Cape Peninsula University of Technology

PERFORMANCE IMPROVEMENT OF LTE AND LTE ADVANCED NETWORKS

By

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DECLARATION

I, Vuyo Pana, declare that the contents of this thesis represent my own unaided work and that the thesis has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my own opinions and not necessarily those of the Cape Peninsula University of Technology.

17 November 2019

Signed **Date**

ABSTRACT

It has been a decade with Long Term Evolution (LTE) as mobile radio access technology (RAT) and in this, period it became the favoured broadband communication technology. LTE, as a 3rd Generation Project Partnership (3GPP) technology, has entered the frozen stage, no future enhancement beyond release 14 only minor revisions. While over the same time, the revolution in mobile handsets, and internet of thing (IoT) “connected devices” have expedited the surge in desire for more data resources, which are ubiquitous. Undoubtedly LTE as a technology has been the most dominant wireless medium, in transporting broadband services for both voice and data. Thus the efficient operations of an LTE Heterogeous network(HetNets) are of ultimate importance, both in terms of the load balance and the performance delivered to users.

The packet scheduling is an advanced radio resource management (RRM) mechanism, which plays a key fundamental role in the delivery of time-frequency resources to users in uplink and downlink. Thus the operation of the packet scheduler determines the overall LTE network performance and also the services level for the user's example (e.g.) the quality of service (QoS), throughput. In this study, two packet algorithm schemes were proposed, firstly one that focuses on modulation and coding scheme(MCS), fairness and QoS called Flexible Fair Allocation Scheme (FFAS). It was evaluated with contemporary algorithms Least Load and Greedy algorithm. The results for FFAS were superior for both simulations scenarios. The second proposed packet scheduling algorithm area of focus was with massive machine type communication (MTC) for HetNets. Where the PR-M2M scheduler was proven to deliver superior outcomes in distributing resources for a human to human(H2H) as well as for Device to device(D2D) communication.

The simulations were piloted in Matlab using the Vienna LTE Downlink System simulator, where we were able to conduct diverse network analysis. The network simulations produced outcomes which indicated FFAS and PR-M2M are the best algorithms for LTE Advanced networks.

In conclusion, it should be noted while access to additional spectrum is an issue, optimal utilization of current license spectrum is of utmost importance. With carrier aggregation as an LTE Advanced feature, operators are able to efficiently use the available spectrum. The scheduling algorithms proposed plays a pivotal roll in controlling how the resources are distributed to users. Therefore these two scheduling schemes will be contributing to improved performance of LTE Advanced networks.

ACKNOWLEDGEMENTS

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DEDICATION

To my wife Somila Sabata and daughters Zimi, Mmangaliso for the love and support during the period of the studies.

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PUBLICATIONS

This study result in the following publications:

- Pana, V., Balyan, V. & Groenewald, B. 2018. Fair Allocation of Resources on Modulation and Coding Scheme in LTE Networks With Carrier Aggregation. *2018 International Conference on Advances in Computing, Communication Control and Networking (ICACCCN)*. 467–470. DOI: 10.1109/ICACCCN.2018.8748355.

- Journal Submission

  Pana, V., Balyan, V. & Groenewald, B. n.d. The Research Article titled "Machine to Machine and Cell to Cell Traffic Handling Using Relay and Carrier Aggregation Prioritize on LTE network," submitted and received a response with the assigned the number 2304853.

GLOSSARY

Abbreviations	Definition
2G	Second Generation
3G	Third Generation
3GPP	3rd Generation Partner Project
BBU	Baseband Unit
CA	Carrier Aggregation
CC	Component carrier
CQI	Channel Quality Indicator
EB	Exabyte
EPC	Evolved Packet Core
EPS	Evolved Packet System
ERAA	Energy-efficient RB Allocation Algorithm
EUTRA	Evolved Universal Terrestrial Radio Access
EUTRAN	Enhance Universal Terrestrial Radio Access Network
FDD	Frequency Division Duplex
GA	Greedy Algorithm
GBR	Guaranteed bit rate
IMT	International Mobile Telecommunication
IMT 2000	International Mobile Telecommunications 2000
IMT ADVANCED	International Mobile Telecommunications Advanced
ITU	International Telecommunication Union
LTE-A	Long Term Evolution Advanced
MAC	Medium Access Control
MBR	Maximum bit rate
MCS	Modulation and Coding Scheme
MHz	MegaHertz
MIMO	Multiple In Multiple Out
MME	Mobility Management Entity

MRFU	Multi-mode Radio Frequency Unit
PCELL	Primary Cell
PDCP	Packet Data Convergence Protocol
PRB	Physical Resource Block
QoE	Quality of Experience
QoS	Quality of Service
RB	Resource Block
RLC	Radio Link Control Link
RRC	Radio Resource Control
RRM	Radio Resource Management
RRU	Remote Radio Unit
SAE	System Architecture Evolution
SCELL	Secondary Cell
TBS	Transport Block Size
TDD	Time Division Duplex
UE	User Equipment
UMTS	Universal Mobile Terrestrial Systems
WP5D	Working Party 5D

CHAPTER ONE
INTRODUCTION OF LONG TERM EVOLUTION

1.1 Introduction

The evolution of cellular technology from voice service to broadband communication has had a major impact on the developing world. This has contributed to information accessibility and resources previously not easily accessible easier to access.

The deployment of Long Term Evolution (LTE) networks currently stands at 194 worldwide and with 19 of those LTE Advanced, these networks are located in 95 Countries(Virgin et al., 2017). One can note from a global picture regarding LTE that the adoption of LTE Advanced is still at an infant stage particularly in the developing world, but that is rapidly changing.

1.2 Background to the research problem

Limited spectrum availability has meant user experience is not always at the expected level. Hence a close analysis of LTE Advanced and particular how CA is implemented and how the scarce bandwidth resources are used optimally. As some MNO in the developing world still has a huge 2G (second-generation) subscriber base. Therefore refarming of current spectrum used in 2G for LTE Advanced is not an easy matter.

The technology of carrier aggregation was commercially implemented for the first time in South Korea in the year 2013 (Lee et al., 2017) and in South Africa by Telkom Mobile in November 2014. The optimization of LTE Advanced networks commercial has taken steady progress, where the spectral usage tested in a commercial network, with a few of the advance feature activated.

All commercially launched LTE networks in South Africa have spectrum availability challenges, so the optimal usage of the licensed spectrum is very important because the legacy Radio Access Technologies (RAT) such as the second-generation (2G) networks is still very much in use. An operator has to meticulous plan how they are going use their license spectrum for all the different, RAT technologies to be able to maximize profit and gain returned on Network investment.

1.3 Statement of the Research Problem

Optimal usage of acquired available spectrum by using carrier aggregation in a commercially launch the LTE-A network in South Africa. The fundamental operations of packet scheduling in delivering resources to users in a fair manner and meeting user requirements as different service applications.

1.4 Three modes of Carrier Aggregation

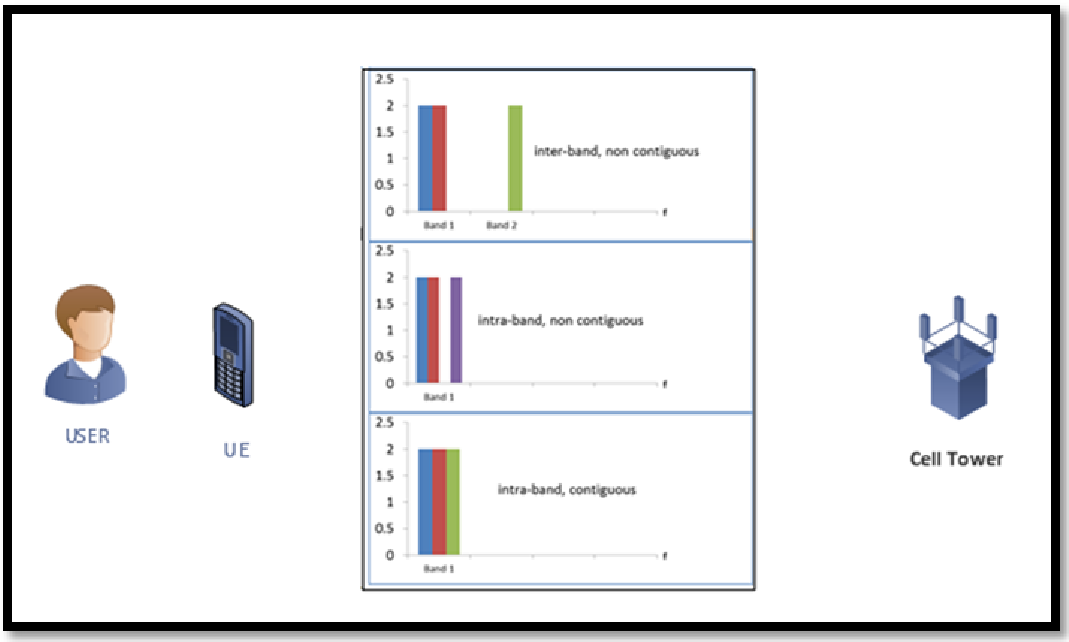

Figure 1.1: Three modes of Carrier Aggregation

The system capacity and spectral efficiency improvement technique called carrier aggregation were issued on the 3GPP LTE Release 10 document. Carrier aggregation is a technique that uses aggregate multiple component carriers (CCs), these component carriers bandwidth range from 1.4, 3, 5, 10, 15 or 20 MHz. The LTE A system has the maximum capacity of 100 MHz that is when one aggregated 5 component carriers of 20 MHz concurrently(Gao et al., 2016). Carrier aggregation has three types of patterns: *inter-band non-contiguous Carrier aggregation*, *intra-band contiguous carrier aggregation,* and *intra-band contiguous carrier aggregation*, as revealed by Figure 1.1 Contiguous component carriers allocated in the same band are referred as intra-band carrier aggregation. Non-contiguous component carriers allocated in the same band are referred to as Intra-band non-contiguous carrier aggregation. Non-contiguous component carriers apportioned in altered bands that are called Inter-band

1.5 Hypotheses and research questions

The LTE scheduler has an impact on the user equipment and can improve the performance of an LTE Network.

1.5.1 Sub-problem 1

Analyse the scheduling algorithm and the factors that have an impact on its operation in LTE Advanced.

1.5.2 Sub-problem 2

What type of LTE scheduler can both benefit the user and Mobile Network operator?

1.5.3 Sub-problem 3

How are downlink and uplink scheduling different and similar?

1.6 Literature review

Recent trends point to the huge increase in demand for mobile data traffic mostly high-bandwidth applications like video conferencing, video chatting, live uploading etc. The mobile data is expected to achieve 52 EB every month and video traffic is expected to grow nearly 70% by 2021 a report admit by Ericsson (Qureshi, 2016).

With the carrier aggregation (CA) technique introduced with Long Term Evolution(LTE) release 10, in LTE Release 10 multiple component carriers (CCs) are aggregated together from different eNodeBs(Cheng et al., 2015). Use of multiple CCs together provides a wider carrier for transmission, a CC can support up to 20MHz and maximum of five CCs can use simultaneously, which provides a total bandwidth of 100MHz. Furthermore, the modulation and coding scheme (MCS) are also utilized to enhance the capacity and reliability of the network. A higher coding rate MCS indicates that a high transmission rate is used for transmission in a better quality channel and a low coding MCS indicates that reliable transmission is done in poor channel conditions (Fan et al., 2011). In order to ensure better transmission with fairness it necessities LTE-A radio resource management (RRM) to optimize performance considering all the three: allocated resource block (RB), MCS used and number of CCs employed.

In order to cope with the increased bandwidth demand due to multimedia applications like online gaming, video streaming etc. the requirement of a resource allocation scheme increases. In literature, several allocation schemes are available which focus on the quality of services (QoS) required. An ant colony method which minimizes the RBs allocated named as ACOH is proposed (Allocation et al., n.d.) which optimizes resources. A scheme which works on channel quality indicator (CQI**)** feedback method and optimizes a number of allocated RBs, allocated power and optimizes the network throughput is proposed in (Zhang et al., 2013). These two schemes do not support CA.

For providing real-time services while maintaining QoS which uses CA is proposed in (Miao et al., 2014), the scheme treats CC and scheduling of packets differently and also without a link adaptation. However, in (Liao et al., 2014) a greedy algorithm (GA) that maximizes the throughput of the network which considers MCS used along with allocated CCs and RBs. An Energy-efficient RB Allocation Algorithm (ERAA) algorithm is proposed in (Rostami et al., 2016) which works with user equipment's (UEs) with variable support to CA. The scheme allocates the resources with fairness and maximizes the overall throughput. However, both these schemes do not support multimedia applications, which require QoS.

The proportional fairness (PF) is used to provide fairness in the distribution of resources among all active UEs (Martin-Sacristan et al., 2015). The joint resource allocation scheme (Rostami et al., 2015) proposes a near-optimal scheme with lower complexity. A linear approach is used to consider resource allocation of LTE-A instead of a non-linear approach (Liu, 2016). For the LTE based MIMO/OFDMA networks an energy-efficient resource allocation is proposed in (Xiao et al., 2015) which provide services to users guaranteed QoS. The QEPEM method proposed in (Mushtaq et al., 2016) improves QoS due to reduced loss of packets in network and also improves fairness in allocation to UEs. It also enhances the QoE and provides multimedia services due to better QoS. With results of the high-level user, satisfaction is achieved by maintaining QoS even in the power saving mode (Mushtaq et al., 2016).

Resource allocation strategies for carrier aggregation networks two kinds: independent carrier scheduling and joint carrier scheduling(Sun et al., 2017). The JCS scheme has one resource scheduler for all the component carriers of eNodeB and on the other hand, whereas ICS each component carrier has independent resource scheduler(Zhang et al., 2010). The performance of ICS can closely match that of JCS, only dependents how well design resource allocation algorithm of the LTE Advanced network is (Sun et al., 2017).

The outcomes achieved is that the cell throughput by (QoS aware fair resource allocation)QA-PFRA is about 70% higher than that obtained by ERAA, and QA-PFRA can also achieve higher throughput compared with GA when the UEs are sparsely distributed in the cell. Furthermore, we can observe that Jain's fairness index obtained by QA-PFRA is about 10% higher than that obtained by GA and 40% higher than that obtained by energy-efficient resource block allocation algorithm (ERAA)(Yan et al., 2016). The algorithm has two stages, one related QoS of the UE's and the second allocating the CC to other UEs.

The Preamble Priority Aware (PPA) Packet Downlink Control Channel (PDCCH) resources allocation algorithm to provide Quality of Service (QoS) differentiation in the Random Access (RA) algorithm introduces the concept of preamble priority awareness for allocating PDCCH resources which allows UEs with prioritized preambles sequences to increase the chances of accessing the network and to reduce the access delay under heavy load in the PRACH. It is also relevant for a user requiring low latency and access guarantees(Astudillo et al., 2017). The slot TTI based resource management of LTE Advanced for low latency. This is done by introducing the enhanced Packet Data Control Channel in LTE-A, which is backwards compatible with 5G (Hwang et al., 2017).

LTE at present has three types of spectrum allocation schemes. These schemes are as follow numbers one focuses on the throughput and the second only focuses on the fairness among users. Lastly, the third scheme is centred on the trade-off between throughput and fairness (Wang and Wang, 2017). The experimental outcomes show that the technique realizes the dynamic occupancy of free resource blocks in adjacent cells improves the throughput on the basis of ensuring the fairness of users, improves the quality of user service at the edge of the cell and the spectrum utilization (Wang and Wang, 2017).

The RRM radio resource management function of LTE Advanced with carrier aggregation is framed as the Integer Linear Programming, considering standard-compliant Long Term Evolved constraints. Furthermore, it is proven that the resultant Integer Linear Programming can be solved optimally using Linear Programming techniques instead of combinatorial or GA. Duality gap is zero, and the computationally-efficient solution offered above coincides with the optimal solution (Cheng et al., 2015). The simulation results demonstrate the high potential of the proposed method, in terms of significant gains in overall network throughput, and improvements in QoS of UEs, measured by UE throughput (Rostami et al., 2017).

1.7 Objectives of the research

Analyse the use of carrier aggregation in LTE Release 10 and beyond and research how it has necessitated changes in the operations of the downlink scheduling. Provide a case study of the different types of schedulers currently used and suggest a scheduling scheme, which satisfies user experience, fairness and optimizes the mobile network so that maximum resource is the utilization.

1.8 Research design and methodology

An assessment will be undertaken of the latest literature information in the area of International Mobile Telecommunication IMT systems. Secondly, network data raw to be closely scrutinized as to how modern LTE Advanced networks operate, that standard of network availability, scheduling criteria, differentiation between data and voice services. Lastly, the simulation will be performed to propose a scheduling algorithm with different traffic load models. The two pictures (Figure 1.2 and Figure 1.3 on page 7) is what constitutes a physical eNodeB which main represent RAN equipment in LTE. The

Figure 1.2: eNodeB baseband unit sample site Huawei

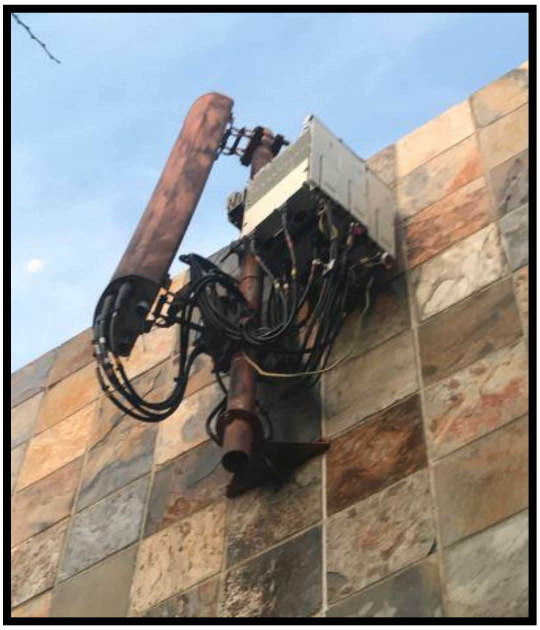

Figure 1.3: eNodeB remote radios for 3 bands 900 MHz, 1800 MHz and 2100 MHz

eNodeB is responsible for scheduling both in the uplink and in the downlink.

1.9 Preface of the thesis

This thesis has six chapters with a brief highlight of each below.

Chapter One: Introduction Long Term Evolution

A brief description on the area the for research work into LTE release 10 primarily observing carrier aggregation and how the scheduling of resources impact performance.

Chapter Two: Long Term Evolution Release 10 and beyond

Evolution of LTE into LTE Advanced and one of the first 4G technologies according to IMT Advanced specification.

Chapter Three: Carrier Aggregation

Overview of carrier aggregation and the implementation of the feature and its implication on schedule.

Chapter Four: Flexible Fair Allocation Scheme (FFAS)

In this chapter, an FFAS is proposed for the downlink of LTE Advanced (LTE release 10). The scheme allocates resource base on type, priority while keeping fairness.

Chapter Five: Heterogeneous Network for C2C and D2D Communication

This is a scheduling algorithms scheme serving both C2C and D2D communication, operating HetNets with Relays Station (RS). RS increases network capacity in dense areas, providing connectivity opportunity for more devices. The PR-M2M scheduling is compared with two well know scheduling algorithms.

Chapter Six: Results and Conclusion

The thesis delivers and conclusion remarks.

1.10 Delineation of the research

- The study is limited to the area of the radio access network (RAN) and the eNodeB.
- Operation of the carrier aggregation
- Scheduling of resources in the downlink
- Schedulers used and type of schedule

1.11 The significance of the research

Carrier aggregation is a 3GPP release 10 feature and the operator with the help of the vendor determines scheduling strategy.

Areas of significance for the research is the user experience improvement, which translates to a better quality of service.

Secondly, fundamental input is for the operator to determine the type of scheduler to use for different types of traffic models about capacity.

1.12 Research output, results and contributions

LTE Technology as a mobile broadband solution that meets the current need for big data with an improve latency which meet the requirements of a gaming enthusiast and massive MTC communication. With carrier aggregation feature enhancement for LTE A Pro aggregating up to 32 CCs for release 14. A detailed outline of the two proposed scheduling algorithms.

1.13 Summary

Mobile-broadband growth globally has had a positive impact on the developing world. It has permitted a cumulative number of people, joining the information society and also profiting from the many facilities and applications provided through the Internet(*Measuring the Information Society Report 2016*, 2016). Hence, improvement in the performance of LTE networks in South Africa by using all the available resources and at times using innovation, helping with growth in other areas of the economy. The feature of CA provides LTE Advanced services that have an improved throughput and shorter latency. LTE Advanced is backwards compatible with LTE and forward compatible with LTE Advanced Pro. LTE Advanced Pro is the next step towards IMT 2020.

CHAPTER TWO
LONG TERM EVOLUTION RELEASE 10 AND BEYOND

2 Background

The mobile communication technology over the decades has been divided into generations (Wiley, n.d.). The current generation the fourth (4G) also referred to as Long Term Evolution (LTE) supports mobile broadband. The initial mobile generation (1G) was an analogue mobile radio system in the 1980s. That was followed by the second generation 2G which provided a predominantly a voice service. The 3rd generation (3G) that followed the earliest mobile system to handle broadband data (Wiley, n.d.). LTE radio technology is the most aggressive deployed mobile technology in the history of the in-

Figure 2.1: Generation of mobile communication systems

dustry(“Wireless Technology Evolution Towards 5G”, 2017). One of the reasons for the success is the careful development of the Third Generation Partnership Project (3GPP) standards. In this chapter, will focus on progression towards LTE and LTE Advanced, ITU (IMT Advanced) and the Evolved Packet System (EPS) architecture.

2.1 Overview of Network Architecture

The Evolved Packet System (EPS) has two distinct parts, radio access network (RAN) Long Term Evolution (LTE) and a non-radio portion the core network of the system architecture denoted as the evolved packet core (EPC). The LTE and EPC networks are full packet-switched(TutorialsPoint, 2016). LTE Advanced is an LTE technology that was launch in 3GPP release 10 and forms part of International Mobile Telecommunication (IMT) Advanced family. LTE Advanced specifications exceed 4G’s requirements as per IMT Advanced standards(Chairman, 2009).

2.2 Progression towards LTE and LTE Advanced

The advancement in mobile device development has progressed so rapidly that advanced data services, such as web browsing, facebook live and online activities are now possible on smartphones. These activities are ubiquitously available, which has driven in part the development and progression in GSM to the latest system of LTE. Smartphone activities are also part of the evolution of the environment where the mobile system is deployed and operational. Among the challenges are other technologies like Worldwide Interoperability for Microwave Access (WiMAX), WIFI and competition between mobile operators. The new advancements meant changes in the design of the mobile network from circuit switch to packet switch where every device is a signed an IP address(Zorba and Verikoukis, 2016)(Dahlman and Sko, 2014). Three of the main design considerations, ***capacity***, ***delay*** and ***data rate*** (***Table 2.1***).

Table 2.1: Three Main Design Parameters for LTE

Parameter	Description
Capacity	**Spectral efficiency** is the measure of ***capacity***. Mobile System Operators are only looking for peak data rates only, but that the average data rate per eNodeB to the end-user provider's service level that meets users' requirements. Which related to Quality of service (QoS). For the operator using the spectrum to the maximum is ideal and no operator has enough spectrum when asked.
Delay	**Latency** the time it takes a packet sent from client to server and back. It is a very important parameter for interactive web browsing, gaming and video conferencing.
Data Rate	With the invention of smart TVs and streaming and file, the transfer has a push for higher ***data rate*** exceeding Megabit per second for the third generation and getting close to Gigabit per second for the fourth generation.

The mobile technology of LTE does not function in isolation it operates operability with the legacy 3GPP technologies (2G/EDGE and UMTS or 3G) and non-3GPP Technologies (Wi-Fi, CDMA2000 and WiMAX).

There are standard bodies namely the International Telecommunication Union (ITU) that define flexible interoperability between these technologies. Latest mobile trends and future prediction indicate that data usage is only going to increase. Few current reports indicate this phenomenon of an increase in mobile data usage(‘Ericsson Mobility Report June 2018’, 2018)(Qureshi, 2016). Another factor that has contributed positively subscription is an increase in low-cost smartphones in the market. As it stands currently more data traffic is being carried on smartphones than on Laptops, desktop, tablets all combined(‘Ericsson Mobility Report June 2018’, 2018).

Table 2.2: Global Figures (‘Ericsson Mobility Report June 2018’, 2018)

Global key figures

Mobile subscriptions	2016	2017	2023 forecast	CAGR** 2017–2023	Unit
Worldwide mobile subscriptions	7,500	7,790	8,880	2%	million
– Smartphone subscriptions	3,760	4,330	7,170	9%	million
– Mobile PC, tablet and mobile router* subscriptions	240	250	320	4%	million
– Mobile broadband subscriptions	4,450	5,300	8,330	8%	million
– Mobile subscriptions, GSM/EDGE-only	2,970	2,420	520	-23%	million
– Mobile subscriptions, WCDMA/HSPA	2,300	2,390	1,750	-5%	million
– Mobile subscriptions, LTE	1,890	2,740	5,490	12%	million
– Mobile subscriptions, 5G			1,080		million
Mobile data traffic*					
– Data traffic per smartphone	2.2	3.4	17	31%	GB/month
– Data traffic per mobile PC	7.8	9.8	27	18%	GB/month
– Data traffic per tablet	3.6	4.6	13	18%	GB/month
Total data traffic***					
Total mobile data traffic	8.8	15	107	39%	EB/month
– Smartphones	7.2	13	100	41%	EB/month
– Mobile PCs and routers	1.3	1.6	4.4	19%	EB/month
– Tablets	0.3	0.5	1.8	26%	EB/month
Total fixed data traffic	70	80	250	20%	EB/month

This increase in data usage is sure to continue and even with a growing subscriber base for mobile broadband communication

2.3 Regulation IMT International Telecommunication Union (ITU) and background

The mobile communication uses radio frequency spectrum and it allocated differs per region. The frequency spectrum is a limited resource used for different possibly interfering technologies (e.g. television and radio broadcasting, radar, medical and land mobile etc.). Therefore it is regulated by national laws enforced by national bodies which work collaboration with global coordinator the International Telecommunication Union (ITU)(‘Handbook on Global Trends in IMT’, 2015).

The ITU a United Nations body in authority for information and communication technology (ICT) worldwide deals with the private sector and governments in terms of regulation and licensing(Zorba and Verikoukis, 2016)(Regula, 2016). ITU undertakes the regulatory and licensing function through the International Telecommunication Union Radiocommunication Sector (ITU-R). The ITU-R carry out its mandate by adopting policies and regulations at Radiocommunication Assemblies and (WRC) World, Regional Radiocommunication Conferences and these endeavours are supported by Study Groups(ITU-R, 2007). The (ITU-R) Working Party 5D is responsible for International Mobile Telecommunication systems, which includes IMT- 2000 (3G) and IMT-Advanced (4G)(Series, 2012).

The WP5D defines a technical specification for International Mobile Telecommunication in collaboration with relevant stakeholders and preserve set of endorsements for IMT-Advanced and its predecessor IMT-2000.

The Standard Development Organization (SDO's) writes the technical specifications for the recommendations as stated by ITU-R(Hspa et al., n.d.). Some of these SDO's represents regions in the global body of 3GPP and are referred to as Organizational Partners in 3GPP. The seven Organization Partners, which form 3rd Generation Project Partnership, are the Association of Radio Industries and Businesses (Japan), China Communication Standard Association (China), The European Telecommunication Standard Institute (Europe), The Alliance Telecommunication Industry Solutions (USA), Telecommunications Technology Association (South Korea), Telecommunications Standard Development Society (India) and Telecommunication Technology Committee (Japan)('3Gpp_Agreement.Pdf', n.d.). There is another two main organization outside of 3GPP developing standards relevant to IMT requirements and shaping the landscaping of mobile communication those are 3GPP2 and IEEE LAN/WAN[5] standard committee(Chevallier and Brunner, 2006)(Holma et al., 2008).

In October 2010, the Radiocommunication Sector (ITU-R) definite two technologies

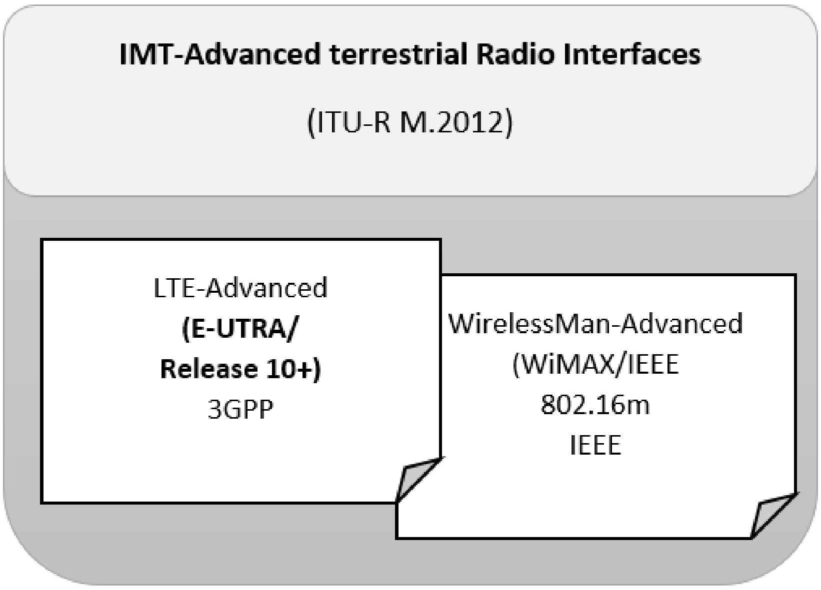

Figure 2.2: Radio interface technologies IMT-Advanced (Dahlman & Sko, 2014)

would form part of its initial release of IMT-Advanced, LTE release 10 (LTE Advanced) WirelessMan-Advanced based on the IEEE 802.16m specification(ITU, 2017)(Dahlman and Sko, 2014). Both these technologies form part of the IMT-Advanced family.

The Work-Study Group Party 5D for Radiocommunication Sector (ITU-R) adopted a similar process for defining IMT-Advanced as was for IMT-2000. Studies were undertaken with specific focus areas like the market, radiofrequency spectrum required and the principles for standardization.

For adoption six candidate technologies presented for assessment in 2009; the assessment was executed in cooperation with external bodies, national and industry fora. One of the technologies assessed was LTE 10th Release. As a result on October 2010, two technologies were confirmed to meet the requirements for the initial release of IMT-Advanced and form part of first release or IMT-Advanced they were Wireless-Man-Advanced based on IEEE 802.16m specification and LTE release 10, Figure 2.2 above.

The standard-developing body 3GPP specifies telecommunication standard in documents called releases. LTE technology started at release 8 as the first LTE release, the

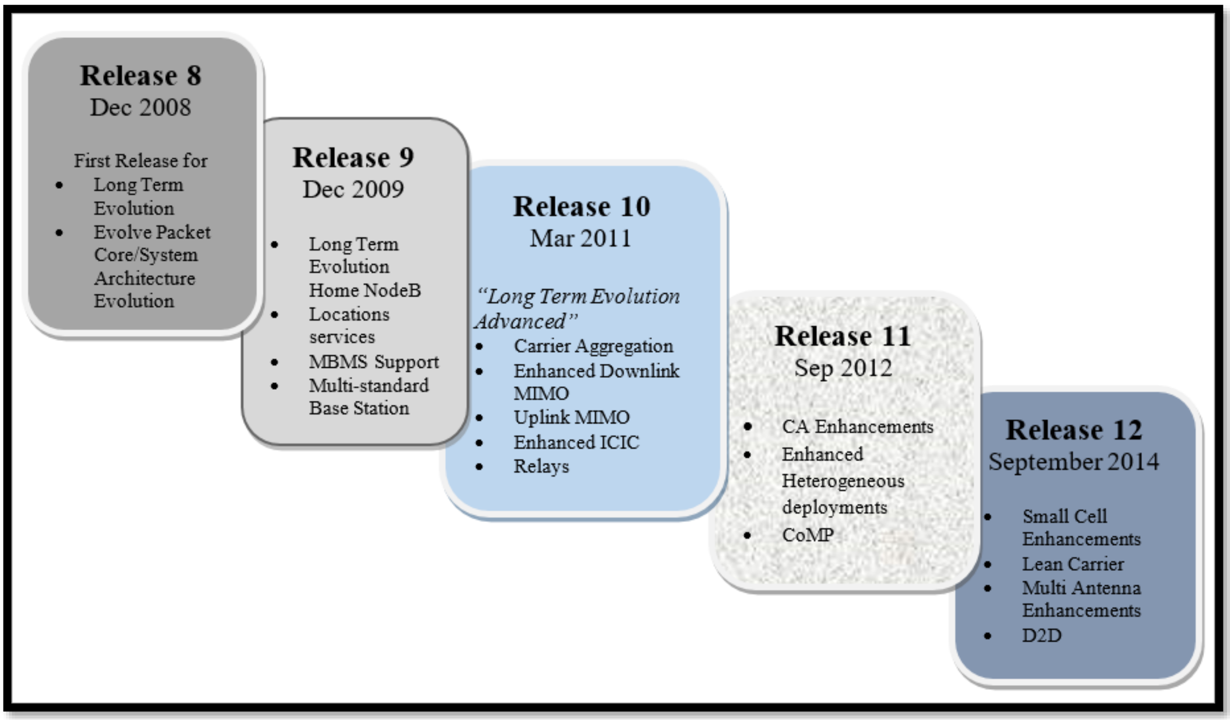

Figure 2.3: Releases of 3GPP for LTE (Dahlman & Sko, 2014)

2.4 LTE Network Architecture

As stated in the introduction, EPS has two parts the SAE (System Architecture) which includes the Evolved Packet Core and LTE RAN (E-UTRAN).

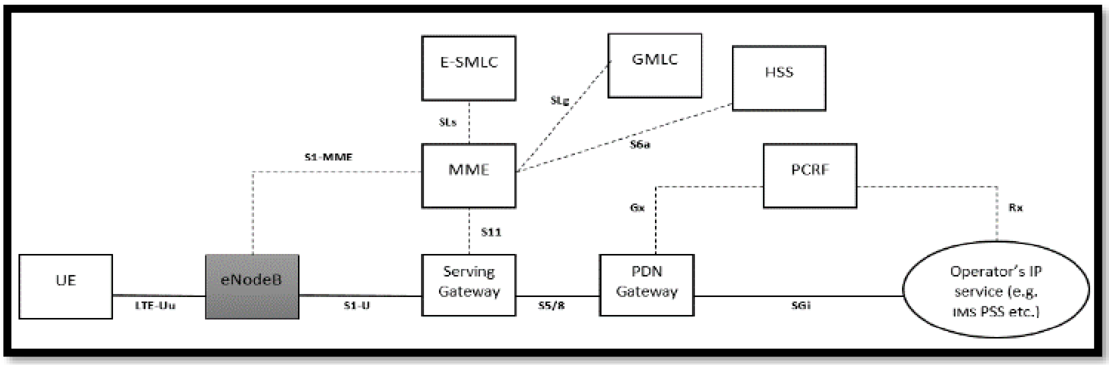

Figure 2.4: The EPS network elements

The EPS bears direct IP data from the gateway in PDN to the UE, an IP packet flow with a defined Quality of Service (QoS) is a bearer. The commencement and the release of bearers as required by applications is the task of both the EPC and LTE.

The Internet Protocol Multimedia Subsystem (IMS) is a component of the EPC, manages the quality of service of the entire system(4G Americas, 2014). The IMS is also an enabler for varies services these range from voice, video, instant messaging.

2.4.1 EUTRAN

The radio access network (RAN) of LTE has a flush architecture consisting of the eNodeB, as illustrated in Figure 2.5. LTE RAN when compared to previous telecommunication technologies, which had a central controlling node (e.g. base station controller (BSC) in 2G and radio network controller (RNC) in UMTS. Whereas in LTE the functions of the controlling node are incorporated to the eNodeB. The flat structure helps not only with the improvement in latency and reduction in capital expenditure.

In the Mobile Network nodes are interconnected via interfaces, which has specific names and functions. The eNodeBs are interconnected via the X2 interface which can be for the control plane and user plane. The X2 control-plane (X2-C interface) is for

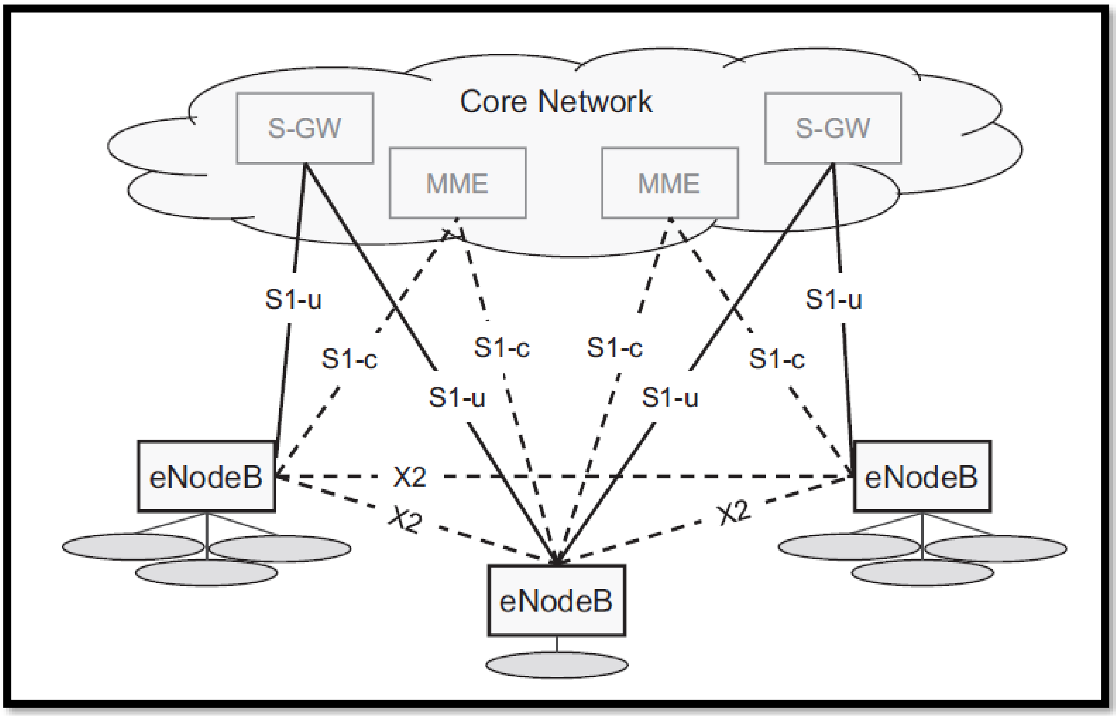

Figure 2.5: LTE RAN Architecture and interfaces (Series, 2012)

transmitting signalling between eNodeBs and the X2 user-plane is for transmitting user data. As for the S1- interface between an eNodeB and the EPC which is also used for control-plane (S1- interface) to the logical node mobility management entity (MME) for transmitting signalling. On the S1 user-plane interface (S1-U interface) between eNodeB and the logical node server gateway (S-GW) transmitting user traffic.

2.4.1.1 Radio Network Protocol Structure

The RAN protocol structure is divided into two planes, the control plane (signalling) and the user plane (data). The control plane protocol the radio resource control (RRC) is

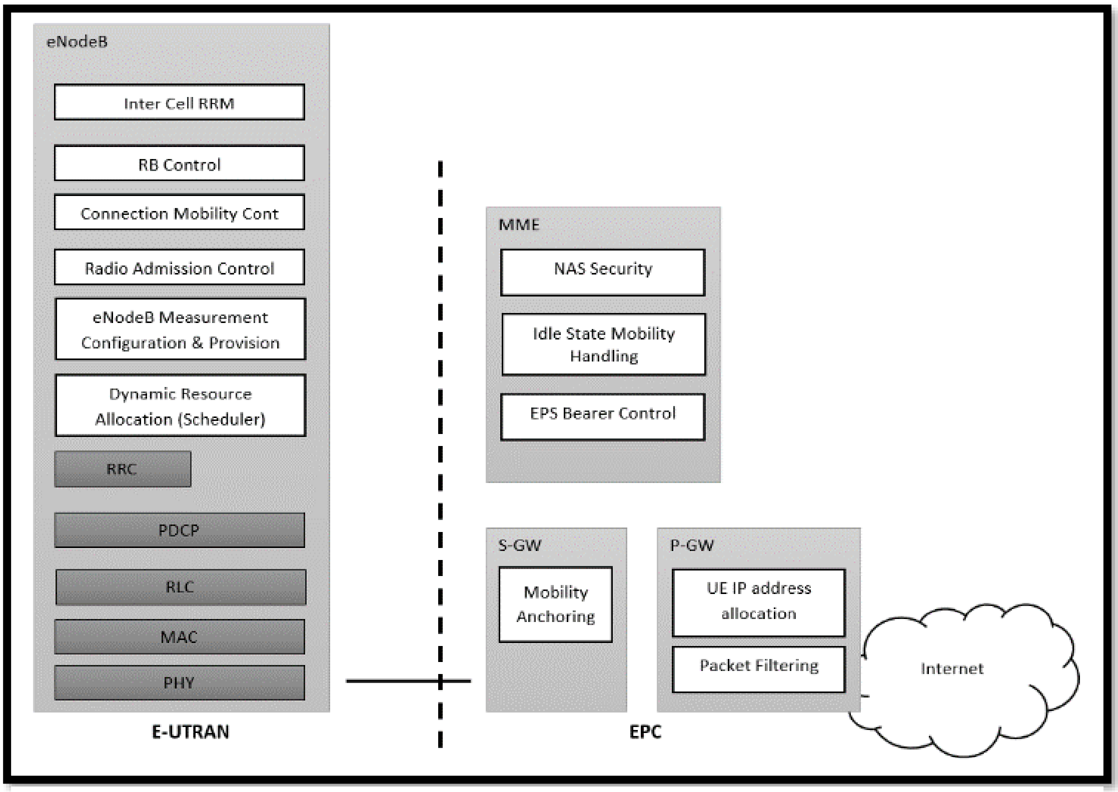

Figure 2.6: Functional split between EPC and EUTRAN

located in the MME for the core network and in the eNodeB for RAN. The operating set of equipment in EPS and in the user equipment stating the procedure to be used in carrying information is called the Access Stratum. The LTE RAN access stratum radio access protocols are comprised of a number of functionalities which mainly has to do with the following user data protocols Packet Data Convergence Protocol, Radio-link Control, Medium-Access Control.

2.4.1.2 Radio Resource Control

The RRC protocol is involved in the transmission of common None-Acess Stratum information and dedicated None-Acess Stratum information. The operation areas of

RRC includes the System Information, inter-Radio Access Technology mobility, connection control and measurements(Universal and Radio, 2017).

2.4.1.3 Packet Data Convergence Protocol layer

The PDCP layer handles Radio Resource Control (RRC) messages in the signalling plane Internet Protocol message in the user data plane. Other functions of the PDCP is in charge of ciphering, in-sequence delivering, removing of duplicated handovers(TSGR, 2015).

2.4.1.3.1 Radio-Link Control

The RLC layer is situated between the MAC layer which is the lower layer and the PDCP layer upper layer. The RLC configuration is controlled by the Radio Resource Control. Retransmission is also performed by the Radio-Link Control layer due to packet loss(Specification et al., 2007a). Communication between the PDCP and RLC is handled by Service Access Poing and to the MAC layer the RLC users logical channels. Activities of the RLC is done by RLC entities which can be configured into three transmission modes Acknowledge Mode, Transparent Mode and Unacknowledged Mode.

2.4.2 Medium-Access Control

The multiplexing of logical channels, uplink and downlink scheduling and HARQ retransmission is handled by the MAC layer(Specification et al., 2007b). Trans Blocks are constructed at the MAC layer as MAC SDUs. There are two MAC entities one located in the eNodeB and the other located in the user equipment and they perform different functions.

2.4.3 Physical Layer

The physical layer form part of the radio interface between the network and user equipment. Data is transport from the physical layer to higher layers and that is done through transport channels. There a number of activities that the physical layer is responsible for in order to execute the data transport service.

These activities are as following error detection; FEC encoding and decoding; HARQ software-combining; rate matching of coded transport (3GPP, 2011)channels to physical channels etc.

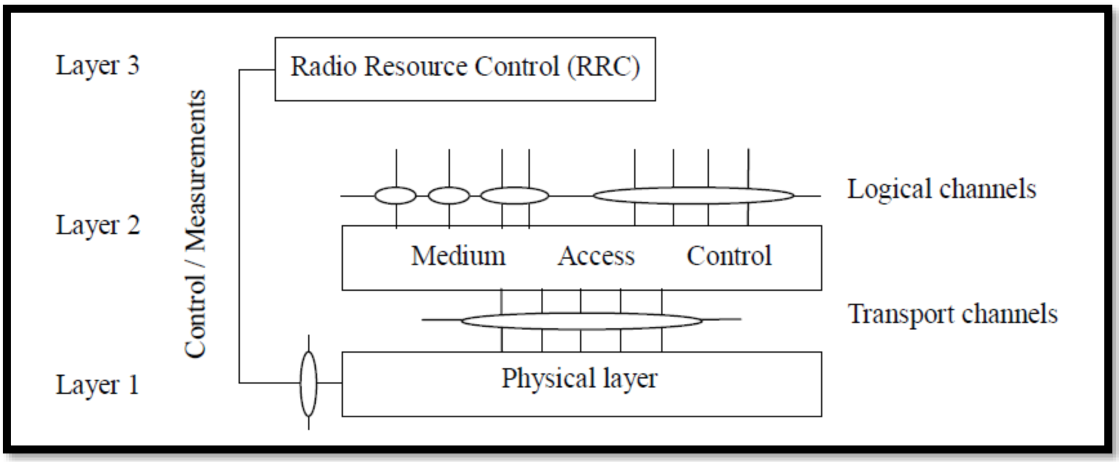

Figure 2.7: Physical layer representation in the Radio Interface (3GPP, 2011)

Figure 2.7 is a representation of the radio interface protocol structure with three layers, the physical layer which is layer1 followed by layer 2 which is subdivided into three MAC, RLC and PDCP. Than finally layer 3 your RRC. Between the Physical (layer 1) and MAC (sub-layer 2), we have a transport channel. Within layer 2 we have the MAC (sub-layer 2) connected to the RLC (sub-layer 2) via the logical channels. Both the logical and transport channels are described by the type of information transfer between the layers.

The LTE physical layer 1 is based Orthogonal Frequency Division Multiplexing making use of a cyclic prefix in the downlink.

On the LTE RAN side, all these functions exist in the eNodeBs, each of which can be responsible for handling multiple cells. In LTE the radio controller function is incorporated in the eNodeB. Due to these different protocol layers of the RAN are able to interact tighter and hence improving efficiency and reducing latency. The advantage of having distributed control is that of reducing one central point of failure and having a node that needs redundancy having high availability.

The eNodeBs are connected to the Core Network via the S1 interface, S1 link has an important feature known as S1-flex. This a concept where multiple CN node (MME/S-

GWs) serve a common geographical area. These nodes connect via a mesh network to the set of eNodeBs. The UE context normally

2.5 The Core Network (CN) EPC

The Evolved Packet Core in the EPS has undergone major evolution compare to Core Network for GSM and UMTS. The radical transformation is the fact it supports packet switch service and does not support circuit-switched. The EPC is ultimately responsible for controlling user equipment and it initiations services with different quality of services. The EPC has four major logical nodes Mobility Management Entity, Packet Data Network Gateway, Serving Gateway and Evolved Serving Mobile Location Centre. Beyond these four logical nodes, there are addition logical nodes such as the Policy Control and Charging Rules Function PCRF, Gateway Mobile Location Centre GMLC and Home Subscriber Server HSS. The Internet Protocol Multimedia Subsystem is located outside the EPS.

A brief description of the node and their functions

2.5.1 The Mobility Management Entity

The MME is the node responsible for the handling of the signal information between the UE and CN. The protocol messages between the UE and CN called Non-Acess Stratum protocols. The MME is also in charge of initiating beares. MME and Serving Gateway may be a location in one physical node or separate one depend on the operate.

2.5.1 The Serving Gateway

Serving Gateway is the node that is responsible for the user plane data to the UE. This node is one of two Gateways and such can be implemented as a separate entity or within one physical node with PDN Gateway.

2.5.1 The Packet Data Network Gateway

Packet Data Network Gateway three main functions manage all the IP address allocation for UEs. Handles quality of service requirements for bears. Last the mobility anchor operability for non-3GPP technologies such as WiMAX and CDMA2000.

The EPC has other nodes which might be located outside related to subscribe location like GMLC, the HSS is a database hosting subscriber information. Finally, the PCRF is responsible for policy handling related to subscriber profile.

CHAPTER THREE
CARRIER AGGREGATION

3 Background

The development of mobile technology standards by 3GPP led to the launch of Long Term Evolution networks in 2008. Within two years in 2010, the enhancements to LTE standard exceeded ITU IMT Advanced requirements for fourth-generation technology. The feature of carrier aggregation forms a basis for LTE Advanced as it combines two or more component carriers to provide higher bandwidth. The component carriers can be adjacent or fragmented even of a different frequency band where the channel bandwidth is of different sizes.

The implementation of upgrades on Mobile network operators radio access networks (RAT) is fundamentally in two ways by means of acquiring more licenced radio spectrum and by optimally using the available spectrum more efficiently. The (ITU) International Telecommunication Union has allocated more radio spectrum for new technologies beyond the third generation for IMT Advanced. One of the main challenges in South Africa is the slow release of spectrum for the cellular mobile operation by the regulator. There is also a matter of digital migration, which was supposed to have been completed by June 2015(Communications et al., 2005).

This chapter is organised as follow. *Carrier aggregation and its basic concept* are described in section 3.1. Then followed by *bandwidth and spectrum flexibility* in section 3.2 linking with *Five rollout solutions for CA* in section 3.3. The last three sections focus on *medium access layer operation*, *Scheduling* and finally *Component Carrier Primary and secondary carrier*.

3.1 Carrier Aggregation and its basic concept

LTE Advanced system bandwidth conforms to the standard system bandwidths of LTE Release 8/9 (Table 3.1). Hence, the component carrier (CC) is set to predetermine system bandwidths. The component carriers also referred to as an LTE serving cell. Each cell has a unique cell identifier and is regulator by the eNodeB. The number of the component carriers for LTE FDD in uplink cannot exceed those in the downlink the system is disproportionate. The maximum number of component carriers combined in carrier aggregation is five on uplink and downlink as per 3GPP release 10.

As mention earlier concerning CA benefits with the widening of transmission bandwidth from the standard 20 MHz for LTE Release 8 to 100 MHz for LTE Advanced release 10(Chairman, 2009). The second advantage for CA is that the combined spectrum does not have to be adjacent even fragmented spectrum, from the same or different frequency bands. LTE Advanced is an IMT-Advanced sanctioned technology and CA is one of the contributing features to that fact. The total transmission bandwidth can reach 100MHz for 3GPP release 10 and it rightly termed 4G technology because it exceeds IMT- Advanced down and uplink throughput specification(Hasiandra and Iskandar, 2017).

3.2 Bandwidth and spectrum flexibility

The standard bandwidths range from 1.4, 3, 5, 10, 15 and 20 MHz for component carriers (CC) and translate to 6, 15, 25, 50, 75 and 100 Resource Blocks (RBs) introduced with LTE Release 8. This flexible bandwidth structure helps network operators

Table 3.1: Channel Bandwidth and allocated RB per Bandwidth

Channel Bandwidth Specified in LTE	
Channel Bandwidth ($BW_{channel}$)	**Number of Resource Blocks(N_{RB})**
1.4 MHz	6
3 MHz	15
5 MHz	25
10 MHz	50
15 MHz	75
20 MHz	100

utilize fragment spectrum, also allows for proper planning and migration from legacy technologies that intern allow users to adapt to new technology.

The CCs in release 10 is backwards-compatible meaning an LTE user with UE that is not CA- capable can access the network and use it as an LTE subscriber.

3.3 Five rollout Solutions for CA

The deployment of carrier aggregations in an LTE network can be done in five scenarios or rollout solutions and these solutions have an impact on the uplink and downlink. As stated earlier that component carrier configuration for uplink and downlink for LTE

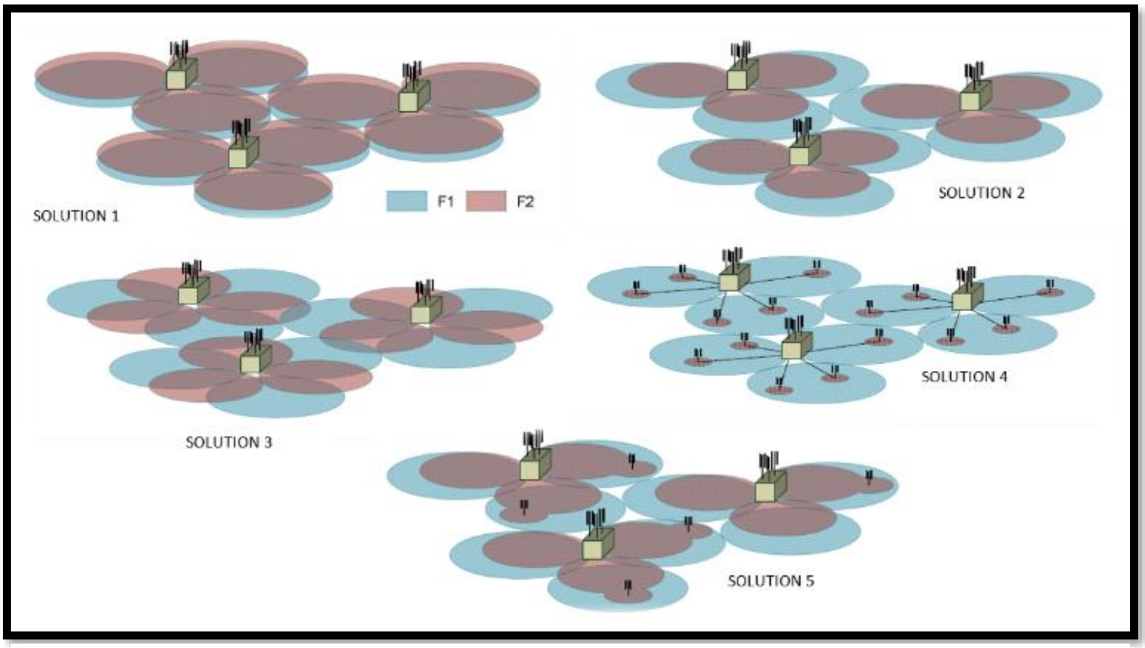

Figure 3.1: Five rollout solutions carrier aggregation

release 10 and 11 differs.

The above diagram represents five solutions for the deployment of carrier aggregation in LTE Advanced networks. Both frequency layer giving quality coverage and movement of uses possible between both layers. Although the diagram shows an example of two frequencies these scenarios applies also to more than two frequencies.

3.3.1 Solution 1

Two frequencies of the same band deployed geographically over the same area and providing similar coverage. Both frequency layers giving quality coverage and movement of users possible between both layers. Carrier aggregation activation for F1 and

F2 at overlapping areas, which can be intra-band contiguous CA and intra-band non-contiguous CA.

3.3.2 Solution 2

In this solution, F2 has a smaller coverage than F1, and F1 is used to provide movement coverage. Frequency 2 is used to increase throughput for users. CA is activated were F1 and F2 are overlapping and F1 and F1 are different band frequencies inter-band non-contiguous carrier aggregation.

3.3.3 Solution 3

This solution also uses two frequencies of different bands. F1 is a primary band for overall coverage and F2 is directed at cell edges of F1. Where these frequencies are overlaid CA is activated and mobility coverage is provided by F1.

3.3.4 Solution 4

The serving cells for F1 is from macro eNodeBs and provide the overall coverage and F2 the remote radio heads (RRH) provide coverage to gaps or hot spots. The overlapping area is where CA is activated for F2 and F1 and both frequencies are of different bands.

3.3.5 Solution 5

This rollout solution closely resembles solution 2, where we have two different frequencies covering the same area. The difference here is that F2 coverage area is increased here via a frequency selective repeater.

3.4 The Medium-access control layer operation

The medium access control (MAC) layer is responsible for the hybrid automatic request (HARQ), logical channel multiplexing, downlink and uplink scheduling. The MAC also handles adding and separating of traffic across multiple component carriers when carrier

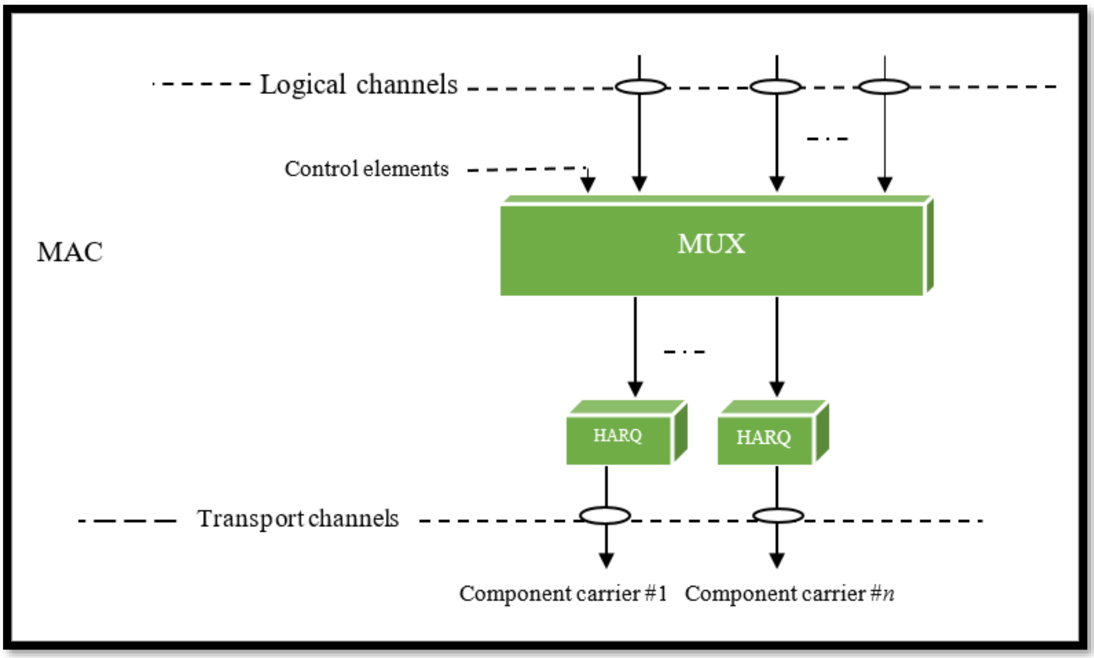

Figure 3.2: MAC operation in multiple component carriers

aggregation is used. MAC layer uses two type logical channels to send information to the RLC layer traffic logical channels (user data) and control logical channels for the RRC. There are few logical channel types for LTE and below mapping diagram (Figure 3.3:

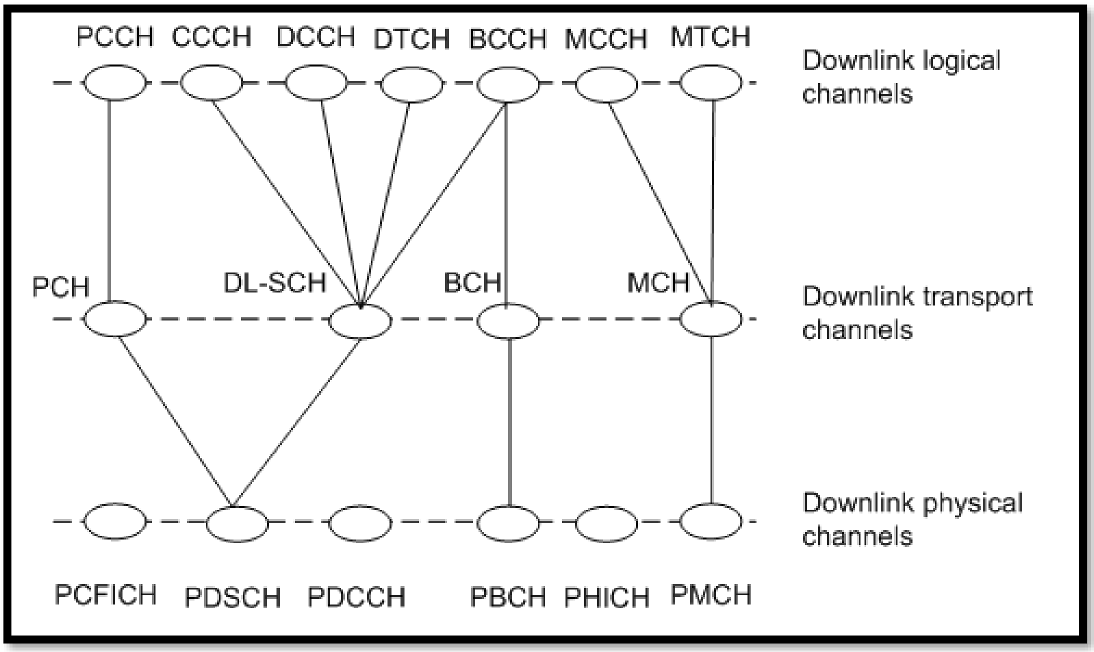

Figure 3.4: Mapping of three type's channels in downlink

Broadcast Control Channel (BCCH), the system information from the network is sent to

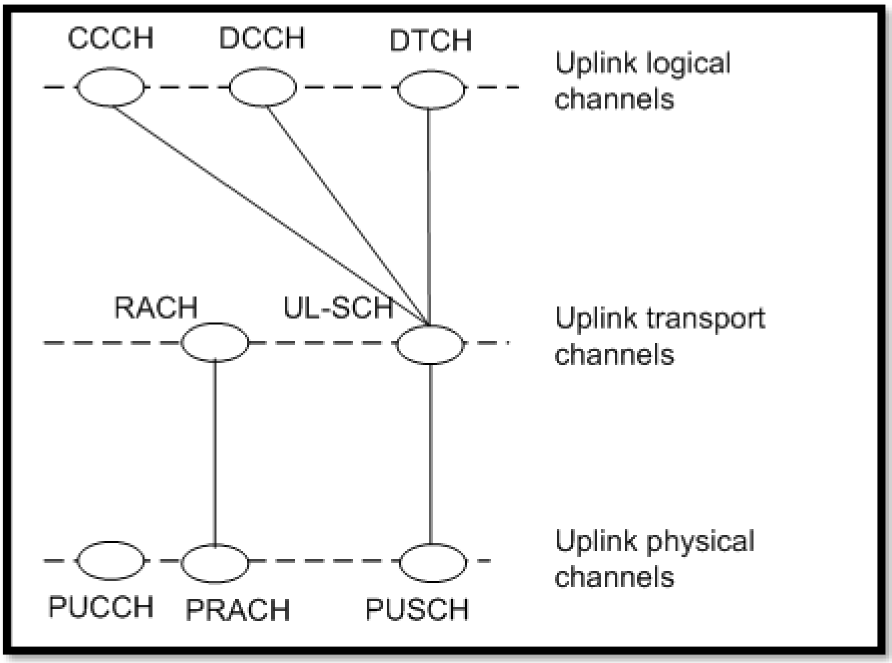

Figure 3.3: Channels mapping in uplink

all the user equipment in the cell. The Terminal uses this system information to access the network

On the physical layer side the MAC layer operating services in the form of transport channels. Transport blocks it how data is structure inside transport channels.

Table 3.2: Three Channel Types for LTE

Classification		**Channel**
Logical channels	Control Channels	BCCH(Broadcast Control Channel
		PCCH(Paging Control Channel)
		CCCH(Common Control Channel)
		MCCH(Multicast Control Channel)
		DCCH(Dedicated Control Channel)
	Traffic Channels	DTCH(Dedicated Traffic Channel)
		MTCH(Multicast Traffic Channel)
Transport Channels	Downlink Transport Channels	BCH(Broadcast Channel)
		DL-SCH(Downlink Shared Channel)
		PCH(Paging Channel)
		MCH(Multicast Channel)
	Uplink Transport Channels	UL-SCH(Uplink Schared Channel)
		RACH(Random Access Channel)
Physical Channels	Downlink Physical Channels	PDSCH(Physical Downlink schared Channel
		PBCH(Physical Broadcast Channel)
		PMCH(Physical Multicast Channel)
		PCFICH(Physical Control Format Indicator Channel)
		PDCCH(Physical Downlink Control Channel
		PHICH(Physical HARQ Indicator Channel)
	Uplink Physical Channel	PUSCH(Physical Uplink Schared Channel
		PUCCH(Physical Uplink Control Channel
		PRACH(Physical Random Access Channel

3.5 Scheduling

The eNodeB has the scheduler located in the MAC layer, which plays a pivotal part in the performance and overall behaviour of an LTE system. The scheduler functions in two principal formats dynamic and semi-persistent. The dynamic scheduling is the elementary procedure of the scheduler wherein the eNodeB every 1 ms (millisecond) trans-

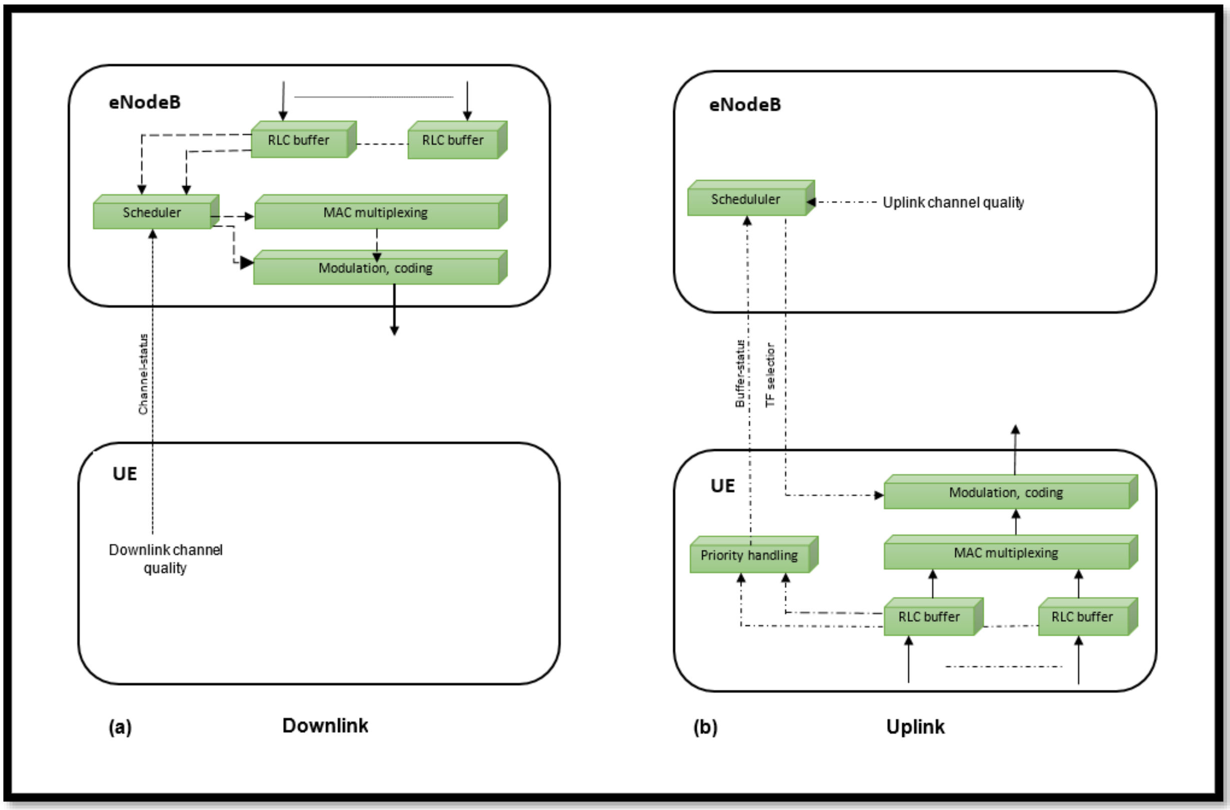

Figure 3.5: Transport-format selection in (a) downlink and (b) uplink

mission time interval (TTI) sends scheduling information to the user equipment. Dynamic scheduling operation happens every subframe by means of grants transmitted on the PDCCH and these grants might be on the carrier as the allocated data resources or on a different carrier in case of the usage of cross-carrier scheduling.

Whereas semi-persistent scheduling (SPS) sends a semi-static scheduling pattern in advance, minimize the control-signalling overhead. SPS is useful for VOIP services where the data packets are periodic, semi-static and little in size and for this kind of service the number of radio resources and timing is predictable(Sesia et al., 2009). This meaningfully compact the overhead of PDCCH equated to dynamic scheduling. The benefit of using SPS is that it allows a larger number of UEs to schedule. The cancellation for SPS can only happen when PDCCH allocated for Pcell overrides an SPS resource allocation. The SPS can only be constructed for the Pcell.

The downlink and uplink scheduling for LTE is separate, even the settings for the parameters on eNodeB for cell level are in depended. Downlink logical channel multiplexing and allocation handled by the eNodeB as see in the left side of Figure 3.4.

3.5.1 Uplink scheduling

The uplink scheduling like its counterpart is also located at the eNodeB and allocated resource to the terminal every 1 ms as compared to HSPA, which was 3ms. The scheduler utilizes the uplink shared channel (UL-SCH) to deliver resources to the user equipment in the uplink. The process of the scheduling user equipment with required data a scheduling grant is sent with additional information such as buffer status report (BSR) along with channel quality indicator (CQI) and other important information(Ferng et al., 2019). The requested resources blocks are transmitted on the UL-SCH with the added transport-format. In executing, this operation the uplink scheduler determine upon the number PRB, their location, their MCS scheme and power for transmission for each UE(Abu-Ali et al., 2014). The design of most uplink schedulers is classified into two fairness-oriented scheduling and channel-dependent scheduling(Ferng et al., 2019).

3.5.2 Downlink scheduling

The downlink scheduler operation is dynamically assessed the user equipment that requires to receive scheduling resources or set of resource blocks using the DL-SCH. The eNodeB configuration per cell basis is such that a few terminals are served per cell. Hence a few terminals can be scheduled simultaneously in a subframe with each terminal have its own DL-SCH and component carrier. Scheduling strategy is determined by the operator and depends on the implementation-specific not part of 3GPP specifications. There basically two resource allocation constraints one in the uplink the transmission power from the diverse RBs coming from the multicell outlook of the inter-cell interference and the power of the headroom of the UEs. Secondly, in the downlink, the constrained is due to the total transmission power in the eNodeB(Sesia et al., 2009).

3.5.3 Scheduling Algorithms

In this section, a brief description given of different types of scheduling algorithms. A scheduler's basic operation is to schedule data to a set of UEs on a shared established of physical resources. Lastly, the scheduling algorithms belong mainly into few categories opportunistic scheduling, fair scheduling(Dahlman et al., 2016) and lately the development of schedulers which are QoS aware(Yan et al., 2016). The importance of the latter is crucial to the performance of the network.

3.5.1 Maximum carrier interference ratio (MAX C/I)

The Maximum C/I algorithm operate on the basis it schedules users with the best channel conditions thus maximizing the system throughput. The algorithms do not evaluate the service type or the fairness but it cannot ensure equity between users due to channel conditions of each user. Therefore, this algorithm does not guarantee user QoS requirements.

3.5.1 Round robin (RR)

Scheduling opportunities on this algorithm allocated among UEs by taking turns in using the resources. This algorithm has a better fairness index compare with Max C/I algorithm. Also, the QoS requirement of users is also not considered by this algorithm. In addition, channel quality is not considered when scheduling UEs, and consequently, the system throughput is low. It is categories as scheduling algorithm falling channel unware type(Capozzi et al., 2013a)

3.5.3.3 Proportional fair (PF)

The PF algorithm is one that falls between RR and Max C/I. The algorithm takes channel quality. Scheduling fairness and modulation coding scheme. This algorithm does not differentiated base on QoS requirements. In some research work, it is used as the benchmark scheduling algorithm and most frequently used in LTE Advanced(Iru et al., 2018).

3.5.5.4 Enhanced proportional fair (EPF)

Enhanced PF scheduling algorithm assistances with meeting the quality of service requirements of diverse services. The scheme ensure guaranteed bit rate for preferential users while providing equity and differentiating among users. The algorithm also makes use of evaluation the channel quality so that high resource efficiency achieved and therefor win in high system capacity.

3.6 Component carriers primary and secondary

In LTE Advanced, there are two types of cells primary cells and secondary cells or supporting cells. The user equipment has a single serving cell providing all-controlling information and functions the primary cell. The information is related to non-access stratum mobility information radio resource connection establishment. Both the secondary and primary cells can be called the serving cell. As mentioned, the supporting cells cannot exceed four as they are always working in conjunction with a primary cell for LTE release 10-carrier aggregation

The PCC notifies the UE about available secondary component carriers (SCCs) according to its QoS and requirements. The connection is then established between SCCs and UE with the help of PCC and after that, data transfer takes place. The role of PCC is therefore important; UE must select PCC, which can provide it greater and faster coverage. LTE and LTE-A use OFDMA for downlink, which uses fixed frames for transmission. The radio frame of 10ms in OFDMA is divided into 10 subframes of 1ms each. The subframe is further divided into two-time slots of 0.5ms duration. These slots contain consecutive six or seven OFDM symbols; the selection depends upon cyclic prefix length. The resource block (RB) in LTE or LTE-A is the basic scheduling unit which has consists of time slot and 12 consecutive frequency subcarriers in the time domain and the frequency domain respectively. The bandwidth of each subcarrier is 15 kHz (4G Americas, 2014) which helps with simplifying radio design, support different radio channels widths.

CHAPTER FOUR
FAIR FLEXIBLE ALLOCATION SCHEME[1]

4 Overview

The functionality of carrier aggregation (CA) is widely utilized in the 4G networks for achieving higher throughputs. The CA employs multiple component carriers (CCs) to provide services to user equipment's (UEs) with CA capability. In this chapter, a flexible fair allocation scheme (FFAS) is proposed which allocates resources fairly with priority. The assignment algorithm allocates CCs to the UEs after a transmission time interval (TTI) which might be different from previous resource allocation and depends upon modulation and coding scheme (MCS). The average throughput of the FFAS is compared with the existing schemes. The simulations are performed for three distributions for two cases where all CCs are of the same bandwidth and another with different bandwidths. Simulations and results prove that the FFAS scheme outperforms the existing scheme.

4.1 Introduction

Due to the huge increase in demand for mobile data traffic mostly high bandwidth applications like video conferencing, video chatting, live uploading etc. The mobile data is expected to achieve 52 EB every month and video traffic is expected to grow by nearly 70% by 2021 a report admit by Ericsson (Qureshi, 2016). A carrier aggregation (CA) technique is introduced by Long Term Evolution Advanced (LTE-A), 3GPP in its Release 10 which can aggregate multiple carriers (CCs) from different eNodeB (Ku and Walsh, 2014). Use of multiple CCs together provides a wider carrier for transmission, a CC can support up to 20MHz and maximum of five CCs can be used simultaneously, which provides a total bandwidth of 100MHz. Further, the modulation and coding scheme (MCS) are also utilized to enhance the capacity and reliability of the network. A higher coding rate MCS indicates that a high transmission rate is used for transmission in a better quality channel and a low coding MCS indicates that reliable transmission is done in poor channel conditions (Fan et al., 2011). In order to ensure better transmission with fairness it necessities LTE-A radio resource management (RRM) to optimize performance considering all the three: allocated resource block (RB), MCS used and number

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Pana, V., Balyan, V. & Groenewald, B. 2018. Fair Allocation of Resources on Modulation and Coding Scheme in LTE Networks With Carrier Aggregation. *2018 International Conference on Advances in Computing, Communication Control and Networking (ICACCCN)*. 467–470. DOI: 10.1109/ICACCCN.2018.8748355.

of CCs employed. In order to cope with the increased bandwidth demand due to multimedia applications like online gaming, video streaming etc. the requirement of a resource allocation scheme increases. In literature, several allocation schemes are available which focus on the quality of services (QoS) required (Allocation et al., n.d.)(Zhang et al., 2013)(Miao et al., 2014). An ant colony method which minimizes the RBs allocated named ACOH is proposed in (Allocation et al., n.d.) which optimizes resources. A scheme which works on channel quality indicator (CQI) feedback method and optimizes a number of allocated RBs, allocated power and optimizes the network throughput is proposed in (Zhang et al., 2013). These two schemes do not support CA. By providing real-time services while maintaining QoS which uses CA is proposed in (Miao et al., 2014), the scheme treats CC and scheduling of packets differently and also without a link adaptation. However, in (Liao et al., 2014) a greedy algorithm (GA) that maximizes the throughput of the network which considers MCS used along with allocated CCs and RBs. An Energy-efficient RB Allocation Algorithm (ERAA) algorithm with variable support to CA. The scheme allocates the resources with fairness and maximizes the overall throughput. However, both these schemes don't support multimedia applications, which requires QoS. The proportional fairness (PF) is used to provide fairness in the distribution of resources among all active UEs (Martin-Sacristan et al., 2015). The joint resource allocation scheme in (Rostami et al., 2015) proposes a near-optimal scheme with lower complexity. A linear approach is used to consider resource allocation of LTE-A instead of a non-linear approach (Liu, 2016). For the LTE based MIMO/OFDMA networks an energy-efficient resource allocation is proposed in (Xiao et al., 2015) which provides services to users guaranteed QoS. The QEPEM method proposed in (Mushtaq et al., 2016) improves QoS due to reduced loss of packets in network and also improves fairness in allocation to UEs. It also enhances the QoE and provides multimedia services due to better QoS. The high-level user satisfaction is achieved by maintaining QoS even in the power saving mode (Mushtaq et al., 2016).

4.2 Background

For LTE Advanced when a UE wants to access the network, initially the connection to access radio resources is established with one carrier for control and data communication. This carrier is termed as a primary component carrier (PCC). After, that PCC notifies the UE about available secondary component carriers (SCCs) according to its QoS and requirements. The connection is then established between SCC or SCCs and UE with the help of PCC and after that, data transfer takes place. The role of PCC is therefore important; UE must select PCC, which can provide it greater and faster coverage.

LTE and LTE-A use OFDMA for downlink, which uses fixed frames for transmission. The radio frame of 10ms in OFDMA is divided into 10 subframes of 1ms each. The subframe is further divided into two-time slots of 0.5ms duration. These slots contain consecutive six or seven OFDM symbols; the selection depends upon cyclic prefix length. The resource block (RB) in LTE a or LTE-A is the basic scheduling unit which has consists of time slot [2]and 12 consecutive frequency subcarriers in the time domain and the frequency domain respectively. The bandwidth of each subcarrier is 15 kHz.

4.3 Network Properties

The CA is be deployed in mainly two scenarios: intra-band and inter-band CA. The intra-band CA is both continuous and discontinuous. The inter-band CA which is inter-band discontinuous CA ('3Gpp_Agreement.Pdf', n.d.)[14]. The network in this chapter mainly implements the discontinuous inter-band CA scenarios that which provides maximum flexibility inefficient utilization of the available resources. The total bandwidth of all the CCs, which belongs to distinct frequency bands, provides a wider bandwidth. However, these CCs channel conditions are different due to distances, path loss and shadowing fading. The LTE users can use only one CC and LTE-A can aggregate a maximum of

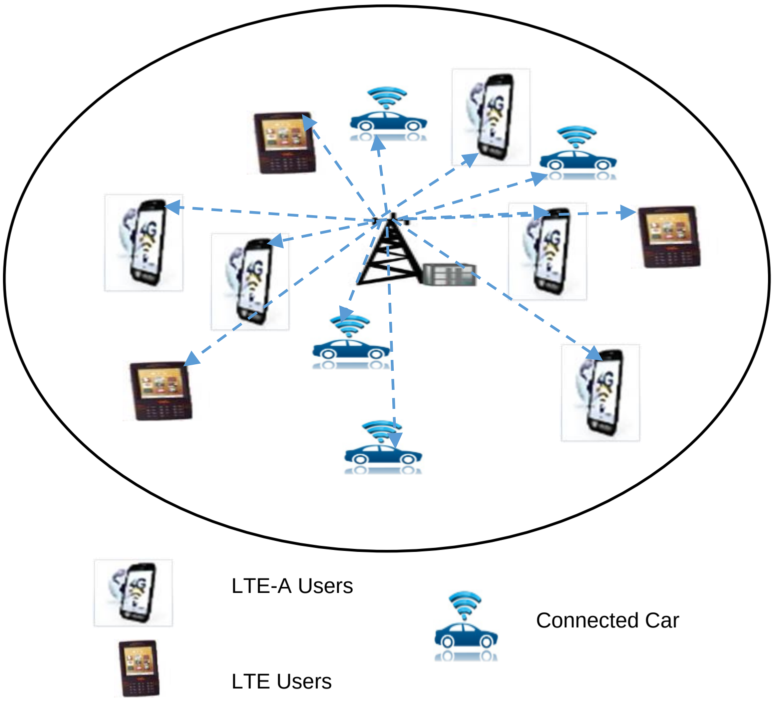


Figure 4.1: The eNodeB with LTE-A users, LTE users and connected car

five CCs. One of the aggregated channels is the primary channel (PC) and the remaining are secondary channels (SCs). The PC of eNodeB provides information on other CCs and helps reliability. The PC sends the information of SCs to UE and then connects with them with the help of PC.

When the UE wants to terminate the same process happens again. In downlink of LTE or LTE-A, scheduling refers to the allocation of RBs belonging to a CC or CCs to UEs. A standard eNodeB with LTE-A, LTE and connected car users is shown in Figure 23.

In order to maximize the system throughput and improve fairness among UEs for allocation of RBs, an algorithm is proposed in this chapter. Consider an LTE-A network with backward compatibility with a set of m active UEs, $1 \leq m \leq M$ in the downlink. The active UEs includes both LTE and LTE-A, $m = m_{LTE} + m_{LTE-A}$. The total number of MCS that are supported are denoted by l, where $1 \leq l \leq L$, l = 1 indicates the lowest transmission rate and l=L indicates the highest transmission rate. The achievable transmission rate with l^{th} MCS is denoted by R_l. The index of CCs is CC_c, $1 \leq c \leq n_{CC}$. and the RBs index is denoted as RB_r, $1 \leq r \leq n_{RB}^c$, where n_{CC} and n_{RB} denotes a total number of CCs and RBs respectively.

4.4 Proposed Flexible Fair Allocation Scheme (FFAS)

In this section, a flexible fair scheme is proposed which assigns resources to the UEs

Table 4.1: Relation between MCS, modulation and TBS Index

MCS Index	Modulation	TBS Index
0-9	QPSK	0-9
10-16	16QAM	9-15
17-28	64QAM	15-26
29	QPSK	Reserved
30	16QAM	
31	64QAM	
TBS: Transport Block Size		

based on MCS and the number of CCs allocated. It provides fairness by assigning a number of CCs because of its MCS. For example, the UE equipment with MCS 64QAM transmits 6-bits for communication as compared to QPSK, which is, transmitted 2-bits, which is due to the distance. The distance from the eNodeB influences the channel quality, which is termed as a channel quality indicator (CQI) and is used as a parameter to decide MCS. The number of CCs assigned to UE(s) are increased or decreased for every TTIs or with the addition of a new UE. The FFAS also check CQI of a UE before allocation of a CC and assigns it to other CCs flexibly.

Consider *m* active UEs with $m = m_{LTE} + m_{LTE-A}$, where m_{LTE} and m_{LTE-A} denotes active LTE and LTE-A users respectively. The total number of UEs which network can support at a time are *M*. In this scheme, the distance of a UE is used to determine which CCs is suitable for an assignment, which depends upon CCs radio channel conditions. Let the utility factor for LTE-A users is denoted by $UF_{m,c}^{l} = l \times \sum_{n=1}^{n_{RB}^{ca}} n$, where l denotes MCS value which is 2 for QPSK, 4 for QAM and 6 for 64QAM, n_{RB}^{ca} denotes the number

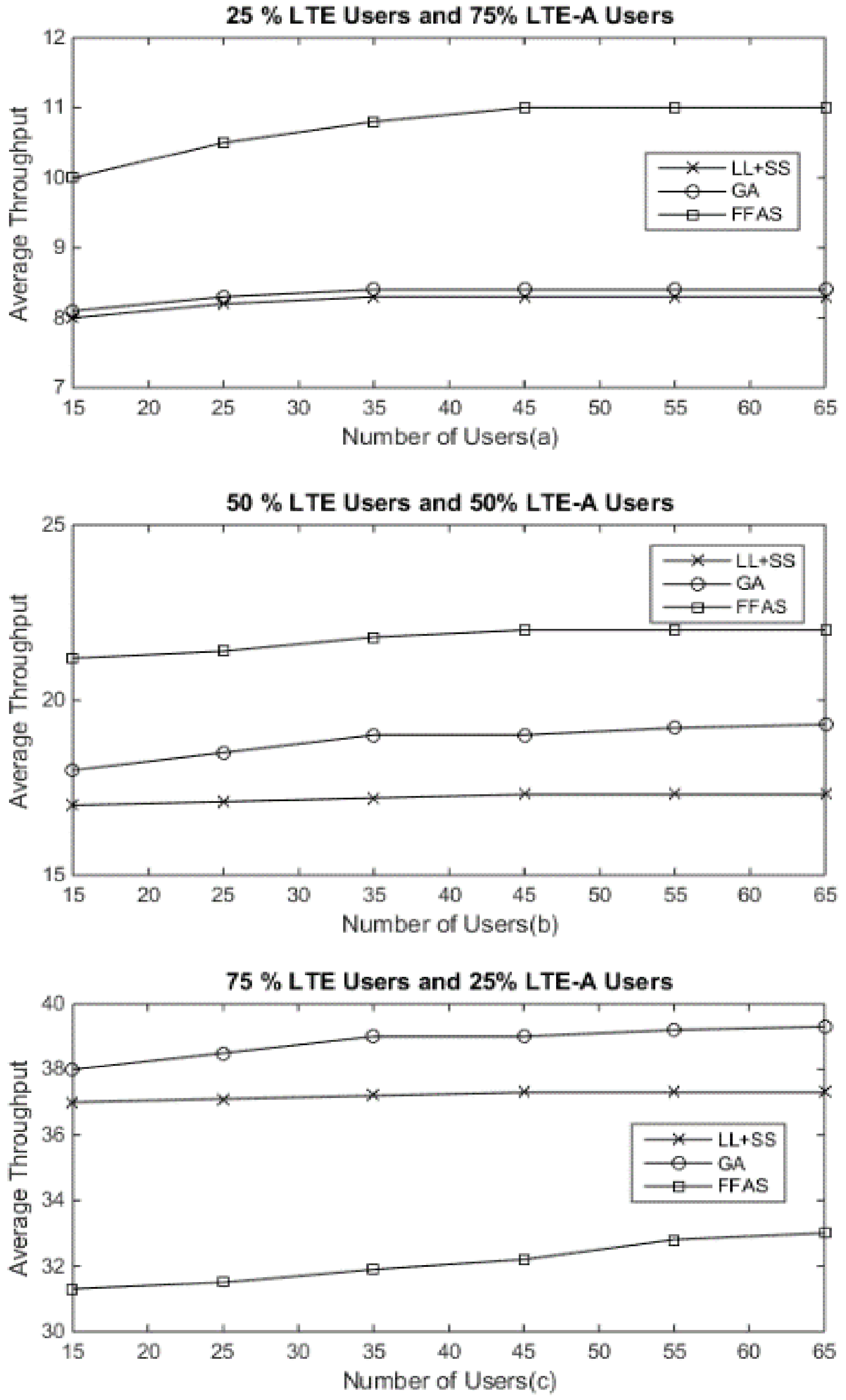


Figure 4.2: Average Throughput vs Number of Users with all CCs at same frequency

of assigned RBs of c^{th} component carrier. The carrier aggregation capability of a UE

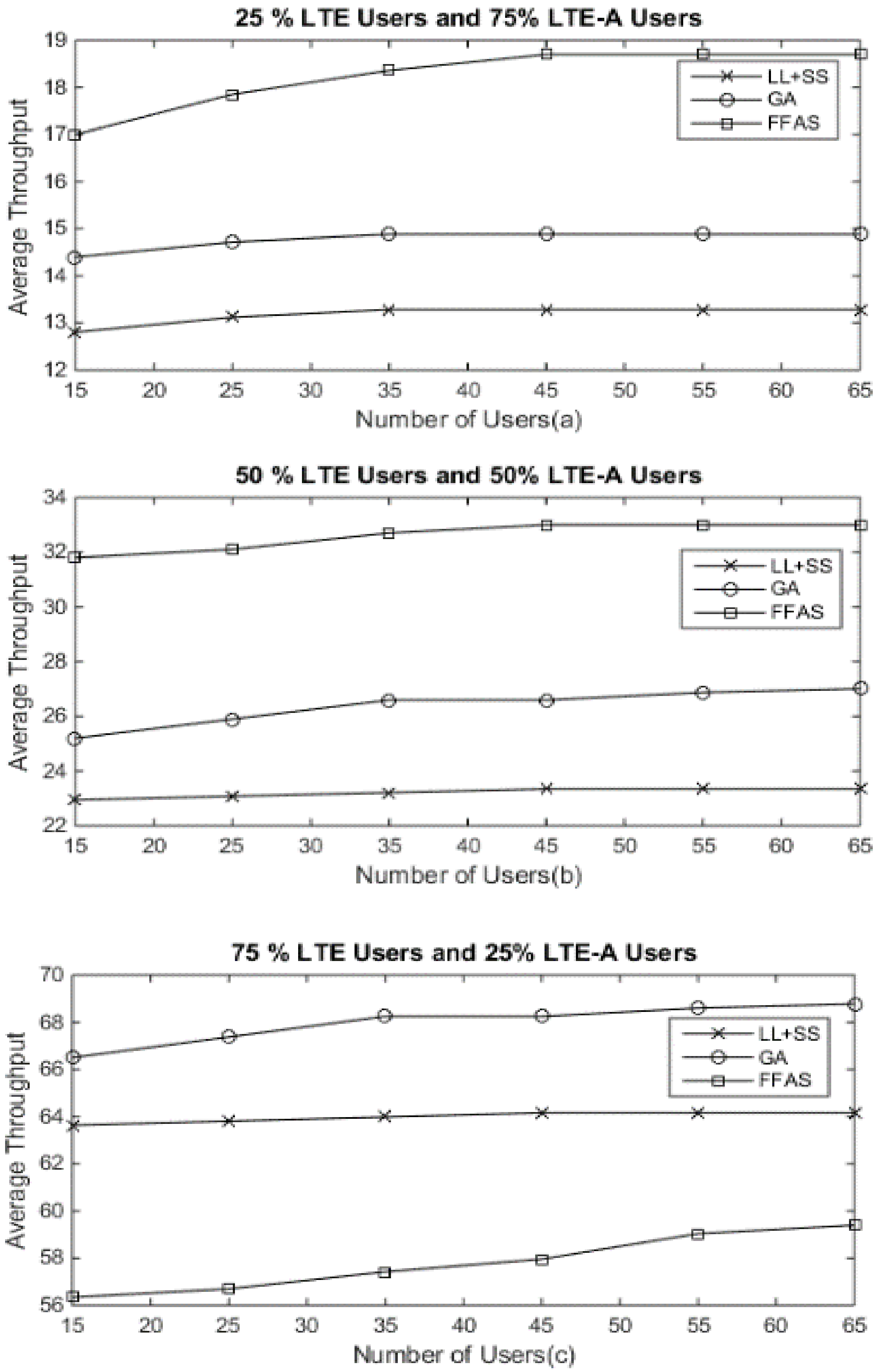
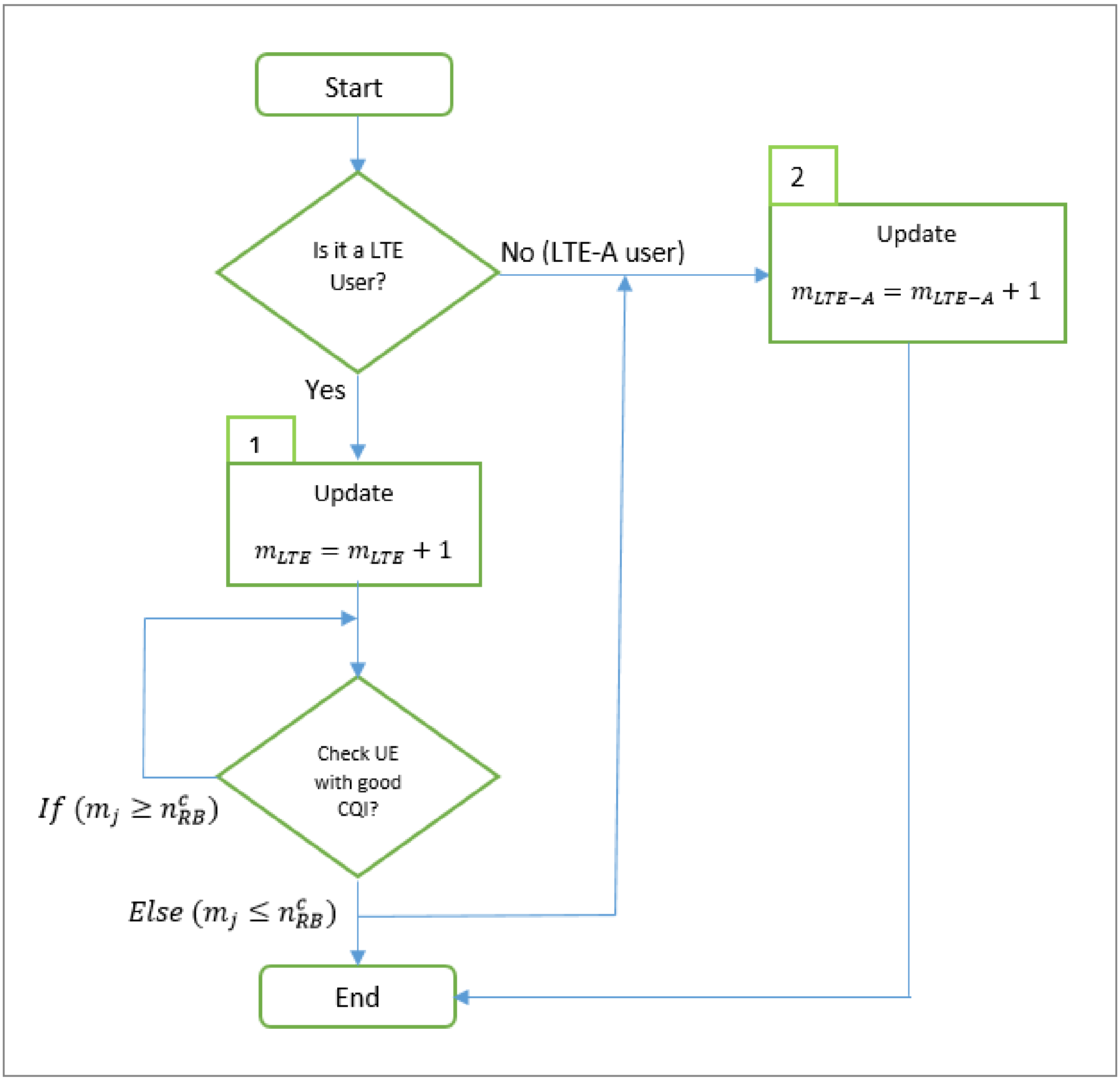


Figure 4.3: Average Throughput vs Number of Users with CCs at different frequency

depends upon the number of antennas in UE. Let the CA capability of an i^{th} UE is denoted by $CA_i, 1 \leq i \leq m_{LTE-A}$ and $2 \leq CA_i \leq 3$. The flexible fair allocation scheme (FFAS) work as follows. For the arrival of a new UE or after any TTI, the radio resources are distributed again between UEs. Check whether the new UE is LTE or LTE-A enabled.



1. If (LTE)
a. Update $m_{LTE} = m_{LTE} + 1$. The RBs of CCs are allocated first to LTE users.
b. Check whether all LTE UEs have good CQI with respect to CC_c, where $1 \leq c \leq n_{CC}$. For m_i UEs with good CQI.

Assign required RBs by m_j users from n_{RB}^c of c^{th} user.
If $(m_j \geq n_{RB}^c)$

Remaining LTE UEs are assigned to remaining CC_c. Repeat step (*b*) with $(m_j = m_{LTE} - m_j - n_{RB}^c)$ and $c = c + 1$. The MCS scheme used here will depend upon the distance of LTE UE as given in Table 1.
Else $(m_j \leq n_{RB}^c)$
Go to step 3. Use the remaining $(n_{RB}^c - m_j)$ RB for LTE-A users.

2. Else

LTE-A user, update $m_{LTE-A} = m_{LTE-A} + 1$. Assign one RB to all LTE-A users for fairness. The algorithm then allocates extra RBs to LTE-A users.

- Sort the UEs, which are running a delay-sensitive application like music etc. Let the delay-sensitive UEs are n_d.
- Assign the number of RBs to n_d UEs depending on the CA capability. When UEs are using the same CC, the MCS indexed will be maximum while when RBs are on different CCs the MCS selected will be minimum. The MCS is selected using Table 1.

While $(CA_k = n_{RB}^{ca}, 1 \leq k \leq n_d)$

- Assign remaining RBs to remaining $(m_{LTE-A} - n_d)$ users fairly.

3. End.
4. End.

4.5 Simulation results for the flexible fair allocation scheme

In order to evaluate the performance of the proposed FFAS, the simulations are done in Matlab. In this chapter, two cases of carrier aggregation are evaluated.

Case 1. Four CCs at 2 GHz frequency bandwidth.

Case 2. Four CCs out of which, two CCs at 800MHz and two CCs at 2GHz frequency bandwidth.

The number of LTE and LTE-A users varies between 15 and 65 i.e. $15 \leq m \leq 65$. The LTE enabled UEs can employ only one CC while LTE-A user equipment can employ two or three CCs. The proposed Flexible Fair allocation scheme is compared with the greedy algorithm (GA) proposed in [7] and least load approach (LL+SS) in (Dean and Fleming, 2002). The GA assigns RBs of CCs while considering a restriction on MCS given in LTE-A standards. The LL+SS assigns the UE to CC with the least used radio resources randomly. The simulations are compared under different arrival traffic distributions of LTE and LTE-A users.

- 25% LTE and 75% LTE-A users.
- 50% LTE and 50% LTE-A users.
- 75% LTE and 25% LTE-A users.

The UEs considered are both stationary and mobile. The mobile user's velocity varies from 1 to 20 m/s. The simulations are an average of 500 simulations and the duration of each simulation is 10s.

The average throughput is compared with a total throughput of all UEs in the cell. The results in Figure 25 and Figure 24 are of Case 1 and Case 2 under different traffic distributions. In case 1, the frequency of all the CCs is same and is at 2GHz while in Case 2, two CCs are at 800MHz, which results in a higher throughput of Case 2 for all traffic distributions. The reason for higher throughput in Case 2 is that lower frequency suffers lesser path loss for all schemes. The FFAS provides better utilization of resources as the allocation is sequential in terms of RBs allocation.

The FFAS scheme outperforms both schemes, as it is flexible in the assignment. It assigns CCs sequentially to LTE users and then to LTE-A users. The results clearly show that when LTE-A users are more throughput is less.

4.6 Conclusion

In this chapter, a flexible fair allocation scheme is proposed for the downlink of LTE-A systems with carrier aggregation. The FFAS allocates the resources based on type, priority while keeping fairness in allocation. The simulations are done for two cases when CCs are with identical in bandwidth and different in bandwidth. The simulations are done to show dominance over other schemes in different traffic distribution of LTE and LTE-A users. In the future, work can be done to evaluate the performance by moving UEs at higher velocities.

CHAPTER FIVE

[3]MACHINE TO MACHINE AND CELL TO CELL TRAFFIC HANDLING USING RELAY AND CARRIER AGGREGATION PRIORITIZE ON LTE A PRO NETWORK

5 Overview

With the advent of artificial intelligence (AI) and smart cities, the amount of connected devices is on the rise. The communication medium perfectly suited to provide service to interconnect all the massive machine-type communications (MTC) is long-term evolution advanced (LTE-A). The design in this paper consists of relay stations (RSs) which are connected to the base stations (BSs). The radio access network (RAN) will consist of a base station/eNodeB(eNB) with one or two hops of RS. The machine to machine (M2M) communication considered here is of the type of smart meters and sensors data calls. These calls are handled according to their delay-tolerant capability. The proposed PR-M2M scheme assigns resources with priority without reserving the resources. The Vienna LTE Downlink level simulator is used to investigate the operation of the proposed scheme. The packet dropping probability and average throughput of the system are simulated with other existing schemes studied in the literature. The results obtained from the simulation indicates that the PR-M2M outperformed existing schemes.

5.1 Introduction

The LTE evolution has been steady over the last decade (5GAmericas, 2017) to meet user requirements, which in part are twofold increase data demand and secondly an increase in the amount of “connect devices”(Gamboa et al., 2017). Previously mobile networks were designed to provide services to cell to cell (C2C) users which predominantly were used for voice calls only(Teyeb et al., 2017). By the year 2022, it is predicted that there will about 29 billion connected devices and 18 billion of those will be IoT devices or M2M devices(Teyeb et al., 2017)(Ye et al., 2016). Currently, globally LTE has about 47 percent of all mobile subscribers and which includes IoT subscribers. These are expected to grow by 45 percent in the next five years. The LTE Advanced Pro networks are designed currently and implemented to serve C2C with machine-type communication (MTC). The MTC systems are divided into two types, massive MTC and critical MTC(Dahlman et al., 2016). This phenomenon of massive MTC, when compared to

[3] Journal submission: The Research Article titled "Machine to Machine and Cell to Cell Traffic Handling Using Relay and Carrier Aggregation Prioritize on LTE network," by Vuyo Pana, Vipin Balyan and Ben Groenewald has been received and assigned the number 2304853

a standard mobile communication is more on the huge volume of devices demanding access to resources in an LTE Advanced Pro network simultaneously. This high volume of devices will negatively impact the performance of mobile communication. Recently, LTE-A Pro studies on a number of solutions for multi-carrier, multiple-input multiple-output (MIMO) and massive carrier aggregation (Liu and Xiao, 2016)(Stefanatos et al., 2017)(Ji et al., 2017)(CHET, 2003) are proposed to meet the demand of users. This contributes to high densification of the radio access portion due to bandwidth expansion. Therefore, another critical part of the LTE-A Pro network (Nokia, n.d.) is the last mile delivering of time-shared resources to the user's (C2C or M2M) via packet scheduling. The most frequently used packet scheduler in literature is proportional fair scheduler (Chao and Chiou, 2013) and at times used as a foundation scheduling scheme (Iru et al., 2018) (Grondalen et al., 2017). The emphasis on fairness (Rostami et al., 2018)(Eladham and Elshennawy, 2017), receiving high attention in current research studies for C2C communication. The work in (Tathe and Sharma, 2019) divides resource scheduling into two types of classes: channel-dependent and channel-independent scheduling. This leads to the development of policies for scheduling whose primary purpose is to reduce complexity, which is one key principle for designing a packet scheduling algorithm. The aim for minimizing complexity is that for each 1 ms transmission time interval (TTI**)** scheduling decision needs to be done in allocating resources and an increase in computation will increase the TTI. The work in (Lassoued, 2019) is based upon operations of HetNets, which are usually designed to deliver greater spectral efficiency and extra capacity. Therefore, they are suitable to provide coverage to a multiplicity of subscribers including massive MTC connections due to enhanced network capacity(Hamdi et al., 2012). The work in (Cells et al., n.d.) is done for the eNB and RS interfaces. The options considered are wireless or wired with higher capacities. The work implemented the interface between eNB and M2M devices to be wireless in order to deliver enough capacity for communication. The implementation of the wireless interface is easy and maintenance requirements are cost-effective as it is self-optimizing. The work in (Farooq et al., 2019) endorses the utilization of wireless backhaul for relay stations.

The chapter is organized as follows, first, the results section is presented with the discussion section 5.3 immediately thereafter. In section 5.4 material and methods detailed, with section 5.6 the conclusion of the chapter.

5.2 Results

The information for network parameters is in Table 5.1 below, the channel bandwidth of the total system is 40 MHz, for CA mode 2 CC at 2.0 GHz frequency and per CC bandwidth is 20 MHz. The total number of *RB*s in one CC is 100 with a subcarrier spacing of

Table 5.1 Network Parameters

Parameter	Value
Total Channel Bandwidth	40 MHz
Frequency	2.0 GHz
LTE bandwidth	20 MHz per CC
Resource Blocks	100
Subcarrier spacing	15 kHz
Subframe period	1 ms
MIMO	8 X 8
scheduler	Proportional fair
Simulation length	5 000 TTI
subcarriers	12 per resource block

15 kHz and subcarriers in one *RB* are 12. The sub-frame period is 1ms. The transmission mode of MIMO used is 8×8 and simulation time 5000 TTI. The work is evaluated using variation in two hops and one-hop relay stations. The work is compared with Pro-

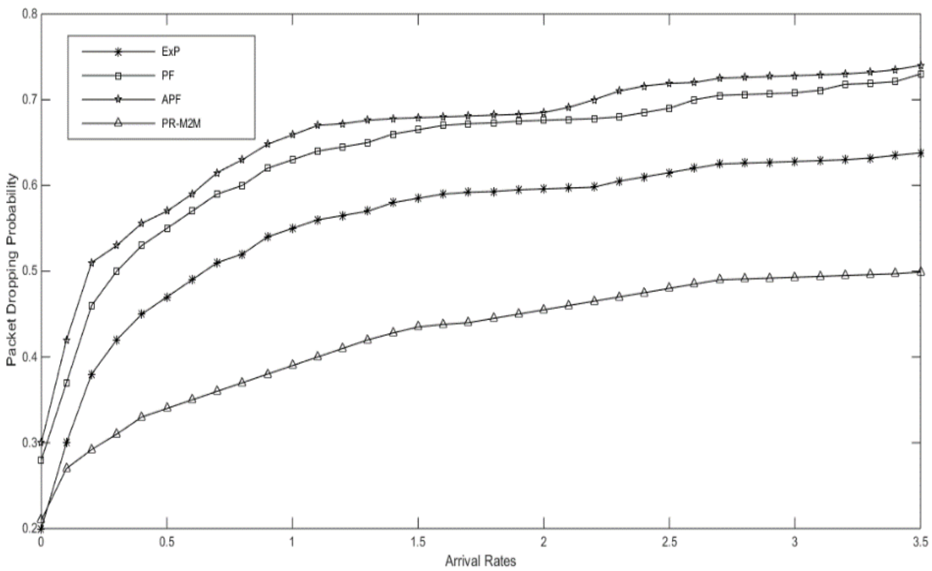


Figure 5.1: Exp, PF, APF and PR-M2M – Packet Dropping Probability comparison

portional Fairness (PF) (Liao et al., 2014)(Ferng et al., 2019)(Qurat-Ul-Ain et al., 2016), Exponential Proportional Fairness (ExPF) (Ramli et al., 2009) and Adaptive Proportional Fairness (APF)(Jonh-Hun et al., 2004). The metrics of evaluation are average packet dropping probability and average user throughput. The evaluations are done using Vienna LTE-A Simulator (Vienna University of Technology (Institute of

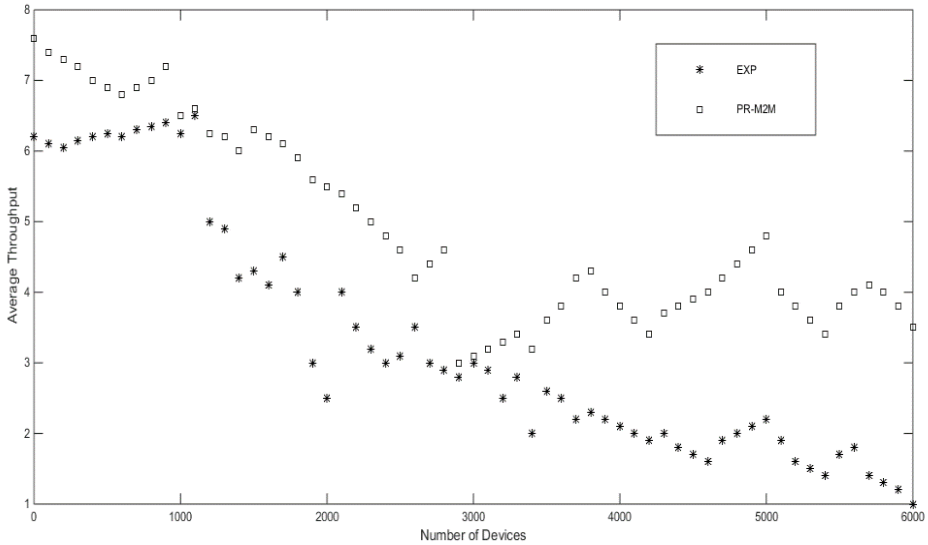


Figure 5.2: EXP and PR-M2M average throughput

Telecommunications), 2016) for link-level simulation. In Figure 5.1, the packet dropping probabilities of all schemes are compared with the proposed PR-M2M relay method, the dropping probability increases with increased arrival rates. The two-hop method of PR-M2M provides least dropping probability as before selection of relay device, the relay link between relay and eNB is checked for SNR together with access link between relay and device. The ones with optimum SNR are selected. In one hop method, the access link with optimum SNR is selected. Figure 5.2, the throughput of devices is demonstrated with and without relays with varying distances. Use of higher AMCs decreases the sensitivity level. Therefore, at cell edges where the signal level is low, the higher AMCs are used in order to maintain the connectivity with eNB and thus lower AMCs are used at the cell edges. This leads to a decrease in the throughput of the device. The two-hop relay is used when the SNR of the device in a particular AMC is below its threshold even after increasing the code rate. In our case, relay devices are mostly fixed, so connectivity with eNB is always with better SNR. The results clearly show that using a relay station for M2M devices with C2C devices increases throughput.

5.3 Discussion

The increase of massive MTC communication has contributed to new standards(Nokia,

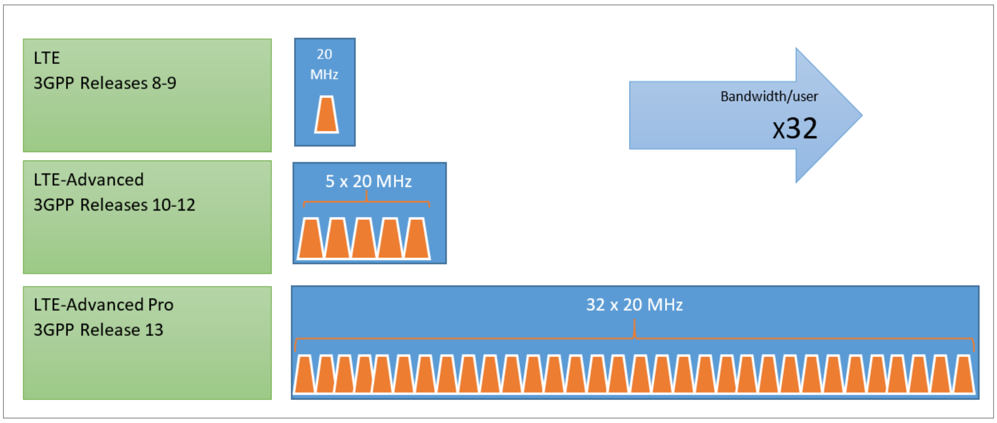


Figure 5.3: Carrier Aggregation of up to 32 CC in LTE A PRO

n.d.)(ITU, 2015)('Handbook on Global Trends in IMT', 2015) been adoption for LTE, to meet the demands of (C2C/D2D) communication. As a result, numerous studies have been conducted in the recent past, exploiting different formulation models (Vardakas et al., n.d.) on the performance of M2M. For the majority, simulations have conducted in which are able to represent actual M2M/C2C traffic scenarios. However, the division of MTC into massive MTC and critical MTC give credence to divide M2M communication into different categories, where service classification is endorsed. The service separation assists in providing guaranteed class service to massive critical MTC communication with an acceptable QoS. A mathematical analysis is offered in (El Fawal et al., 2018) with a deduction that M2M/H2H traffic in emergency scenarios should not have users priorities settings. In another research piloted in (Akpakwu et al., 2017), where the focus is given to the congestion control mechanism. As can be noted different design objectives are followed to meet the requirements of massive MTC. A fairly detailed study is presented in(Grondalen et al., 2017) for diverse types of scheduling algorithms relating to the key design fundamentals. The works main focus is presenting performance and design scheduling algorithm comparison for user datagram protocol (UDP) and transport control protocol (TCP) traffic. One of the main concerns for M2M network designs has to with interference which is mitigated in the solution for HetNets(Telecommunications, 2015). There also studies which focus on partial usage of spectrum for IoT (Zhang et al., 2016) and mode selection (Sarkar et al., 2019) in for HetNet (Figure 3) towards 5th generation networks (5G). In the study on M2M communication for Smart Grid Application (Vardakas et al., n.d.)(Chau et al., 2017) the authors make use of the analytic method to evaluate the performance scheduling algorithm in comparison to simulation. Both simulation and formulation models are acceptable evaluating LTE A network behaviour with regards to massive MTC. As in our study, we are utilizing the Vienna Downlink System (Vienna University of Technology (Institute of Telecommunications), 2016) simulator which widely utilized and industry reputable. An observation from the surveyed studies there is a number of fragmented suggestions non exploiting.

In this chapter, the proposed PR-M2M algorithm provides an assignment on the priority to relays, which form the part of the communication process. The fraction of the bandwidth is not reserved for M2M communication, depending on the user subscription profile, which is aligned with the requesting of resources as available in the literature. The proposed scheme also differentiates between M2M users based on their type: delay-tolerant and delay-sensitive.

The operations of HetNets are usually designed to deliver greater spectral efficiency and extra capacity(Lassoued, 2019). Therefore, they are suitable to provide coverage to a multiplicity of subscribers including massive MTC connections due to enhancement network capacity(Hamdi et al., 2012). The eNB and RS interface has an option to be wireless or be wired provides higher capacity. For this study, the interface to be implemented between eNB will wireless as it delivers enough capacity for M2M communication(Cells et al., n.d.). The implementation of the wireless interface is easy and maintenance requirements are cost-effective as it is self-optimizing. The following study(Farooq et al., 2019) endorses the utilization of wireless backhaul for relay stations.

The operations are conducted with C2C communication and M2M domains. The design of a packet scheduler must adhere to certain principles (Capozzi et al., 2013b) stated below:

(1) complexity and scalability
(2) QoS provisioning
(3) Fairness
(4) Spectral efficiency

These principles are found in the PR-M2M algorithm, easy to design, implementation and spectral efficiency are guaranteed with the utilization of carrier aggregation as it is a fundamental aspect of LTE A/LTE A Pro(Grondalen et al., 2017)(Haidine and El Hassani, 2017)(Americas, 2015)(Recchione, 201AD).

5.4 Material and Methods

The network model given in Figure 5.4 consists of M2M devices, which directly communicates with neighbouring RSs through LTE short-range (SR) links, the RSs, however, transfer the received data to the BS using the long-range (LR) LTE links. The multiple access scheme used in the LTE downlink is OFDMA. A physical (PHY) frame structure for LTE

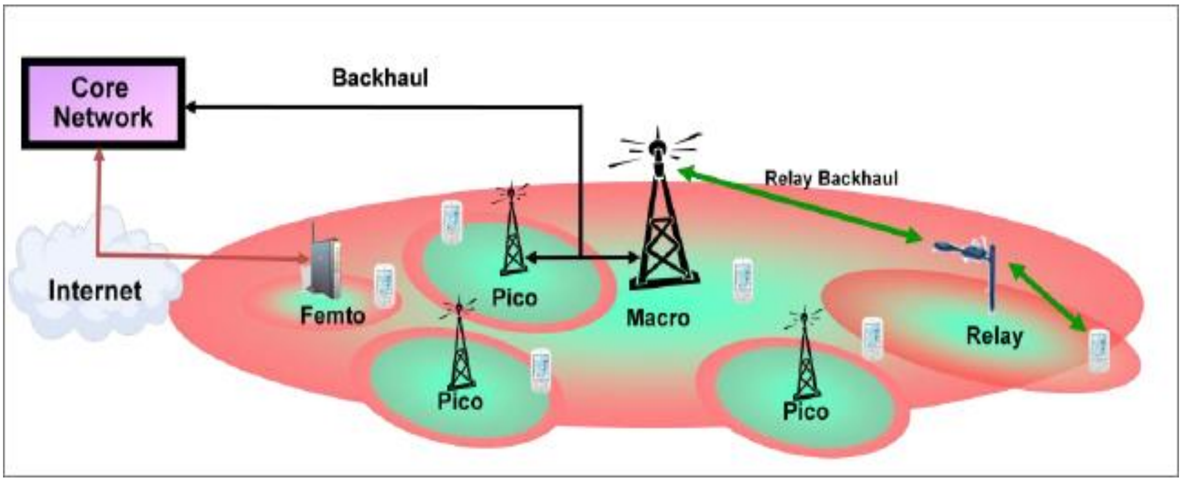


Figure 5.4: Heterogeneous LTE Advanced network(Telecommunications, 2015)

has 10 subframes in the time domain with two slots in each, 14 OFDM symbols that can be carried in each subframe. The frequency-domain subchannel has 12 carriers. The number of sub-channels varied with bandwidth like each channel of capacity 1.4 MHz and has six sub-channels. For a mobile station (MS) in LTE, the transmission unit is called as a resource block (RB) within a subframe (in time) and a subchannel (in frequency) (Balyan

Table 5.2: Channel Bandwidth and allocated RB per Bandwidth

Channel Bandwidth Specified in LTE	
Channel Bandwidth ($BW_{channel}$)	**Number of Resource Blocks(N_{RB})**
1.4 MHz	6
3 MHz	15
5 MHz	25
10 MHz	50
15 MHz	75
20 MHz	100

and Groenewald, 2017). The scalable bandwidths are supported in LTE standards. The bandwidth and associated RBs are given in Table 2 (Balyan and Groenewald, 2017). The work in this paper assigns a fraction of available 20 MHz bandwidth for M2M to RS communication, RS to BS and cell-to-cell (C2C) communications. The bandwidth is not blocked or reserved as done in most of the work in literature; the assigned BW to each format of communication is flexible. This is mainly due to the diverse nature of C2C communication and the introduction of data aggregation at RSs. Further, with the use of carrier aggregation (CA) for LTE-A, the available bandwidth can be extended up to five carriers i.e. 100MHz.

5.4.1 LTE Resource Allocation

In this section, a channel model and data rate calculation explained followed by assignment scheme. The assignment scheme is applicable to the existence or absence of RSs.

5.4.2 Channel Model

The channel gain on the communication link between any two nodes denoted by *i* and *j* using a subcarrier *k* is

$$G_{i,j,k} dB = -\left(\lambda log d_{i,j} + \kappa + \beta_{i,j,k}\right) + 10 log R_{i,j,k} \tag{5.1}$$

λ *is* path loss exponent, $d_{i,j}$ denotes distance in km between node *i* and *j*, κ is propagation loss, $\beta_{i,j,k}$ represents log-normal shadowing with a standard deviation of 8 dB and zero mean. The Rayleigh fading power is denoted by $R_{i,j,k}$, using the Rayleigh parameter as *a* with expected value denoted by *E*. $E[a^2] = 1$.

5.4.3 Data Rates

When N subcarriers are allocated for transmitting to *j* carriers from *I* nodes. The transmit power and total noise power of a transmitting node *i* denoted by $P_{i,j,k}$ and $N_{i,j,k}$. The signal-to-noise ratio (SNR) is given by

$$SNR_{i,j,k} = \frac{P_{i,j,k} \times G_{i,j,k}}{N_{i,j,k}} \tag{5.2}$$

Where $i = 1 \ldots . I$; $k = 1 \ldots N$

The transmitting nodes have a peak power limitation that power used on all the subcarriers should not exceed $\sum_{k=1}^{N} P_{i,j,k} \leq P_{i,max}, i = 1 \ldots I$. Also, let the achievable discrete rate between node *i* and *j* while transmitting over subcarrier *k* is denoted by $r_{i,j,k}$. The total rate of any node using *N* subcarriers will be

$$R_{i,j} = \sum_{k=1}^{N} r_{i,j,k} \times SNR_{i,j,k} \tag{5.3}$$

For continuous rates, the formula for Shannon capacity can be used i.e. $log_2(1 + SNR_{i,j,k})$. The discrete rate and MCS associated with it are given in [2](Universal and Radio, 2017)(3GPP TS 36.213, 2016). Therefore, the rate $R_{i,j}$ of transmission between node *i* and *j* using a MCS of rate r_l bits/symbol adopted by all allocated subcarriers assigned is

$$R_{i,j} = \frac{r_l N_{RB}^{(i,j)} N_{SC}^{RB} N_{Symbol}^{SC} N_{Slot}^{TTI}}{T_{TTI}} \quad (5.4)$$

where $N_{RB}^{(i,j)}$: number of RBs allocated from node *i* to *j*.

N_{SC}^{RB}: number of subcarriers/RB.

N_{Symbol}^{SC}: number of symbols/ subcarriers in one time slot.

N_{Slot}^{TTI}: number of time slots/TTI.

TTI: Duration of a time slot.

5.4.4 Resource Allocation Algorithm

The work in this chapter is incorporating M2M devices communication with cell-to-cell (C2C) communication. The M2M devices are smart meters and sensor which periodically transferring the information. The work in literature reserves a fraction of resources for them, which might result in wastage of resources. The time (t) for which the M2M devices accesses the network resources is less than their time (T) after which they access the network i.e. for which reserving resources for it not a practical solution. The paper divides the incoming M2M requests into two types: delay tolerant and delay sensitive denoted by n_{dt}^{M2M} andn_{ds}^{M2M}. The delay *sensitive* are given priority over delay tolerant in CA. The M2M requests considered in this chapter are both the stationary and moving sensing M2M devices (connected to a moving vehicle or object). The use of RS reduces the duration of these requests. The delay sensitive requests are from RS to BS communication. The CA is mostly used for handling RS to BS requests and delay sensitive M2M to RS request. The proposed resource allocation scheme uses channel state information (CSI) for an efficient allocation of RBs in time frequency-domain. The eNB/BS is assigned a set of carrier component (CC) to serve the devices. The M2M devices are mostly not mobile in nature while C2C devices are mostly mobile. This leads to heterogeneous nature of devices in terms of their CA capability, carrier qualities and QoS required by them. Let the available *RBs* with the BS are N_{RB}. The assigned *RBs* to a node are $n_{i,j,c}^{RB}$, *i* for communication with node *j*, where $n_{i,j,c}^{RB} \subseteq N_{RB,j,c}$, *c* denotes the CC of the *RB* and the total M2M requests at node *i* are $n_{total} = n_{dt}^{M2M} + n_{ds}^{M2M} + n_{c2c}$. The number of CCs used here are

(c_c). The performance of the system can be further improved by changing the MCS used by the device on a *RB.* Let the MCS available are *l*, where$1 \leq l \leq L$, 1 provides the lowest transmission and *L* provides the highest transmission rate achieved by a device on a *RB*.

Phase 1: Depending upon respective priorities and connectivity to nearby RS, all the M2M requests are assigned one RB and suitable MCS to meet the QoS requirements.
Phase 2: All the M2M and mobile devices with multiple antennas are assigned *RBs* of same or different *CC*s with the same MCS adopted on all the *CC*s.

The M2M delay-sensitive devices must achieve a rate r while it transmits data D_{max}. The rate using *RB* ($n_{i,c}^{RB}$) on *CC* (*c*) and MCS (*l*) is denoted by $r_{i,c}^{l}$. At TTI, the eNB scheduler receive the QoS and channel quality requirements of devices, this information is used to generate a matrix A of size $n_{total}(t) \times N_{RB}(t)$, where $n_{total}(t)$ and $N_{RB}(t)$ are a number of devices sending a connection request and a number of resource blocks available at a time *t*. The $(a, b)^{th}$ element of this matrix is $A(a, b)$. The device requests are arranged in order of priority i.e. delay sensitive requests are given preference. The elements of the matrix are delay sensitive M2M devices (n_{ds}^{M2M}), $1 \leq a \leq n_{ds}^{M2M}$, followed by delay tolerant and C2C devices, $(n_{ds}^{M2M} + 1) \leq a \leq n_{dt}^{M2M} + n_{c2c}$.
The algorithm named as a priority in relays for M2M devices (PR-M2M) works as follows. First, the eNB request devices to provide details of their QoS and carrier quality requirement for the current slot. The eNB then assigns a CC and corresponding *RB* to a device depending upon the received information. The primary carrier is assigned first to a device then CA is used for delay-sensitive devices.

If ($N_{RB} \neq 0$)

Select devices in the order of their descending priority and assign *RBs* of a *CC* as a primary carrier and then assign secondary carriers. Assign $n_{j,c}^{RB}$ i.e j^{th} *RB* of c^{th} *CC* to the device $n_a, 1 \leq a \leq n_{ds}^{M2M}$. The CA capability of the devices is denoted by $c_a, 1 \leq c_a \leq 5$. Let *z* be the set of available *RBs* that will be assigned to the device n_a, then $z \leq c_a$

If (all the *RBs* ∈ the same *CC*)

Assign the maximum value of MCS in TTI as all *RBs* can use the same MCS.

Else

Find $(\max_{c \in c_c} l_c)$ $i.e$ maximum value of MCS possible for all CCs and use this MCS on all CCs.

End

Update $N_{RB} = N_{RB} - z$.

Else if ($N_{RB} = 0 \text{ and } n_{ds}^{M2M} \neq 0$)

Find C2C devices which are not on two-year contract $i.e$ using pre-paid services. Reassign *RBs* to them, assign only one primary carrier to them and release remaining *RB* for utilization by priority M2M devices. Go to step 1.

The *RB*s assigned to the delay-sensitive M2M devices are assigned to other devices when they become free.

5.5 Conclusion

As future networks are designed with consumers in mind and the service to be the differential that dictates how the different virtual users are best served. The consumer interface is rapidly changing from C2C to include D2D and hence the packet loss ratio, fairness enhancement are parameters which must meet the highest acceptable standard. Therefore, the work in this paper maximizes the throughput and reduces the packet-blocking probability. In the main, the PR-M2M Algorithm scheme is designed to meet the demand for M2M and C2C communication which are more prone to higher packet dropping and lesser throughput. The work is better than novel schemes available in the literature. The results obtained indicate the scheme is superior to two industry-approved resource allocation schemes herein. The findings study indicates that with HetNets, the PR-M2M scheme is crucial in handling the influx of machine-to-machine (M2M) communication because it gives higher throughput and better packet dropping probability.

CHAPTER SIX
RESULTS AND CONCLUSION

6 Objectives and Research Process

The objective of the research was to improve the performance LTE, this improvement relates to radio resource management (RRM). The functionality CA has brought with it challenges for the implementation of the packet scheduler. However, the challenges were used to design packet scheduler As algorithms that are utilized as a part of scan UE criteria relates to CA.   With LTE standardization frozen by 3GPP in mid-2017, that has brought to end development on LTE technology beside minor changes.

This usher in the next phase where improvements on current deployments investigated. As mention in the introduction, that spectrum availability is a major issue and hence design of the packet scheduler is of vast interest. The packet scheduling controls the number of users who serviced and at times the QoS. Performance improvement and loading the network optimally which ensure spectrum efficiency.

Latest literature review of the packet scheduling along with carrier aggregation and along with standards developments. Live mobile network statistics with analyse on the operation of carrier aggregation along with close inspection on packet scheduling configuration.

6.1 Research Achievements

The study was able to achieve flexible allocation of CCs to LTE A users, by analysing the MCS of each user. This was done while fairness in RB distribution was maintained. Secondly, the study was also able to provide a solution to the challenges associated with massive MTC communication by proposing a packet scheduling algorithm scheme that separate MTC devices into two categories delay-tolerant and delay-sensitive with priority give to delay-sensitive. The operation of this scheme also highlights the features of LTE Advanced networks with relay station configuration.

6.2 Research Contributions

This section highlights the contribution of the research the work.

Implementation of two new RRM allocation algorithm schemes FFAS and PR-M2M

6.3 Contributions under FFAS

- Sequential delivering CCs to LTE users first and then secondly to LTE A
- Better utilization of resources as the allocation is sequential in terms of RBs
- Better performance for LTE and LTE A with increase traffic
- Testing carrier aggregation within the same frequency band

6.4 Contributions under PR-M2M

- Using relay nodes provides RBs to delay-sensitive M2M communications
- Better throughput at the cell edge
- Least dropping probability at cell edge due to the two-hop-hop

The advantage of using CA, best serve all users in the LTE advanced network both to users with CA enable device and whose devices are not CA enable. The contribution eNodeB resources scheduling as related to fair resource allocation while also checking the priority of the user's request. This ensures that the quality of service is guaranteed. Second with the advent of IoT where not only C2C communication is transpiring but also, we have massive MTC with thousands of D2D connection.

6.5 Research Summary and Conclusion

This research highlights the importance of packet scheduling in LTE Advanced networks as mention earlier of the different solution criteria.

- Operating of LTE Advanced with design network of the same band carrier aggregation. (FFAS)
- Operating of LTE Advanced with design network of the different band carrier aggregation. (FFAS)
- Operating of LTE Advanced with design network of the different band's carrier aggregation and relay stations for M2M communication. (PR-M2M)

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