,  $\zeta_{R_x}$  is the receiver losses.  $l_p$  is the pathloss, which is calculated using the free-space path loss model:

$$l_p = 42.6 + 26 * \log\left(\frac{d}{Km}\right) + 20 * \log\left(\frac{fq}{MHZ}\right) \quad (4.18)$$

$d$  = distance between the  $i$ th user and the eNB

$fq$  = network operating frequency (800 to 2000MHz)

For a strategic game, coalition formation is defined as  $(N, v); S \subseteq N$  for which a payoff  $f$  is defined as  $f: R^+ \rightarrow 2^N$ . [99, 104, 109],  $S$  is the coalition formed from among the grand coalition while  $N$  is the number of users.  $f$  is the utility function defined on the coalition,  $S$  that distributes the payoff to users in the coalition. This algorithm assumes that the coalition is formed spontaneously and that given  $n$  users, the set of possible coalition formed would be  $2^N$  with  $2^n$  elements.

To ensure that the cell-edge users are satisfied, the algorithm looks to the Shapley value solution concept [99, 110, 111] to ensure a fair distribution of the earned payoff occurs in the process of allocation. Substituting the user demands and the number of users in the Shapley value solution concept equation, the payoff  $\phi_i(N, f)$  earned by the  $i$ th user, from (4.7) is given as:

$$\begin{aligned} \phi_i(N, f) = & \frac{1}{N} \sum_{S \subseteq N \setminus \{i\}}^k |S|! (|N| - |S| - 1)! \left[ \left( \left( \frac{C_i}{\sum_{k=1}^K C_k} \right) * C_T \right) \right. \\ & \left. - \sum_{k=1}^K v_k \right] \end{aligned} \quad (4.19)$$

$v_k$  is the total payoff of all members of the coalition and the marginal contribution of the  $i$ th user in this coalition is given as  $\left[ \left( \left( \frac{C_i}{\sum_{k=1}^K C_k} \right) * C_T \right) - \sum_{k=1}^K f_k \right]$  and  $\forall i \in S \subseteq N; \left( \left( \frac{C_i}{\sum_{k=1}^K C_k} \right) * C_T \right) \geq \sum_{k=1}^K f_k$ .

The fairness of payoff requires that the values obey some axioms:

- i. Symmetry: for two users  $i$  and  $j$ , say at the cell edge whose contributions in the coalition are the same, their payoff have to be the same:

$$\left\{ \left( \frac{C_i}{\sum_{k=1}^K C_k} \right) * C_T = \left( \frac{C_j}{\sum_{k=1}^K C_k} \right) * C_T \right\} \phi_i(N, f) = \phi_j(N, f) \quad (4.20)$$

- ii. Dummy User: the  $i$ th user in the coalition is a dummy user if its contribution amounts to zero:

$$\forall S: \frac{C_i}{\sum_{k=1}^K C_k} = \sum_{k=1}^K f_k \quad (4.21)$$

(4.21) translates that  $\forall f$ , if  $i$  is a dummy user, then  $\phi_i(N, f) = 0$ .

- iii. Additivity: this axiom supposes that if the game is divided into two parts, then the payments  $f = f_1 + f_2$ . It therefore means that,

$$\phi_i(N, f_1 + f_2) = \phi_i(N, f_1) + \phi_i(N, f_2) \quad (4.22)$$

$$\therefore (N, f_1 + f_2) = (f_1(t) + f_2(t))(S) = f_1(t)(S) + f_2(t)(S); \forall S \subseteq N.$$

The Shapley value is challenging to compute seeing, intuitively that the coalition ordering involves a prohibitively large amount of calculations. To overcome this complexity, therefore, the algorithm employs the Owen multi-linear extension method [104] to speed up the computation therefore effectively reducing the computational complexity that is involved and also speeding up the computational process. This method is a function defined on a  $n$ -cube,  $1^N$  which is linear in variables and coincides at the corners of the cube. The function helps in computing the value of large games as well and gives a generalization of the Shapley value [104].

In the Owen Method [49], there exists a unique multilinear function,  $\underline{f}: [0,1]^n \rightarrow R^n$  that coincides with  $2^N$  which yields  $\underline{f}(x_1, \dots, x_n) = \sum_{S \subseteq N \setminus \{i\}} (\prod_{i \in S} x_i \prod_{i \notin S} (1 - x_i)) f(S) \forall (x_1, \dots, x_n) \in [0,1]^n$ .  $x_i \ i = 1 \dots n$  as the payoff for individual users in the coalition.  $\prod_{i \in S} x_i \prod_{i \notin S} (1 - x_i) = P_x(\chi_S)$  is a product probability defined on  $\{0,1\}^N \forall S \subseteq N$ .  $P_x(\chi_S)$  is the probability of the formation of random coalition. Therefore, the expected value is given as:  $\underline{f}(x_i) = \sum_{S \subseteq N} P_x(\chi_S) f(S) = E_{P_x}(v)$ . From this, the Shapley value  $(N, f); S \subseteq N$  using the multilinear extension  $\underline{f}, \forall i \in N$ , the payoff accrued added to the rate demand of the user and given as [49]:

$$\phi_i(N, f) = \int_0^1 \frac{\partial f}{\partial x_i}(t, \dots, t) dt \quad (4.23)$$

From equations (4.15) and (4.23), the  $i$ th user would then earn and achieve the rate given by equation (4.24) which satisfies its rate demand; described as:

$$C_i = v_i + \phi_i(N, f) \quad (4.24)$$

Figure 4.1 presents the flowchart description of the workflow of the CRAA from when the user enters the network and what determines the need to join a coalition. At the instance of traffic flow arrival, the user needs resources to enable it communicate through the network. The eNB checks that there are available radio resources to effect the communication. After which it checks that the user's SINR meets the required SINR. Otherwise, it checks that there are users in close proximity to this user. If there are none and the user, due to its position as a cell-edge user does not meet this requirement, it is then dropped. However, if the user's SINR value meets the required SINR and there are available radio resources, it is served with further considering the coalition formation process. The Figure 4.2 further describes the integration of the CRAA in the eNB and the position of the CRAA. The Figure 4.2 shows that, for the CRAA to get in action after the CQI has been checked and the SINR values identified, it needs the PDCP to identify application port numbers. After the identification, the users SINR values are further examined to verify that it either meets the required SINR, or it does not. The applications' requirements are then checked, after which they users are entered into coalitions that fit their traffic bearer in the network. A user with SINR value less than the required SINR will not be served if such user is not in close proximity to another user with similar traffic stream. This inability to enter the user into a coalition also follows the description in Figure 4.1.

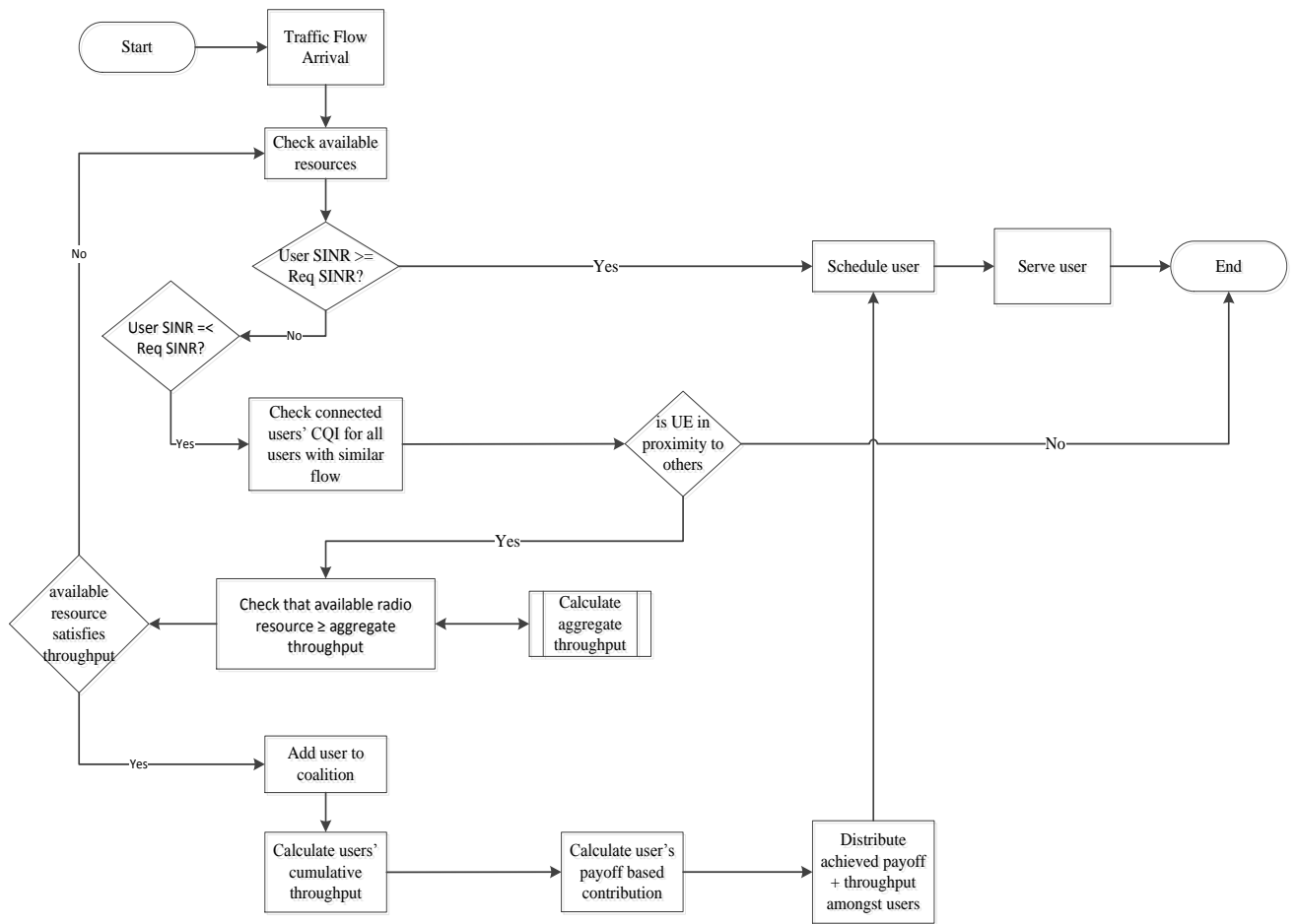


Figure 4. 1: Standalone flowchart of the proposed CRAA

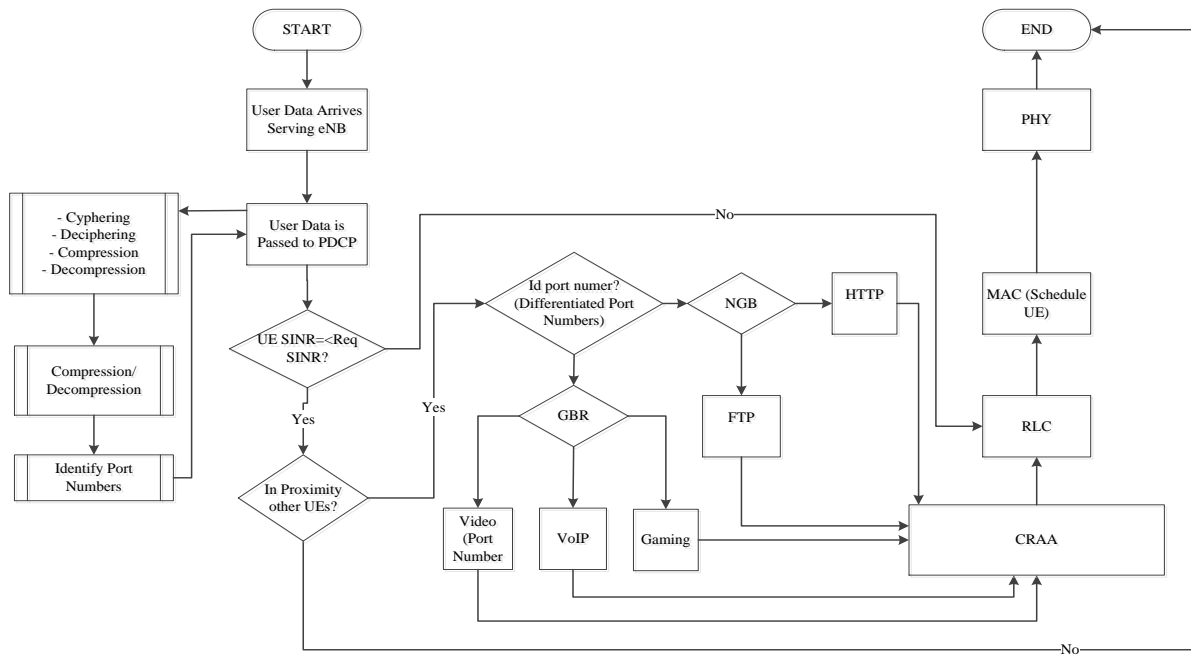


Figure 4. 2: Flowchart description of the proposed CRAA as an integral part of the eNB

### 4.3 Simulations

Traditionally, performance evaluation of wireless networks' technologies is carried out by simulating the system which can assume different models of the system using the abstraction of the real world from which the performance results are obtained and analysed to enable evaluation and validation. A system can be deterministic, stochastic, dynamic, event-driven, continuous or discrete. Whatever form the system takes largely depends on the systems natural working states.

In evaluating the performance of mobile network technologies, system level simulation is always an important methods of evaluations [26]; to achieve this, [26] developed the Vienna LTE System Level Simulator; a MatLab tool developed under an academic GNU license. Regarding performance evaluation, two distinct routes are always engaged by researchers: system level and link level simulations respectively. While link level simulation is concerned with investigating MIMO gains, AMC feedbacks, channel encoding and decoding and, physical layer modelling, the system level simulation is responsible for network related performance parameters such as resource allocation, mobility handling and interference management [26].

The Vienna LTE is a Matlab-based system-level simulator for the LTE/LTE-Advanced network system with a high degree of flexibility. The simulator is under the academic non-commercial license that gives researchers standard-compliant simulation environment [26, 112]. As an open source software environment, it enables reproducible research in the area of wireless communications and comparison of novel algorithms [112]. The simulator has been used to assess network signal qualities, and system-level performance evaluation just as obtainable in real-life scenarios [26, 112] for LTE networks for which it was intended. The Vienna LTE Simulator is also a useful tool for the validation of new algorithms in wireless communications [112]. The simulation allows for the analysis of the whole network performance. In these kinds of scenario, it also assumes that every component of the mobile network as obtained in real-life is present through the power of abstraction.

This study employed the system-level simulator version which is capable of implementing algorithms focused on resource allocation and scheduling, multi-user handling, mobility management, admission control, interference management and network planning and optimisation [112]. Available tools for simulating the attributes mentioned here are largely proprietary which makes independent validation rather difficult and time consuming thus leading to issues with feasibility [26, 112]. Not to talk about the access level which a user has (as already mentioned in section 1.7). The simulator's performance and ability to carry out technical research works in wireless communications has been validated by comparing its performance against the requirements of the 3GPP technical specifications [112]. The simulation is designed, using the setups described by [22]. The simulation scenarios are based on the working principles of a network in real life, which is a core principle of extensive simulation. Table 4.1 presents the simulation design parameters for the network in which the CRAA performance was tested. The



simulation setup allows users' speed of 1.2Km/h with forty users evenly distributed over the cell area with random mobility.

The simulation leverages on the IP protocol suite to provide the end-to-end communication that is required for all users. However, in the case of the video traffic scenario, the Real-time Transport Protocol (RTP) [113] is used over the IP protocol suite to achieve the end-to-end connection required for video transmission. All other application scenarios run on the IP protocol to achieve their purpose in this study.

Parameters	Values	
	eNB	Relay
Cell Radius	500m	100m
Transmission power	46dBm	26dBm
Subcarrier spacing	15KHz	
Carrier frequency	2GHz	
Subframe duration	0.5ms	
System bandwidth	20MHz	
Number of resource blocks	100	
Antenna scheme	2x2 MIMO	Omni
Mobility	random direction	
UE speed	1.2km/h	
UE power	20dBm	
Applications (Traffic models)	FTP, HTTP, Video, Gaming and VoIP	

Table 4. 1: Simulation design parameters

#### **4.4 Performance Evaluation of CRAA**

This section presents the numerical and simulation results of the CRAA performance evaluation. The performance of the algorithm is also further supported by results of the throughput distribution during the data transmission. The distribution is used to show how the algorithm performs, compared to the others. Using the number of users in the network as the basis for determining the size of the coalition has been observed, from user performance evaluation to increase further the complexity of computation, which leads to high delays in the algorithm execution, therefore negatively affecting the required QoS from the perspective of transmission delay. To overcome this, the users form coalitions around their traffic flow type per TTI, which simplifies the process by reducing the number of possible coalitions. Using SINR as the UEs contribution in the coalition helps in avoiding UEs having any further knowledge (forward predicting) of other members of the coalition and their capacity thus handing over the entire process to the eNB.

Different parameters, as presented in this section are used to comparatively evaluate the performance of the proposed CRAA in other to show its efficiency compared to existing algorithms. In assessing the CRAA, parameters such as Throughput, Spectral Efficiency and Fairness are compared with those of the other algorithms. An extensive number of simulations were performed using different traffic models running through the network per time. The results of the findings, using simulations of the five (5) data traffic types (FTP, HTTP, Video, Gaming and VoIP) are presented in the subsequent sections of this Chapter. These data traffic, each, has a different set of QoS requirements with respect to the throughput so as to allow the network user a reasonable level of quality of experience.

#### 4.4.1 Throughput

Network throughput, measured in bits/second (bps) demonstrates the total number of bits successfully delivered to the receiving end of the network on an end-to-end network. The measure of throughput is an indication of how fast data bits flow through the network thus representing the data rates accrued to users. The average throughput achieved by users, no matter the demand is subject to the number of available radio resources as well as the number of users in the network. Network users dynamically contend for available radio resources either to transmit similar services or other service variations that exhibit a degree of greed favourable to the user's demands. This explains why, when more users are admitted into the network, the performance of each user is proportionately reduced; thus, the higher the number of users in the network, the further the throughput is reduced. A reduction in the number of available radio resources resulting from the admission of more users affects the total network capacity (read, throughput) and the sum spectral efficiency of the network. To satisfy better QoS for high multimedia data transmission, networks systems are required to provide rates in the range of 10Mbps on both the UL and DL respectively. Numerical and simulation results show that the proposed CRAA significantly improved the network users' throughput compared with those in the literature.

Figure 4.3 illustrates the performance of the algorithm in mixed media scenario where the five-traffic flow through the network therefore allowing for users to aggressively bid for resources to satisfy their demands. The results indicate that the performance of the CRAA is higher than the MLWDF and EXP algorithms. From the results in Figure 4.3, the CRAA increased the user's throughput by taking advantage of the payoff gained from joining the coalition. The simulation results show that the CRAA achieved a peak throughput of 7.99Mbps and a minimum of 0.56Mbps. This implies that at peak performance, the CRAA improved the throughput by

30.27% higher than the MLWDF and EXP-Rule respectively. At low SINR values, even while the traffic is at the peak, the CRAA also achieved 39.79% performance improvement. This performance at low SINR shows that the CRAA performs significantly higher. This achievement further justifies the reason for a user, particularly in the cell edge to join a coalition of services to achieve higher throughput that enables it to experience real ubiquity as promised in an LTE and the future generation of networks. The CRAA's significant improvement in the throughput achieved by the user in both the numerical evaluation and simulations shows that by forming a coalition, network users will achieve higher throughput than when they act alone at the cell-edge [114-120]. Intuitively, for every user in the coalition, the higher the payoff the user earns, the higher the throughput it will achieve which further improves the user's quality of experience in the network.

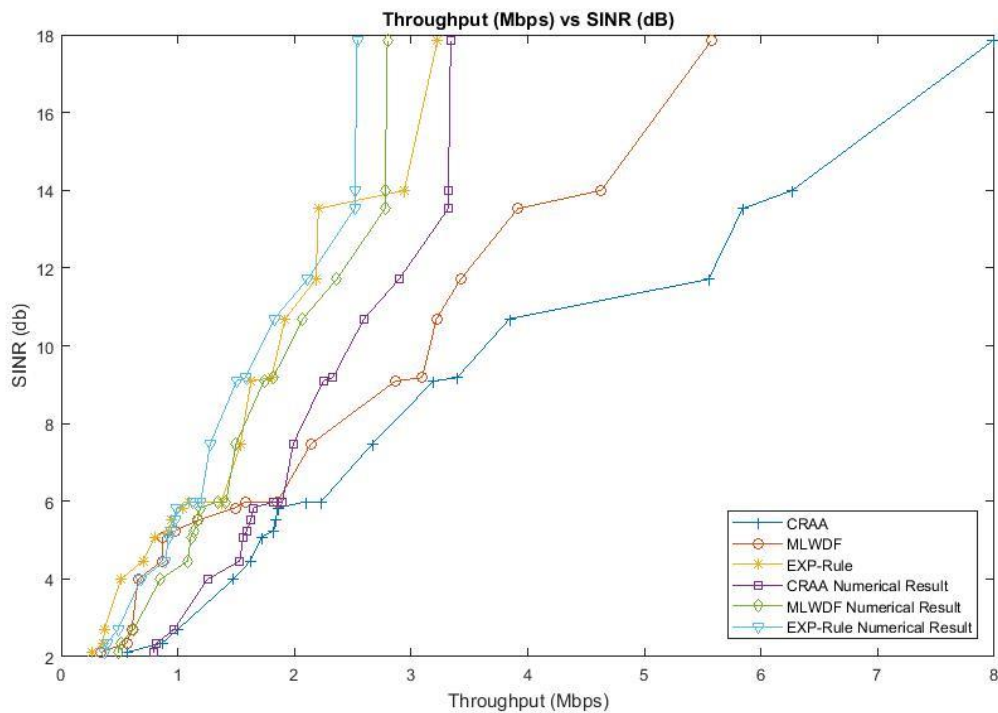


Figure 4. 3: Throughput (Mbps) vs. SINR

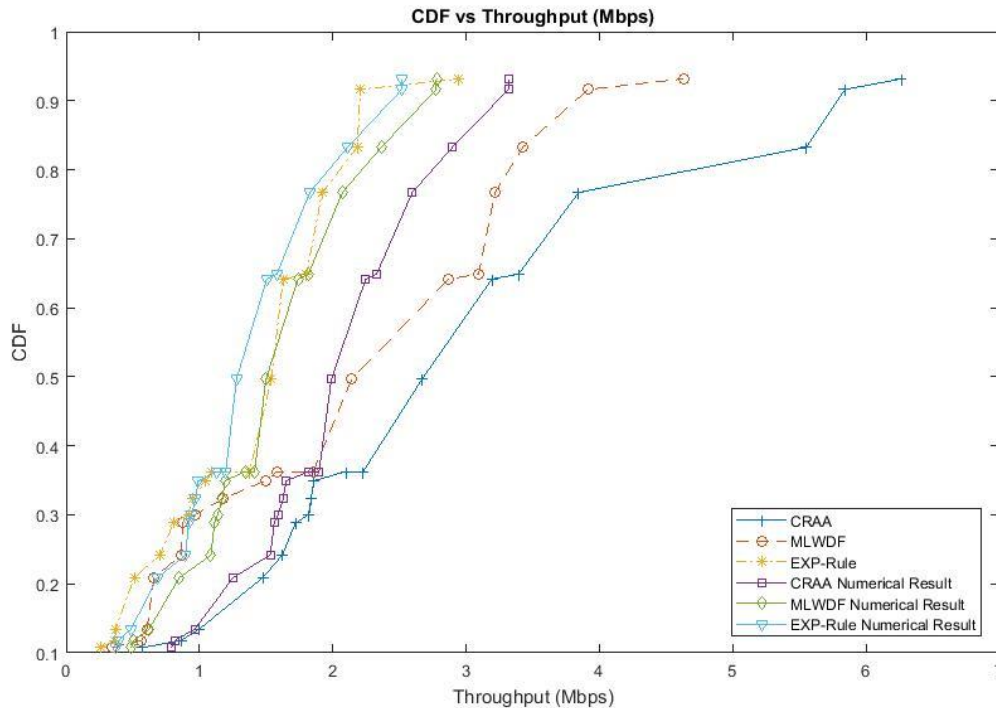


Figure 4. 4: CDF vs Throughput (Mbps)

The performance in Figure 4.3 is further experienced in the subsequent results where, in some cases, the MLWDF and EXP-Rule algorithms are neck-in-neck with the CRAA in performance measures at some points during the transmission; while the traffic flows are unbundled to evaluate the proposed CRAA's performance using specific traffic flows. The performance of the algorithm, as presented in in the Figure 4.3, is further reinforced by comparing the distribution of the throughput performance using the Cumulative Distribution Function (CDF) in Figure 4.4. The result from Figure 4.4 shows that there is a stable distribution of high throughput performance for all the algorithm, however, the CRAA maintained a sustained throughput of 7.995 Mbps at 90%. This sustained performance shows that the CRAA is capable of delivering higher throughput to network users in comparison to what the other algorithms can offer.

In Figure 4.5, the performance of the algorithm is evaluated using File Transfer Protocol (FTP) traffic model. The result shows an improved performance using the CRAA as the resource

allocation algorithm. Using the FTP traffic model, the MLWDF closely attained about the same rate with the CRAA until the SINR goes beyond 10dB where more and bigger payoff for the users see the CRAA increasingly outperformed it, the difference is on clear notes. At SINR values between 2dB to 3.08dB, the three algorithms experienced a close convergence, though the CRAA achieved higher than them all. As the SINR values of the user increases, the payoff obtained by a user in the coalition also increases thus increasing the performance of the user, which validates the theory of collaboration. The rate accrued to the user under the CRAA satisfies the higher QoS policy and rate requirement for the service transmission thus making a greater impact on the spectral efficiency, as the results in Figure 4.9a would show later. The Figure 4.4b also shows the distribution of the throughput while FTP traffic is run in the network. The distribution in Figure 4.6 shows that the CRAA, also at 90%, delivers higher through for the network users in comparison with the other algorithm. This value agrees with the numerical results of the algorithm.

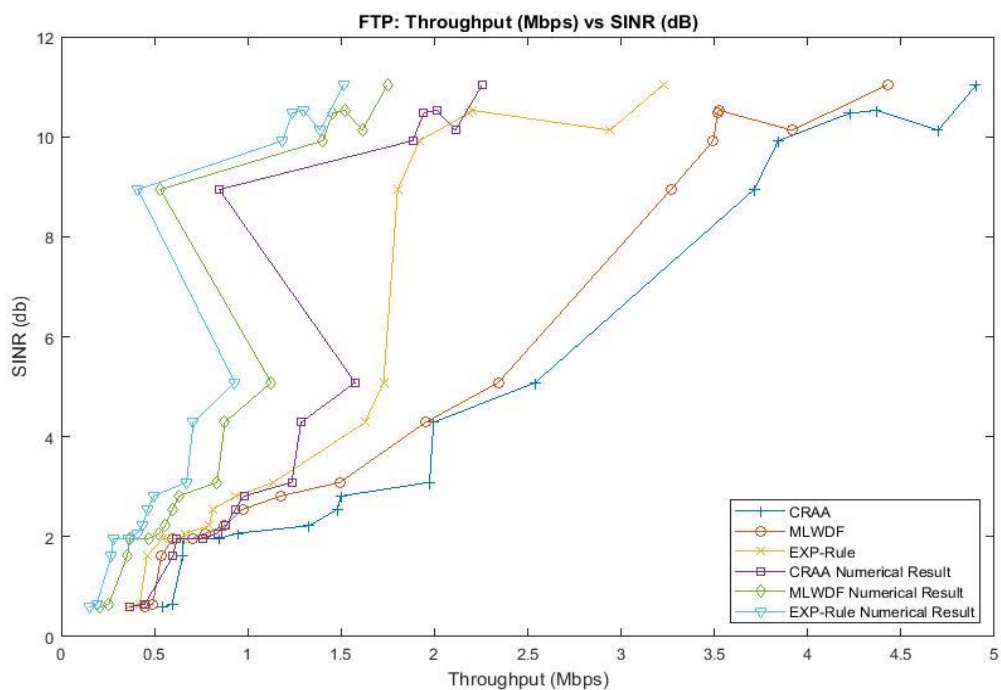


Figure 4. 5: Throughput (Mbps) vs SINR using FTP Traffic

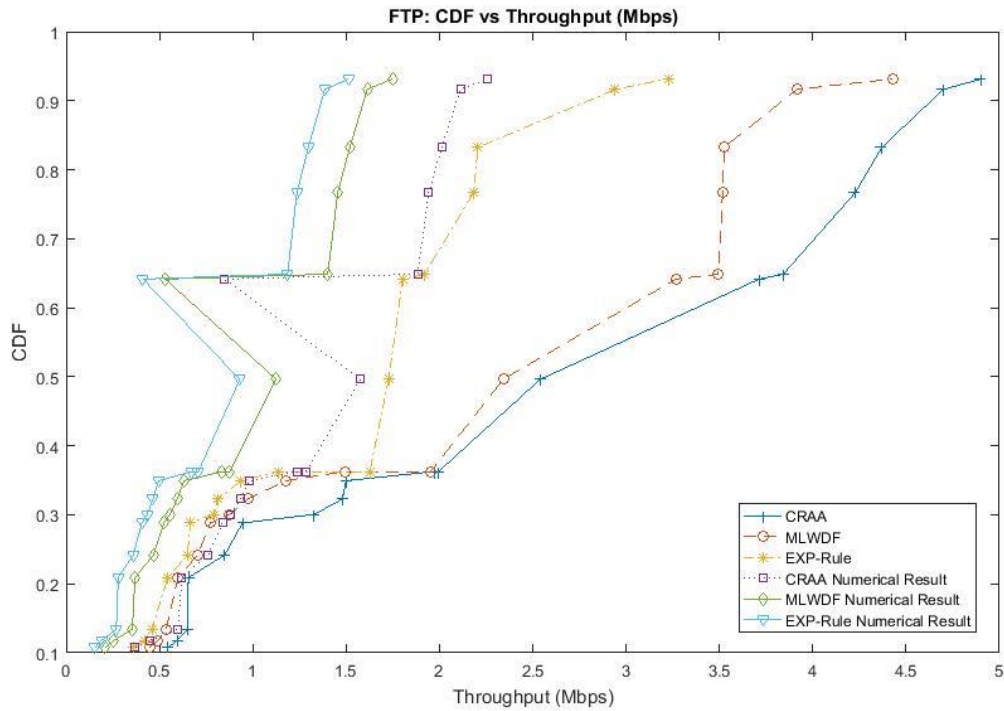


Figure 4. 6: CDF vs Throughput (Mbps) using FTP Traffic

Figure 4.7 uses the Hypertext Transfer Protocol (HTTP) to evaluate the performance of the CRAA. Again, the performance of the CRAA is higher, the difference, from the results in Figure 4.7 does not appear to be very much. Though the performance of the CRAA is not much higher here, it is, however, a tangible improvement especially when faced with an increase in the number of users in the network. The impact of increasing the numbers of the user has already been identified to negatively affect the total network performance by reducing the number of available radio resources which consequently reduces the amount of throughput been offered to the user. Considering such instance, the CRAA proves to be an efficient technique for resource allocation in this system's implementation and comparative evaluation. In comparison to the works done in the literature [114, 115, 120], the CRAA has significantly improved the user's throughput as compared with the performance of the MLWDF and the EXP-Rules in both the numerical evaluation and the simulation results. The CRAA's performance distribution is further

compared with the MLWDF and EXP-Rule algorithms in Figure 4.8. Results show that the CRAA provides higher throughput distribution (at 98%) more than the other algorithms. As with the results from previous scenarios, the results show that the CRAA significantly improved the throughput for network users.

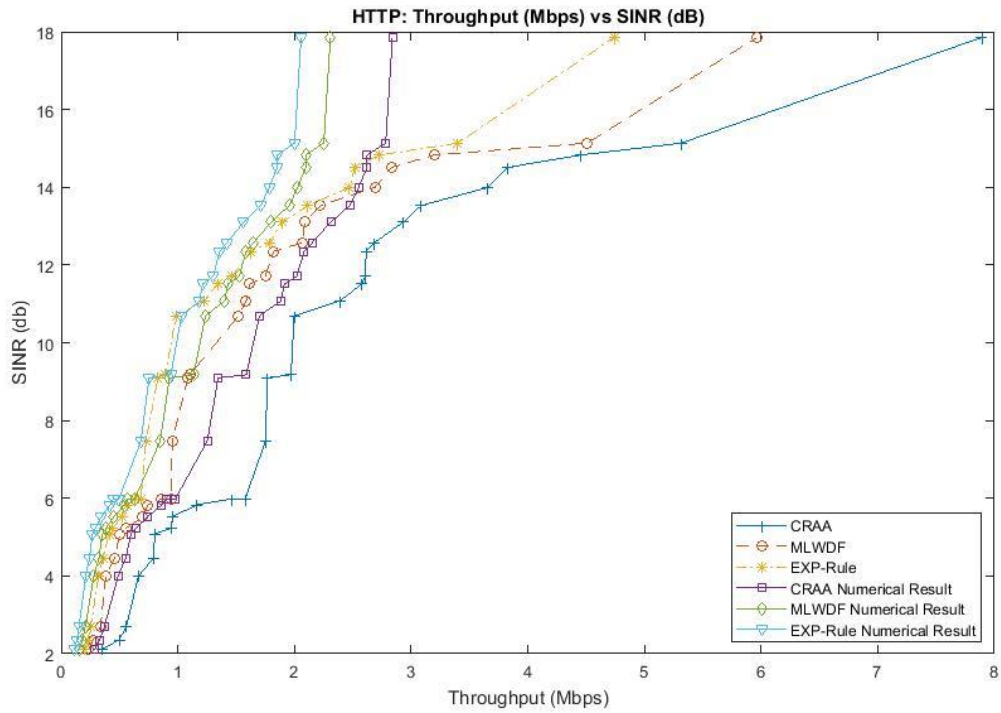


Figure 4. 7: Throughput (Mbps) vs. SINR using HTTP Traffic



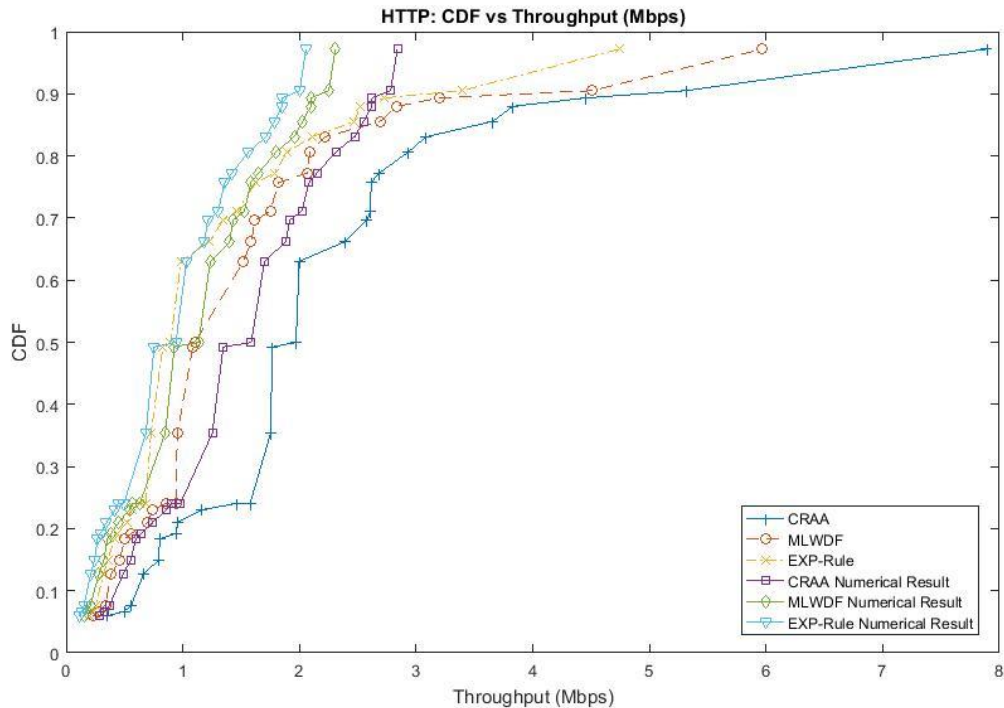


Figure 4. 8: CDF vs Throughput (Mbps) using HTTP Traffic

The performance of the CRAA is further evaluated by running video traffic through the network. In this scenario, the reason for the user to join the coalition is for it to gain high throughput that will satisfy its video traffic demand. Results in Figure 4.9 indicate that the user gained higher throughput that meets its needs while using the CRAA. The consistency of the system performance following from Figure 4.3 shows that the CRAA continues to perform higher rate by achieving high throughput that meets user demands. Though at some times, it gets lower than it initially made in the results shown in Figure 4.3, it is however consistent with ensuring higher performance that would be a source of high quality of experience to network user both at the cell-edge and network black holes. These traffic models and their flows are a very important consideration in multimedia transmission as the constitute about 80% of the LTE-Advanced QoS service class definition, exhibiting every characteristic required in multimedia services. Comparing this results with the works of [119, 120], show that the CRAA made a significant

improvement to the users' throughput when compared with the throughput achieved using MLWDF algorithm in this scenario. From the foregoing, the CRAA achieves the intended purpose of providing higher throughput for users to satisfy their various traffic demands through the formation of a coalition for a common goal. This improvement in performance that has so far been achieved further strengthens the theory from Section 4.5; that having users form coalition to pool resources together for a common good would enable them, especially at the cell edge to achieve higher rates and better QoS. The results in Figure 4.9 is further substantiated by the result of the performance distribution in Figure 4.10. The results in Figure 4.10 shows that the CRAA, as in Figure 4.10 is stable higher at 80% of the time. This further indicates that the CRAA yields better performance than the other algorithms.

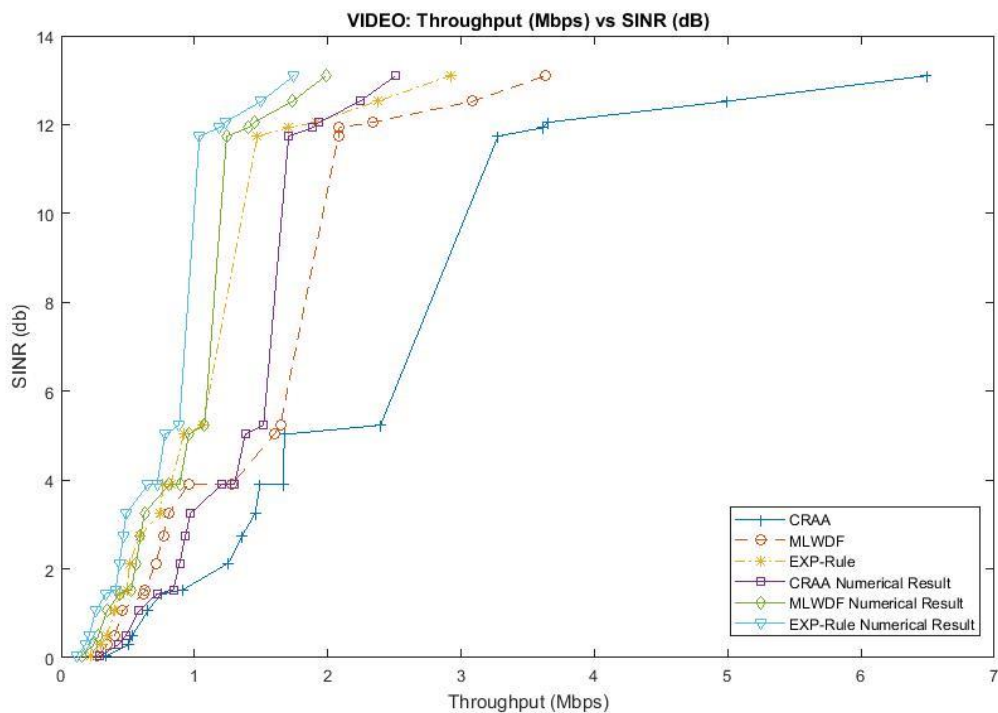


Figure 4. 9: Throughput (Mbps) vs. SINR using Video Traffic

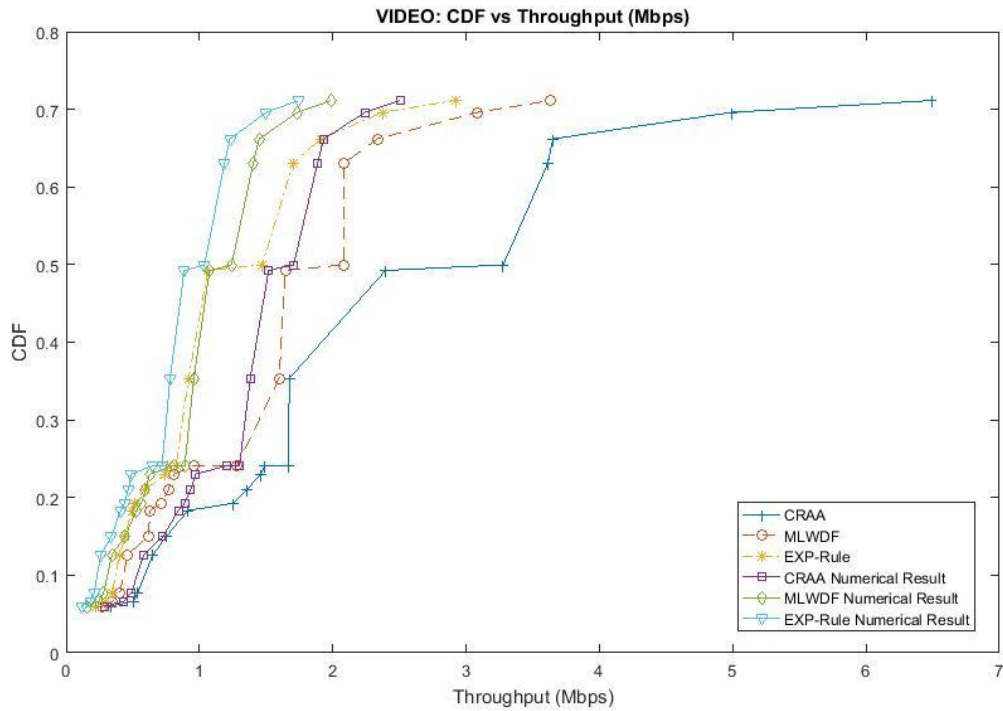


Figure 4. 10: CDF vs Throughput (Mbps) using Video Traffic

Figure 4.11 presents the result for the scenario where the users form a coalition to satisfy needs of the mobile game player using the gaming traffic model. Gaming is one field of computing that is generating enormous traffic and will continue to do so as the systems get smarter and game applications get more intelligent in the future. Advancement in smart devices means the games industry will continue to evolve in smart game development to suit both home and public place entertainment needs. Real-time gaming requires a large number of resources for users to enjoy excellent quality of experience. This makes gaming-traffic a bigger model of consideration in the field of resource allocation, especially that most of the games available now, and for the future are and would be online-based to provide ubiquitous entertainment needs to people. In the result in Figure 4.11, the proposed CRAA's performance appears to be entirely neck-in-neck with the MLWDF and EXP-Rule as they allocate resources to accommodate this traffic flow while experiencing SINR values between 0dB to 2dB. However, in the long-term, the result proves that

the CRAA can provide more resources to the users. By providing more resources through the payoffs, the CRAA, therefore, achieved higher data rate than the MLWDF and the EXP-Rule algorithms. The CRAA's high performance with respect to the gaming traffic flow is more evidenced as the payoff values begin to increase. The increase in payoff enabled the CRAA to offer throughput values at 41.67% higher in performance; at low SINR values. This increment is also higher at peak SINR value where the CRAA performance is 41.57% greater than the MLWDF and EXP-Rule algorithms, respectively. Compare with the scenario of running a mixed traffic through the network; the CRAA maintains the significant improvement that it is intended to provide. This differentiating increase is also typical for the other traffic models thus justifying the idea that performance of the network can be achieved if users collaborate to form coalition and pools resources equitably to satisfy their common needs. The results from the experimental work of [114] shows that the CRAA achieved the objective of improving the throughput for users, especially mobile game players, where in the case, the CRAA allows the user to gain higher throughput than the MLWDF and EXP-Rule respectively. The performance of the CRAA is further shown using CDF to compare with the performance of other algorithms in Figure 4.12. The results shows that the CRAA renders higher throughput than the other algorithms.

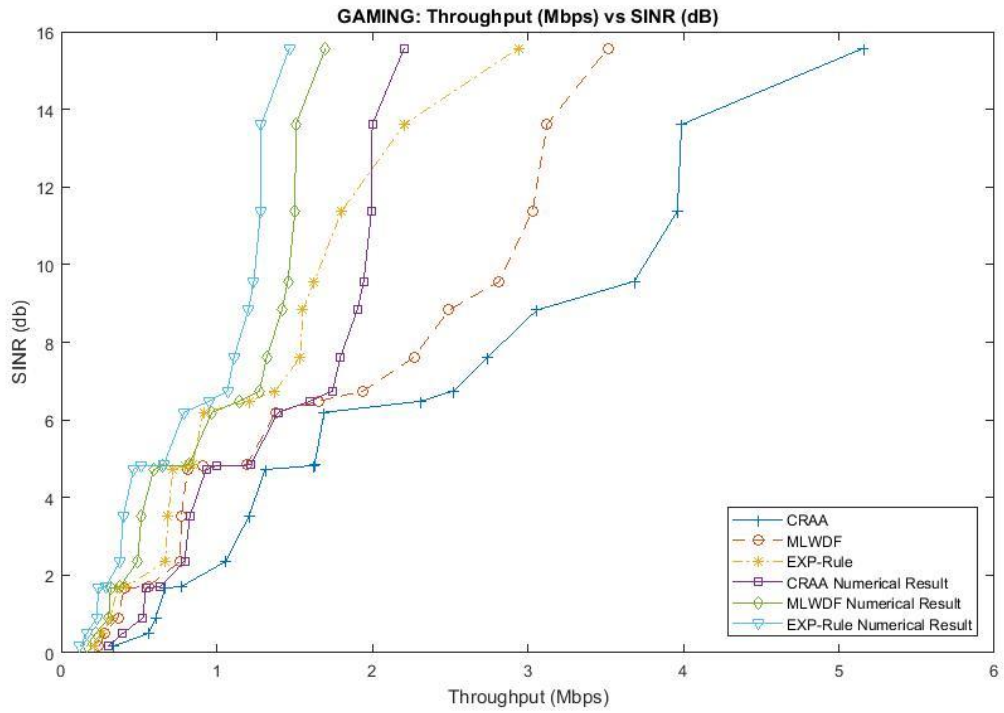


Figure 4. 11: Throughput (Mbps) vs SINR using Gaming Traffic

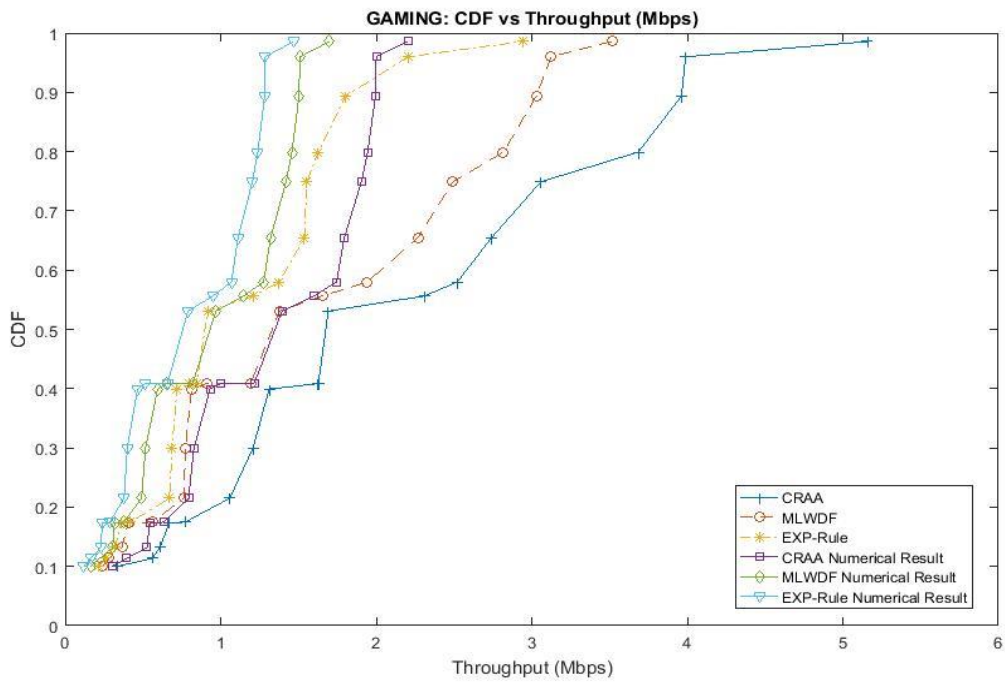


Figure 4. 12: CDF vs Throughput (Mbps) using Gaming Traffic

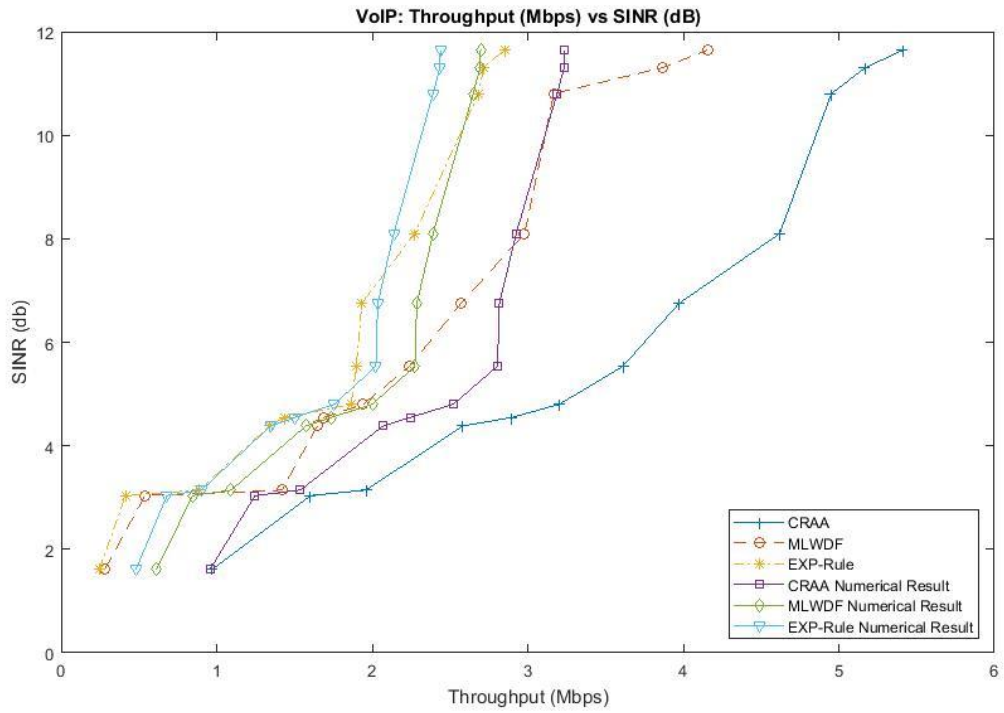


Figure 4. 13: Throughput (Mbps) vs. SINR using VoIP

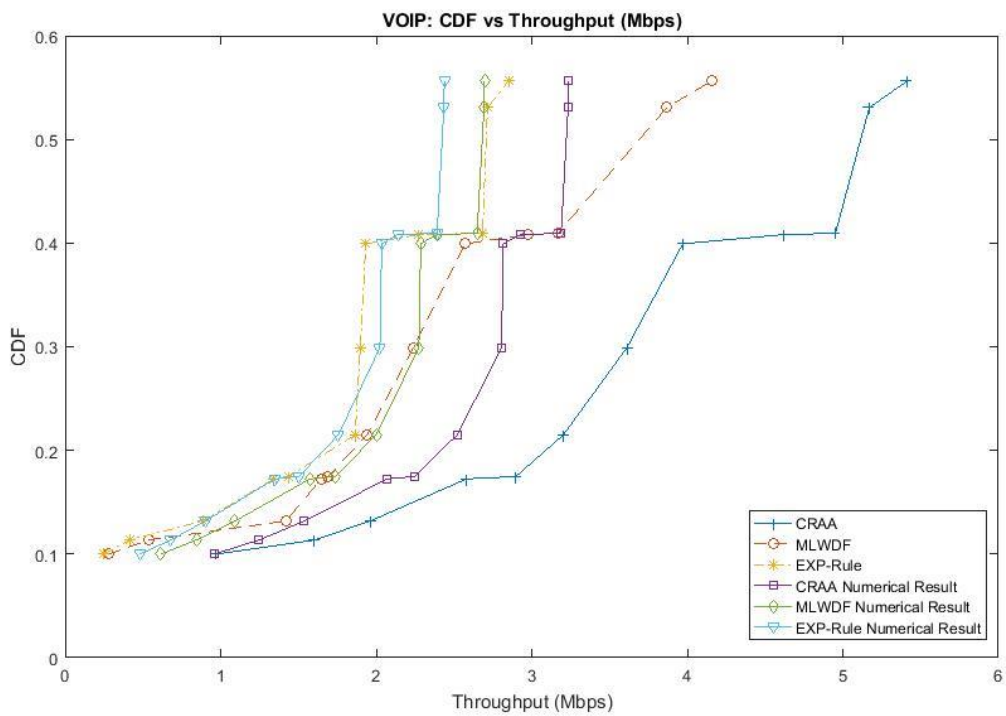


Figure 4. 14: CDF vs Throughput (Mbps) using VoIP

In Figures 4.13 and 4.14, the CRAA, like in the previous scenarios, shows an improvement in the throughput achieved by users transmitting Voice over IP (VoIP) through the network. VoIP traffic model is used here because, currently, the Vienna LTE Simulator does not have an implementation of the Voice over LTE (VoLTE) protocol that allows voice services to run on the LTE network. The result shows that the CRAA increased the users' throughput by 26.6% higher than the MLWDF and the EXP-Rule algorithm. When compared with the results of experiments in the works of [114-120], the results support the claim that the CRAA made an improvement to the throughput achieved by users while transmitting VoIP packets through the network. By this improvement, the CRAA further indicates that for network users at the cell edge, it is possible to achieve a good quality of experience by joining a coalition to collaborate with other users of similar traffic flow to pool more resources that would enable each member of the coalition to communicate at reasonable service quality.

#### **4.4.2 Spectral Efficiency**

Spectral efficiency is the measure of the wireless network's ability to transmit data in its assigned spectrum. Spectral efficiency is measured in bit/second/Hz (bps/Hz) and it defines the maximum data rate per bandwidth. It is used as a performance evaluation metric to analyse the performance of access technologies, digital communications scheme, diversity techniques and channel resource reuse and resource management. This metric is associated with the amount of bandwidth and operator needs, the number of eNBs that need to be deployed in the network and the network users are charged for accessing the network. In this project, the emphasis is to use spectral efficiency (SE) to evaluate resource reuse regarding allocation. A high SE apparently translates to high and efficient network performance relating to the network's QoS policy profile.

The result in Figure 4.15 shows that the CRAA makes better use of the available resources than the others do. At 3.56bps/Hz, the CRAA is utilising 63.7% of the bandwidth. This performance

is relatively higher than the algorithms in comparison. This is of great importance to the operators as it is an indication of the networks' efficiency and a number of users supported by the network while using the CRAA. The CRAA's SE performance shows that it is capable of providing higher bandwidth efficiency than the other algorithms as validated by [116]. The performance in Figure 4.15 also shows that the CRAA enables higher resource management for the system. The CRAA will allow network operators to fully utilise their allocated spectrum, which may translate to an increase in their profit margin.

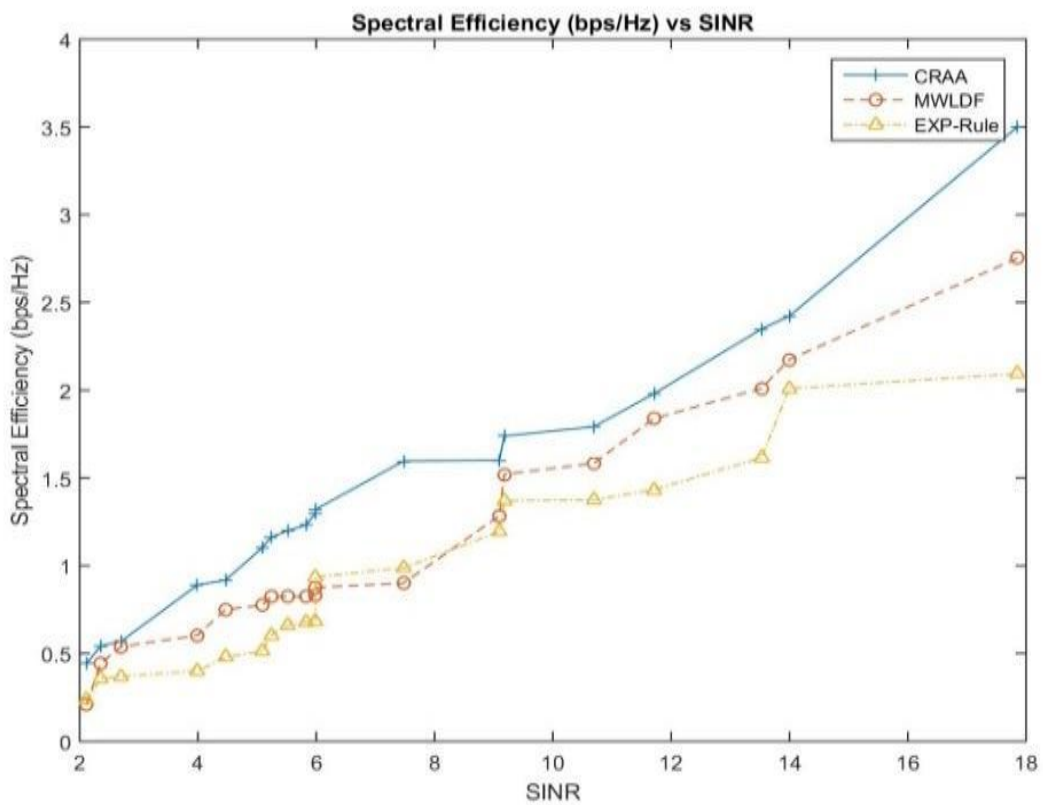


Figure 4. 15: Spectral efficiency vs. SINR

#### 4.4.3 Fairness

Fairness indicates how fair resource usage in the network, ensuring that there are no areas of bottleneck in the network thus translating to efficient resource management that yields high



throughput for users of the network. Different indices exist that are used to measure fairness. To measure fair resource allocation, however, this project employs the Jain's index which is defined by the equation [58]:

$$f(C_1, C_2, C_3, \dots, x_i) = \frac{(\sum_i^n C_i)^2}{n \sum_i^n C_i^2} \quad (4.25)$$

Where  $0 \leq f(C_i) \leq 1$ , given  $C$  is the throughput for each flow upon which coalition is formed, and user,  $i, \forall i = 1, \dots, n$ .

Using the Jain's definition of fairness as in the equation (4.25) [58], the result in Figure 4.16, from the notion of fairness, a maximum of 1 is the value for which a fair allocation can be adjudged to be fair to every participant. This implies that on a scale of 0 to 1, an allocation is fair only if the fairness index is greater than 0 and less than 1. From the Figure 4.16, the other algorithms had better satisfy the notion of fairness more than the CRAA, which, though not an impressive performance with respect to the other satisfies the Shapley's impression of fairness. The fairness of the CRAA, however, in this case, is not since, apart from HTTP traffic model, it achieved values greater than 0.5 on the scale. On this note, therefore, the algorithm can be seen to be a fair resource allocation algorithm. From the literature, it also shows that the CRAA fairness index [114] is appropriate, in as much as its fairness index does not outperform those of MLWDF and EXP-Rule with respect to some of the services.

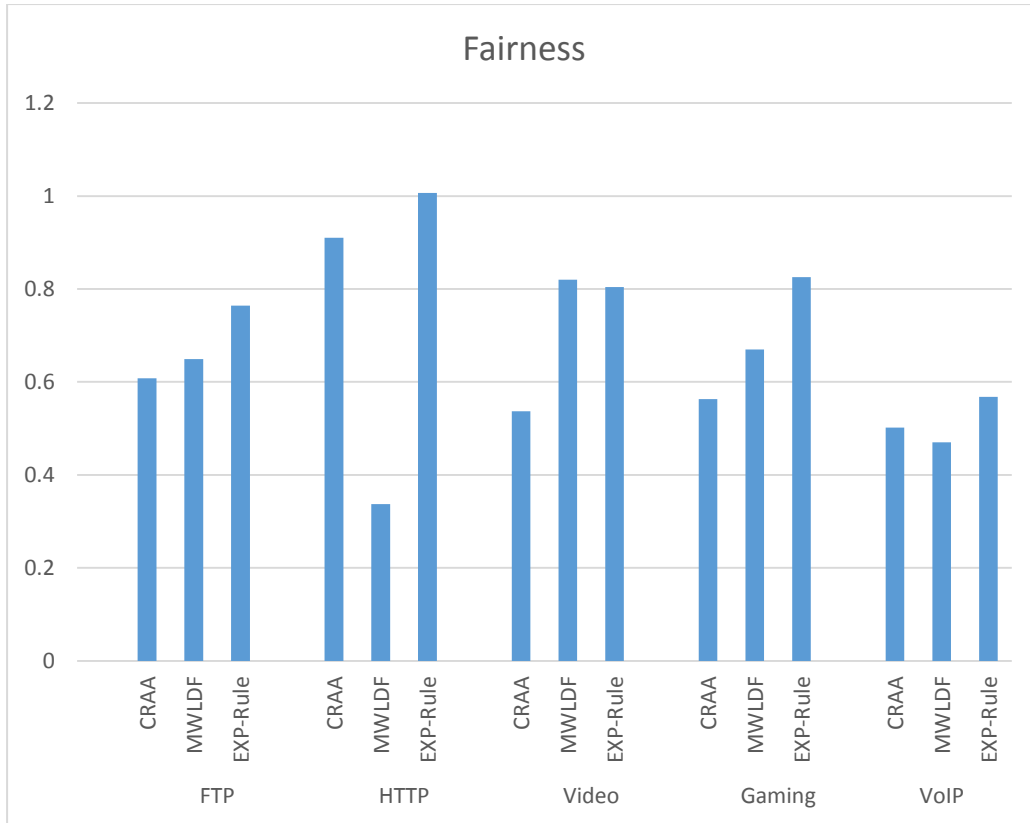


Figure 4. 16: Fairness Index Measurement

#### 4.5 CRAA and Relay Networks

As already described, the introduction of the RS in LTE-Advanced is primarily to increase coverage and user throughput, not particularly at the cell-edge but most importantly, wherever within the cell it is required. The RS of interest in this project remains the Type II RSs, which have control of their cell IDs and can terminate users; also making direct contacts with the EPC using the proxy link through the eNB. Theoretically and following other simulations in the literature, the use of RSs in the network greatly improves the amount of throughput that users receive in the network. This section discusses the use of CRAA in the relay network, and what impact it has brought into the system, comparing, as in the previous section, the MWLDF and EXP-Rule algorithms are used to evaluate the performance of the CRAA.

### 4.5.1 Throughput

Section 4.3.5.1 described the importance of throughput achieved by users, measures users' perception of the network's and its QoS provisioning. It forms the basis on which a network can be deemed efficient in providing ubiquitous services to its users. The Section 2.5.2 discussed the relay network and its importance in the entire LTE-Advanced network and its contribution with respect to enhancement in the entire network coverage and throughput. In this section, as would be seen in the subsequent results, the implementation of relay network shows a further enhancement in throughput for users, which will be beneficial to users at the cell edge of the network with the resultant effect of the CRAA. In the previous evaluation of the network, the network first used a combination of the traffic models then further unbundled to measure the performance using each traffic type at a time. In addition, in the relay network, these scenarios are recreated to test the performance of the CRAA. Figures 4.9 to 4.18 show the performance of the CRAA against the MLWDF and the EXP-Rule algorithms.

The result in Figures 4.17 and 4.18 show the network performance when multimedia application traffic moves through the network. As obtained in the previous scenarios where there are no RSs in the network, the CRAA again appear to indicate a significant increase in throughput for the network users. Here, the CRAA indicates the importance of coalition formation to enhance network performance for the user, by achieving 16.4Mbps of throughput for the user in a network running multimedia services. In this scenario, the CRAA's ability to achieve higher throughput than in the previous scenarios is due to the unique importance of using relays stations in the network. In Section 2.4, the importance of using RS has been emphasised as bringing the network closer to the users. In this scenario, while the network is closer to the user, the use of the CRAA coalition formation means that the users of the network would achieve even in higher throughput.

In Figure 4.17, there is a sharp increase in the amount of throughput being achieved by the users where, as in Figure 4.3 (Section 4.3), the CRAA obtained a throughput of 0.57Mbps at low SINR and a peak throughput of 7.99Mbps, it, however, achieved 1.95Mbps at low SINR and a peak throughput of 16.39Mbps which implies an increment of 70.77% at low SINR and 51.25% peak, respectively as shown in the CDF evaluation in Figure 4.18. The difference here is quite large compared to when the RS was not involved in the network. The deployment of RS in the network has further pushed the bounds of the achieved through thus improving the users' performance with respect to throughput by bringing the users closer to the network where, ordinarily, they would have a lower SINR; by deploying the RS, the users required SINR is further increased even when they stay farther away from the macro eNB.

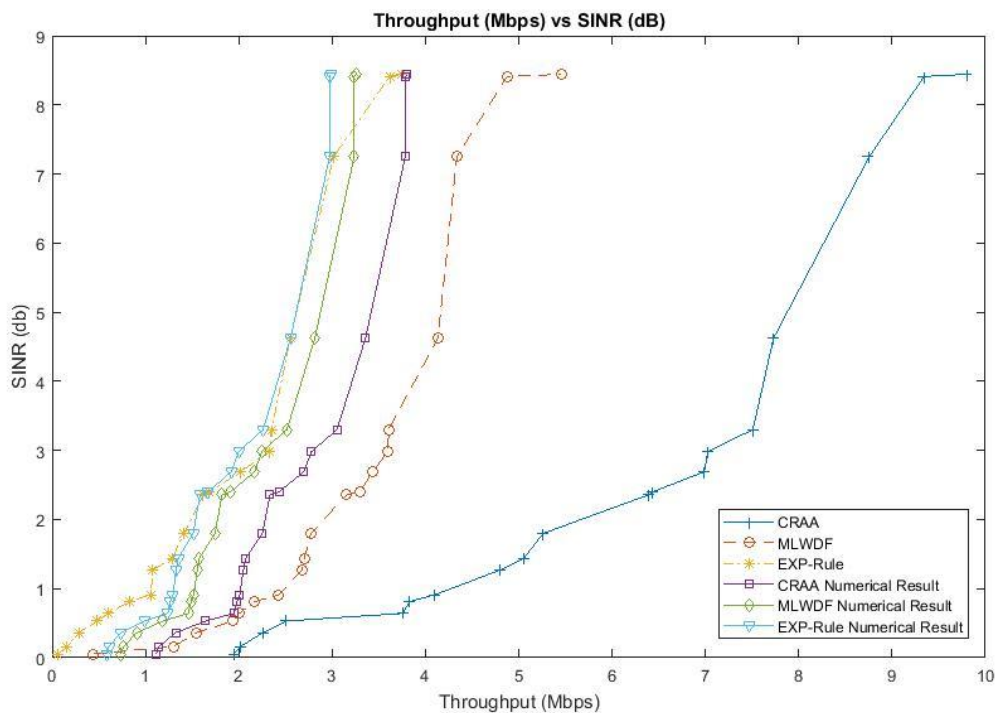


Figure 4. 17: Throughput (Mbps) vs. SINR in the Relay Network

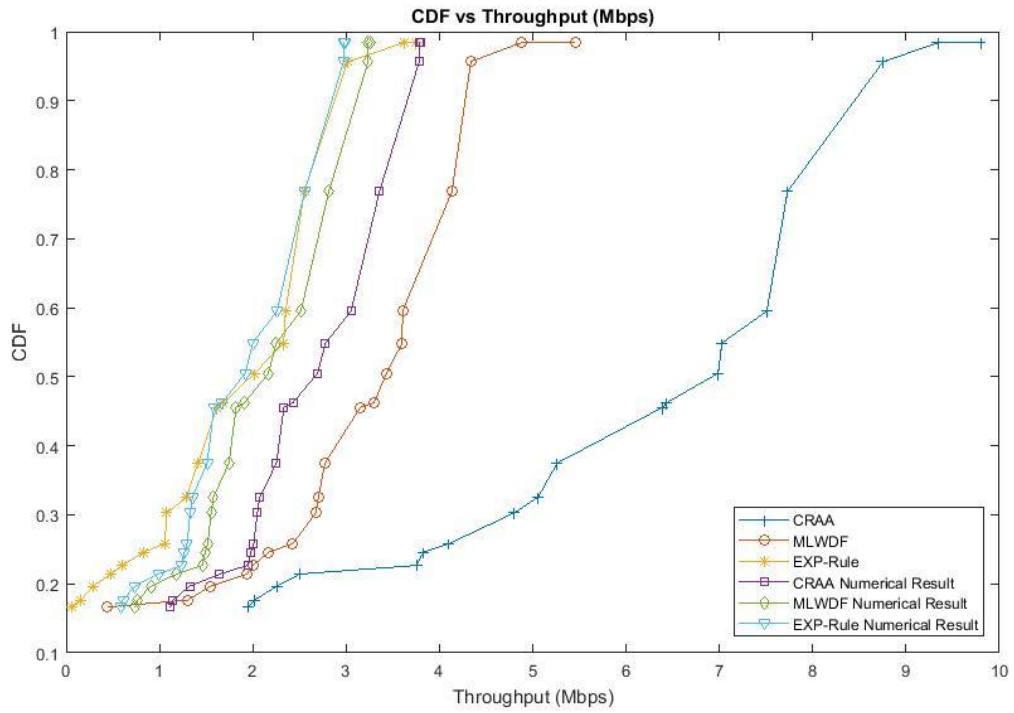


Figure 4. 18: CDF vs Throughput (Mbps) in the Relay Network

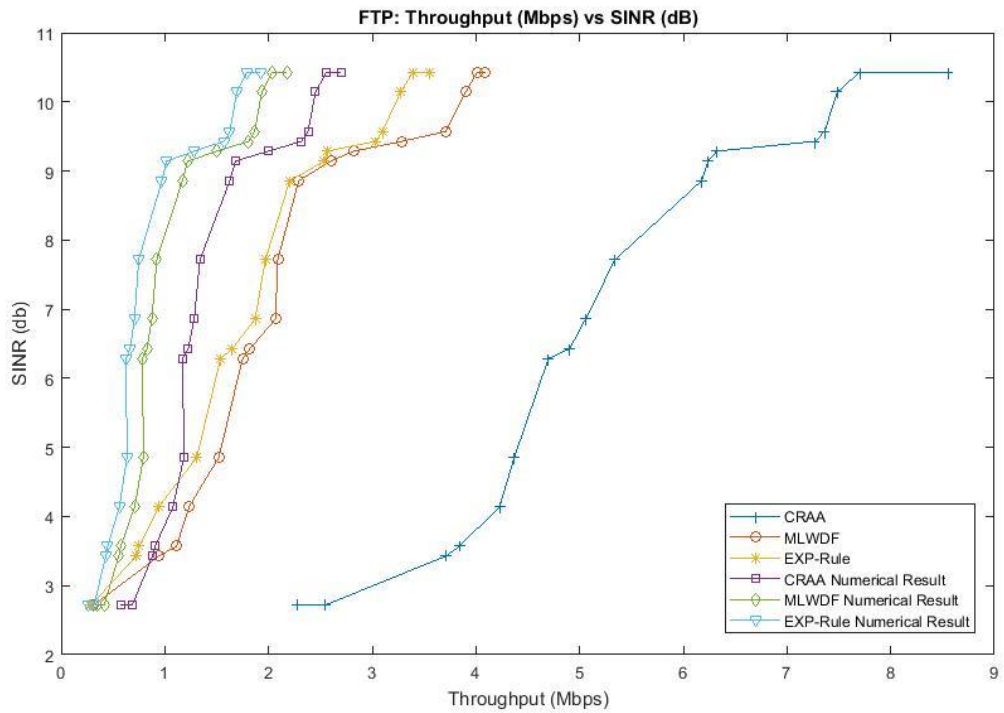


Figure 4. 19: Throughput (Mbps) vs. SINR in the Relay Network using FTP Traffic Model

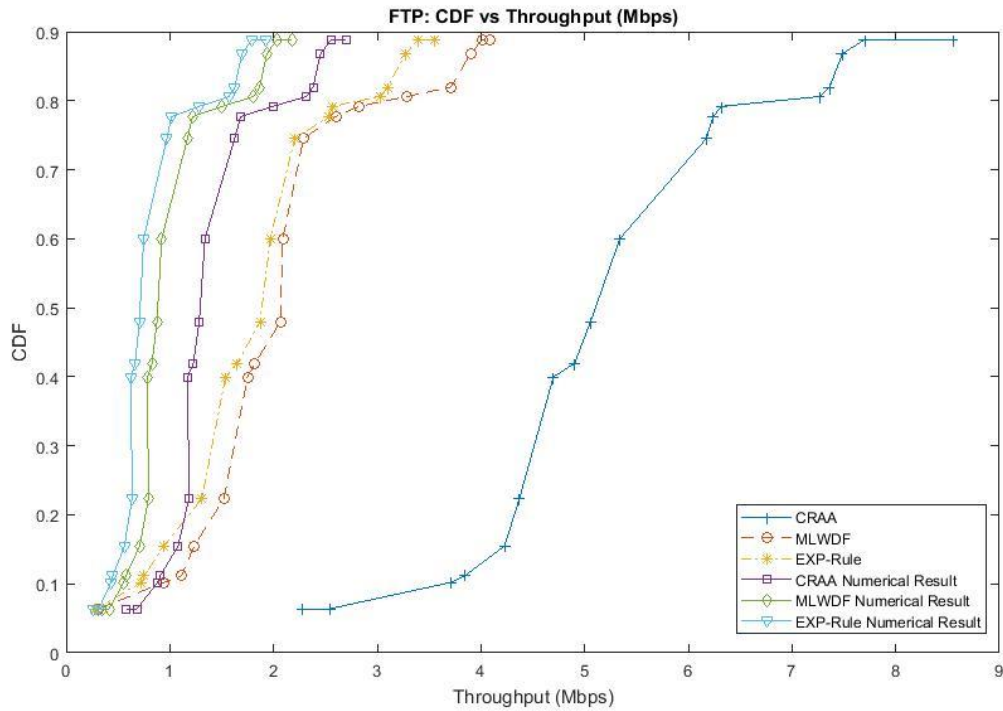


Figure 4. 20: CDF vs Throughput (Mbps) in the Relay Network using FTP Traffic Model

To further test the proposed CAA and its performance, the FTP traffic is feed through the network. The results are presented in Figures 4.19 and 4.20. The performance of the CAA as in Figures 4.19 is higher that than those of the EXP-Rule and MLWDF performance. The results show that at SINR value as low as 2.8dB, while the CAA is capable of delivering 2Mbps of FTP packet data, the EXP-Rule and MLWDF algorithms could only achieve 0.6Mbps. This implies that even if the RS is employed in the network to improve the performance of the cell-edge users or those users in a black hole if the aim is not completely achieved by the introduction of the RS, the use of CAA, therefore, promises to be a further boost in performance for such users. Results of the numerical evaluation and simulation show that the CAA significantly improved the throughput of the users.

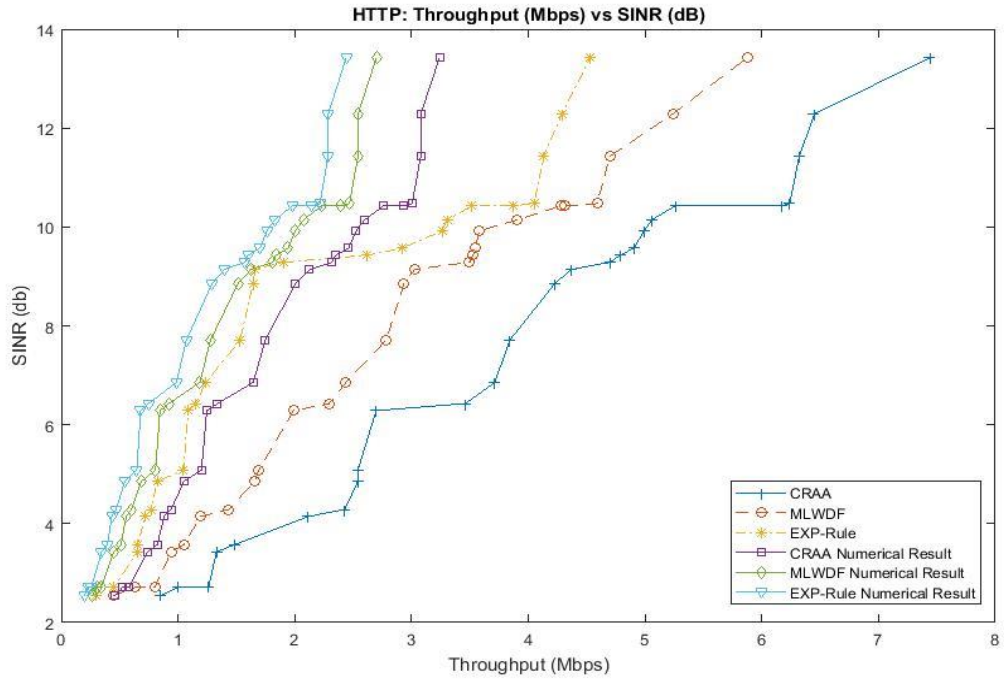


Figure 4. 21: Throughput (Mbps) vs. SINR in the Relay Network using HTTP Traffic Model

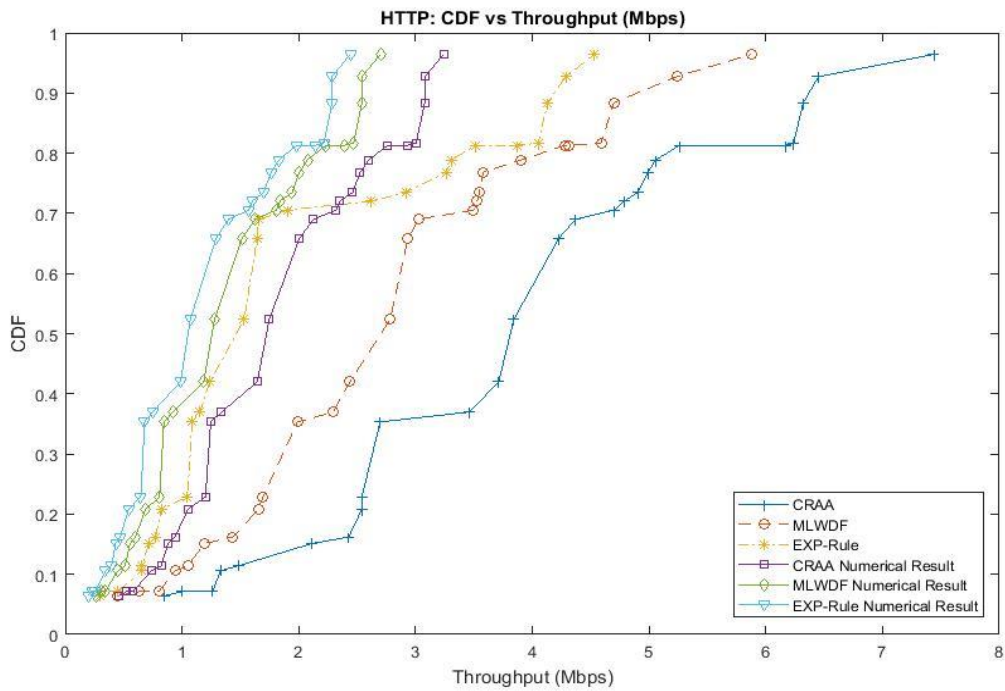


Figure 4. 22: Throughput (Mbps) vs. SINR in the Relay Network using HTTP Traffic Model

In Figure 4.21, the performance result for using the CRAA while it allocates radio resources in a relay network using HTTP traffic is presented. As with all the previous performance results, the proposed CRAA again exhibits a significant amount of improvement of throughput been delivered to network users. From the Figure 4.21, the CRAA achieved 0.8Mbps with low SINR figure. Then at high SINR figures, the CRAA can deliver 8.86Mbps throughput to the users. Compared with the results obtained without RSs in the network as Figure 4.3 (Section 4.3) shows, where the CRAA achieved 0.3Mbps at low SINR values and 7.8Mbps at high SINR value, it is evident that there is an improvement in the amount through for the network users. The users experienced enhanced throughput in the Relay network because the RS makes in strengthened the signal quality received by the users who are already in coalition to boost their throughput. This increment further justifies the contribution of the CRAA as an efficient resource allocation technique.

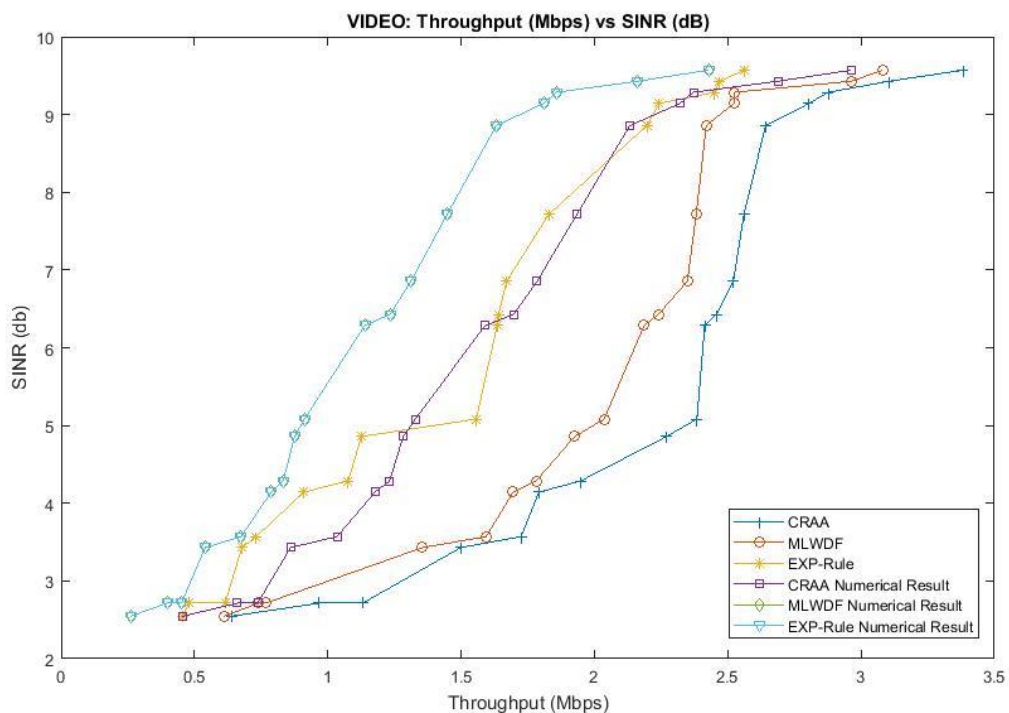


Figure 4. 23: CDF vs Throughput (Mbps) in the Relay Network using HTTP Traffic Model



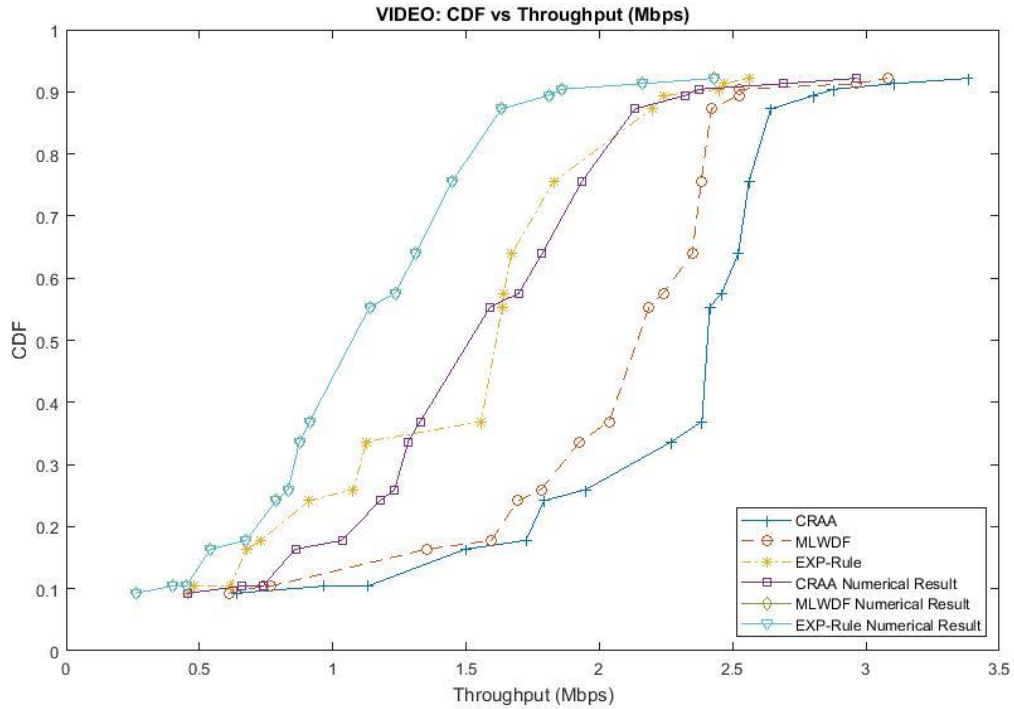


Figure 4. 24: Throughput (Mbps) vs. SINR in the Relay Network using Video Traffic Model

Figure 4.23 presents the performance of the CRAA while running video traffic through the relay network. The CRAA evidently shows higher performance in this scenario. Its performance as in the previous scenarios indicates that the CRAA is capable of enabling users of the network to achieve higher throughput at the cell edge to satisfy their on-the-go video service demands, therefore, indicating an improvement on the quality of experience that the users will attain while CRAA is in use in the network.

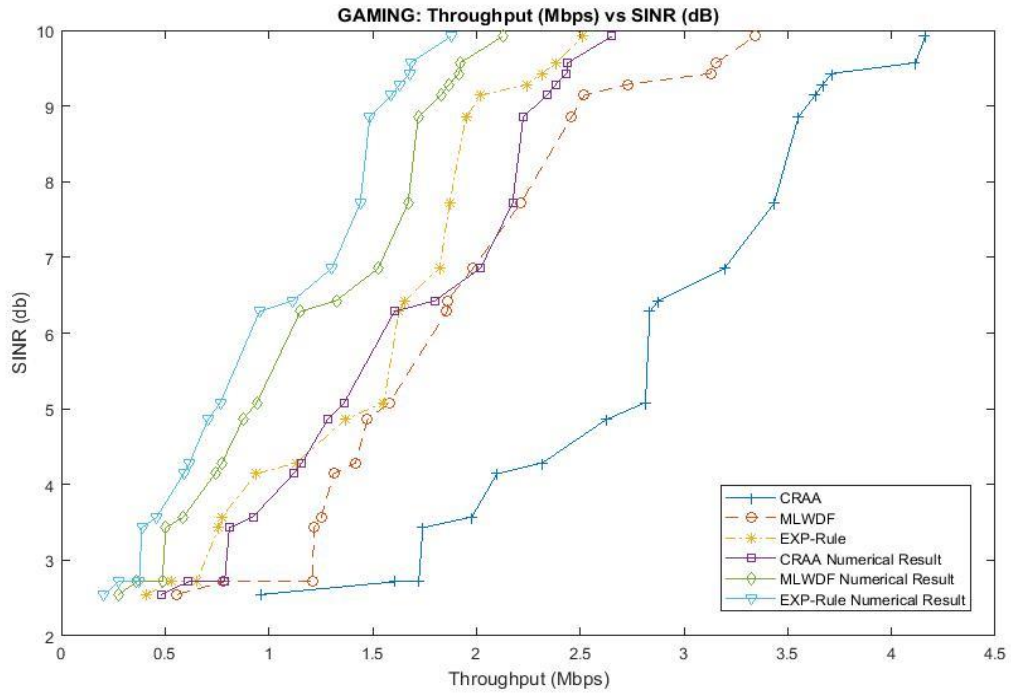


Figure 4. 25: Throughput (Mbps) vs SINR in the Relay Network using Gaming Traffic Model

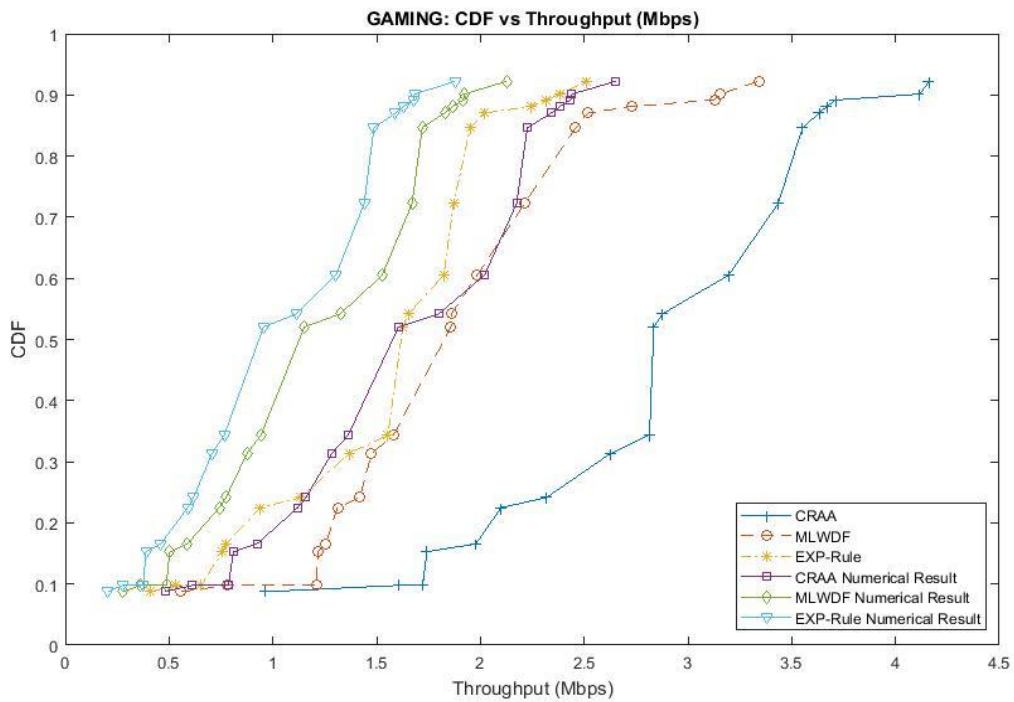


Figure 4. 26: CDF vs Throughput (Mbps) in the Relay Network using Gaming Traffic Model

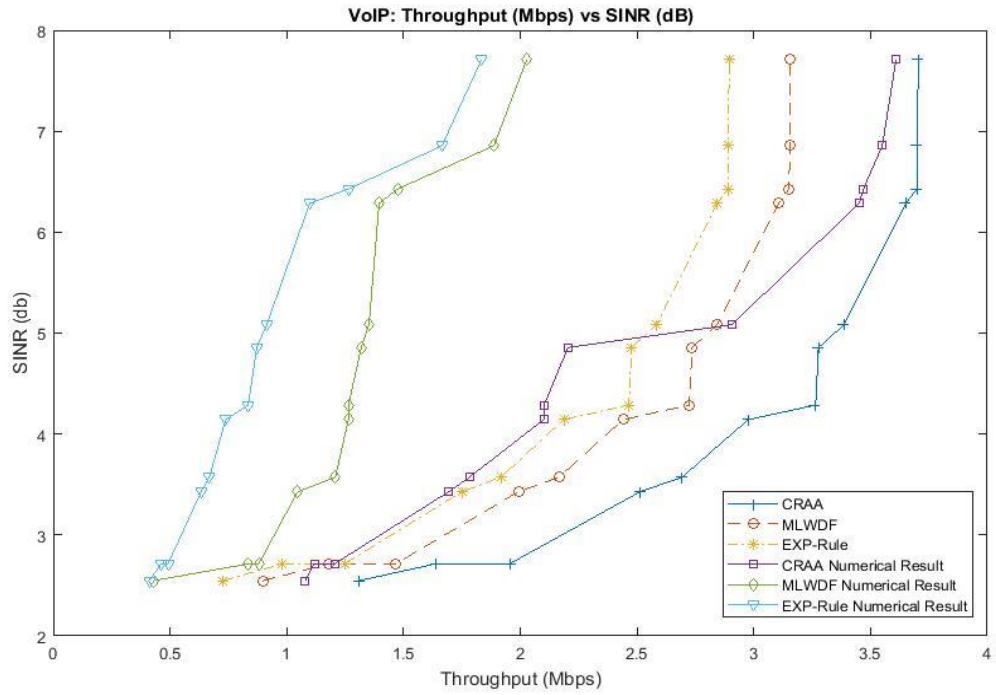


Figure 4. 27: Throughput (Mbps) vs. SINR in the Relay Network using VoIP Traffic Model

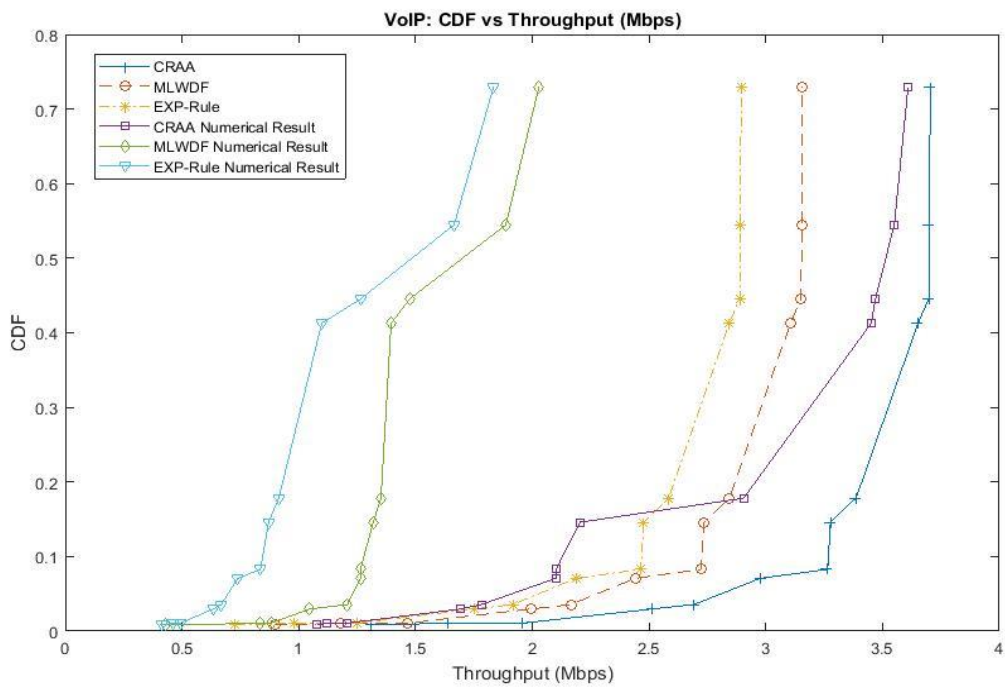


Figure 4. 28: CDF vs Throughput (Mbps) in the Relay Network using VoIP Traffic Model

From the results so, the proposed CRAA has proven to have contributed significantly to increasing the amount of throughput that users get to satisfy their traffic demands. This significant increment in the throughput is again evident in Figure 4.27 where the CRAA is the resource allocation algorithm while VoIP traffic is running through the relay network. As obtained in the previous results, in Figure 4.27, the CRAA achieved 13.1Mbps throughput for users of the network. The increment in Figure 4.27 is 37.31% higher than the throughput achieved by the MLWDF, which is the closest to the performance of the CRAA while running VoIP traffic through the network. The increment achieved by the CRAA in Figure 4.27 is of significant importance to cell-edge users who will be running free VoIP applications at low network signal strength. This scenario further shows that the coalition formation in the CRAA is capable of providing a significant level of quality of experience to the users through efficient management of radio resources in the network.

#### **4.5.2 Spectra Efficiency using Relays in the Network**

Spectral efficiency, as discussed in section 4.3.5.2 is used by the operator to determine the number of users the network may support and the possible bit rate it may offer such number. Seeing that the RS enables the operators to admit more users further or offload users from the macro onto the smaller cells controlled by the RS, it is therefore important that a relay supported network be able to offer more spectral efficiency than that in which there was none. This can be seen in the high spectral efficiency experienced in the relay network where the percentage difference is 77.99% under low SINR and 26.58% at peak SINR. This improvement is also a pointer to the performance of the RS deployment. The impact of the CRAA can further be seen as it performs far greater than the others, which are a result of its ability to share resources quite well amongst more users than the other algorithms. It can be noticed that the algorithm achieved

67.07% higher than the others at lower SINR and 22.51% when the SINR peaks. The results for these simulations are presented in Figure 4.17.

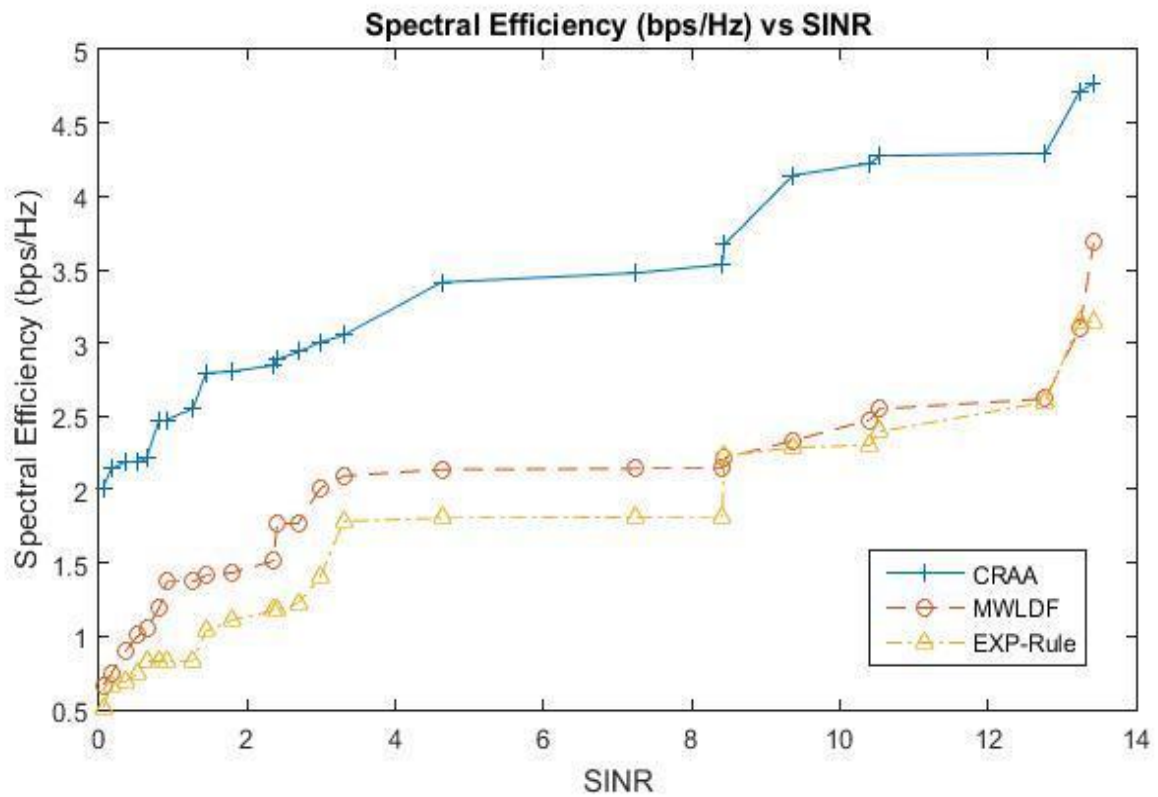


Figure 4. 29: Spectral Efficiency (bps/Hz) vs SINR in the Relay Network

#### 4.6 Conclusion

Following from reviews in the previous Chapter, in this Chapter, The Collaborative Resource Allocation Algorithm (CRAA) was designed in other to enable high throughput for network users. The algorithm was tested using numerical method and a series of system level simulation. The algorithm’s testing was performed by comparing with existing algorithms and using different traffic models that run through the network. Findings from the results, as presented in sections 4.3 and 4.4 shows that the CRAA achieve higher throughput for network users than the existing algorithms, which it was compared with.

## Chapter Five

### PLANNING AND OPTIMISATION OF CELLULAR NETWORKS

#### 5.0 Introduction

Planning of Cellular Networks continues to evolve in line with the standard specification to enhance network capacity and the data rate for users. Planning takes on the task of delivering a network with cells that can accommodate as many users as possible. This intuitively implies modelling the expected traffic demands envisaged for such networks and meeting the acceptable standard of QoS.

The complexity of the cellular network may lead to many unpredictable deployment outcomes, for example, errors in eNB/SeNB deployment, issues in cell location, network description database, and antennae positioning. eNB/SeNB positioning needs to be properly planned; putting their neighbours in perspective. With their neighbour in the picture of the design plan, we look at the users' Required SINR threshold, which triggers handover especially in a dense network where this threshold is expected to be of much quality when the intermediate SeNB boosts it. Planning in this research focuses on the selection of optimal site location allocations for small cell, SeNBs.

#### 5.1 Network Dimensioning

When planning a cellular radio or its core network, dimensioning is the first and basic step that the planning engineer takes. This phase determines, by estimation, the required number of network elements that may cover a given geographical area under consideration for network coverage. Intuitively, the output from this step is the number of eNBs that would support the volume of traffic (data/voice) generated in this area. Network planning in the overall sense is an

iterative process of design, synthesis and realisation. The process of dimensioning may follow simple steps of making and selection of: Traffic Analysis, Coverage Estimation, Capacity Evaluation, Cell ID, and Transport Evaluation. The end game of network planning is to deliver a cellular network that meets the users' requirements.

### 5.1.1 Traffic Analysis

In traffic analysis during planning, the engineers focus on the volume of traffic that the eNBs can handle during busy (peak periods) hours and quite times. This analysis is usually user data-centric which of course is the dominant data in the backhaul, then alongside other traffic such as signalling, transport overheads and new X2 interfaces [121]. Analysing these components of the backhaul gives engineers a picture of an eNB's expected backhaul traffic volume for the busy and quite time of the day, which, in turn, allows adequate provisioning to be made for the last mile transport network. Now, the backhaul traffic is brought into consideration first during radio network planning since QoS would depend completely on the end-to-end data delivery for every user, all of which pass through this section of the network. Traffic analysis results are passed onto the coverage planning and site location. Example configuration parameters for the dimensioning of traffic are as in Table 3.1.

<b>VoIP</b>	
<b>Model</b>	<b>Two State Activity Model</b>
silence length (sec)	3.33, neg. exp.
talk spurt length (sec)	5, neg. exp.
codec	GSM-EFR 12.2 Kbits/s
frame duration (msec)	20
call duration (sec)	114.2

<b>Video Streaming</b>	
frame rate (frame/sec)	10, const.
incoming frame size (bytes)	800, neg. exp.
outgoing frame size (bytes)	10, neg. exp.
<b>File Download</b>	
inter-request time (sec)	300, neg. exp.
file size (bytes)	2097512, lognormal
<b>Online Gaming</b>	
distribution	Fisher-Tippett
uplink params	a=45, bytes, b=5.7
downlink params	a=120, bytes, b=36
<b>Video Calls</b>	
encoder	H.263
mean frame size (bytes)	457
mean frame rate (fps)	15
incoming and outgoing traffic frame size (bytes)	gamma distribution ( $\rho, \mu$ ), $\rho = 8.50609$ , $\mu = 53.76463$
incoming and outgoing traffic frame inter-arrival time (sec)	constant (0.067)
<b>HTTP</b>	
main object size (bytes)	10719, lognormal
embedded object size (bytes)	7758, lognormal
number of embedded objects	5.64, Pareto

Table 5. 1: Link utilisation configuration parameters [122]



### **5.1.2 Coverage Estimation**

Coverage estimation determines the maximum range of signal propagation. At this point, it is necessary to perform link budget for the cell to determine the maximum allowed distance of the UE from the eNB, that is, determination of the maximum allowable path loss (MAPL) between the eNB and UE, both on the DL and UL [123]. Therefore, one of the critical deliverables of this stage is the cell radius. To perform this process, different propagation models are readily available to planners. The choice of propagation model needs to be carefully made since the environment in most cases dictates what model can be adopted for the scenario.

Coverage estimation depends on four primary parameters: SINR, Pathloss (L), cell radius (d) and coverage area ( $A_{\text{coverage}}$ ). The coverage area is the percentage area within a cell that receives power above a given minimum. The coverage is a combination of cell sites where the eNB/SeNB is installed. The design of the cell area is such that it provides coverage with the expectation of future optimisation purposes; this implies that the cell area aims to provide coverage to an area with the expectation of a possible increase in population in the nearest future [122].

### **5.1.3 Capacity Evaluation**

Capacity evaluation is critical in network dimensioning as it enables the designers and planning engineers to satisfy, especially the cell edge user with their throughput requirements. This stage is greatly affected by the system bandwidth. In Chapter 2, we already stated that LTE-Advanced uses a range of bandwidths (1.5, 3, 5, 10, 15 and 20MHz) all of which determines the number of RBs available for transmission in the cell. The number of RBs affects the cell capacity in direct proportion. Due to the high demand from users, it is also vital to factor both the UL and DL rate requirement per users. This gives a realistic picture of what is happening and what is expected. Literally speaking, it is important for designers and planning engineers to be empathetic to users at this stage to properly manage users' behaviours and patterns. However, unlike the LTE-

Advanced, the case for 5G is different since the considered bandwidth is in the range of 800MHz. This study however based the estimation on the OFDMA, which implies that the radio resource assumptions are the same while there is the change in the allocated bandwidth for the scenarios discussed in this chapter and their effects on the results and analysis.

## **5.2 Site location-allocation using Memetic-Bee Swarm Site Location Allocation Algorithm (MBSSLAA)**

This section presents the MBSSLAA algorithm for locating small cells in the 5G network. The MBSSLAA locates the sites in such a way such that each small cell supports the enormous traffic demand that is envisaged in the future, as the 5G will be supporting the IoT. The traffic demands are assumed to follow the models of [124, 125]. Sites, in mobile networks, can be interchangeably used with the position of the eNB/SeNB or the eNB/SeNB itself. A site may support more than one cell, particularly when we consider sectorization, which over time has become a good networking practice as contained in many literatures. Note that a small cell, in this case, is only a single cell and does not support antennae sectorization. The location of a site plays high importance in the network as it needs to satisfy users' specific requirements and operators need to deploy a small amount of locations possible to achieve quality coverage due to the cost and maintenance of available infrastructures and amortisation costs. Also, the role of environmental legislation is a factor that must be considered during network deployment [126] to avoid a high number of its deployments while satisfying capacity requirements for the coverage region. Site selection and location are carefully carried out in order to meet both operator and users' requirements. This stage considers cost, capacity and coverage. This site is required to be located such that meets the defined constraints on these three factors. These constraints are defined such that they meet both user requirements and the operators' KPIs.

To achieve this, this study employs the facility location allocation technique [127] to deploy an ultra-dense network of the small cell, which is a case for coverages improvement and support for high data rates provisioning in 5G networks for it to efficiently support IoT and other accompanying connections in the future 5G networks. Location-Allocation is used in the field of Management and Operations Research to locate a set of new facilities with the objective of reducing cost and meeting customers' demands optimally [128]. In this form of location-allocation problem, the aim is to locate new facilities (small cells' SeNBs) such that their cost is minimised. Therefore, an optimal number of these facilities are to be placed in areas of interest (places where there is need to support high volume data traffic due to the population of users) to satisfy the users' demands using three primary parameters of consideration: location, facilities and customers (users).

The equations (3.1) to (3.3) model the site location problem for SeNBs in the 5G Networks and beyond to improve coverage through network densification by deploying a minimal number of SeNBs. The model is more importantly concerned with cost minimisation while providing high capacity and large coverage thus increasing the network coverage to cover more users at greater quality of services by keeping the number of the facilities as small as possible. The model consists of variables such as candidate site, the number of SeNB, customers' demand and the capacity of the cell site. The model takes the following assumption that:

- One facility supplies each user's demand, ignoring the opening cost of new facility
- Facilities are uncapacitated
- Parameters are deterministic, supplying all demands

$n$ : Number of users in the area

$r_{ij}$ : Users' demand [124, 125],  $\forall i \neq j, j = 1, 2, \dots, N$

$a_{ij}$ : Location of the users' demands,  $j = 1, 2, \dots, N$

$\varphi$ : Total capacity required to satisfy the number of users in this coverage region.

$m$ : Number of facilities (SeNBs)

$\bar{x}_i$  Candidate site for new facilities  $i = 1, 2, \dots, N$

$w_{ij}$ : Number of data packets delivered to user at the candidate site

$d_{ij} = d(\bar{x}_{ij}, a_{ji})$ : Distance between users' demand point the facility at candidate location  $i, j$

$\bar{x}_{ij} = \begin{cases} 1 & \text{if } i \text{ is allocated } \bar{x}_i \text{ and serves } j \\ 0 & \text{otherwise} \end{cases}$  is a decision variable for location allocation

$Z_{ij} = \begin{cases} 1 & \text{if user is served by facility in the candidate site } i, j \\ 0 & \text{otherwise} \end{cases}$

$A_{coverage}$ : Area covered by a facility

With these parameters defined, the objective function is given as:

$$Max A_{coverage} = \sum_{i=1}^N \sum_{j=1}^N w_{ij} \bar{x}_{ij} d(\bar{x}_{ij}, a_j) \quad (5.1)$$

s. t

$$\sum_{i=1}^N w_{ij} = r_{ij}, j = 1, 2, \dots, N \quad (5.2)$$

$$\varphi \geq \sum_{i=1}^N w_{ij} \quad (5.3)$$

$$w_{ij} \geq 0, j = 1, 2, \dots, N, i = 1, 2, \dots, N \quad (5.4)$$

$$d(\bar{x}_{ij}, a_{ij}) < \bar{x}_{ij} \quad (5.5)$$

The solution to the problem of network coverage by the ultra-dense network of small cells can be arrived by solving the equations (5.1) to (5.4). The equation (5.1) ensures that the right numbers of small cells are deployed to this area to keep cost very low. In addition, the equation (5.1) uses

the variable  $\bar{x}_{ij}$  to indicate that the small cell facility is allocated to this candidate location. The equation (5.2) ensures that this small cell covers all the users within the radius of this candidate site and that their demands can be satisfied. In equation (5.3), the constraint is defined to ensure that the demands of the users in this location do not surpass the capacity of the facility to be placed at this candidate location. The traffic demand from users in equation (5.3) follows the model of the work done by [124, 125]. The constraint of equation (5.4) is designed to ensure that a small cell would not be placed in an area with zero demand, as this would amount to a waste of resource and a further addition of unnecessary cost. The equation (5.5), in addition, also ensures that there is minimum possibility of handover by controlling the speed of the network users. It is important to note that in this model there is no capacity constraint on the facilities. Two different solution techniques are applied to this problem in order to find the optimal solutions. These are: the Exact Equation and Metaheuristic Methods for which the MBSSLAA is used to in section 5.2.4.

### 5.2.1 Using Exact Equation to Cover an Area

By using the exact equation to address the location allocation problem for small cell coverage in ultra-dense network of small cells, the decision variable  $Z_{ij}$  is used as a constraint in the equation (5.6) to determine that this candidate site would serve users and their demands,  $W_{ij}$  from this location.

$$A_{coverage} = \sum_{i=1}^N \sum_{j=1}^N Z_{ij} W_{ij} d_{ij} \quad (5.6)$$

The optimal location,  $(x_i, y_j)$  on a two-dimensional plane that optimises  $A_{coverage}$ , is achieved by differentiating the equation (5.6) w.r.t  $x_i$  and  $y_j$ . The resulting equation is further solved by setting the resulting derivatives to zero as described in the equations (5.7) and (5.8).

$$\frac{\partial A_{coverage}}{\partial X_i} = \sum_{i=1}^N \sum_{j=1}^N Z_{ij} W_{ij} \left[ \frac{\partial d_{ij}}{\partial X_{x_i}} \right] = 0, i = 1, \dots, N \quad (5.7)$$

$$\frac{\partial A_{coverage}}{\partial Y_j} = \sum_{i=1}^N \sum_{j=1}^N Z_{ij} W_{ij} \left[ \frac{\partial d_{ij}}{\partial Y_{x_j}} \right] = 0, j = 1, \dots, N \quad (5.8)$$

Solving the equations (5.7) and (5.8) yields  $2m$  values of  $(x_i, y_j)$ . To compute the  $m$  sources and  $n$  destinations, which satisfies the constraints, there are  $S(n, m)$  possible assignments of  $n$  destinations to  $m$  sources as described by the combinatorial equation in Equation (5.9):

$$S(n, m) = \frac{1}{m!} \sum_{k=0}^m \binom{m}{k} (-1)^k (m-k)^m \quad (5.9)$$

Equation (5.9) implies that equation (5.7) and equation (5.8) have to be solved  $S(n, m)$  times to find which allocation of source-destination is an absolute best location for the candidate site as shown in system of equation presented in equations (5.10) to (5.16).

Under the assumption that achieved throughput is directly proportional to distance of the user from its serving SeNB, i.e., considering that the signal strength, which determines the achievable user throughput depends on the users' distance from the serving SeNB, the objective function then becomes:

$$A_{coverage} = \sum_{i=1}^N \sum_{j=1}^N Z_{ij} W_{ij} [(X_{x_i} - X_{a_{ij}})^2 + (Y_{x_i} - Y_{a_{ij}})^2]^{1/2} \quad (5.10)$$

Differentiating equation (5.10) further yields two components in the equations (5.11) and (5.12):

$$\sum_{i=1}^N \sum_{j=1}^N \left\{ \frac{Z_{ij} W_{ij} (X_{x_i} - X_{a_{ij}})}{[(X_{x_i} - X_{a_{ij}})^2 + (Y_{x_i} - Y_{a_{ij}})^2]^{3/2}} \right\} = 0; i = 1, 2, \dots, N \quad (5.11)$$

and

$$\sum_{i=1}^N \sum_{j=1}^N \left\{ \frac{Z_{ij} W_{ij} (Y_{x_i} - Y_{a_{ij}})}{[(X_{x_i} - X_{a_{ij}})^2 + (Y_{x_i} - Y_{a_{ij}})^2]^{\frac{1}{2}}} \right\} = 0; i = 1, 2, \dots, N \quad (5.12)$$

To locate the optimal location from where the SeNB would serve the traffic demands, the Equations (5.11) and (5.12) are iteratively solved using Equations (5.13) to (5.16). In the Equations (5.13) and (5.14), the superscripts of  $X$  and  $Y$  are the iteration parameters.

$$X_{x_i}^{k+1} = \sum_i^N \sum_{j=1}^N \left[ \frac{\frac{Z_{ij} W_{ij} X_{a_{ij}}}{D_{ij}^k}}{\sum_{j=1}^n \left( \frac{Z_{ij} W_{ij}}{D_{ij}^k} \right)} \right], \quad (5.13)$$

$$Y_{y_j}^{k+1} = \sum_{i=1}^N \sum_{j=1}^N \left[ \frac{\frac{Z_{ij} W_{ij} Y_{a_j}}{D_{ij}^k}}{\sum_{j=1}^n \left( \frac{Z_{ij} W_{ij}}{D_{ij}^k} \right)} \right], \quad (5.14)$$

The points generated by the equations (5.13) and (5.14) represent the optimal coordinates of the candidate site that satisfies users' demand from the location. However, there is always the need for a convenient starting coordinate in the area of interest to always yield convergence in the algorithm. This is achieved through weighted coordinates as expressed in the Equations (5.15) and (5.16):

$$X_{x_i}^0 = \sum_{i=1}^N \sum_{j=1}^N \left[ \frac{Z_{ij} W_{ij} X_{a_{ij}}}{\sum_{j=1}^n Z_{ij}} \right]; i = 1, \dots, m \quad (5.15)$$

$$Y_{y_j}^0 = \sum_{i=1}^N \sum_{j=1}^N \left[ \frac{Z_{ij} W_{ij} Y_{a_{ij}}}{\sum_{j=1}^n Z_{ij}} \right]; i = 1, \dots, m \quad (5.16)$$

### 5.2.2 Metaheuristics Methods

From a fixed point in the area of interest, generate a  $p$  subset of fixed points that would define the coordinates of the location where a SeNB will be located. Supposing that these are the points generated by using the exact equations (5.15) and (5.16) represent these points to be generated by the metaheuristic algorithms. To find the optimal location from the  $p$  subset of fixed point; the algorithms heuristically reallocate each fixed point to the nearest facility. After all points are reallocated, the equation (i) is used to improve the locations by defining two given points in a  $k$  ( $k$  in this instance is considered to be a 2-dimensional space) dimensional space, say,  $q_i = (q_1, \dots, q_k)$  and  $s_j' = (s'_1, \dots, s'_k)$  where the distance,  $l_p$  between  $q$  and  $s'$  is given by:

$$l_p(q_i, s_j') = \|q_i - s_j'\|_p = \left[ \sum_{i=1}^k |q_i - s'_j|^p \right]^{1/p} \quad (i)$$

From equation (i), to assign the SeNB at a candidate site, the location-allocation problem with  $l_p$  in two dimensions is therefore described as:

$$\text{Max} \sum_{i=1}^N \sum_{j=1}^N w_{ij} \|\bar{x}_{ij} - a_{ij}\|_p \quad (5.17)$$

s. t

$$\sum_{i=1}^m w_{ij} = r_j; j = 1, \dots, m \quad (5.18)$$

Conjecture that  $w_{ij}$  is constant, looking back at the equation (5.17), the dual of the equation for  $p > 1$  is defined as:

$$\text{Max} g(u) = \sum_{i=1}^N \sum_{j=1}^N a_j U'_{ij} \quad (5.19)$$



s. t

$$\sum_{j=1}^N U'_{ij} = 0; i = 1, \dots, m \quad (5.20)$$

$$\|U'_{ij}\| \leq \bar{x}_{ij}; i = 1, \dots, m; j = 1, \dots, n \quad (5.20)$$

$$q_i = \frac{p}{p-1}, U'_{ij} = (U'_{ij2} > U'_{ij1}) \quad (5.21)$$

$U'_{ij}$  = Transpose of  $s'_j$ .  $U'_{ij}$  are the dual variables that satisfy the position allocation which minimises the OPEX and CAPEX of the operator as well as improving coverage and enhancing the users' throughput. Decades of research have produced algorithms to solve optimization problems using heuristic. Heuristic algorithms are mostly for solving different problem varying from economics to telecommunications and engineering researches. This study applies two different algorithms, Memetic and Bee Swarm leading up to the development of MBSSLAA to achieve an efficient SeNBs (small cells) location allocation that provide efficient services to users and their various demands in a densely populated area.

### 5.2.3 Memetic Algorithm

Memetic algorithm (MA) is a modification of the genetic algorithm that uses the local searches initially engineered to solve the travelling salesman problem [129]; the travelling salesman problem, for emphasis is considered as a classic testbed for solving combinatorial optimisation problems so as to find their optimum solution [129]. This implies therefore that the algorithm is based on the principle of natural selection that balances between parents and children's genes to help evolve more efficient and suitable solutions that solve an existing problem of interest. The MA algorithm can effectively be applied in a variety of problems which include but not

restricted to: discrete, continuous, large scale, constrained and multi-objective optimisation problems and also in problems of uncertainties [130].

The algorithm works through a population of solutions from which it selects the best of the solution that could survive well enough beyond its parents as a successive storm. By going through the feasible solutions, the algorithm evolves the best option through the knowledge of the parents and the problem itself to evolve a child that works better than the parent solution. From the extant literature, MA has a widespread application as a combinatorial optimisation technique in different fields, especially; it is also proven as an effective tool for heuristic optimisation.

Memetic Algorithm first begins by considering an initial population of  $N$  candidate locations randomly distributed over the region of interest. Another population,  $pop_{child}$  that is the same size of  $pop$  is further generated by using the genetic operations: selection, crossover, and mutation.  $pop$  and  $pop_{child}$  are then merged into a new population,  $pop_1$ . Each candidate site in  $pop_1$  is evaluated by reverse relation with  $pop_{child}$  and  $pop$ . A new and more resilient population  $pop_{child2}$  then emerges as a result of the evaluation.  $pop_{child2}$  is formed by selecting the most efficient sites from the candidate locations in  $pop_{child}$ . using  $pop_{child2}$ , through an iterative process, a further generation of locations are realised and this is repeated until the criterion for stopping is reached.

Over the course of implementation, the algorithm maintains a population of feasible solutions from which it continually evolves the best-fit solutions to the problem. Each candidate site in the population represents a feasible solution to the modelled problem but need to be carefully selected to ensure that the best of the solutions that meet the defined constraints is always selected such that it meets the network requirements and KPI definition. The iterative process of

the algorithm ensures that every individual member of the population is constantly updated with the hope that a better solution will be formed using the components already mentioned. The pseudo-code listing for MA is presented in list 5.1.

List 5.1: Pseudocode of the MA

```

Input: problem Data:  $q_i, s_j' \in p \subset N$ 

Output: Optimized Solution  $x_{best}$ 

Initialization();

Population  $N \leftarrow \text{createStartSolutions}();$ 

Sort( $N$  by fitness);

 $\bar{x}_{ij} \leftarrow \bar{x}_i$  from  $N$ ;

For all iterations

     $\bar{x}_{ij} \leftarrow \text{select}(N);$ 

    For all  $\bar{x}_i$  in  $N$  except elite solutions

        With probability  $p_{crossover}$ 

            Do  $\bar{x}_{ij} \leftarrow \text{recombined}(q_i, s_i' \in p);$ 

            Else  $\bar{x}_i \leftarrow \bar{x}_{ij} \in p;$ 

        End-With

     $Pop \leftarrow \bar{x}_{ij};$ 

End-For

For all  $\bar{x}_i$  in  $p$ 

     $\bar{x}_{ij} \leftarrow \text{mutate}(\bar{x}_i);$ 

    With probability  $p_{new}$  Do  $\bar{x}_i \leftarrow \text{createStartSolution}();$ 

    With probability  $p_{lsearch}$  Do  $\bar{x}_i \leftarrow \text{localSearch}(x);$ 

```

$p \leftarrow \bar{x}_i;$

***End-For***

***Sort*** ( $p$  by fitness);

***If***  $\bar{x}_i \in Pop > \bar{x}_{ij}$

***Then***  $\bar{x}_{ij} \leftarrow \bar{x}_i;$

***End-For***

#### 5.2.4 Bee-Swarm Algorithm

Unlike the MA, which is based on genetic evolution, the Bee Swarm Algorithm (BSA) is a population based metaheuristic that employs the intelligence and behaviour of the honeybees to find its source of food. Bee swarm algorithm utilises both local and global search capacity and uses these to exploit and explore solution strategies, just the same way the natural bees use their foraging behaviour to explore and search for promising food locations randomly. In the instance of an algorithm, this technique is used to solve combinatorial optimisation problems [131]. The swarm of bees contain different types of patterns that adjust the trajectories of its constituent members such as the scouts, onlookers, foragers, recruits, dancers, etc. Each member type performs different and specific functions, representative of the kind of information it carries about the food sources. The scouts fly around looking for potential sources of food; the number is adaptively adjusted to fit the situation the swarm faces. The onlooker processes the information from the scouts and passes this information to the dancers who then pass the information to the foragers that move according to the information from the dancers.

In the Bee Swarm Algorithm (BSA), the position of a food source represents a possible solution to the optimisation problem, and the nectar amount of food source corresponds to the quality

(fitness) of the associated solution. The number of the employed bees or the onlooker bees is equal to number of solutions in the population. At the first step, the BSA generates a randomly distributed initial population,  $N$  solutions (food source positions), where  $N$  denotes the size of population. After initialization, the population of the positions (solutions) is subjected to a repeated cycles,  $C = 1, 2, \dots, C_{max}$ , of the search processes of the employed bees, the onlooker bees and the scout bees. An employed or onlooker bee then probabilistically produces a modification on the position (solution) in its memory about this new source and tests the fitness of the new source. If the nectar amount in the new source is larger than the previous one, the bee then forgets the old source and adopts the new source. The onlooker bees then evaluate the information acquired from the employed bees and select the source with a probability related to the source's nectar amount.

The onlooker bee chooses its food source depending on a probability value,  $p_i$  associated with the food source.  $p_i$  is given as:

$$p_i = \frac{fit_i}{\sum_{n=1}^{SN} fit_n} \quad (a)$$

Where  $fit_i$  is the fitness value of the solution  $i$  by its employed bee.  $i$  is proportional to the nectar amount of food source in the position  $i$  and  $N$  is the number of food sources which is equal to the number of employed bee ( $BN$ ). The bees use this method to exchange information with the onlookers.

To produce a candidate food position from the old one, the BS uses:

$$v_{ij} = \bar{x}_{ij} + \phi_{ij}(\bar{x}_{ij} - \bar{x}_{kj}) \quad (b)$$

The variables  $k \in \{1, 2, \dots, BN\}$  and  $j \in \{1, 2, \dots, D\}$  are randomly selected indexes. The variable  $k \neq i$  is a random number. The variable  $\phi_{ij}$  is a random number between  $[-1, 1]$ .  $\phi_{ij}$  is a control variable for the production of neighbouring food sources around  $x_{ij}$  whose modification ensures the comparison of food sources. From equation (b), when the value of  $(\bar{x}_{ij} - \bar{x}_{kj})$  reduces, the change in the position,  $\bar{x}_{ij}$  also reduces thus indicating a close to optimum solution. When a parameter of the algorithm exceeds a predefined limit, it is further set to an acceptable value. By doing this, a food source whose nectar has been abandoned is randomly replaced with a new source. However, when the food source can no longer be replaced (i.e., improved anymore), then it means the position does not meet the requirement and it is completely discarded. The pseudocode for the BSA is presented in List 5.2.

List 3.2: Pseudocode of the BSA.

**Initialise**  $q_i, s_j' \in p \subset N$

Randomly generate  $0.5 * N$

Evaluate equation (5.20)

**Set** *BeeFlyCycle* = 1

**Initiate** employed bee

**For**  $i = 1$  to  $0.5 * N$

    Generate a candidate site,  $\bar{x}_{ij}$

    Evaluate  $\bar{x}_{ij}$

**If**  $\bar{x}_{ij} < \bar{x}_i$

$\bar{x}_i = \bar{x}_{ij}$

**Else**

$Trial_i = Trial_i + 1$

**End For**

Evaluate  $p_i$  ( $t = 0, i = 1$ )

**Initiate onlooker bee**

**While**  $t \leq 0.5 * N$  **Do**

**If**  $rand(0,1) < p_i$

Generate candidate solution  $\bar{x}_{ij}$

Evaluate  $\bar{x}_{ij}$

**If**  $\bar{x}_{ij} \leq \bar{x}_i$

$\bar{x}_i = \bar{x}_{ij}$

**Else**

$Trial_i = Trial_i + 1$

$t = t + 1$

**Endif**

$i = i + 1$

**if**  $i = 0.5 * N$

$i = 1$

**Endwhile**

**Initiate scout bee**

**If**  $\max(Trial_i) > d(\bar{x}_{ij}, a_j) < \bar{x}_i$

Replace  $\bar{x}_i$  with the new solution

$BeeFlyCycle = BeeFlyCycle + 1$

**If**  $BeeFlyCycle \geq$  equation (5.20)

*End search*

*End*

### **5.2.5 Memetic Bee Swarm Site Location-Allocation Algorithm (MBSSLAA)**

This section presents the workings of the proposed MBSSLAA. The MA and BSA motivated the development of the MBSSLAA for location algorithm including the flowchart description and the pseudocodes describing how the SeNB locations are sited. The essence of the algorithm is to select the optimal location for a SeNB in an ultra-dense network of small cells for 5G and beyond network to enhance the coverage and area capacity of the network, which, from the previous discussion is a significant implication of SeNB deployments.

It is worthy of note that several works through the literature have employed the combination of more than one metaheuristic methods to find the solutions to NP-Hard combinatorial problems like site location in cellular access and distribution networks. As [129] puts it, when individual metaheuristic methods are applied, they tend to give good results. However, top quality solutions seem to require the combined efforts of several methods, in particular for a problem with a large solution space from which optimum solutions have to be selected [129] such as in the allocation of candidate sites to serve a large group of users as obtained in the 5G networks' small cells.

The algorithm contains the memes, which are the basic block of genetic information of the MA and three types of bees: experienced foragers, onlookers and scout bees respectively. The idea is to allow the MA to evolve an optimal solution from the candidate sites in the coverage area. This population of candidate sites is further optimised through the rational behaviour of the BSA. To find the optimal location from among the candidate sites evolved by the MA, the BSA replaces the local search that is instead made in the MA thus renderings a more optimal degree of



efficiency to the optimal solution and positioning the allocation of the locations in such a way that satisfies operators' objectives. The procedure for the MBSSLAA is presented, using the flowchart in Figure 5.1.

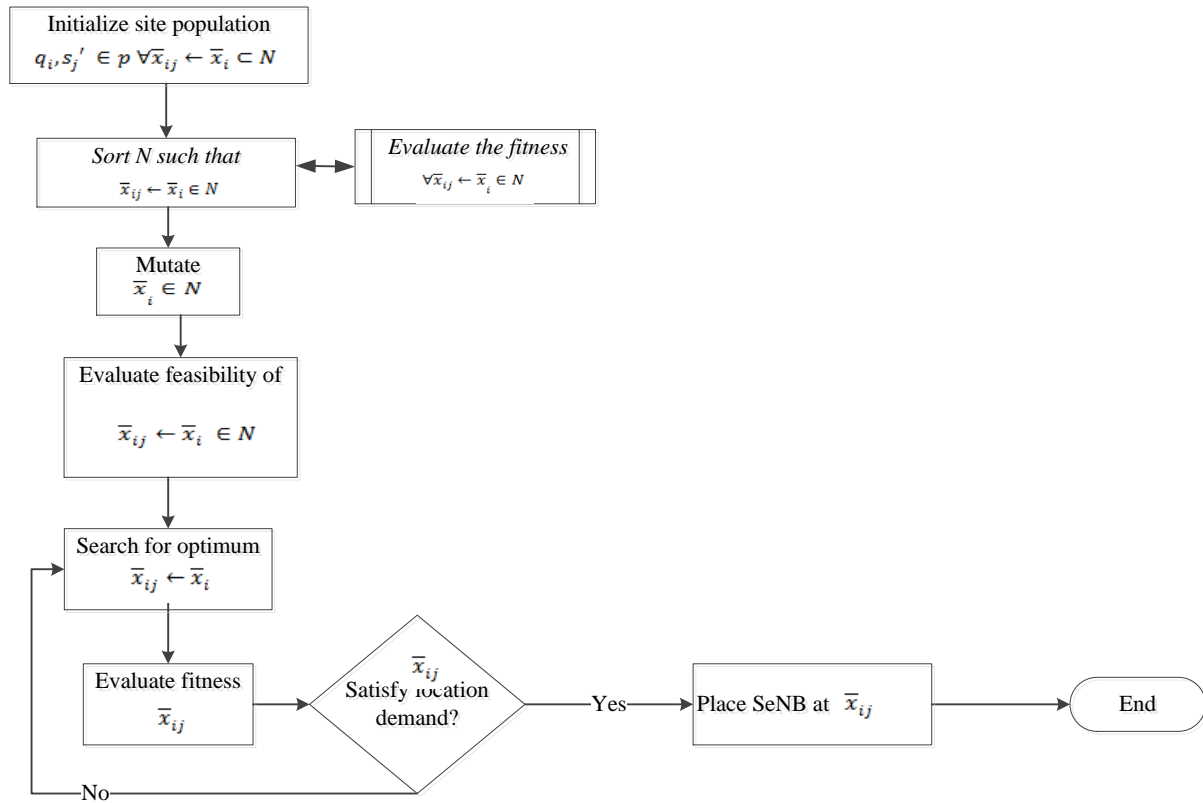


Figure 5. 1: Flowchart of the MBSSLAA

As a population-based heuristics, the MBSSLAA uses the MA procedure as described in Section 5.3.2 to generate and evaluate an initial population of parent candidate locations that are distributed across the coverage region of interest and taking cognisance of the different demands for such locations. The coverage region containing a population of candidate sites from which the optimal location is to be selected is as described by Figure 5.2 using a 2-dimensional plane. Using the general objective function defined for locating a site at the candidate sites, the individual candidate locations in this population are evaluated. Another offspring population with exact number/size of feasible sites as the parents' solution is further generated and

evaluated in comparison with the parents' genes to determine their dominance factors which lead to their acceptance or rejection as the evolved new population. The space containing the number of feasible sites,  $\bar{x}_{ij} \leftarrow \bar{x}_i \in N$  from which the optimal  $\bar{x}_{ij}$  can be selected through heuristics, is described using the Figure 5.2.

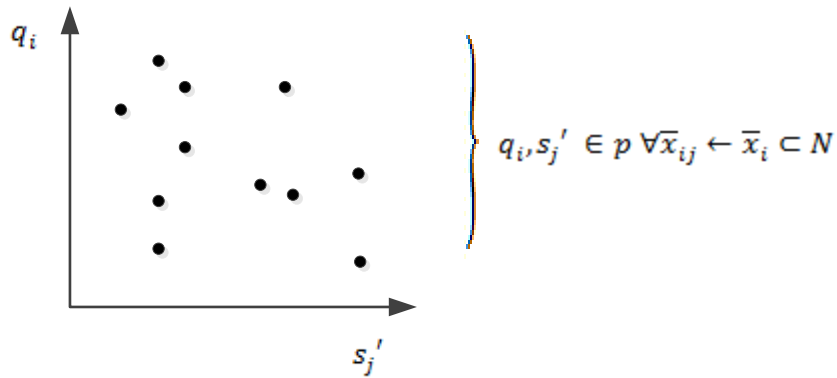


Figure 5. 2: Illustration of candidate sites from which optimum SeNB location is to be selected

This process ensures that the best sites that fit are selected to serve the population of users' demands coming from these locations. The resulting offspring population of candidate site from the MA procedure is further evaluated using the BSA to find the most feasible location for the SeNB site that fits the description of the location modelled in the system of equation. This two-phased process is to ensure that the accepted locations can help to reduce costs while they efficiently serve the users' demands in the region. The resulting sites, described by the Figure 5.3, from this procedure are adopted as the sites that can efficiently support the user population and their traffic demand. Following the flowchart presented in Figure 5.1, the MBSSLAA pseudocode is further listed in List 5.3.

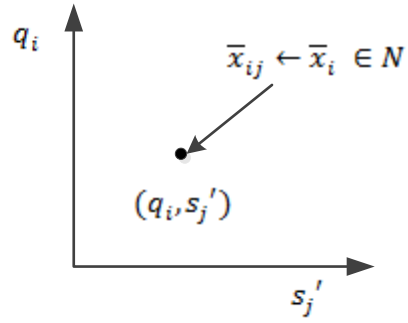


Figure 5. 3: Optimal site location for SeNB

List 5.3: Pseudocode of the MBSSLAA

**Input:**  $q_i, s_j' \in p \subset N$

**Output:** Optimized Solution  $\bar{x}_{ij}$

**Initialization();**

Population  $N \leftarrow \text{createStartSolutions}();$

**Sort**( $N$  by fitness);

$\bar{x}_{ij} \leftarrow \bar{x}_i$  from  $N$ ;

**For all iterations**

$\bar{x}_{ij} \leftarrow \text{select}(N);$

**For**  $\forall \bar{x}_i \in N$

With probability  $p_{\text{crossover}}$

Do  $\bar{x}_{ij} \leftarrow \text{recombined}(q_i, s_i' \in p);$

Else  $\bar{x}_i \leftarrow \bar{x}_{ij} \in p;$

End-With

Pop  $\leftarrow \bar{x}_{ij};$

**End-For**

**For all  $\bar{x}_i$  in  $p$**

$\bar{x}_{ij} \leftarrow \text{mutate}(\bar{x}_i);$

**For  $i = 1$  to  $0.5 * N$**

Generate  $\bar{x}_{ij}$

Evaluate  $\bar{x}_{ij}$

**If  $\bar{x}_{ij} < \bar{x}_i$**

$\bar{x}_i = \bar{x}_{ij}$

**Else**

$Trial_i = Trial_i + 1$

**Endif**

**End For**

Evaluate  $p_i$  ( $t = 0, i = 1$ )

**While  $t \leq 0.5 * N$  Do**

**If  $\text{rand}(0,1) < p_i$**

Generate  $\bar{x}_{ij}$

**Evaluate  $\bar{x}_{ij}$**

**If  $\bar{x}_{ij} \leq \bar{x}_i$**

$\bar{x}_i = \bar{x}_{ij}$

**Else**

$Trial_i = Trial_i + 1$

$t = t + 1$

**Endif**

$i = i + 1$

*if*  $i = 0.5 * N$

$i = 1$

**Endwhile**

**If**  $\max(\text{Trial}_i) > d(\bar{x}_{ij}, a_j) < \bar{x}_i$

Replace  $\bar{x}_i$  with the new solution

**Sort** ( $p$  by fitness);

**If**  $\bar{x}_i \in \text{Pop} > \bar{x}_{ij}$

**Then**  $\bar{x}_{ij} \leftarrow \bar{x}_i$ ;

**End-For**

Place( $\bar{x}_{ij}$ )

**End**

### 5.3 Conclusion

In this Chapter, site allocation for 5G network small cells was discussed. The Chapter discussed the Exact Equation, Memetic and Bee Swarm algorithms. The Chapter also discussed the dimensioning needs of future networks with respect to traffic analysis, coverage estimation, and capacity estimation. Following from reviews of these algorithms as fundamentals, the MBSSLAA was then designed to help in the deployment of the small cells to allow users take advantage of the high throughput that 5G will be offering network users to satisfy the expected high traffic. In Chapter Six, the MBSSLAA is tested and the performance are presented therein.

## Chapter Six

### PERFORMANCE EVALUATION OF NETWORK COVERAGE USING MBSSLAA

#### 6.0 Introduction

In Chapter Five, the MBSSLAA is introduced using analytical models and pseudocodes. In this Chapter, the algorithm's performance is tested by through system level simulation. As would be seen further down, the simulations are carried out using the ATDI network simulator in which three cities in the UK are used as case studies for densely populated environments. The performance of the algorithm is then evaluated and compared with existing methods of cellular network deployment.

#### 6.1 Simulation

Although the network specification is currently undergoing going system definition upon which the industry is yet to agree as a standard, the authors in [132] used the ATDI's ICS Designer to model the network as an overlay over the LTE-A network. In the same way, this study used the idea of overlaying the 5G small cell ultra-dense network scenario on an LTE-A network of three macrocells. The overlaying is done using the ATDI's ICS Designer through which 102 of small cells are deployed over the three macrocells; covering an area of  $3\text{Km}^2$  of Manchester City and Birmingham City. Each macrocell in this scenario covers an area of  $1\text{Km}$  with a radius of  $0.5\text{Km}$ . The small cells' locations are finely selected through the process of gene evolution and bee swarming to ensure that the site that meets the best requirement of the users is chosen to serve the number of users in these locations. The total distance covered by each small cell is unique to the small cell but varies between 10 to 100m depending on the location and traffic demand. Using the same parameter of implementation but a single macrocell, the simulation is

repeated for Urmston, a town in Greater Manchester. All parameters used in simulating the network are based on realistic network deployment as obtained in the industry and are listed and described in Table 6.1.

Simulation Parameters		
	eNB	SeNB
Power	46dBm	23dBm
eNB Height	10m	2m
Carrier Frequency	6GHz	
Bandwidth	800MHz	
Pixel Resolution	1x1	
Available RBs	4000	
Path loss Model	Walfisch Ikegami, Cost 231 Hata and Free space	
Cell Selection	Nearest Server/Highest SINR	
User Distribution	Random	
Antenna	Tri-sector; electrical tilt	Omni directional
SINR Threshold	-10.0 dB	
Area Type	Dense-Urban	
UE's speed	1.2km/h	
UE's Tx power	20dBm	

Table 6. 1: Design parameters for MBSSLAA

The choice of ATDI ICS Designer as the simulator is to allow the evaluation of the network performance in such a way that it realistically mimics the real environment by taking advantage of the cartographic data and maps that come with the tool. Mobile network simulations usually

involve the placement of an eNB on a grid then randomly placing the users or deterministically place them around the eNB, but this is not a tractable model as opined by [133]. Because this method is not tractable, several works have instead, used complex system-level simulations to evaluate coverage and offered rates in the regions of interests [133]. Using system-level simulation is considered as a more desirable method of evaluating network coverage since it idealises true-life scenarios and presents the ability to deploy networks that meet users' requirements. This narrative justifies the idea of using the proprietary simulator in this project. The design model is laid over the City of Manchester to represent a deployment scenario over the dense urban environment.

The ATDI ICS Designer comes with radio network planning and spectrum management tool that has an inbuilt Bing Map that can further project onto Google Map and uses the necessary environmental cartographic parameters required to measure the radio propagation properly. These include digital elevation model, map images, colour palette, clutter layer, building layer and vector layers. To obtain accurate radio coverage results, the necessary eNB configuration information uses field best practices for network operators. The eNB's basic parameters here include the height of eNB antennae, antennae type, transmission power, and electrical antennae tilt. The network is deployed using 800MHz bandwidth and carrier frequencies of 6GHz. Different channels models are tested to ascertain the validity of the MBSSLAA results under different circumstance. These channel models include the Walfish-Ikegami, Cost 231 Hata and Free space propagation models.

The coverage distance is chosen to ensure that the network covers a clutter area of different demography that includes roads, train stations, shopping areas and open places. The area of coverage considered in this study depicts an area that continually experiences high user density



at any one time, especially during the peak periods of the day. Around the macro cells, we located 102 small cells with the use of MBSSLA.

One thousand, two hundred (1,200) users were generated to indicate user traffic demand in the regions of interest. These users are randomly distributed over different clutters of the service area, covering shopping centres, homes, bus stations, business offices, roads and the train stations. These areas of interest usually require high capacity especially during peak periods because they exhibit high population most hours of the day.

## **6.2 Coverage**

Deploying small cells' SeNBs amongst others has a variety of advantages such as increased data rate and power savings. However, SeNB deployment also comes with the problem of backhauling challenges [134]. On the backhaul network, backhauling a dense network of small cells with the volume of traffic that would be passing through it is a challenging feat that will require numerous end-to-end connections as well as an increase in amortisation cost to the operators. One of the solutions to this problem includes deploying a near minimum number of small cells that can efficiently cater to the need of the users in the coverage region.

Ensuring that every user in the coverage area is covered, the study considered the best server basis approach of cell selection for both macro and small cells. This method, as shown in the performance, helps to reduce the number of handovers that takes place within the densified network. On that basis, a user is covered if the SINR from any of the small or macro cells in the selected candidate position is greater than or equal to the chosen threshold, therefore, having it served by the transmitter.

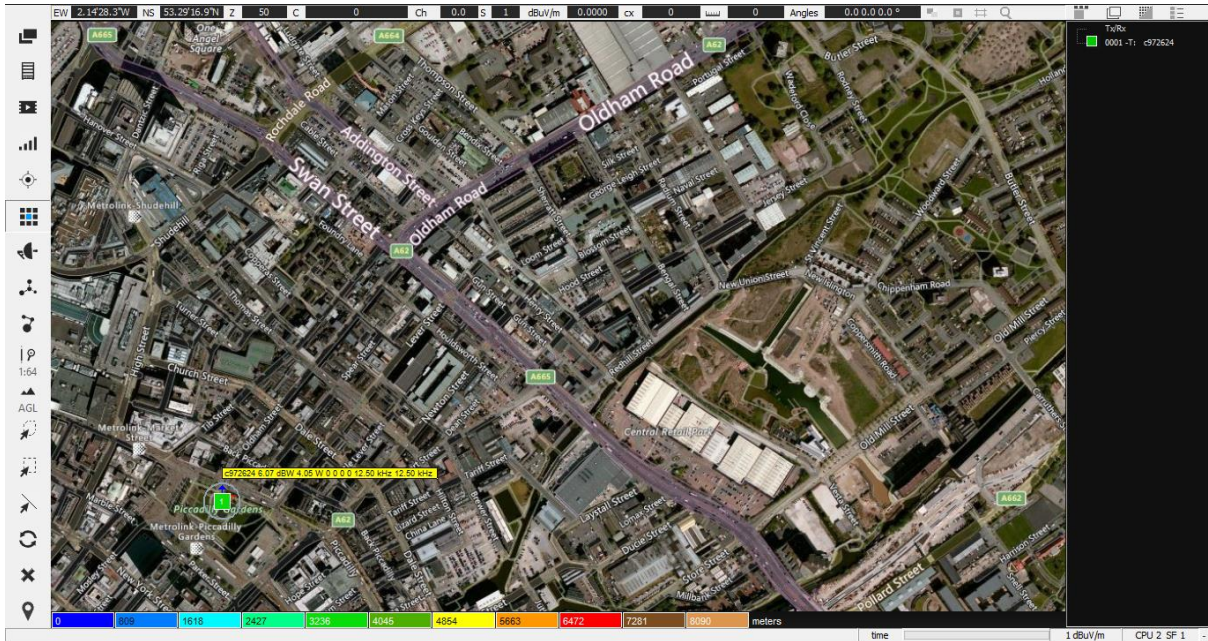


Figure 6. 1: Image of Manchester City Centre

### 6.3 Coverage Analysis

The essence of the MBSSLAA is to deploy an ultra-dense small cells network to improve the macro cell coverage for network operators and increase coverage such that meets the user's requirements on a 5G network. This is key to the evolution of the 5G network, as seen in the literature and especially because it is fundamental to supporting IoT. As already stated, the process of network coverage involves the requirement collection and analysis, coverage and capacity design, site selection, simulation and report writing. Coverage and capacity planning forms the basis upon which these other steps work through the process. It, therefore, implies network characterisation for an in-depth analysis and sizing the network inferred from the users' demands that need to be satisfied. Coverage planning estimates the coverage distance of the eNB using the settings of an original cell needs to satisfy its resident and transit users and to take cognisance of the cell edge. The size of the network is obtained by measuring the uplink rate, and this is applied to determine the total radius of the cell. This is also applied to the downlink to ensure efficient transmission even on the edge of the cell.

For the network deployment scenarios, the study considered the use of industry-standard path loss models, which are modified for the 5G network. The authors in [52] have used these standard path loss models to measure network performance for a 5G scenario. The results of the study also show that there is a significant improvement in the performance of the throughput for users of the network. The models used in this study are Walfisch-Ikegami, Cost-231-Hata and Free space models. Their performances on the different location allocations techniques of consideration in this study are elucidated in the subsequent sections of this Chapter. Also, while [52] was able to deploy 330 small cells. While using the MBSSLAA in this study, the MBSSLAA provided high signal strength across an area of  $3\text{Km}^2$  by implementing 102 small cells as components of the ultra-dense network.

Coupled with the issues that already exist generally in network planning and location allocation, the case of 5G and the frequency bands in which it would be operating present different challenges such as the ease with which the millimetre waves can be distorted as well as the short distance coverages which they can only cover. The authors in [135] established that even human bodies also attenuate the signals in the network, this is notwithstanding the general effects from buildings and other structures on signals. This further strengthens the case for the need for the MBSSLAA to be used in future network densification to deploy an ultra-dense network that deploys few number of SeNB in the bid to satisfy user demands with the appropriate QoS.

Frequent handover is also a potential drawback for 5G network's millimetre wave frequency mainly due to their vulnerability to random obstacles. Network densification in the next generation of networks will make handovers even more challenging because, considering the radius of the small cells, handover will be more frequent in the 5G networks. The probable loss of beamforming information due to channel change is also another issue to be dealt with in 5G network handover and cell reselection [135]. By deploying few numbers of small cells in the

area, the MBSSLAA shows that it is possible to reduce the frequency of handover in the network while sustaining high throughput for users across the area of interest.

Because of existing high-rise buildings in urban areas, it is harder to plan site locations due to the effect of reflection, diffraction that radio signals get to suffer which always necessitate the consideration for the establishment of lines of sight and non-lines of sight. Sometimes, this mostly implies that a closer cell does not get to serve the UEs closer to it, which usually affect other schemes of site location allocation.

#### **6.4 Covering a Service Area**

In order to cover the selected service areas (Manchester City, Birmingham City and Urmston), the study first assumed a neutral ground in the City Centre then placed an eNB. In a further distance 1000m from this point, two other eNBs are installed, thus creating a network of three macro cells to cover an area of measured at  $3\text{km}^2$ . This area, by an educated assumption, covers the busiest parts of the city especially at peak period due to the influx of shoppers, workers and residents thus making it a densely populated area of the city. Figure 6.2 shows the network coverage using an ultra-dense network of small cells.

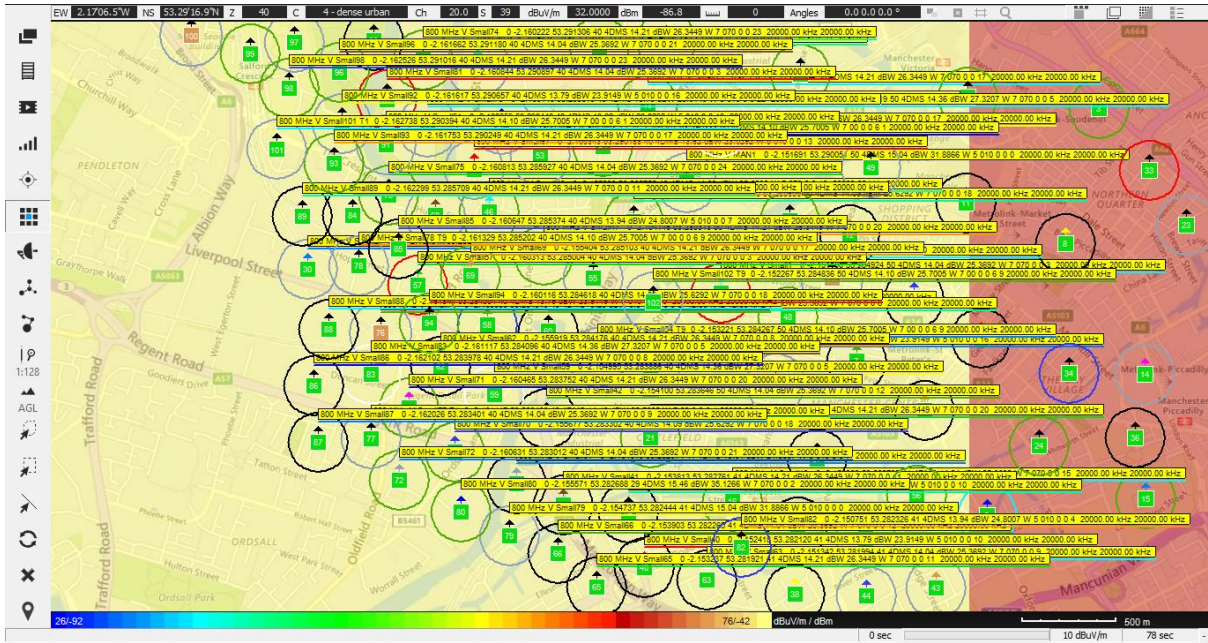


Figure 6. 2: 5G Ultra-Dense network coverage of Manchester City Centre

In the previous generation (4G), operators use RSs, picos and femtocells to achieve this. However, things relatively changed in the 5G architecture: the introduction of network densification through the use of small cells to reduce coverage distances and improve capacities delivered to the users. Network densification through small cells is easy but posed a threat on the side of cost to the operators. During network densification, the operators need to deploy a few small cells to provide high-quality service in the service area.

The MBSSLAA is applied to ensure the deployment of a limited number of small cells to cover the service area. The Memetic side of the algorithm evolves and recombines the candidate sites based on the classic principles of evolutionary algorithms; the selected offspring are further reselected using Bee Swarm side of the hybridisation. This iterative process continues until the candidate position meets the objective function of the algorithm; at which point a small cell is placed at the selected site. This process continues until the service area is sufficiently covered; ensuring that each small cells, as well as the eNBs, have enough resources (power and

bandwidth) to serve this area efficiently. One strong justification for small cell coverage using the MBSSLAA is especially in the area of vehicle-to-vehicle (V2V) communication which requires little or no tolerance at all for a hole in the network coverage due to inefficient infrastructure coverage or a temporary failure of services [136].

## **6.5 SINR Distribution**

The primary idea behind radio network planning is to ensure that acceptable signal strength is received from the transmission node (eNB/SeNB) at the UE based on the desired minimum power defined by the network operator [50]. The SINR distribution of the network was collated using the Monte Carlo simulation method in the same manner as in [20] which is also a function in the ATDI ICS Designer for data evaluation. To present the results of the SINR across the coverage area, the data from the simulation is plotted against the cumulative distribution (CDF) of the SINR. This is so because the CDF is a function which is normally used in comparing more than one systems in wireless networks to determine whether a system meets the minimum performance criteria and to ascertain which system is better. The importance of CDF in this evaluation is to show the percent of location in which the MBSSLAA performance is below or greater than the other methods of selecting candidate sites that better meet the needs of network users in a 5G ultra-dense network of small cells. Using the CDF further shows the probability of attaining higher SINR values at different locations across the coverage area. Because the SINR is an essential metric in network coverage that determines the throughput, which can be achieved, predicting its distribution accurately and ensuring that it is optimal is key to network planning.

The result in Figure 6.3 presents the SINR distribution of the MBSSLAA using the Walfish-Ikegami channel model for Manchester City coverage. The result indicates that the proposed MBSSLAA yielded a high network-wide SINR distribution, which is higher than the other techniques employed in the network simulation. Note that the SINR is fundamental to the

throughput that can be achieved by the network users around different locations of the coverage area. Therefore, by finely distributing small cells across the network, the MBSSLAA is capable of satisfying the network users' requirements by deploying a few number (102) of SeNBs throughout the coverage regions. The SINR values obtained from the simulation determine the link quality and measure the achievable throughput [26] the users can attain while they remain connected to the network at a certain distance, irrespective of their mobility status. Mobility status here implies the network user been stationary or mobile within the region of interest. The results in Figure 6.3 shows that the probability that a network planner using the MBSSLAA would attain higher SINR across the region is higher. The MBSSLAA yielded 23dB of SINR across 20% of the area while it peaked at 35dB in 85% of the coverage area. The Memetic Algorithm (MA) attained the next higher SINR distribution by achieving 25dB over 80% of the area.

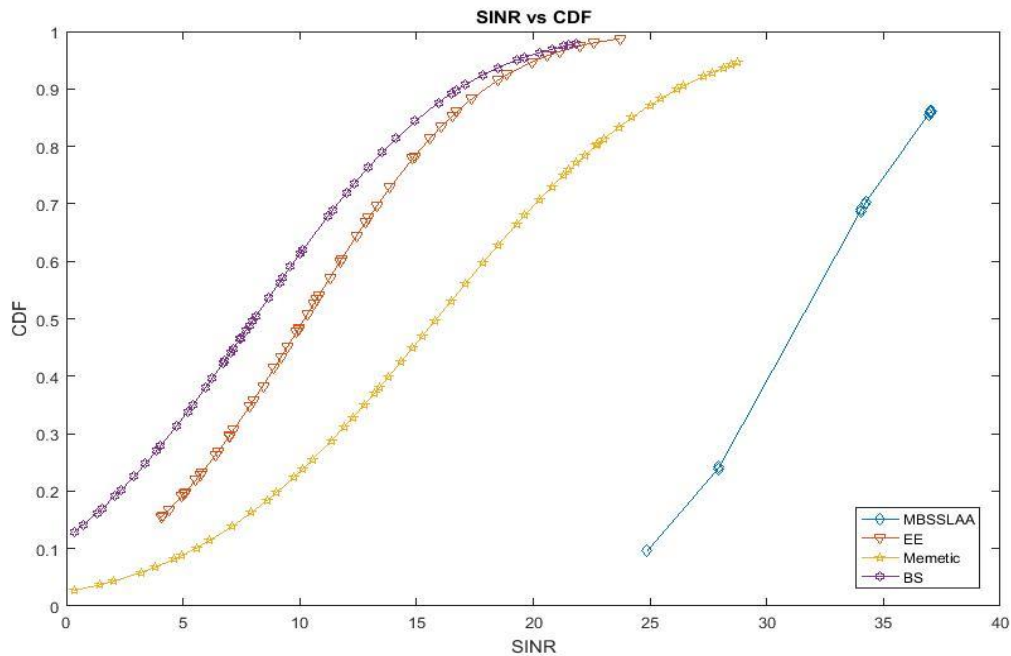


Figure 6. 3: SINR distribution for Walfisch-Ikegami (Manchester City)

From the results, it can be seen that by gradually evolving and selecting the site locations through the natural process of evolution and bee swarm, the SeNBs ensures that candidate sites are located in areas of higher traffic demands with a high signal strength, which would further impact on the achievable throughput that the users get. This result meets the network criteria from the solution's system model. Also, in Figure 6.4, the performance of the MBSSLAA is presented using the Cost 231 Hata model in the Manchester City. As obtained in the previous results in Figure 6.3 where the MBSSLAA performed higher than the existing methods of site location allocation, the MBSSLAA, again, yielded higher SINR distribution by supporting high SINR of 28dB over 84% of the region of interest, at peak performance. This indicates that concerning the deployment of small cells in the future, the MBSSLAA is capable of deploying a minimal number of SeNBs while ensuring that users are guaranteed high network performance.

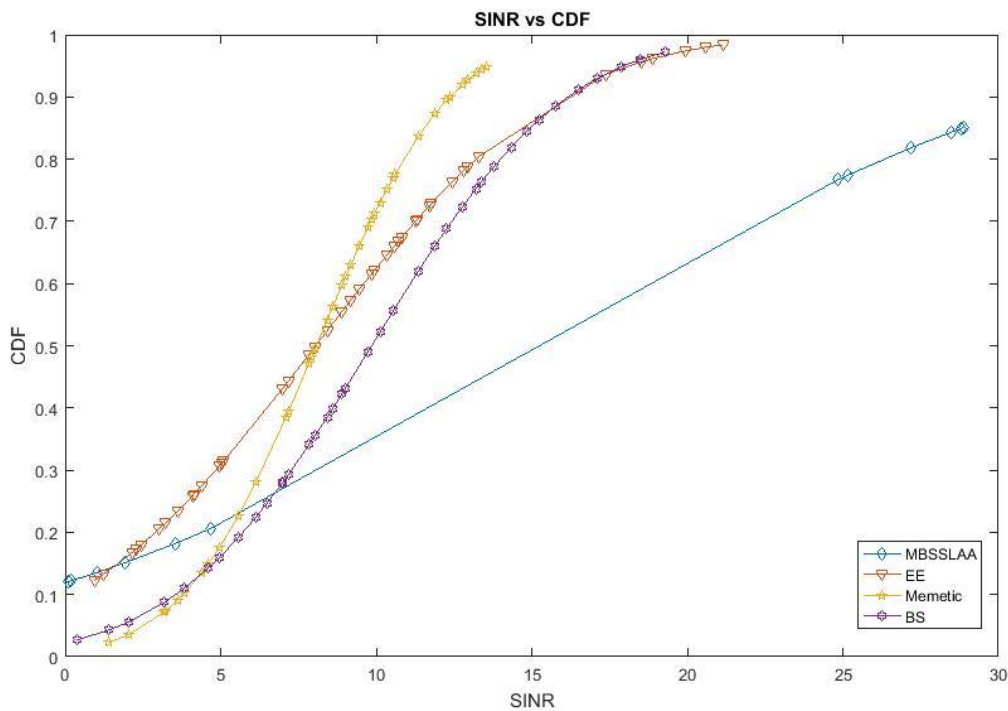


Figure 6. 4:SINR Distribution for Cost-231-Hata (Manchester)



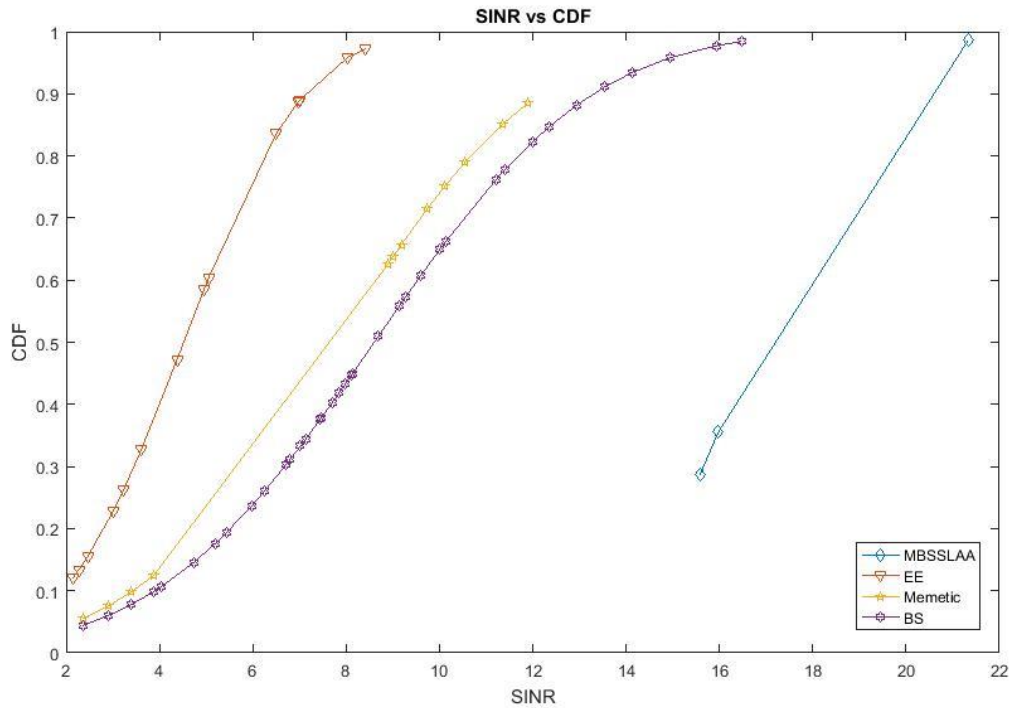


Figure 6. 5: SINR distribution for Free Space (Manchester)

The results in Figure 6.5 show the performance of the MBSSLAA while using the Free Space channel model for covering Manchester City. In this result also, the MBSSLAA performs higher by covering 99% of the area with 28dB peak SINR that show the capability of the MBSSLAA to achieve higher performance under different channel models.

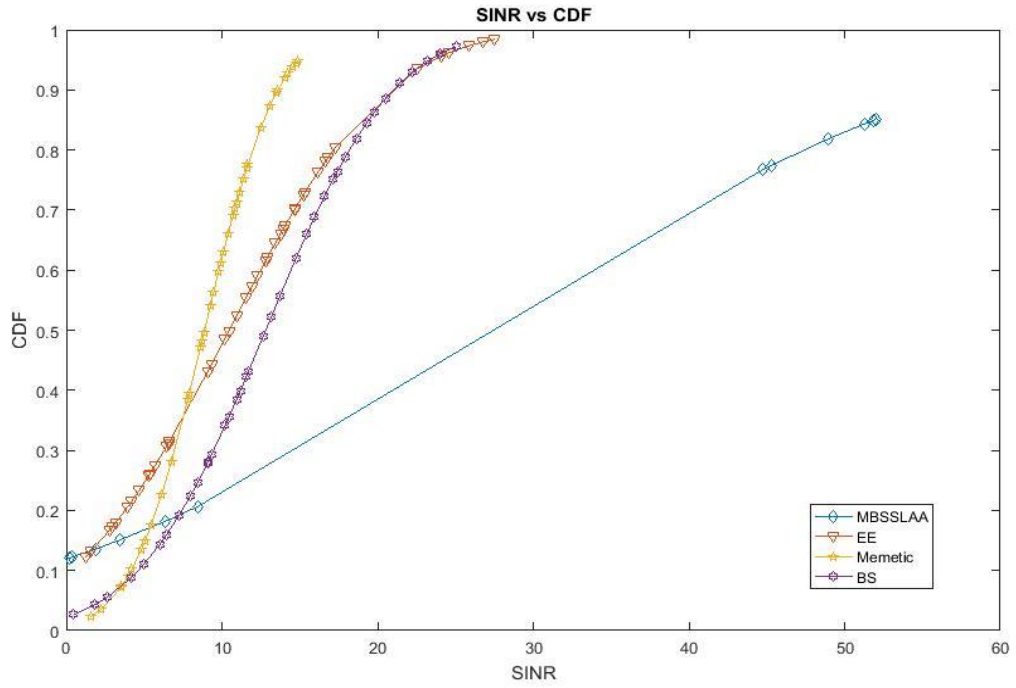


Figure 6. 6: SINR distribution for Walfisch-Ikegami (Urmston)

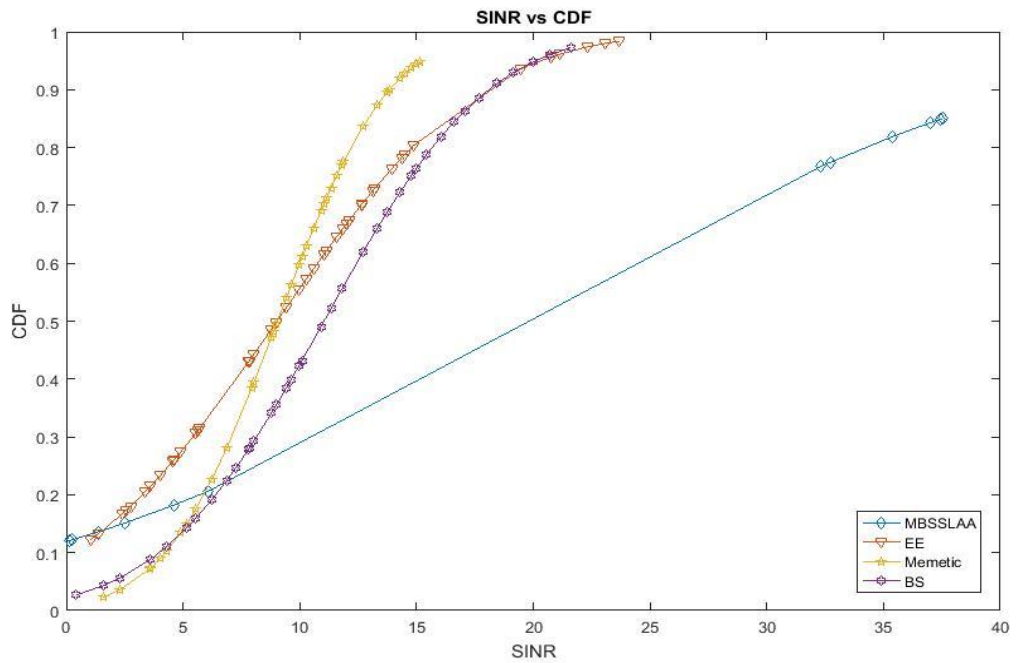


Figure 6. 7: SINR distribution for Cost-231-Hata (Urmston)

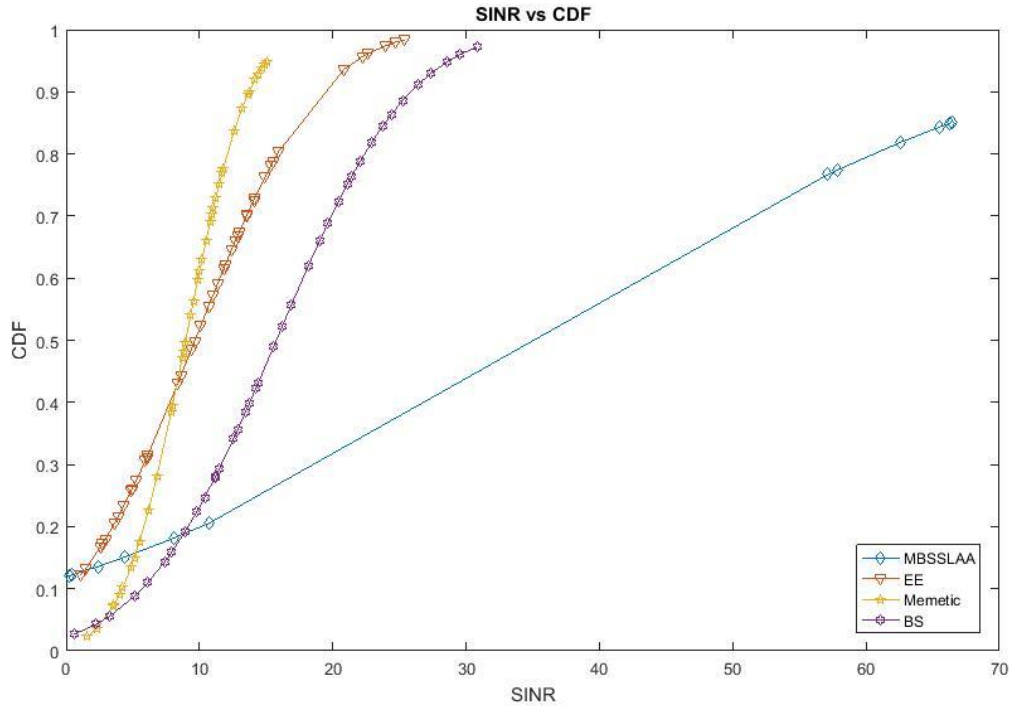


Figure 6. 8: SINR distribution for Free Space (Urmston)

Figures 6.6, 6.7 and 6.8 are the SINR distribution results obtained by deploying a network of small cells using the MBSSLAA in Urmston. In Figure 6.6 where the Walfisch-Ikegami model was used to test the algorithm implementation, the result shows that the MBSSLAA achieved the highest SINR (66.47), compared to the compared to the other algorithms of interest. Considering that SINR of vital importance to the amount of throughput that can be delivered to network users, the MBSSLAA distribution shows that give the same parameters, it is capable of providing higher performance over 85% of the coverage region. This would later translate to higher throughput over this space. In Figure 6.7, the network was further deployed used the Cost-231-Hata model. Again, the result indicates that the MBSSLAA gives higher performance than the algorithms that are being compared. Figure 6.8 also shows the performance of the MBSSLAA using the Free Space model in Urmston, and the performance also indicates higher performance for the scheme.

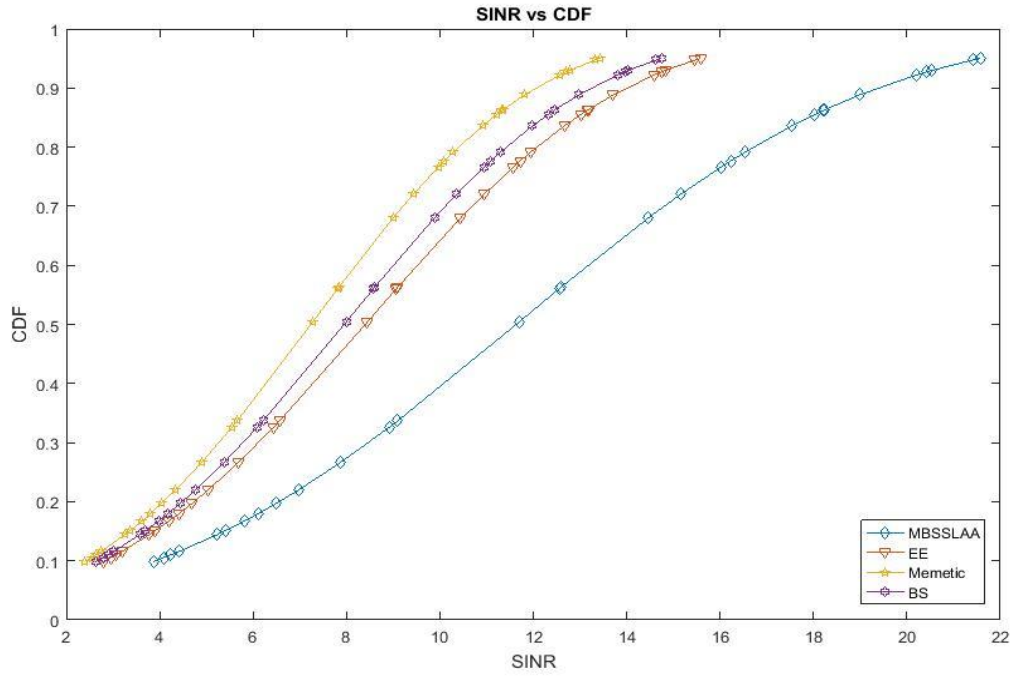


Figure 6. 9: SINR distribution for Walfisch-Ikegami (Birmingham)

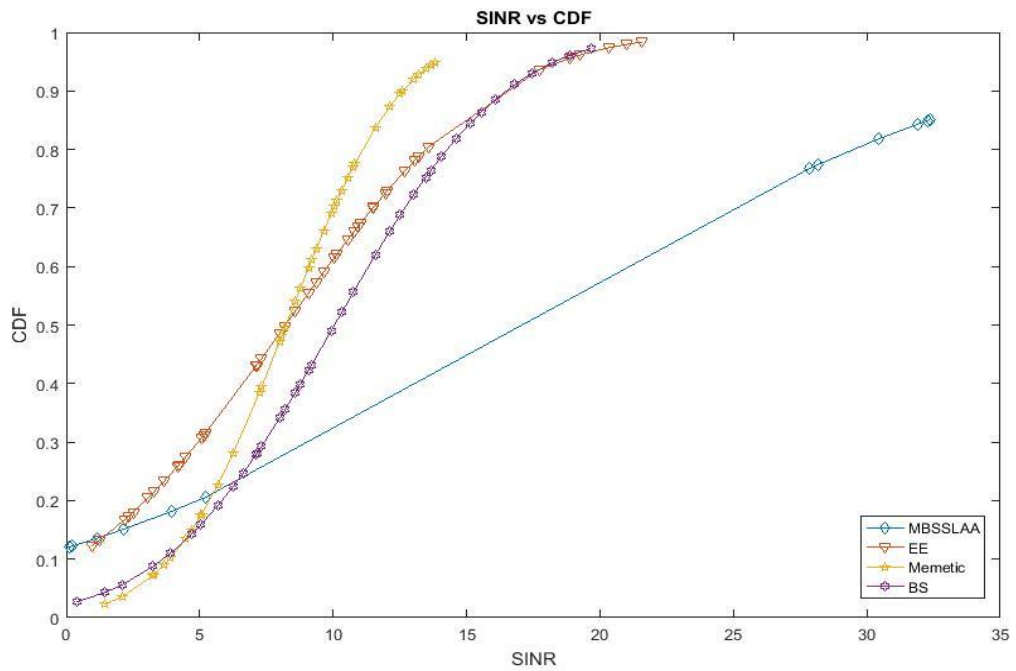


Figure 6. 10: SINR distribution for Cost-231-Hata (Birmingham)

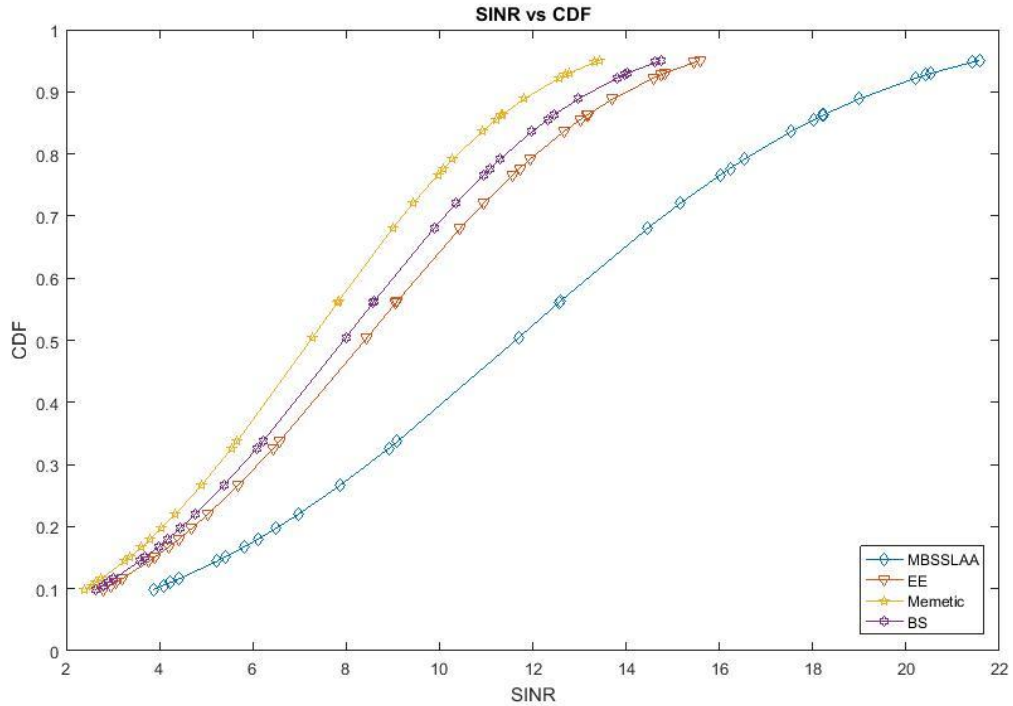


Figure 6. 11: SINR distribution for Free Space (Birmingham)

In Figures 6.9, 6.10 and 6.11, the study presents the SINR distribution from simulating the MBSSLAA using Birmingham City as coverage area. In Figure 6.9, the Walfisch-Ikegami model is used to deploy the network of small cells. Results show that the MBSSLAA provides the highest amount of SINR (21.83db) in over 95% of the coverage. This level of coverage indicates that the algorithm is capable of achieving the highest throughput delivery in over 95% of the coverage area. Supposing that throughput is the only measure of the quality of service to be measured at any one time, this then means that the algorithm is capable of ensuring high quality of service in over 95% of the coverage area. In Figure 6.10, the result obtained by using the Cost-231-Hata model is also presented. The results here also indicate that the MBSSLAA is capable of delivering higher performance than the other algorithms. The MBSSLAA achieved 32.36db across 85% of the coverage area. In the same way, using the Free Space model, Figure 6.10 indicates that the MBSSLAA yet again renders higher SINR in the coverage area. The result

shows that the algorithm is capable of rendering 21.58db across 95% of the coverage area. The results from Figures 6.9, 6.10 and 6.11 indicate that the MBSSLAA yields higher performance that would enable high throughput across large and small coverage areas of interest concerning small cell deployments.

## **6.6 Throughput distribution in 5G networks using MBSSLAA**

This section describes the distribution of throughput in the region of interest by comparing the performance of the MBSSLAA with those of the other methods. This comparison is achieved using the CDF as obtained in Section 6.6a. Throughput, as posited in Section 6.5, is a function of the SINR distribution across the area. Intuitively, the throughput distribution follows the partens of the SINR distribution in which the MBSSLAA, as the results show, attain higher performance index compared to the other methods of densifying the network with small cell. The high throughput are quite uniform across the area. As evidenced by [54], the SINR distribution tends to remain constant as the network densifies, therefore, resulting in high distribution across the coverage area. The SINR values have increased in part because the mmWave network is a noise-limited network arising from the increased signal power and considering that small cells generate lower interference [52, 54]. The effect of this constant and increase in SINR value distribution is significantly represented in the distribution of throughput in the region. This agrees with [54] assertion that communications in mmWave frequencies are noise limited, which, generally speaking, implies that by increasing network density through the use of small cells dramatically increases the SINR values and the achievable throughput in the area of interest. The SINR distribution achieved by MBSSLAA using the industry-standard path loss models also appears to have exceeded the ones attained by the proposed models in [51]. Thus, the performance affirms that using the MBSSLAA to select the candidate sites for small cells carefully helps in increasing throughput across the area and ensuring that all users achieved required QoS. The results

obtained in this section, therefore, shows that the MBSSLAA has higher throughput distribution while deploying the ultra-dense network of small cells.

While using Walfisch-Ikegami model as presented in the Figure 6.12, the algorithm provided high SINR values ranging from 23.9dB with a low distribution; it further increased to 37.07dB which is the highest that was attained with the model. The distribution shows that using the MBSSLAA, signal strength was highly distributed across 85% of the coverage region thus insinuating that a significant proportion of the users in the area are capable of achieving throughput as high as 2900Mbps. This, however, is not the same with the other methods. Using memetic algorithm, the SINR value, though lower than what is achieved by using the MBSSLAA, indicates that users of the network will attain some low throughput distributed across the region. The Memetic method, like the other methods, ensures that users with SINR less than 1dB also would also be able to achieve good QoS. The SINR distribution also shows that the method provides 98% good through distribution coverage to the area of interest. The Exact Equation (EE) and Bee Swarm (BS) methods achieved lower throughput coverage in 92% and 97% of the area respectively which implies that it covers more of the areas than the MBSSLAA but with mostly low throughput which would result in bad quality of service to the users spread over this area.

As with the Walfisch-Ikegami model, the Cost-231-Hata model, in Figure 6.13, also indicates high distribution shows that about 10% of the area is covered with low throughput and a more significant percentage of the area is guaranteed to achieve a high data rate of over 2700Mb. This level of coverage also indicates that 82% of the coverage area is guaranteed to attain good service quality that meets the proposed standard specification for data transmission in the 5G networks. Unlike as it is with Walfisch-Ikegami model, in the case of the cost-231-Hata, the memetic algorithm appears to achieve lower throughput though maintaining it across 90% of the

coverage area. In the same vein, the EE and BS methods show higher distribution than the MBSSLAA and the memetic. The EE and BS, using the Cost-231-Hata indicate the possibility of covering the area at 97% and 98% coverage, respectively with both providing 21.1dB and 19.3dB of SINR, which is enough to provide efficient throughput for users of the network.

Additionally, as with the previous models, in this model, the MBSSLAA shows higher performance than the other three methods. The MBSSLAA, here, achieved the highest SINR value at 21.34db. Also, it indicates that network densification coverage can cover over 98% of the area. Using the Free space, the BS attained a higher distribution and SINR values than the EE and the memetic methods. These results show that the MBSSLAA is capable of distributing a considerably low number of small cells across the coverage space with a good signal strength which is required to provide high throughput for the users with a small number of small cells that are needed to serve the area efficiently.

The Figures 6.6a, 6.6b and 6.6c present throughput distribution across the area of Manchester City which was covered using the MBSSLAA. In general, the four methods yield high throughput across all the coverage region which conforms to the range of the expected amount of increase in throughput that the 5G evolution platforms speculate to achieve to serve the number of connected devices and the heavy demands that would result from users of the network. The MBSSLAA, however, gives higher throughput distribution under the different channel models, compared to the other techniques.



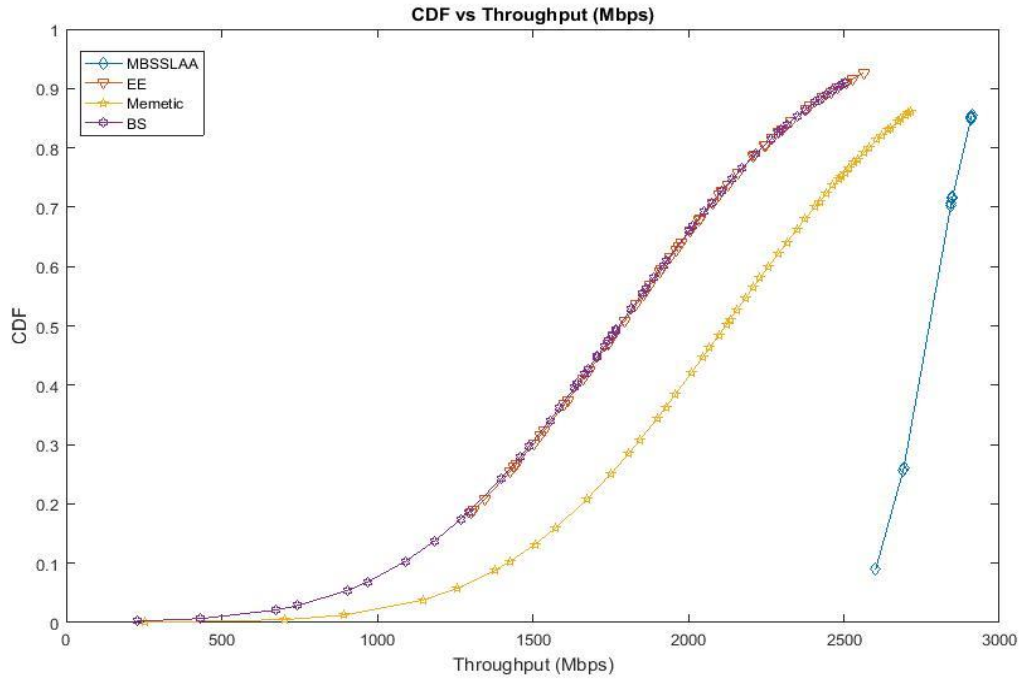


Figure 6. 12: Throughput distribution using Walfisch-Ikegami (Manchester)

The high throughput in small cells comes as a resultant effect of reducing the coverage area for the small cell base stations, which allows spectrums reuse, therefore, lessen the number of users that are competing for the available resources [54]. This is why it is essential to have a minimal number of small cells that would efficiently cover a densely populated urban area such that network users would attain a high quality of experience. Figures 6.12, 6.13 and 6.14 show that deploying ultra-dense network ensures high through distribution across the coverage area. The high-throughput density achieved by the MBSSLAA meets the requirements for ultra-dense small cell deployment as opined by [137, 138] that enables high connectivity for the various users under such network coverage.

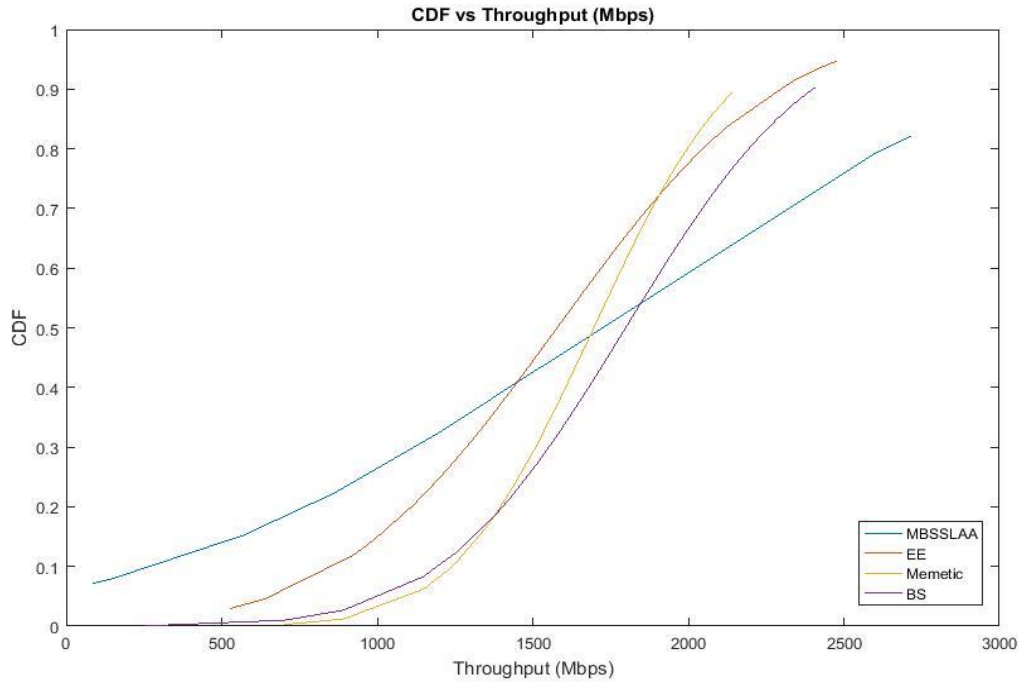


Figure 6. 13: Throughput distribution using Cost 231 Hata (Manchester)

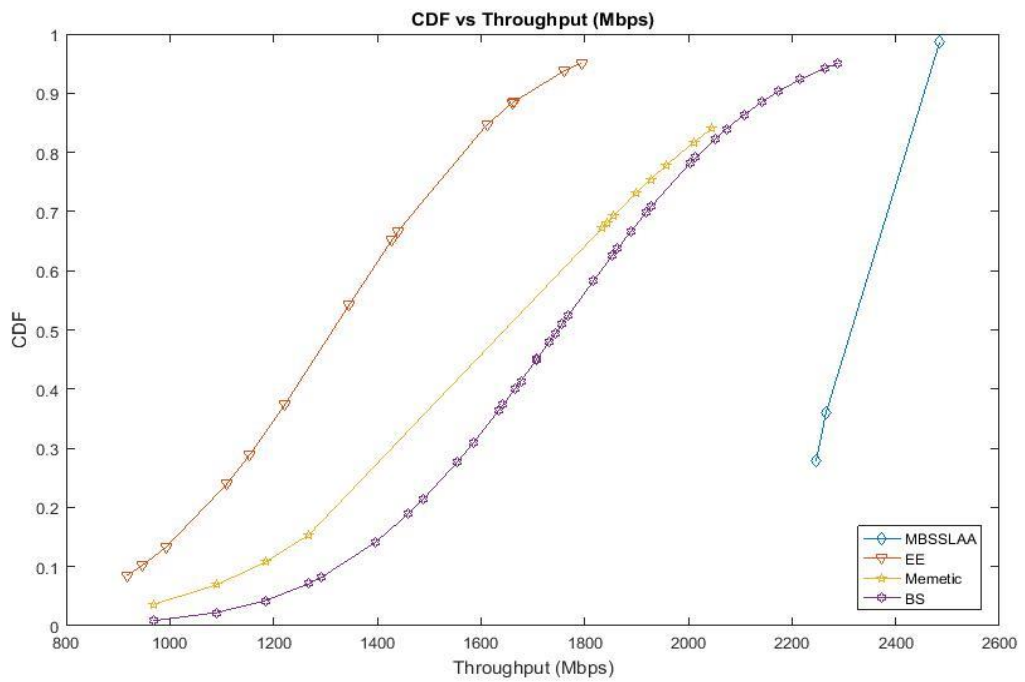


Figure 6. 14: Throughput Distribution using Free space (Manchester)

As with the SINR distribution across the coverage region, the study evaluated the throughput distribution of the different site location-allocation algorithm in the area of interest. In Figure 6.13, findings from the results indicate that the exact equation and bee swarm methods are capable locating the small cells such that cover 98% of the coverage area of interest while providing a high amount of throughput to the network users. From the same result, the MBSSLAA shows a capability of locating sites in the area with the more significant amount of throughput (2911.54Mbps) while covering 85% of the area; which is low coverage, compared with the performance achieved by the exact equation method and the bee swarm methods.

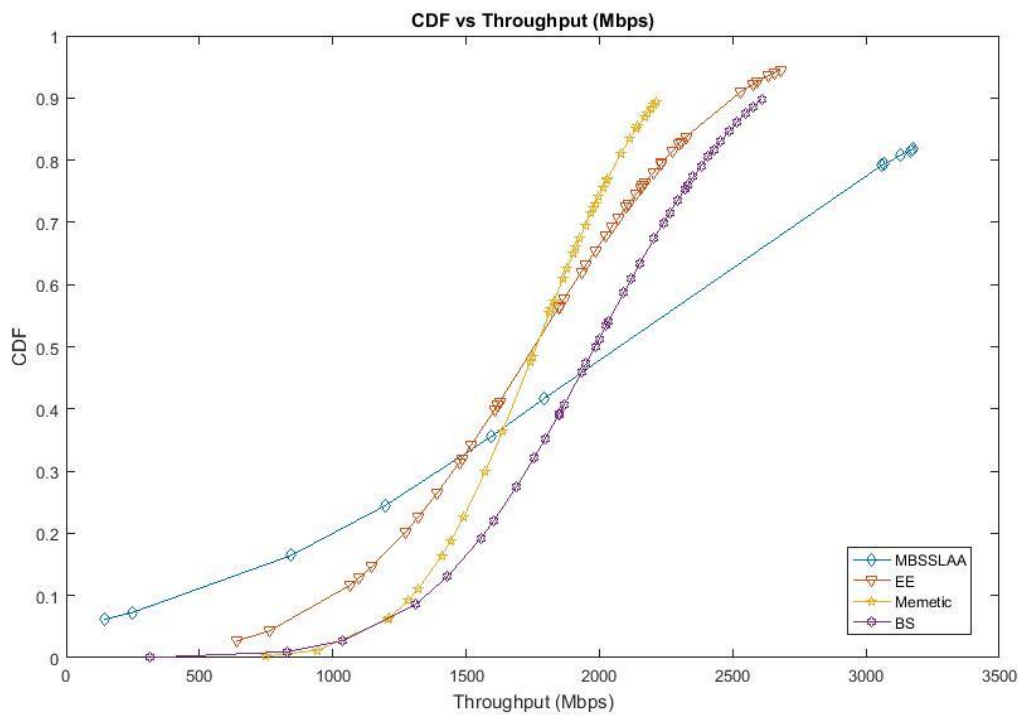


Figure 6. 15: Throughput distribution using Walfisch-Ikegami (Urmston)

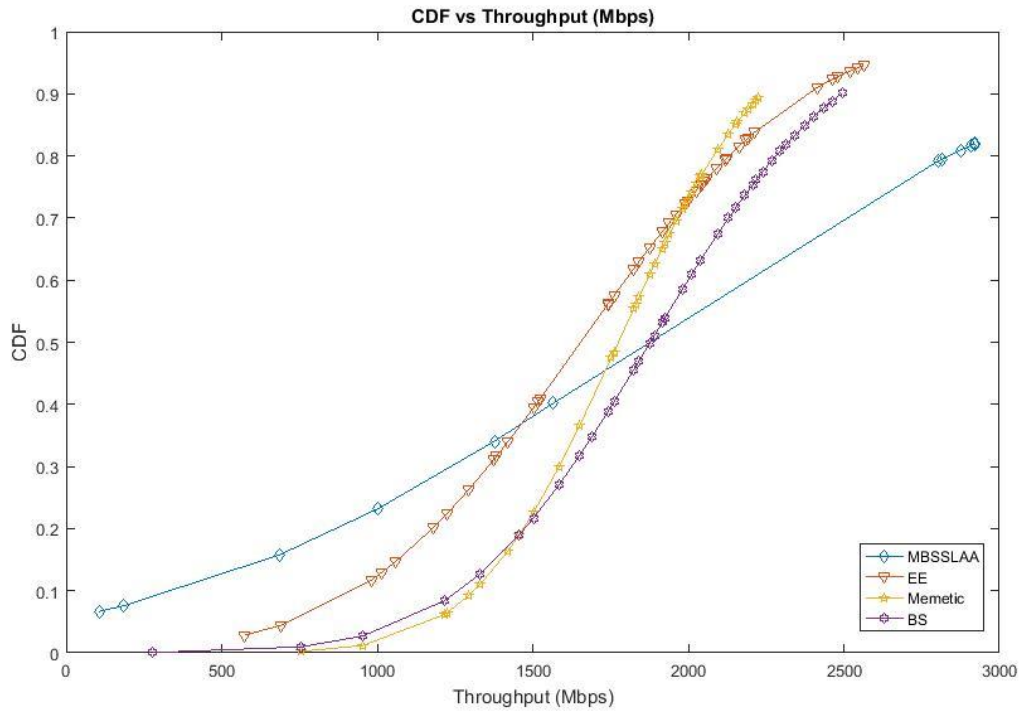


Figure 6. 16: Throughput distribution using Cost 231 Hata (Urmston)

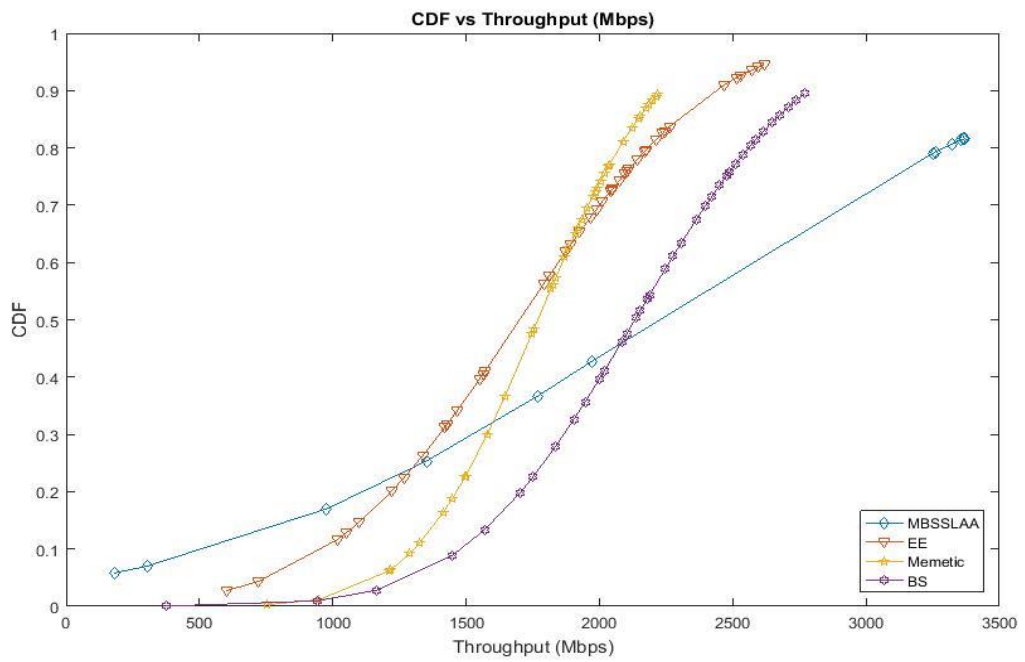


Figure 6. 17: Throughput distribution using Free Space (Urmston)

The results of the simulations for Urmston are further provided in Figures 6.15, 6.16 and 6.17. Considering the trends from the SINR distributions in Section 6.5, the amount of throughput achieved using these algorithms intuitively follow the same trend since throughput is a function of the SINR. The Figure 6.15 presents the result of using the Walfisch-Ikegami model. In this scenario, the MBSSLAA achieved throughput of 3176.53 (Mbps) across over 81% of the coverage area compared to the other algorithms. This achievement further indicates the capability of the MBSSLAA to deploy small cells such that would support the full implementation of the IoT in the future. Using the Cost-231-Hata model, the result in Figure 6.16 also follow the trends from the previous scenarios. In this case, results from the study show that the MBSSLAA achieved throughput of 2921.98 (Mbps) across over 81% of the coverage. In the same trend, the Figure 6.17 presents the results of the scenario using Free Space model. The result shows the MBSSLAA in this scenario, achieved 3369.64 (Mbps) across 82% of the area of interest. The trends of the results from these scenarios all strengthen the fact that the MBSSLAA can be used to deploy small cells in the 5G network to help it support the deployment of IoT.

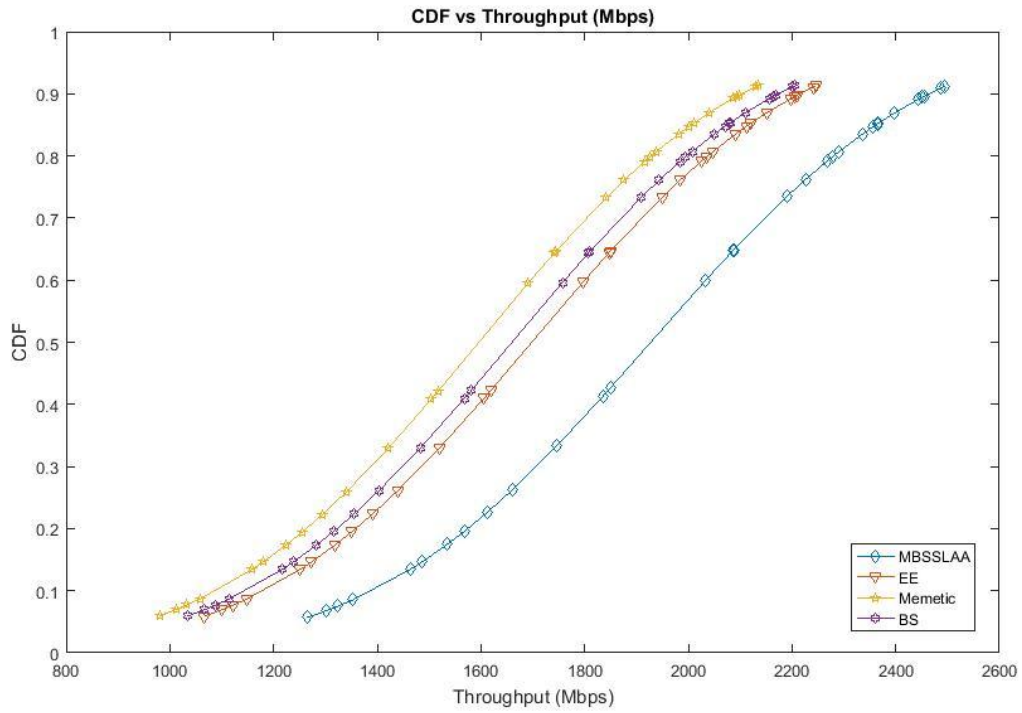


Figure 6. 18: Throughput distribution using Walfisch-Ikegami (Birmingham)

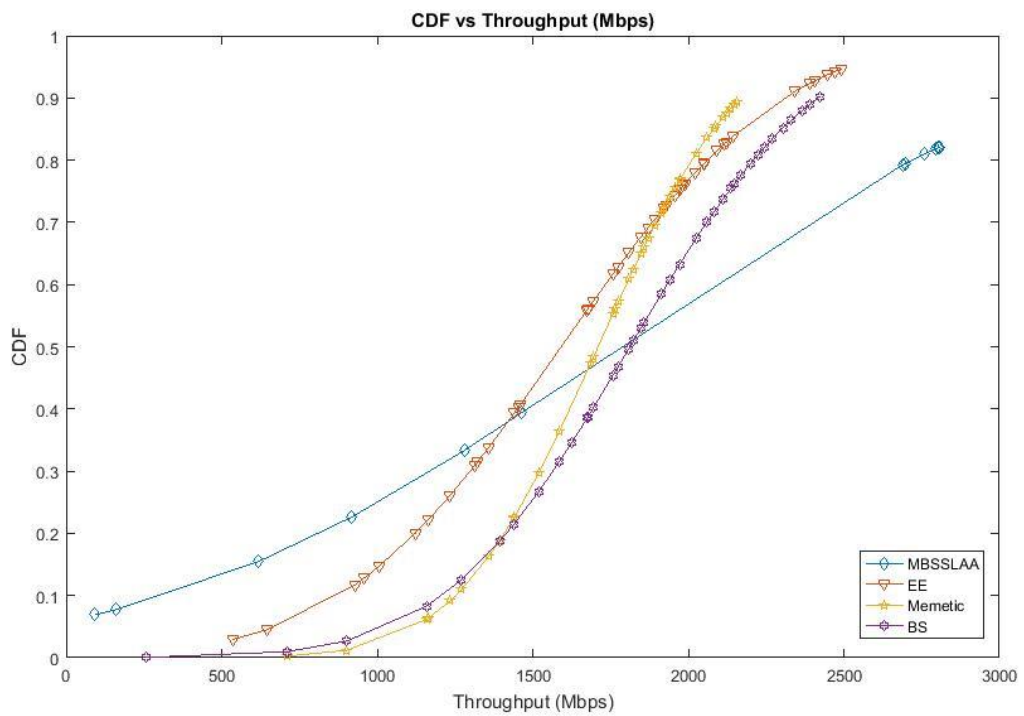


Figure 6. 19: Throughput distribution using Cost 231 Hata (Birmingham)

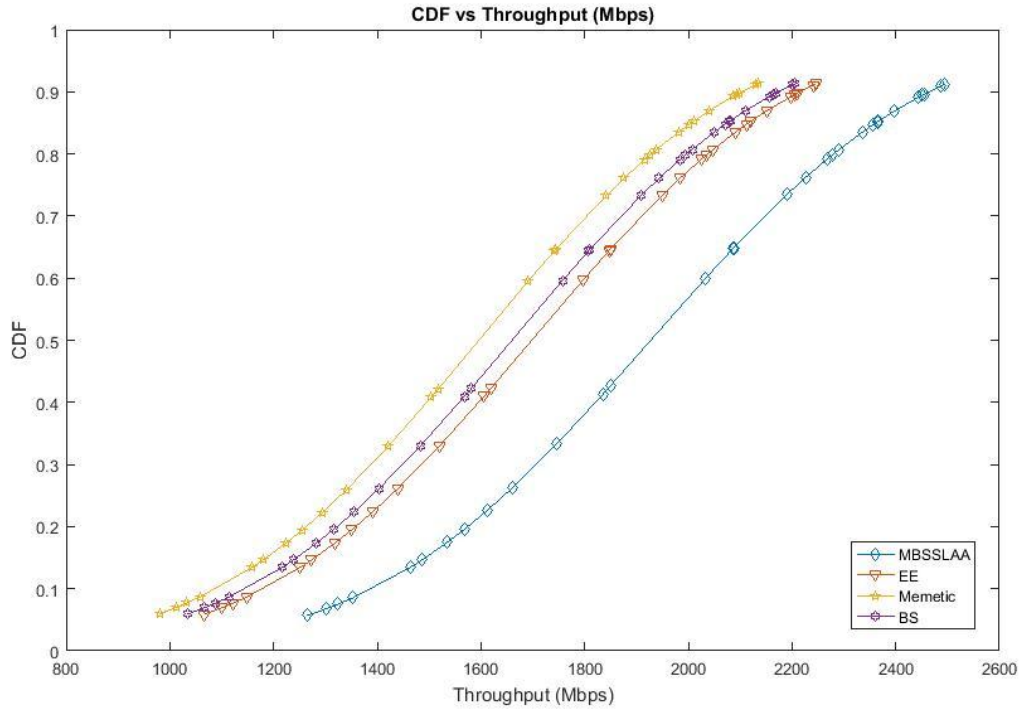


Figure 6. 20: Throughput distribution using Free Space (Birmingham)

As with the previous scenarios, the simulation results from using the algorithms to deploy small cells in Birmingham city are further represented in Figures 6.18, 6.19 and 6.20. In Figure 6.18, using the Walfisch-Ikegami model, the MBSSLAA was able to achieve throughput of 2493.77 (Mbps) over 91% of the coverage area. While using the Cost-231-Hata model, as shown by the result in Figure 6.19, the MBSSLAA achieved 2806.08 (Mbps) over 82% over coverage. This high throughput achievement is also similarly experienced by using the Free Space. In Figure 6.20, using the Free Space, the MBSSLAA achieve a high throughput of 2493.77 (Mbps) across 91% of the coverage area.

## 6.8 Impact of MBSSLA on 5G Use Cases

- High throughput distribution. From the performance evaluation of the MBSSLAA, it is apparently clear that the MBSSLAA is capable of deploying few small cells over a large densely populated urban area in such a way that it guarantees high throughput across the

area of interest. High throughput distribution, considering the requirements of the 5G use cases implies high-quality experience for network users. This is in support of the Figure 2.19, which shows the effects small cells deployment would have on a network.

- Low amortisation cost. By deploying only a few small cells that satisfactorily meet the requirements of the users, the MBSSLAA ensures that the costs of maintaining the small cell facilities are kept as low as possible.
- High SINR distribution across the area of interest as evidenced by the results means greater support for IoT deployment in a 5G ultra-dense network of small cells that are deployed using the MBSSLAA.

## **6.9 Conclusion**

In the previous Chapter, the MBSSLAA was presented as a means for deploying small cells in the 5G networks. In this Chapter, the algorithm was used to deploy small cells in different environments to verify its ability to efficiently deploy small cells such that they would satisfy the demands of network users. Findings from the simulation results show that the algorithm meets the ability to locate small cells in places that allow the network users get high network throughput as promised by the 5G networks.



## Chapter Seven

### CONCLUSION AND FUTURE WORKS

#### 7.0 Conclusion and the Future

Following from the literature reviews through to the performance analysis of the two algorithms, as presented in Chapters Four and Six, this project has shown that the algorithms developed in this work are capable achieving higher performance than existing mechanisms of resource allocation and small distribution. This Chapter presents the conclusion to work done as well as the future direction of the research in the field.

#### 7.1 CRAA

Existing literature have shown the importance of efficient resource allocation in improving the quality of experience for users. There is a growing trend in application development as mobile network users continue to grow as a result of the advancement in mobile device capabilities; leading up to the increase in traffic demands from users of various traffic requirement. This study and existing literature have shown that, for the increasing traffic in the mobile network to be efficiently supported, especially at the cell-edge, there are always the needs to develop and improve resource allocation strategies that would provide for the needs of the network users and their demands.

This study proposed the Collaborative Resource Allocation Algorithm (CRAA) that utilises the Market Game to enable users to form a coalition around different traffic flow such that improves the throughput of users as well as the spectral efficiency of the network. Numerical evaluation and simulation results from the findings show that; when compared with existing algorithms (MLWDF and EXP-Rule) and the works in the existing literature, the CRAA contributes to a

significant increase in the throughput achieved by the users. It also significantly improved the network's spectral efficiency and with sufficient fairness in the allocation of resources. The CRAA thus meets the aim of the study as it concerns optimisation, especially for existing OFDMA networks. The improvement made in the achieved throughput for network users under the CRAA is sufficient enough to give users at the cell edge a good quality of experience.

## **7.2 MBSSLAA**

The ultra-dense network has usually been about indoor network deployments to cover for low coverages and high-capacity demands of indoor users, mainly, office-based close groups. This, however, has to change to provide for the ultra-high traffic demands from outdoor users also, as well as cover for the short coverage distances that result from the use of mmWave in the 5G networks.

This study analysed the coverage of 5G small cell network deployed by the proposed network deployment algorithm, MBSSLAA. The network parameters of evaluation assumed a realistic network, which responds to the instantaneous bit rate required by users in the coverage area. The result of the coverage evaluation shows that the small cell deployment in the 5G network is capable of efficiently supporting various applications that would be running through the network, in real time, considering the amount of throughput that is offered in the network coverage scenarios.

The network model considered both indoor and outdoor users in the 5G mmWave where the line of sight and non-line of sight scenarios are modelled using the distance-dependent scenarios where it is shown that the achievable rates are significantly higher than the previous network deployment strategies and that the SINR and rate performance are mostly determined by the by the base station density which, when strategically deployed, can be minimised to save cost on the

side of the network operators. The rate provided by this deployment is efficient for the users when the considerable amount of traffic that would be going through the network as a result of technological development are brought into perspective.

In this project, using the 6GHz carrier frequency, which, from speculations in the literatures and the several models it has been used to suggest that it would be included in the 5G network range of frequencies, I have been able to deployed the 5G small cell network, which to the best of my knowledge, is the first of its kind in this future technology, by simulating the proposed MBSSLA Algorithm which finely distributes the small cell network in order to efficiently serve the users in a the selected highly populated regions of Manchester Metropolitan City, Birmingham City and Urmston.

Results from the simulations show that the algorithm is an efficient technique for deploying small cells. As seen in the throughput distribution in sections 6.7 and 6.8 of Chapter Six, the network capacity and user through provided by the network meets the network requirements needed for the 5G network to efficiently support the use cases defined for the network and shows that an operator does, in fact, not need to deploy a large number of small cells in order for it to meet the coverage requirements of its connected users. Also, by deploying a rather small number of small cells which can meet the coverage requirement, an operator gets to keep the costs of operation low as well as their capital expenditure, which further meets one of the defined constraints that the algorithm needs to achieve.

### **7.3 Research Limitation**

- The CRAA does not support users' ability to be in more than one coalition at any one time.
- The CRAA works only for OFDMA networks and hybrids of the OFDMA.

- Because the CRAA works for only OFDMA and its hybrids, it does not fall back to support users in a previous generation of network. This implies that previous generations and others that uses TDMA, CDMA and WCDMA are incapable of supporting the CRAA.
- The processing time for the algorithm means the CRAA increases delays in packet delays to the users.
- The MBSSLAA is designed to cater to the needs of deploying small cells in dense urban areas. The rural areas are not considered because, the demands from these areas are not large enough to command the deployment of small cells seeing that their demands can be catered to by macro cells.

#### **7.4 Future of CRAA**

The CRAA has a great future with the 5G network and beyond. This is because there is a strong indication that the OFDMA or its hybrid will eventually emerge as the air interface for the 5G network. Additionally, literature have shown that in the eventual deployment of the 5G ultra dense network of small cells, to have a more reliable algorithm for resource allocation means there is a need for resources to be mapped to specific service. This perception is in tandem with the implementation of the CRAA. Also, considering the throughput achieved by users with respect to the CRAA, it will be important to have an implementation of the CRAA in the future as this would help users in the IoT to achieve higher rates that would improve their quality of experience. Also, the implementation of the CRAA can be replicated in all types of OFDMA networks. Furthermore, the CRAA will not be affected by the carrier frequency, at such, it will be effective in the 5G network. also, because of the number of bandwidth that would be in the 5G network, the CRAA will further increase the throughput for users, as observed from this study; especially for IoT devices whose requirements are low throughput.

## **7.5 Future of MBSSLAA**

Unlike the CRAA, because the MBSSLAA is developed, not based on the air interface but the location and traffic demand, therefore, the MBSSLAA can be used in the location planning for other networks utilising relay stations, femto cells, pico cells and radio resource head. The MBSSLAA can be used to for different wireless network. If properly adapted, the algorithm can be used also for heterogeneous implementation across an area of interest, either for the purpose of densification or for the purpose of regular network deployment. Additionally, network densification through the deployment of ultra-dense network of small cells would tremendously increase the CAPEX and OPEX. However, small cells are necessary if the 5G network is to have a lasting impact in the future of service delivery. The MBSSLAA has shown the capability to deploy small number of small cells over a large densely populated area while providing high quality of service to the network users in an ultra-dense network.

## **7.6 Conclusion**

This study started with by introducing the different generations of mobile network technologies that are currently in existence. In progression, a detailed literature review was performed to give nuance to the study interest. From the literature review, it was determined that in order to help network users transmit at higher throughput, it is necessary to have them collaborate with one another. In addition, to help 5G small cells attain high throughput distribution across the coverage region for uses to meet higher throughput, it was also decided to have an efficient location allocation algorithm in place. To this end, two different algorithms were designed as illustrated in Chapters Four and Six. The performance evaluations of the algorithms using numerical methods and simulation show that the algorithms attain higher throughput than the existing methods with which they have been compared.

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## Appendix I

### Numerical and Simulation Data for CRAA

<b>Multimedia</b>						
	<b>Throughput (Mbps)</b>					
<b>SINR</b>	<b>CRAA Sim</b>	<b>MLWDF Sim</b>	<b>EXP-Rule Sim</b>	<b>CRAA Num</b>	<b>MLWDF Num</b>	<b>EXP-Rule Num</b>
2.114598812	0.568	0.341714286	0.261142857	0.788681987	0.48783325	0.376019984
2.355251001	0.865142857	0.564571429	0.364571429	0.816038961	0.507848539	0.392497719
2.700528835	0.998857143	0.605714286	0.369142857	0.966331196	0.620978361	0.486957429
3.989625679	1.475428571	0.659428571	0.510571429	1.252569608	0.849846484	0.684271308
4.463299645	1.621714286	0.864	0.702	1.530748348	1.086349704	0.895509192
5.082552133	1.72	0.873142857	0.806857143	1.560526091	1.112359699	0.919128423
5.239239179	1.821714286	0.972571429	0.918857143	1.589712553	1.137970478	0.942453201
5.515718539	1.836571429	1.176	0.949714286	1.626971109	1.170828067	0.972474036

5.829098741	1.859428571	1.493714286	1.045714286	1.650605764	1.191763447	0.991656775
5.987064756	2.098285714	1.578285714	1.092571429	1.820540335	1.344251916	1.132577922
5.987064756	2.228571429	1.853142857	1.376	1.896909349	1.413806654	1.19749891
7.475350888	2.668571429	2.141714286	1.538285714	1.989507959	1.49890275	1.277415725
9.095313966	3.193142857	2.867428571	1.627428571	2.246371879	1.7387165	1.50514732
9.177326176	3.393142857	3.093714286	1.803428571	2.328701115	1.816582129	1.5797763
10.69278762	3.844	3.217714286	1.92	2.596574632	2.072618108	1.827075585
11.7123904	5.549714286	3.424571429	2.184	2.896862772	2.363466773	2.110793834
13.52744578	5.842285714	3.915428571	2.205714286	3.318276365	2.776298559	2.51701309
13.99510273	6.266285714	4.629714286	2.940571429	3.319403385	2.777408062	2.518108968
17.85619205	7.992	5.576	3.226285714	3.339483522	2.797180154	2.537641345

<b>FTP</b>						
		<b>Throughput (Mbps)</b>				
<b>SINR</b>	<b>CRAA</b>	<b>MLWDF</b>	<b>EXP-Rule</b>	<b>CRAA</b>	<b>MLWDF</b>	<b>EXP-Rule</b>
	<b>Sim</b>	<b>Sim</b>	<b>Sim</b>	<b>Num</b>	<b>Num</b>	<b>Num</b>
0.588339	0.5462857	0.445714286	0.361142857	0.37055649	0.206544164	0.152766412
0.656861	0.5948571	0.491714286	0.420571429	0.44865003	0.255372369	0.190334648
1.611995	0.6508571	0.535714286	0.460571429	0.5995188	0.354652269	0.268305276
1.961783	0.6548571	0.599428571	0.543857143	0.61993028	0.368569213	0.279398539
1.965172	0.8491429	0.704	0.649714286	0.76003635	0.46707359	0.359007055
2.067926	0.9451429	0.773142857	0.665714286	0.83782682	0.523919773	0.405780853
2.221138	1.3291429	0.876	0.792571429	0.88342791	0.557923711	0.434036512
2.547296	1.4811429	0.972571429	0.812228571	0.93229925	0.594905357	0.464993555
2.813404	1.4994286	1.176	0.9376	0.97998274	0.63150966	0.495860757



3.086675	1.9737143	1.493714286	1.138285714	1.23519689	0.835503363	0.671684205
4.287082	1.9954286	1.953142857	1.627428571	1.28533598	0.877044963	0.708214952
5.082552	2.5405714	2.341714286	1.727428571	1.57515297	1.125180302	0.930796336
8.945102	3.7131429	3.267428571	1.803428571	0.84718707	0.530859233	0.411530681
9.919974	3.8422857	3.493714286	1.92	1.88358315	1.401627226	1.186103944
10.47251	4.2285714	3.517714286	2.184	1.94234195	1.455458491	1.236551001
10.52684	4.3702857	3.524571429	2.205714286	2.01240275	1.52006265	1.297366212
10.92726	4.6994286	3.915428571	2.940571429	2.11254145	1.613131695	1.385460511
11.0385	4.904	4.429714286	3.226285714	2.25608188	1.747877203	1.513911391

HTTP						
SINR	Throughput (Mbps)					
	CRAA Sim	MLWDF Sim	EXP-Rule Sim	CRAA Num	MLWDF Num	EXP-Rule Num
2.114598812	0.348571429	0.232	0.204857143	0.288778905	0.157349513	0.115459755
2.355251001	0.497142857	0.274857143	0.228571429	0.332320278	0.183293226	0.135065048
2.700528835	0.558857143	0.338285714	0.254285714	0.371194402	0.206935756	0.153065587
3.989625679	0.661714286	0.382857143	0.31944	0.487826888	0.280534847	0.209898706
4.463299645	0.793142857	0.458285714	0.357714286	0.553159028	0.323466532	0.243590493
5.082552133	0.802285714	0.502857143	0.410514286	0.598712666	0.354104956	0.267869812
5.239239179	0.948571429	0.561142857	0.441314286	0.646521998	0.386868482	0.294044192
5.515718539	0.950857143	0.701714286	0.521302857	0.736549979	0.450206631	0.345243362
5.829098741	1.161142857	0.741714286	0.561714286	0.861729843	0.541682384	0.420515419
5.987064756	1.467428571	0.859428571	0.626971429	0.900762733	0.57097823	0.444937685
5.987064756	1.577142857	0.940571429	0.682914286	0.979982742	0.63150966	0.495860757

7.475350888	1.753142857	0.953142857	0.726857143	1.252406193	0.849711314	0.684152558
9.095313966	1.766857143	1.085714286	0.829142857	1.346484003	0.928297804	0.753593731
9.177326176	1.970285714	1.102857143	0.894068571	1.586404932	1.135062349	0.939801306
10.69278762	1.997714286	1.521142857	0.984457143	1.700214028	1.235931274	1.032262288
11.07712173	2.390857143	1.586285714	1.223428571	1.884089555	1.402089732	1.186536456
11.51007001	2.576	1.619428571	1.344285714	1.914310026	1.429736	1.212418995
11.7123904	2.610285714	1.749714286	1.462857143	2.019650441	1.526770639	1.303697056
12.34707571	2.613714286	1.821714286	1.626857143	2.082744041	1.585352634	1.359109362
12.5737607	2.685714286	2.067428571	1.782857143	2.151933162	1.64996067	1.420467541
13.10559493	2.932571429	2.089142857	1.898285714	2.311320416	1.800107899	1.563961893
13.52744578	3.085714286	2.224	2.110857143	2.474021278	1.955013357	1.71315051
13.99510273	3.657142857	2.690285714	2.472	2.549570463	2.027426434	1.783236253
14.51010635	3.827428571	2.832	2.518857143	2.621826577	2.096937821	1.850697654
14.82916854	4.453714286	3.197714286	2.731428571	2.62281068	2.097886165	1.851619209
15.13466171	5.314285714	4.508571429	3.397714286	2.781460294	2.251292482	2.001074702

17.85619205		7.893714286	5.966857143	4.741714286	2.840173716	2.308306979	2.056799275
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VIDEO						
SINR	Throughput (Mbps)					
	CRAA Sim	MLWDF Sim	EXP-Rule Sim	CRAA Num	MLWDF Num	EXP-Rule Num
0.031427	0.3337143	0.270285714	0.224285714	0.28483049	0.155025165	0.113710884
0.29144	0.5017143	0.345714286	0.294285714	0.43089625	0.244115261	0.181626712
0.506738	0.5348571	0.403428571	0.344	0.48782689	0.280534847	0.209898706
1.055722	0.6514286	0.459428571	0.400571429	0.58280933	0.343343872	0.259320263
1.441054	0.7482857	0.616	0.442857143	0.72360271	0.440968369	0.337727536
1.531444	0.9142857	0.629714286	0.492	0.84162056	0.526729828	0.40810815
2.128375	1.2537143	0.709142857	0.513714286	0.88837383	0.561641264	0.437137863
2.731961	1.3554286	0.766857143	0.587428571	0.93193285	0.594626065	0.464758892
3.25407	1.456	0.808571429	0.746171429	0.97098621	0.62456479	0.489987418
3.892353	1.4902857	0.954285714	0.761714286	1.20317137	0.809206648	0.648679499
3.901539	1.6662857	1.281142857	0.823428571	1.3002417	0.889479902	0.719193988

5.027939	1.6742857	1.597714286	0.9184	1.38090727	0.957424365	0.779527995
5.23363	2.3954286	1.644571429	1.062857143	1.51863998	1.075808724	0.88595737
11.73923	3.2777143	2.08	1.470857143	1.70605934	1.241155128	1.037076659
11.93013	3.6125714	2.084571429	1.701714286	1.88537526	1.403264096	1.187634734
12.05108	3.6514286	2.333714286	1.9088	1.93344927	1.447290417	1.228882789
12.52351	4.9897143	3.084571429	2.371428571	2.24107775	1.733724521	1.500373315
13.10104	6.496	3.635428571	2.9192	2.50982047	1.98929109	1.746301138

GAMING						
		Throughput (Mbps)				
SINR	CRAA Sim	MLWDF Sim	EXP-Rule Sim	CRAA Num	MLWDF Num	EXP-Rule Num
0.169708706	0.333714286	0.242857143	0.211428571	0.300964758	0.164552787	0.12088757
0.499609451	0.56	0.281714286	0.264571429	0.395154099	0.221730917	0.164394273
0.898562689	0.608	0.364571429	0.319142857	0.525839755	0.305368104	0.229339863
1.666260089	0.669714286	0.405714286	0.360571429	0.543807099	0.317247613	0.238686017
1.705672751	0.771428571	0.559428571	0.420571429	0.633549139	0.377917428	0.286871941
2.355251001	1.058285714	0.764	0.672	0.793539412	0.491373673	0.378929349
3.51604431	1.206857143	0.773142857	0.686857143	0.827272207	0.516120102	0.399328519
4.721426137	1.312	0.812571429	0.718857143	0.931932849	0.594626065	0.464758892
4.823122457	1.622857143	0.9076	0.797142857	1.002066797	0.648632504	0.51037511
4.837138818	1.628571429	1.193714286	0.845714286	1.216936222	0.820486119	0.658535325
6.193368585	1.691428571	1.378285714	0.915714286	1.394398248	0.968891625	0.789766584

6.48035029	2.310857143	1.653142857	1.210285714	1.599361483	1.146462287	0.950201643
6.745910314	2.521142857	1.941714286	1.376	1.745078017	1.276127963	1.069370724
7.612337881	2.740571429	2.267428571	1.538285714	1.794599372	1.320763397	1.110740947
8.828421335	3.058285714	2.493714286	1.554285714	1.904099793	1.420385549	1.203658693
9.568694519	3.684571429	2.817714286	1.627428571	1.9449852	1.457887786	1.238832552
11.37880869	3.962285714	3.029714286	1.803428571	1.994848348	1.503834351	1.282062755
13.61005105	3.988571429	3.124571429	2.205714286	2.000299741	1.50887105	1.28681052
15.57599823	5.16	3.515428571	2.940571429	2.205406791	1.700139272	1.468288844



VoIP						
SINR	Throughput (Mbps)					
	CRAA Sim	MLWDF Sim	EXP-Rule Sim	CRAA Num	MLWDF Num	EXP-Rule Num
1.608579	0.9708571	0.28	0.245714286	0.95620668	0.613194572	0.480388578
3.036741	1.6028571	0.5392	0.413142857	1.2466247	0.844932185	0.679955555
3.144269	1.9613143	1.419428571	0.885714286	1.53803016	1.092698817	0.901268186
4.38315	2.5805714	1.646857143	1.339428571	2.07001002	1.573502752	1.347883043
4.546183	2.8971429	1.690285714	1.435428571	2.24386781	1.736355116	1.502888883
4.8023	3.2034286	1.941714286	1.864571429	2.52125108	2.000249472	1.756908937
5.535581	3.6114286	2.24	1.897714286	2.80530631	2.274433856	2.023681659
6.747306	3.9714286	2.570285714	1.932571429	2.8175509	2.286324472	2.035303497
8.099029	4.6194286	2.979428571	2.273142857	2.92554158	2.391411203	2.138177301
10.80295	4.952	3.168	2.683428571	3.18836375	2.648576744	2.390991313
11.30579	5.1702857	3.868571429	2.715428571	3.23379343	2.693200254	2.434990202

11.64759		5.4142857	4.157142857	2.850285714	3.23705015	2.696400885	2.438147338
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## Appendix II

### Numerical and Simulation Data for CRAA with Relay Network

<b>Multi Traffic</b>						
	<b>Throughput (Mbps)</b>					
<b>SINR</b>	<b>CRAA Sim</b>	<b>MLWDF Sim</b>	<b>EXP-Rule Sim</b>	<b>CRAA Num</b>	<b>MLWDF Num</b>	<b>EXP-Rule Num</b>
0.0541	1.948571429	0.443428571	0.064	1.113855374	0.736890814	0.585917964
0.163013	2.020571429	1.301714286	0.161142857	1.146541152	0.763176466	0.60864382
0.363135	2.258285714	1.548571429	0.285714286	1.322563822	0.908173128	0.735735877
0.529568	2.504	1.936	0.477714286	1.644830507	1.186641264	0.986959529
0.642229	3.755428571	2.004571429	0.601142857	1.946707596	1.459471112	1.240319811
0.811159	3.829714286	2.171428571	0.829714286	1.978534435	1.488777159	1.267879623
0.911993	4.100571429	2.427428571	1.057142857	2.009651824	1.517517765	1.294965191

1.268913	4.801142857	2.677714286	1.078857143	2.049268825	1.554229949	1.329643276
1.440637	5.056	2.702857143	1.286857143	2.074340184	1.577530795	1.351698141
1.799658	5.261714286	2.773714286	1.413714286	2.253384239	1.745331536	1.511475508
2.355487	6.389714286	3.152	1.616	2.333230283	1.820878134	1.583902377
2.400931	6.434285714	3.299428571	1.684571429	2.429605837	1.912578365	1.672177068
2.690062	6.987428571	3.432	2.020571429	2.694858576	2.167428031	1.919278444
2.984801	7.026285714	3.601142857	2.330285714	2.779340355	2.249236177	1.999066619
3.30132	7.508571429	3.604571429	2.350857143	3.052837211	2.515740138	2.260230808
4.624609	7.730285714	4.133714286	2.552	3.357522632	2.814948948	2.555199651
7.24789	8.754285714	4.336	3.014857143	3.782868668	3.235391025	2.971801048
8.410315	9.342857143	4.874285714	3.617142857	3.784003652	3.236516072	2.972918269
8.442744	9.8	5.454857143	3.744	3.8042238	3.256561508	2.992826095

<b>FTP</b>						
	<b>Throughput (Mbps)</b>					
<b>SINR</b>	<b>CRAA Sim</b>	<b>MLWDF Sim</b>	<b>EXP-Rule Sim</b>	<b>CRAA Num</b>	<b>MLWDF Num</b>	<b>EXP-Rule Num</b>
2.714286	2.27371429	0.308571429	0.272	0.578343216	0.340334312	0.256933442
2.714286	2.54057143	0.310857143	0.285714286	0.684815319	0.413550802	0.315517937
3.428571	3.71314286	0.944	0.725714286	0.881102402	0.556177746	0.432580774
3.571429	3.84228571	1.113142857	0.750857143	0.906855378	0.575583019	0.44878989
4.142857	4.22857143	1.234285714	0.941714286	1.079390722	0.709405305	0.562264239
4.857143	4.37028571	1.521142857	1.308571429	1.183498195	0.793146918	0.634677226
6.285714	4.69942857	1.749714286	1.537142857	1.172420421	0.78413594	0.626836524
6.428571	4.904	1.821714286	1.650285714	1.226169726	0.828071976	0.665173553
6.857143	5.05714286	2.067428571	1.870857143	1.283189692	0.875257619	0.70663852
7.714286	5.34057143	2.089142857	1.969142857	1.33828566	0.921389581	0.747457945
8.857143	6.17485714	2.290285714	2.204571429	1.625657908	1.169666924	0.971411336

9.142857	6.23885714	2.6	2.537142857	1.680876607	1.218678893	1.016379899
9.285714	6.32114286	2.820571429	2.564571429	1.994138386	1.503178589	1.281444738
9.428571	7.26971429	3.283428571	3.029714286	2.319322061	1.807689908	1.571238609
9.571429	7.36228571	3.709714286	3.098285714	2.380572863	1.865857083	1.627153864
10.14286	7.48571429	3.900571429	3.274285714	2.453366461	1.935266464	1.694074435
10.42857	7.70057143	4.013714286	3.393142857	2.557004534	2.034566987	1.790158169
10.42857	8.55885714	4.092571429	3.547428571	2.704834441	2.177073771	1.928675411

HTTP						
Throughput (Mbps)						
SINR	CRAA Sim	MLWDF Sim	EXP-Rule Sim	CRAA Num	MLWDF Num	EXP-Rule Num
2.547296	0.849142857	0.446857143	0.300571429	0.46241625	0.264163861	0.19715454
2.714286	0.995428571	0.634285714	0.300571429	0.524754426	0.304653413	0.228778529
2.714286	1.261714286	0.8	0.450285714	0.579228667	0.340930551	0.25740616
3.428571	1.329142857	0.941714286	0.652571429	0.736882426	0.450444406	0.345437018
3.571429	1.481142857	1.048	0.658285714	0.821948188	0.512195961	0.396086362
4.142857	2.114285714	1.193142857	0.715428571	0.880081761	0.555411858	0.431942365
4.287082	2.427428571	1.435428571	0.772571429	0.940153878	0.600899979	0.470033411
4.857143	2.540571429	1.654857143	0.821714286	1.050942138	0.686900294	0.542981957
5.082552	2.540571429	1.692571429	1.046857143	1.20066277	0.807154783	0.646888501
6.285714	2.697142857	1.989714286	1.086857143	1.246461623	0.844797472	0.679837294
6.428571	3.461714286	2.293714286	1.152	1.33828566	0.921389581	0.747457945

6.857143	3.713142857	2.438857143	1.238857143	1.644650362	1.186481557	0.986813111
7.714286	3.842285714	2.782857143	1.532571429	1.747764835	1.278542646	1.071604415
8.857143	4.228571429	2.936	1.643428571	2.00612913	1.51425987	1.291892099
9.142857	4.370285714	3.027428571	1.658285714	2.126821708	1.626469253	1.398129029
9.285714	4.699428571	3.497142857	1.902857143	2.319850768	1.808191028	1.571719648
9.428571	4.787428571	3.526857143	2.622857143	2.351375869	1.838102044	1.600453729
9.571429	4.904	3.546285714	2.916571429	2.460882936	1.942449941	1.70101203
9.919974	4.992	3.579428571	3.261714286	2.526212785	2.005008209	1.761516873
10.14286	5.057142857	3.905142857	3.306285714	2.597653402	2.07365647	1.828083738
10.42857	5.261714286	4.277714286	3.516571429	2.761523957	2.231961094	1.982201465
10.42857	6.174857143	4.314285714	3.869714286	2.927947974	2.393757138	2.140477011
10.47251	6.238857143	4.588571429	4.050285714	3.004979959	2.468944507	2.214251143
11.42857	6.321142857	4.699428571	4.131428571	3.078526821	2.540884987	2.284956206
12.28571	6.451428571	5.236571429	4.288	3.079527698	2.541864985	2.285920117
13.42857	7.445714286	5.881142857	4.532571429	3.240624884	2.69991432	2.441613226



VIDEO						
SINR	Throughput (Mbps)					
	CRAA Sim	MLWDF Sim	EXP-Rule Sim	CRAA Num	MLWDF Num	EXP-Rule Num
2.547296	0.63885714	0.611428571	0.457142857	0.456689405	0.260499899	0.260499899
2.714286	0.96685714	0.740571429	0.477714286	0.660936553	0.396866883	0.396866883
2.714286	1.13028571	0.766857143	0.614857143	0.736882426	0.450444406	0.450444406
3.428571	1.49828571	1.354285714	0.677714286	0.859890007	0.540310347	0.540310347
3.571429	1.72457143	1.594285714	0.731428571	1.035182796	0.674505935	0.674505935
4.142857	1.792	1.694857143	0.910857143	1.176913147	0.787787645	0.787787645
4.287082	1.94857143	1.781142857	1.076571429	1.231967017	0.832842748	0.832842748
4.857143	2.26971429	1.925714286	1.125714286	1.282764335	0.874903493	0.874903493
5.082552	2.38457143	2.036571429	1.556571429	1.327929356	0.912678971	0.912678971
6.285714	2.41371429	2.186285714	1.635428571	1.590199011	1.138398305	1.138398305
6.428571	2.45828571	2.239428571	1.64	1.69722616	1.23326264	1.23326264

6.857143	2.52114286	2.348571429	1.670857143	1.785215042	1.312284126	1.312284126
7.714286	2.56057143	2.381714286	1.828571429	1.933742401	1.447559544	1.447559544
8.857143	2.64228571	2.419428571	2.196571429	2.132993338	1.632238308	1.632238308
9.142857	2.80457143	2.522857143	2.243428571	2.321193027	1.809463326	1.809463326
9.285714	2.87657143	2.525714286	2.450285714	2.37131518	1.857051205	1.857051205
9.428571	3.10514286	2.964	2.469714286	2.689418088	2.162169265	2.162169265
9.571429	3.38514286	3.080571429	2.561142857	2.964467607	2.429380643	2.429380643

<b>GAMING</b>						
		<b>Throughput (Mbps)</b>				
<b>SINR</b>	<b>CRAA Sim</b>	<b>MLWDF Sim</b>	<b>EXP-Rule Sim</b>	<b>CRAA Num</b>	<b>MLWDF Num</b>	<b>EXP-Rule Num</b>
2.547296	0.962285714	0.557714286	0.412571429	0.480011419	0.275479988	0.205957537
2.714286	1.604571429	0.782857143	0.529142857	0.612290978	0.363347366	0.275231593
2.714286	1.722285714	1.212571429	0.652571429	0.7866314	0.486340393	0.374793907
3.428571	1.741714286	1.216	0.757714286	0.80989818	0.503339771	0.388779494
3.571429	1.978285714	1.253714286	0.773714286	0.92394396	0.588543977	0.459651949
4.142857	2.099428571	1.312	0.940571429	1.119674944	0.741555439	0.589943472
4.287082	2.318857143	1.418285714	1.133714286	1.159900344	0.773979907	0.618013288
4.857143	2.625142857	1.475428571	1.366857143	1.282764335	0.874903493	0.706326231
5.082552	2.814857143	1.581714286	1.554285714	1.36363401	0.942784837	0.766480037
6.285714	2.835428571	1.858285714	1.626285714	1.605458224	1.151834204	0.955107011
6.428571	2.877714286	1.860571429	1.653714286	1.799854253	1.325515654	1.115155412

6.857143	3.195428571	1.984	1.822857143	2.019922779	1.527022785	1.303935084
7.714286	3.434285714	2.212571429	1.870857143	2.174126995	1.670761798	1.440274344
8.857143	3.552	2.459428571	1.950857143	2.226180901	1.719688069	1.486956777
9.142857	3.632	2.52	2.02	2.340730593	1.827995071	1.590739724
9.285714	3.669714286	2.730285714	2.245714286	2.383323798	1.86847472	1.629673816
9.428571	3.712	3.128	2.315428571	2.435150495	1.917870017	1.677282354
9.571429	4.115428571	3.156571429	2.384	2.440808948	1.923271991	1.6824953
9.919974	4.163428571	3.340571429	2.512	2.652734626	2.126742763	1.879675234

VoIP						
Throughput (Mbps)						
SINR	CRAA Sim	MLWDF Sim	EXP-Rule Sim	CRAA Num	MLWDF Num	EXP-Rule Num
2.547296	1.31087738	0.898375968	0.727060689	1.078857143	0.430857143	0.411428571
2.714286	1.63827453	1.180831726	0.981634979	1.117714286	0.835428571	0.461714286
2.714286	1.95449805	1.466635978	1.247052179	1.204571429	0.88	0.491428571
3.428571	2.51304201	1.99237889	1.749289681	1.693714286	1.046857143	0.633142857
3.571429	2.69228541	2.164940665	1.916855706	1.781714286	1.208	0.668571429
4.142857	2.97612141	2.440756777	2.186578024	2.100571429	1.264	0.738285714
4.287082	3.26479803	2.723679926	2.465062562	2.101714286	1.264	0.835428571
4.857143	3.2772068	2.73588415	2.477107942	2.204571429	1.318857143	0.870857143
5.082552	3.38654036	2.843544255	2.583465773	2.905142857	1.352	0.914285714
6.285714	3.651958	3.105725547	2.843114756	3.451428571	1.395428571	1.098285714
6.428571	3.69775541	3.151064219	2.888093004	3.469714286	1.475428571	1.265142857

6.857143		3.70103769	3.154314604	2.89131832	3.550285714	1.886857143	1.665142857
7.714286		3.70424551	3.157491389	2.894470701	3.609714286	2.028571429	1.834285714