Addis Ababa University

Addis Ababa Institute of Technology

School of Electrical and Computer Engineering

Users Throughput Enhancement of LTE Network using Carrier Aggregation for Addis Ababa

By

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Declaration

I, the undersigned, declare that this thesis is my original work, has not been presented for a degree in this or any other university, and all sources of materials used for the thesis have been fully acknowledged.

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Date of submission: December 10, 2019

This thesis has been submitted for examination with my approval as a university advisor.

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Abstract

Mobile broadband services are undergoing a period of dramatic growth causing a tremendous increase in data traffic. One main reason for this rise of traffic is being driven by the growing number of mobile subscribers. This increment in data traffic is handled by new technologies. LTE-Advanced extends the capabilities originally defined in LTE to increase data throughput by using a combination of new technologies, like Orthogonal Frequency Division Multiple Access (OFDMA), Carrier Aggregation (CA) and Multi Input Multi Output (MIMO) techniques. CA is one of the most significant LTE-Advanced features that combine multiple Component Carriers (CCs) across an available spectrum to create a wider bandwidth channel for increasing the network data throughput and overall capacity.

This thesis analyzes throughput enhancement using CA technique, by conducting radio propagation using WinProp and system level simulation using Matlab, for different CA scenarios of a selected high traffic area in Addis Ababa city, Ethiopia. The addition of 10 MHz CC over 20 CC provides 49%, and 20 MHz provides 105% throughput gains at cell center for case of 1800 MHz (band 3). All the three frequency bands (1800 MHz, 2600 MHz (band 7) and 3700 MHz (band 43)) with two 20 MHz CC provide over 100% throughput gain at the cell center, compare to 1 CC at 1800 MHz. When using low frequency bands, such as the 1800 MHz band, the Signal to Interference and Noise Ratio (SINR) value is low thus providing a better throughput from the cell center to edge.

Keywords: *LTE, LTE-Advanced, SINR, Throughput, Frequency band, Carrier aggregation, Component carrier*

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Acronyms and Symbols

Acronyms

1G	First Generation
2G	Second Generation
3G	Third Generation
3GPP	Third Generation Partnership Project
4G	Fourth Generation
CA	Carrier Aggregation
CCs	Component Carriers
CDF	Cumulative Distribution Function
CoMP	Coordinate MultiPoint
DL	Downlink
EDGE	Enhanced Date rate for GSM Evolution
eNodeB	evolved NodeB
E-UTRAN	Evolved Universal Terrestrial Radio Access Network
EPC	Evolved Packet Core
EPS	Evolved Packet System
FDD	Frequency Division Duplexing
FDMA	Frequency Division Multiple Access
GSM	Global System for Mobile Communication

HSDPA	High Speed Downlink Packet Access
HSPA	High Speed Packet Access
HSUPA	High Speed Uplink Packet Access
IP	Internet Protocol
LTE	Long Term Evolution
LTE-Advanced	Long Term Evolution Advanced
MAC	Media Access Control
MIMO	Multi Input Multi Output
MME	Mobility Management Entity
OFDMA	Orthogonal Frequency Division Multiple Access
PCell	Primary serving Cell
P-GW	PDN (Packet Data Network) Gateway
PRB	Physical Resource Block
PS	Packet Switch
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
RBs	Resource Blocks
RLC	Radio Link Control
RNs	Relay Nodes
RR	Round Robin
RRH	Remote Radio Head
SCell	Secondary serving Cell
S-GW	Serving Gateway

SINR	Signal to Interference and Noise Ratio
TDD	Time Division Duplexing
UDPM	Urban Dominant Path Model
UE	User Equipment
UL	Uplink
UMTS	Universal Mobile Telecommunication System
WCDMA	Wideband Code Division Multiple Access

Symbols

Δ	Change in given variable
x	Multiplication
λ	Wave length

Chapter 1

Introduction

1.1 Background and Motivation

Globally there is a rise of data traffic, which is being driven by the growing number of mobile subscribers, particularly smart phone users, who are connecting to faster networks and consuming bandwidth-hungry video content [1]. Report in [2] indicates that, globally mobile data traffic will increase seven folds between 2017 to 2022, with a compound annual growth rate of 46%.

According to [3], by the end of 2018, there were 456 million unique mobile subscribers in Sub-Saharan Africa, representing a subscriber penetration rate of 44%. Around 239 million people, 23% of the population, also use the mobile internet on a regular basis. The total subscriber will be 600 million in 2025 with a growing rate of 4.6%, representing around half the population. Ethiopia and Nigeria will record the fastest growth rates between 2019 and 2025, at 11% and 19% respectively. During 2019, Third Generation (3G) will overtake Second Generation (2G) to become the leading mobile technology in the region, with just over 45% of total connections by the end of the year. Fourth Generation (4G) accounted for 7% of total connections, compared to the global average of 44%. 4G adoption will overtake 2G in 2023 and rise to 23% connections by 2025.

In Ethiopia, ethio telecom is providing a data and other services using 2G and 3G all over the country, and including 4G, Long Term Evolution (LTE) mobile technologies in case of capital city Addis Ababa. As the Packet Switch (PS) data taken from ethio telecom in Figure 1.1 shows, in Addis Ababa there is a dramatic increase in data traffic. The total data traffic increases by 76% and LTE traffic increases by 152% in one year duration.

This increment in data traffic also currently leads for the capacity problem especially on 3G network [4].

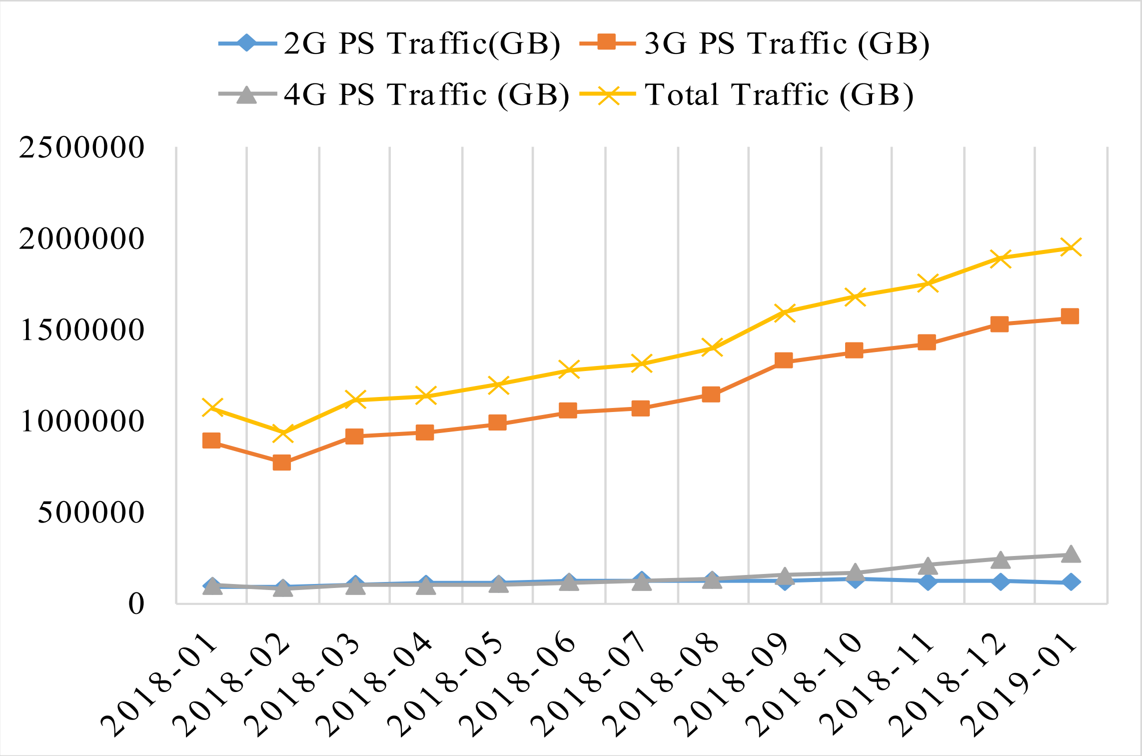


Figure 1.1: Ethio telecom PS traffic [4]

Keeping the traffic increment, the total capacity of the network will have a capacity issue in near future as it is calculated as follows. The total number of sites in Addis Ababa is 740 sites which consists of 630 2G sites (1890 cells), 740 3G (6968 cells) and 332 LTE sites (996) [4, 5]. The cell throughput is assumed to be 0.05, 4 and 40 Mbps for 2G, 3G and LTE, respectively [6]. Thus, from this data the current network data capacity can be found (C_c), 67806.5 Mbps.

With 80.81% down link ratio (DLr) and 8.47% busy hour ratio (BHr), in Addis Ababa [7], the monthly average mobile data flow capacity (DF) of the network in Peta Byte (PB) can be calculated using Equation (4.1) [6], and becomes 13.37 PB/month.

$$DF = \frac{\frac{C_c}{8} * 3600 * 30}{BH_r * DL_r * 10^{15}} \tag{1.1}$$

The forecast data demand for Addis Ababa in paper [6] shows it will be 20.27 PB/month in 2021, but cannot be handled with the current capacity. This implies using of new technologies, and also capacity enhancement using different enhancement techniques is an essential issue.

To increase the capacity of wireless communication systems, the Third Generation Partnership Project (3GPP) has developed the technology of LTE. LTE has been specified starting in Release 8 in 2008 and continued to Release 9 in 2009. It doesn't end there, the development of LTE has been continuing to reach the very high-speed data services. The 3GPP has been submitted Long Term Evolution Advanced (LTE-Advanced), Release 10, to be the standard for the 4G system since it will support high peak data rates for User Equipment (UE), up to 1 Gbps in static and pedestrian environments, and up to 100 Mbps with high mobility speed in Downlink (DL) and 500 Mbps in Uplink (UL) [8, 9, 10].

LTE-Advanced system is seen as the next major evolutionary step in the continuing development of LTE system. The expectation of implementing LTE-Advanced system is to fulfill the requirement of International Mobile Telecommunications (IMT)-Advanced requirements. The major components that have been developed in LTE-Advanced system are a wider bandwidth through aggregation of multiple Component Carriers (CCs), evolved use of advanced antenna techniques with multi-antenna extensions in both UL and DL and relaying techniques in order to meet the IMT-Advanced targets [9].

Carrier Aggregation (CA) is one of the LTE-Advanced options that permit Mobile Network Operators (MNOs) to combine multiple CCs across the available spectrum to create a wider bandwidth channel for increasing the network data throughput. CA has a potential to enhance network performance and data rates in the DL, UL, or both. It can support aggregation of Frequency Division Duplexing (FDD) as well as Time Division Duplexing (TDD). The technique enables the MNOs to exploit fragmented spectrum allocations and can be utilized to aggregate licensed and unlicensed carrier spectrum as well [11].

In case of ethio telecom CA is implemented on 3G network with 5 MHz bandwidth per CC. The LTE deployed is an Release 8 with a 20 MHz bandwidth and single CC on band 3 (1800 MHz).

1.2 Statement of the Problem

Addis Ababa data traffic is growing in a fast manner which shows high data requirement will be an issue in the near future, in addition to the current quality problems observed 3G services due to capacity issue. This increasing demand of data service issues will increase the demand for high capacity mobile networks.

One of the solutions to answer the above problems is to use LTE-Advanced and different solutions that come with it. LTE-Advanced CA is one of the solutions for operators to manage mobile network traffic growth. The CA technology has already been trialed and implemented in several countries and operators.

This thesis focuses on studying the performance analysis of one of the key features of LTE-Advanced: Carrier Aggregation, for Addis Ababa topology and considering ethio telecom existing sites information. The dominant path loss model is used for propagation, which is more accurate than empirical. By doing this comparative system performance for each of the following mobile networks done.

- Mobile network that uses different bandwidth carriers within a single band;
- Mobile network that uses contiguous carriers within a single band; and
- Mobile network that uses contiguous carriers in different bands

1.3 Objective

1.3.1 General Objective

This thesis work, generally, investigates users throughput performance improvement by using CA on different frequency bands in LTE radio networks, for case of Addis Ababa city.

1.3.2 Specific Objectives

In particular, the following specific objectives are set::

- Ethio telecom traffic data analysis, for high traffic area sellection
- Existing LTE radio network data collection from ethio telecom, for simulation parts
- Propagation on WinProb for path loss analysis
- Simulation on Matlab for different CCs and for different frequency bands
- Compare and analysis simulation results

1.4 Methodology

In this thesis some literature's review followed by collection of a different data on the current LTE network which help for traffic data analysis, sites location identification and different source inputs for WinProp and Matlab simulators. The sites location identified is one of the high traffic area in Addis Ababa, based on LTE traffic data.

Then, path loss is taken by doing simulating for 1800MHz, 2600MHz and 3700MHz frequency bands using WinProp. In the WinProp the inputs like sites location (longitude and latitude), azimuth and height are taken from existing sites information.

The Matlab simulation is done by taking path loss information, and other technical inputs, which delivers the throughput value by mapping the Signal to Interference and Noise Ratio (SINR) to throughput mapper, where the SINR is find from the path loss analysis. Finally, based on different CA scenarios outputs are analyzed. The overall process is summarized in Figure 1.2.

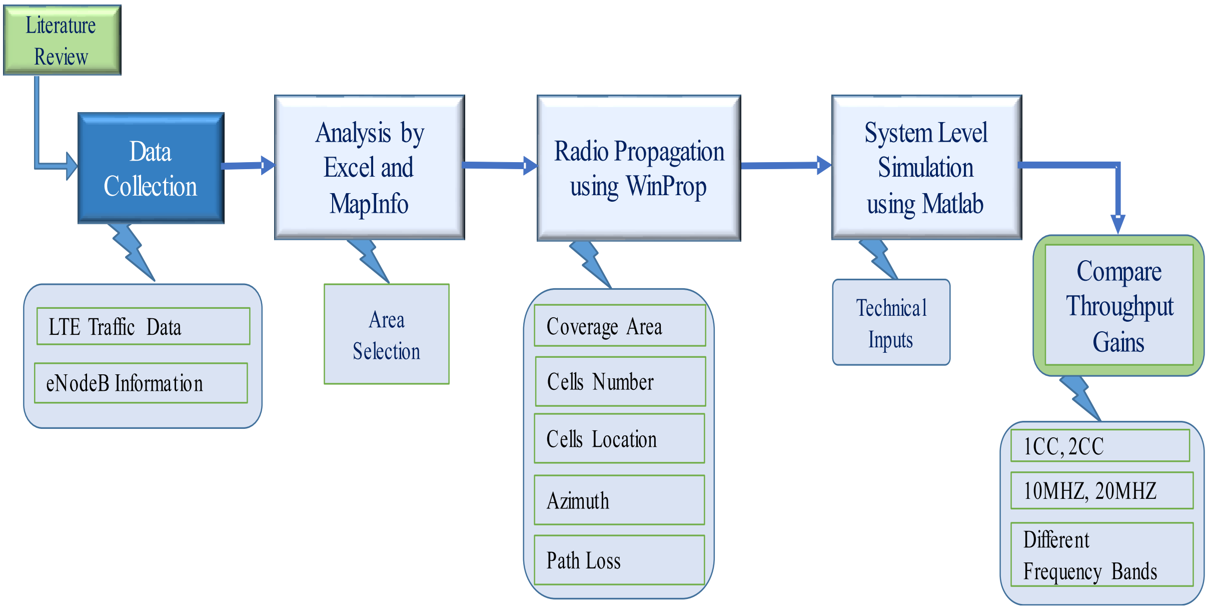


Figure 1.2: Methodology

1.5 Literature Review

Some of related works with this thesis are reviewed as following:

The paper in [12], investigate possible performance enhancements through the use of LTE-Advanced enhancements, specifically: Coordinate MultiPoint (CoMP) and CA, to relax the downlink backhaul capacity bottleneck for self-backhauled LTE-Unlicensed small cells. This proposed approach done through system simulations of a selected realistic deployment scenario in Addis Ababa. The results of the simulation shows that deployment of self-backhauled LTE-Unlicensed small cells in dense urban hot-spots can provide notable throughput gains, particularly for the case CA enhancements in the small cell backhaul links.

The paper in [13] provides a thorough performance analysis of the key aspects affecting the capacity and spectrum efficiency of LTE networks. The overall analysis is divided into three major parts namely technology, spectrum and topology aspects. Though the system-level simulations they show the network performance under various configuration settings. Performance evaluations show that the introduction of small cells in dense environments can greatly increase the network capacity in conjunction with the CA technology.

The research in [14] aims to analysis the effect of CA and types of CA which can be optimum in Bandung city. Research start from planning and dimensioning LTE-Advanced radio access network using Atoll software in Bandung area. The scenario bandwidth configuration of maximum CA is 40 MHz and using two CCs, by using frequency 1800 MHz and 2100 MHz. Simulation result show the network covered 100% of high-speed internet user on simulation area. CA increase Received Signal Code Power (RSRP) around 3 dB and decrease Block Error Rate (BLER) around 0.02 - 0.07%. Inter-band CA with Primary serving Cell (PCell) 1800 MHz and total bandwidth 40 MHz has the best mean throughput (43.35 Mbps).

The paper in [8] proposes throughput evaluation for LTE-advanced network access in the particular service area employing CA technique. From several kinds of CA, they evaluate which one the best CA configuration in term of network throughput. 30 MHz aggregated bandwidth and two CC serve as a PCell and Secondary serving Cell (SCell) are used in the simulation. Simulation results show that the configuration of wider PCell bandwidth resulting better performance of the throughput. In particular, in CA intra-band scenario, the throughput of non-contiguous CA has better performance compared with CA contiguous. Whereas in the inter-band CA scenario, CC combination with lower frequency resulting better throughput performance.

The authors in [15], made tests to study the effects that the use of CA with three carriers has on the mobile operator's network. Measurements were also made to observe the behavior of two users that use simultaneously CA with three carriers. From measurements, CA brought a significant gain on the average user throughput. Also, during the tests, they observed that carrier aggregation has significant software and hardware implications, particularly on the UE. So, CA-capable hardware, in combination with numerous parameters and optional functionality, demands comprehensive and flexible UE test and verification solutions to ensure successful deployment and a high performance in the field.

In the paper [11], a simulation of 2CC and 3CC CA was done using the Vienna LTE System Level simulator, and the simulation results revealed there is 11.6% increase in the average cell throughput using 3CC CA as compared to 2CC CA. However, this gain in data throughput came at the expense of 18.3% reduction in the fairness index whose compensation could result into scheduler design complexity. The results also shows that the best CC combination in an inter-band 2CC CA was when CCs from 1800 MHz frequency and 2100 MHz were aggregated.

From the above related papers methods for system level simulation have be taken. There main difference from this thesis is, the real 3D topology is considered in addition to the existing sites information.

1.6 Contribution

As mentioned in the objective section, this research performs performance analysis of carrier aggregation for LTE-Advance network at different scenarios. This different scenarios output shows the throughput values at different bandwidth and bands. Thus, the results obtained in this thesis work can be used as an input for operators, regulators and for the research community. It can be also use as a solution to enhance the capacity of Addis Ababa network, as there is a problem on 3G network and 4G network will have an issue in near future.

1.7 Scope and Limitation

1.7.1 Scope of the Thesis

The main scope of this thesis is to study the impact of CA in LTE networks, regarding throughput, by considering real cases in selected area. One of LTE-Advanced capacity enhancement techniques, CA, will be analyzed on different scenarios, by considering real deployment scenario.

1.7.2 Limitation of the Thesis

There will a number of cases that are not be considered during simulation, some limitation of this thesis will be:

- The UL physical layer not considered, DL is considered
- Use only 1x2 Multi Input Multi Output (MIMO) technique
- Some selected frequency bands used
- Two bandwidth only considered, 10MHz and 20MHz

1.8 Thesis Layout

This thesis consists of six chapters. Chapter 1 consists of background and motivation, problem statement, general and specific objectives, the methodologies used in this thesis, some related literature review, contribution, scope and limitation of the thesis. Chapter 2 introduces the basics of LTE and LTE-Advanced technologies. The CA technology is presented in depth in Chapter 3. Chapter 4 deals with the system design which includes the area selection steps, the simulation set up for the case study area and the procedures followed. Chapter 5 comprises of the results obtained from the simulation and discussion based on the results. Chapter 6 presents a concluding remarks for the thesis and recommendations for future works.

Chapter 2

Overview of LTE Systems

2.1 Evolution of Mobile Technologies

Mobile technology systems were first introduced in the early 1980s with the First Generation (1G) systems, which used analogue communication techniques. The 2G systems introduced in the early 1990s, the first to use digital technology, which permitted a more efficient use of the radio spectrum. The most popular 2G system is Global System for Mobile Communication (GSM). The 2G systems were originally designed just for voice, but were later enhanced to support the Short Message Service (SMS). This success leads for the development of 2.5G, by introducing the core network's packet switched domain and by modifying the air interface, so that it could handle data as well as voice [16].

The performance of 2G systems improved using techniques such as Enhanced Date rate for GSM Evolution (EDGE) and then introduced more powerful 3G systems in the years after 2000. The world's dominant 3G system is the Universal Mobile Telecommunication System (UMTS), which was developed from GSM by keeping the core network almost unchanged, while completely changing the technology used on the air interface. The 3G system was later enhanced for data applications, by introducing the 3.5G technologies of High Speed Downlink Packet Access (HSDPA) and High Speed Uplink Packet Access (HSUPA), which are collectively known as High Speed Packet Access (HSPA) [16].

For many years, voice calls dominated the traffic in mobile telecommunication networks, but with the dramatically increase of mobile data in the years around 2010, 2G and 3G networks started to become congested leading to a requirement to increase network capacity. This leads to new technologies like LTE and LTE-Advanced.

2.2 LTE

LTE mobile broadband is developed by the 3GPP and adopted by the European Telecommunications Standards Institute (ETSI), which is popularly called a 4G. The LTE project aim is to have average user throughput of three to four times (100 Mbps) the Release 6 HSDPA in the DL and two to three times (50 Mbps) the HSUPA in the UL, the peak data rate in Release 6 HSPA of the 3GPP specifications is 14Mbps in the DL and 5.7 Mbps in the UL [16, 17].

2.2.1 Overview of Basic System Architecture

Figure 2.1 describes the architecture and network elements in LTE. This figure also shows the four main high level domains of the architecture : UE, Evolved Universal Terrestrial Radio Access Network (E-UTRAN), Evolved Packet Core (EPC), and the services domain [18].

EPC, E-UTRAN and UE together represent the Internet Protocol (IP) connectivity layer. This part of the system is also called the Evolved Packet System (EPS). The main function of EPS is to provide IP based connectivity, and it is highly optimized for that purpose only. All services will be offered on top of IP, and circuit switched nodes and interfaces seen in earlier 3GPP architectures are not present in E-UTRAN and EPC.

UE is a hand held device that the end user uses for communication. It also contains the Universal Subscriber Identity Module (USIM) that is a separate module from the rest of the UE, which is often called the terminal equipment. Each UE is connected to the evolved NodeB (eNodeB) by means of the Uu interface.

The IP Multimedia Sub-System (IMS) is a good example of service domain that can be used in the services connectivity layer to provide services on top of the IP connectivity provided by the lower layers. For example, to support the voice service, IMS can provide Voice over IP (VoIP) and inter-connectivity to legacy circuit switched networks Public Switched Telephone Network (PSTN) and Integrated Services Digital Network (ISDN) through media gateways it controls.

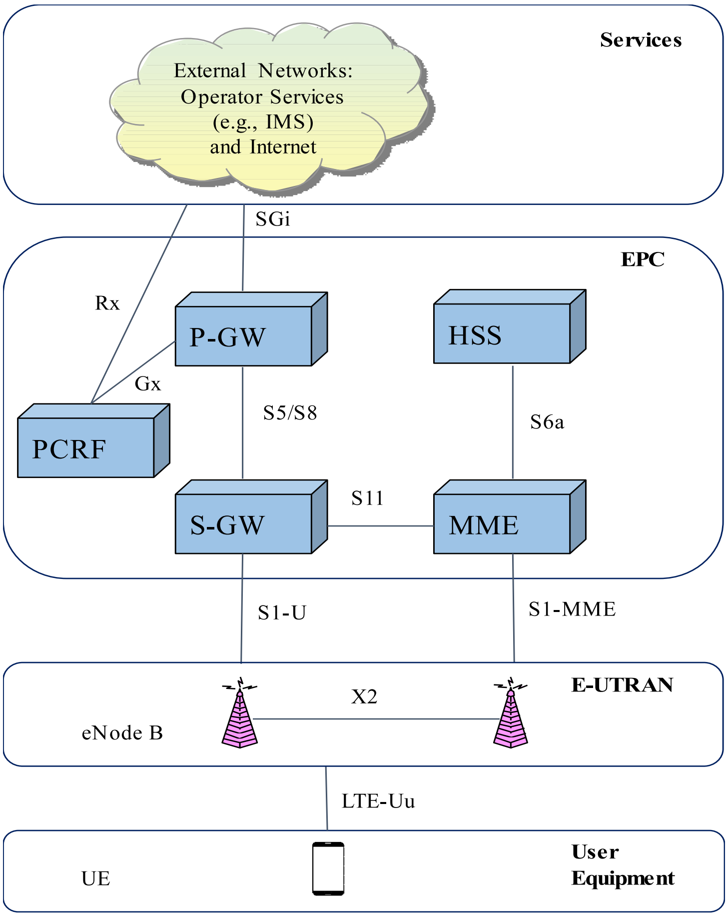


Figure 2.1: LTE system architecture (adapted from [18])

2.2.1.1 Evolved UMTS Terrestrial Radio Access Network

The E-UTRAN has one component, the eNodeB, and handles the radio communications between the EPC and the UE. The eNodeB is a radio base station that is in control of all radio related functions in the fixed part of the system. Functionally eNodeB acts as a layer two bridge between UE and the EPC. It performs ciphering/deciphering of the user plane data, and also IP header compression/ decompression, which means avoiding repeatedly sending the same or sequential data in IP header.

The eNodeB is also responsible for many control plane functions, such as Radio Resource Management (RRM), that is controlling the usage of the radio interface, which includes, for example, constant monitoring of the resource usage situation, prioritizing and scheduling traffic according to required Quality of Service (QoS) and allocating resources based on requests.

Each eNodeB is connected to the EPC by means of the S1 interface. It can also be connected to nearby eNodeBs by the X2 interface, which is used for signaling and packet forwarding during handover.

2.2.1.2 Evolved Packet Core

The main parts of the EPC are the Mobility Management Entity (MME), PDN (Packet Data Network) Gateway (P-GW), the Serving Gateway (S-GW) and the Home Subscriber Server (HSS). In addition, the EPC also contains other types of nodes such as Policy and Charging Rules Function (PCRF) responsible for charging and QoS handling [19], as shown in Figure 2.1.

P-GW: is the outermost entity of the EPC that bridges the inner nodes of the EPC and the external Internet, through SGi interface. It performs filtering of IP packets and allocates IP addresses to the UE.

S-GW: is a mobility anchor for a UE, the data for a specific UE pass through the S-GW regardless of the serving eNodeB to which the UE is connected.

HSS: stores and handles user-specific information such as subscription information, authentication information, and security information.

MME: is a central node of the core network that exchanges signaling with the UE. The MME performs bearer management such as establishment, modification, and release of connection. In addition, the MME also performs a mobility-related function such that it tracks radio resource control idle UEs' location for paging. Regarding security, the MME performs the authentication procedures to check the validity of the UE, and allocates temporary identities to the UE to provide user identity protection. The MME further provides security keys to the eNodeB, to enable the eNodeB to perform ciphering and an integrity check.

2.2.2 Technologies in LTE

2.2.2.1 LTE Multiple Access

If information is modulated only to one carrier adjusting the phase, amplitude or frequency it is called Single Carrier (SC) modulation. With the Frequency Division Multiple Access (FDMA) principle, different users would be using different carriers or sub-carriers to access the system simultaneously having their data modulation around a different center frequency. There is a constant spacing between neighboring sub-carriers. One of the approaches to multi-carrier is to send two Wideband Code Division Multiple Access (WCDMA) carriers next to each other, also the dual carrier WCDMA (dual cell HSDPA) [18].

To address the resulting inefficiency from the possible guard band requirements, the approach is to achieve orthogonality between the different modulations, and to create the sub-carriers so that they do not interfere with each other but their spectrum could still overlap in the frequency domain. This is what is achieved with the Orthogonal Frequency Division Multiple Access (OFDMA) principle, where each of the center frequencies for the sub-carriers is selected from the set that has such a difference in the frequency domain, in which the neighboring sub-carriers have zero value at the sampling instant of the desired sub-carrier, as shown in Figure 2.2 [18].

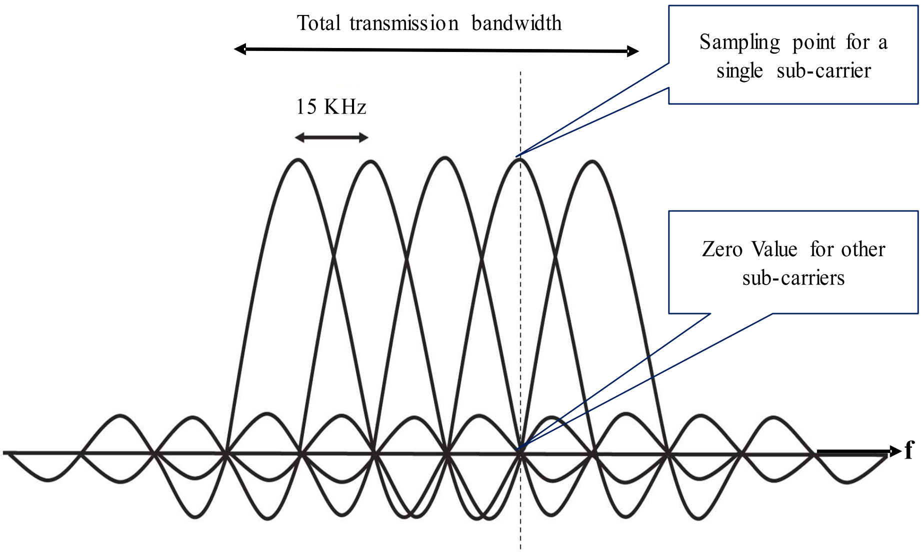


Figure 2.2: Orthogonality between sub-carriers (adapted from [18])

The motivations fo OFDMA in LTE are low complexity of base-band receiver, good performance in frequency selective fading channels, good spectral properties and handling of multiple bandwidths, link adaptation and frequency domain scheduling. Compatibility with advanced receiver and antenna technologies.

The parameterization in OFDMA is based on the 15 kHz sub-carrier spacing. This ensure sufficient robustness to large velocity and frequency error. The actual resolution of the resource allocation in frequency domain, both for the DL and UL, is 180 kHz.

The resource allocation over 180 kHz and for the 1 ms sub-frame corresponds to a single LTE Physical Resource Block (PRB), which is equal to 12 sub-carriers. The smallest allocation is thus 6 PRBs, equal to 1.08MHz and the largest 100 PRBs, equal to 18MHz. For normal deployment the corresponding bandwidths are then 1.4 and 20MHz respectively [20].

In the uplink direction the Single Carrier FDMA (SC-FDMA) facilitates power efficient terminal transmitter implementation since there are no parallel wave-forms transmitted but the transmission principle is based on the use of a digital Quadrature Amplitude Modulation (QAM) modulation coupled with the cyclic prefix use after a block of symbols.

2.2.2.2 Frame Structure

The frame structure is based on the 10 ms frame which then contains 1 ms sub-frames. The sub-frame is divided between control and data parts as shown in Figure 2.3. The control part corresponded to the Physical DL Shared channel (PDCCH), while rest of the sub-frame is filled with data, which corresponds to the Physical DL Control Channel (PDSCH).

The allocation space for the PDCCH is dynamically signaled every sub-frame on the Physical Control Format Indicator Channel (PCFICH), which informs whether a single OFDMA symbol is needed for the PDCCH capacity needs or if two or three symbols are used [20].

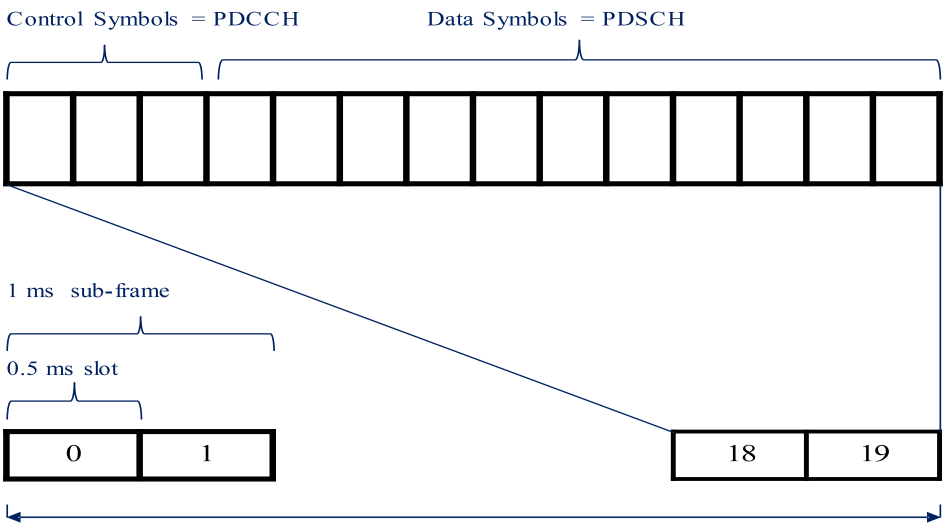
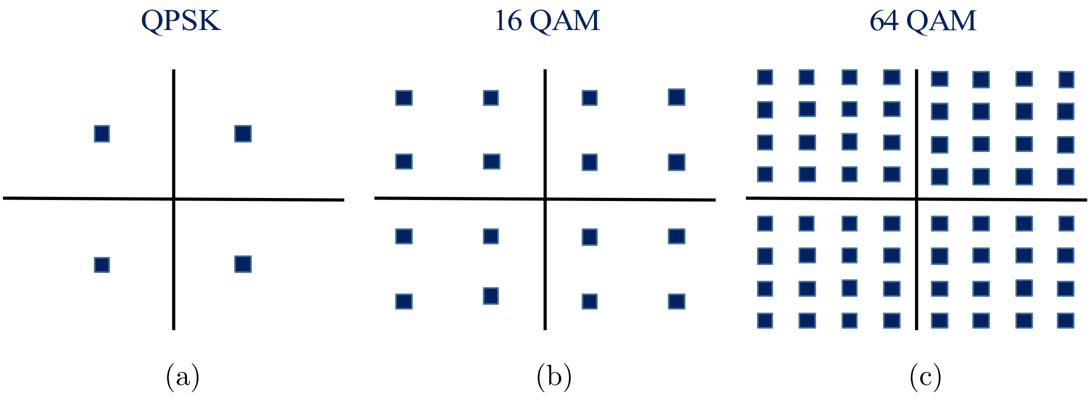


Figure 2.3: LTE DL frame structure (adapted from [20])

2.2.2.3 Modulation Schemes

The use of higher-order modulation, by allowing for more bits of information to be communicated per modulation symbol is straightforward means to provide higher data rates within a given transmission bandwidth. Quadrature Phase Shift Keying (QPSK), 16QAM and 64QAM are the modulation methods available in LTE. The first two are available in all devices while support for 64QAM in the UL direction depends on the UE capability. Different modulations are shown in Figure 2.4 [18, 21].



(a) (b) (c)

Figure 2.4: LTE modulation constellations for (a) QPSK, (b) 16QAM, (c) 64QAM (adapted from [21])

In the case of QPSK modulation, the modulation alphabet consists of four different signaling alternatives, shown in Figure 2.4a. With four different signaling alternatives, QPSK allows for up to 2 bits of information to be communicated during each modulation-symbol interval.

For 16QAM modulation, as shown in Figure 2.4b, 16 different signaling alternatives are available which allows for up to 4 bits of information to be communicated per symbol interval. By extension to 64QAM, as shown in Figure 2.4c, with 64 different signaling alternatives, allows for up to 6 bits of information to be communicated per symbol interval. The maximum bandwidth utilization of 16QAM and 64QAM are thus in principle two and three times that of QPSK respectively, which can be expressed in bits/s/Hz [21].

2.2.3 Radio Protocols

Figure 2.5 illustrates the Radio Access Network (RAN) protocol architecture, which is divided in to the user and control planes. The different protocol entities of the RAN are summarized as follows [21].

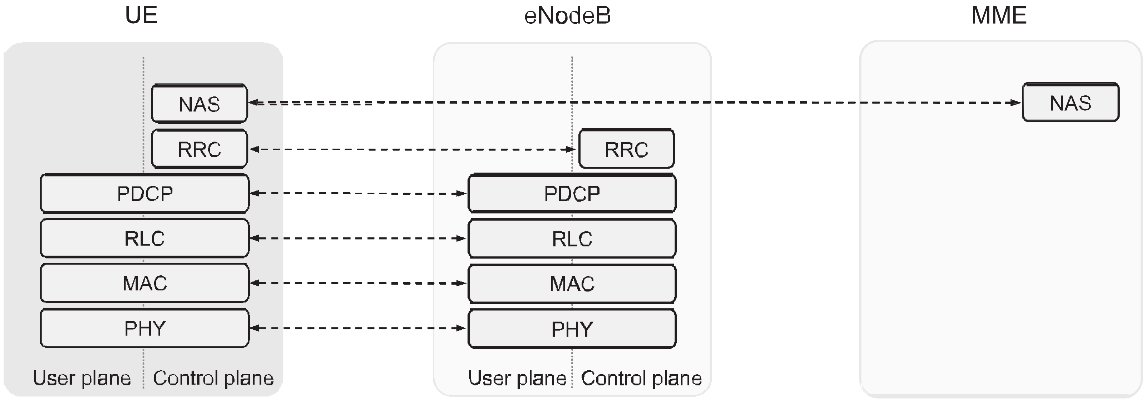


Figure 2.5: RAN protocol architecture [21]

Packet data convergence protocol (PDCP): performs ciphering, integrity and protection IP header compression. It also performs in-sequence delivery and duplicate removal in case of handover. There is one PDCP entity per radio bearer configured for a device.

Radio Link Control (RLC): is responsible for segmentation/concatenation, duplicate detection, re-transmission handling and in-sequence delivery to higher layers. The RLC provides services to the PDCP. Like PDCP, there is one RLC entity per radio bearer configured for a device.

Medium Access control (MAC): handles multiplexing of logical channels, Hybrid Automatic Repeat Request (HARQ) re-transmissions, and UL and DL scheduling. The scheduling functionality is located in the eNodeB. The MAC delivers services to the RLC in the form of logical channels.

Physical layer (PHY): handles modulation/demodulation, coding/decoding, multi-antenna mapping, and other typical physical-layer functions. The PHY provides services to the MAC layer in the form of transport channels.

2.3 LTE-Advanced

LTE-Advanced is a major enhancement of the LTE standard. LTE-A delivers true 4G speeds, unlike current LTE networks, and is also known as True 4G. LTE-A uses several techniques to meet higher network-performance standards [22]. Some of them include:

- Increased peak data rate, DL 3 Gbps, UL 1.5 Gbps
- Higher spectral efficiency, from a maximum of 16bps/Hz in R8 to 30 bps/Hz in R10
- Increased number of simultaneously active subscribers
- Improved performance at cell edges, e.g. for DL 2x2 MIMO at least 2.40 bps/Hz/cell.

The main new functionalities introduced in LTE-Advanced Release 10 are CA, enhanced use of multi-antenna techniques and support for Relay Nodes (RNs). LTE-Advanced continues to evolve, with new CA configurations and there are new features introduced in continuous releases of the 3GPP specifications, such as CoMP introduced in R11. The CA is the main aim of this thesis and elaborated in Chapter 3.

2.3.1 Enhanced Multiple Antenna Technologies

In LTE Release 8 MIMO antenna schemes is supported. In DL direction up to four transmit antennas may be used. Spatial division multiplexing of multiple modulation symbol streams to both a single UE using the same time-frequency resource (also referred to as Single User MIMO (SU-MIMO)) and to different UEs using the same time-frequency resource (also referred to as Multi User MIMO (MU-MIMO)) are supported. In UL direction only MU-MIMO is used, that is one modulated symbol stream per UE only to be received by the eNodeB, whereas multiple UEs may transmit on the same time-frequency resource [23].

LTE-Advanced extends the MIMO capabilities of LTE Release 8 to eight in the DL and four in the UL layers. In LTE-Advanced UL direction the same principles as defined in LTE Release DL apply whereas in LTE-Advanced DL direction the existing LTE Release 8 scheme is extended as shown in Figure 2.6 . Transmit diversity is also possible in both DL and UL direction.

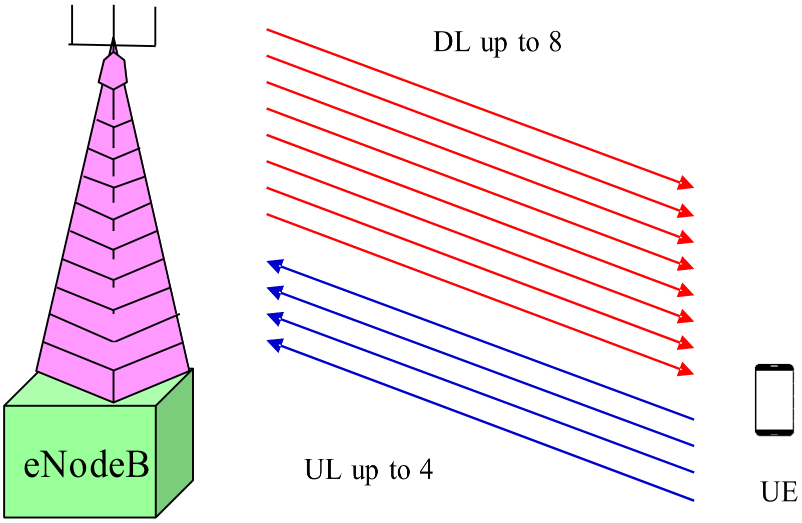


Figure 2.6: MIMO in LTE-Advanced

2.3.2 Relay Nodes

In LTE-Advanced, the possibility for efficient heterogeneous network planning is increased by introduction of RNs. The RNs are low power base stations that will provide enhanced coverage and capacity at cell edges and it can also be used to connect to remote areas. UEs communicate with a RN, which in turn communicates with a donor eNodeB as shown in Figure 2.7. The donor eNodeB may, in addition to serving one or several RNs, also communicate with non-relayed UEs directly [23, 22].

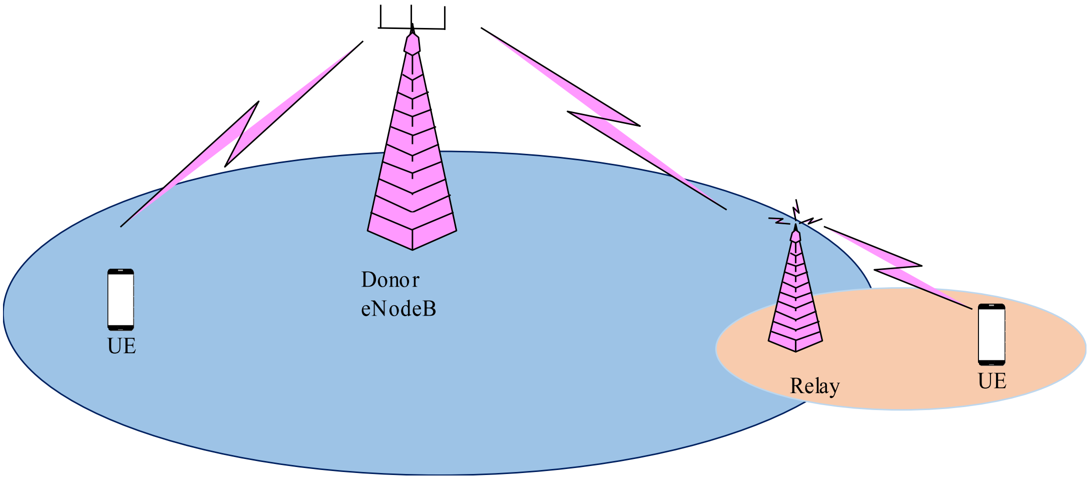


Figure 2.7: Relaying

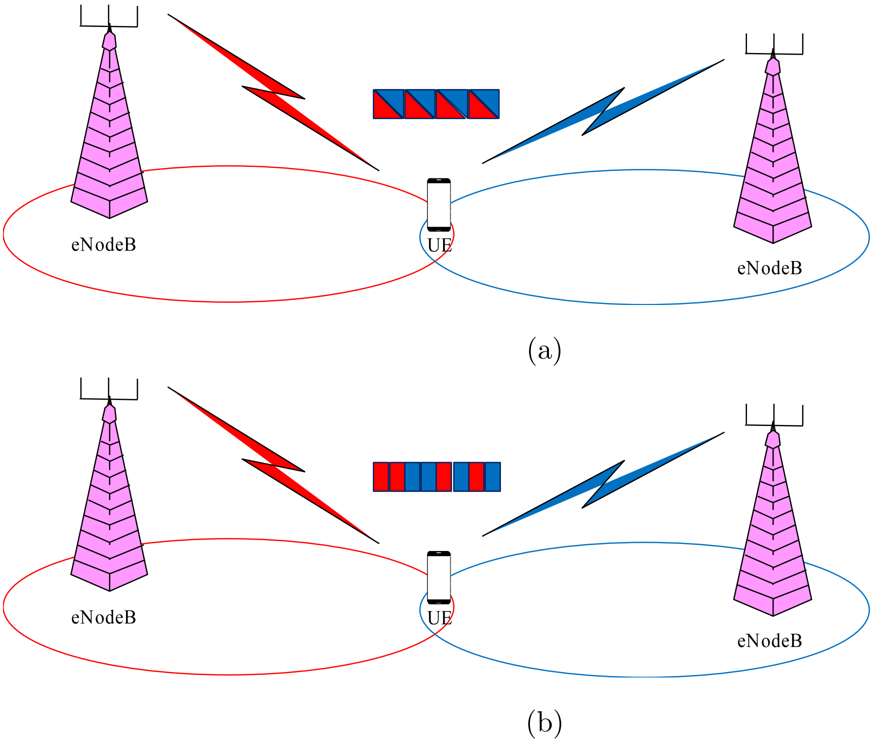
The RN transmits its own Cell-ID and own synchronization and reference signals the by creates its own cell. The UE communicates only with the RN and is oblivious of the donor eNodeB. So, from an UE perspective this RN looks like a conventional eNodeB.

2.3.3 Coordinated MultiPoint

The main reason to introduce CoMP is to improve cell edges network performance. In CoMP a number of transmit points provide coordinated transmission in the DL, and a number of receive points provide coordinated reception in the UL. A transmit-receive point constitutes of a set of co-located transmit-receive antennas providing coverage in the same sector. The set of transmit-receive points used in CoMP can either be at different locations, or co-sited but providing coverage in different sectors, they can also belong to the same or different eNodeBs [24].

CoMP can be done in a number of ways, and the coordination can be done for both homogeneous networks as well as heterogeneous networks. In Figure 2.8 two simplified examples for DL CoMP is shown.

When two or more transmit-points transmit on the same frequency in the same sub-frame it is called Joint Transmission, Figure 2.8a. When data is available for transmission at two or more transmit-points but only scheduled from one transmit-point in each sub-frame it is called dynamic point selection, Figure 2.8b. For UL CoMP a number of receive-points



(a)

(b)

Figure 2.8: Downlink CoMP a) Joint transmission; b) Dynamic point selection

receive the UL data from one UE, and the received data is combined to improve the quality [24].

Chapter 3

Carrier Aggregation

CA is a key feature of LTE-Advanced that enables operators to create larger carrier bandwidths for LTE services by combining separate spectrum allocations. It is the primary feature deployed with commercial LTE-Advanced service by operators. The need for CA in LTE-Advanced arises from the requirement to gain bandwidths larger than supported by LTE while at the same time ensuring backward compatibility. The benefits of this aggregation include higher peak data rates and increased average data rates for users [25].

3.1 Types of Carrier Aggregation

CA in LTE-Advanced is designed to support aggregation of a variety of different arrangements of CCs including carriers of the same or different bandwidths, adjacent or nonadjacent CCs in the same or in different frequency bands. There are three types of CA, depending on CC combinations, as shown in Figure 3.1.

Intra-band contiguous CA: is used when multiple CCs belonging to the same band are allocated in a contiguous manner, it uses a single band and is the simplest form of LTE CA to implement. The spacing between center frequencies is a multiple of 300 kHz to be compatible with the 100 kHz frequency of LTE Release 8/9 and preserving orthogonality of the sub-carriers with 15 kHz spacing [26].

Intra-band non-contiguous CA: is used when multiple CCs belonging to the same band are allocated in a non-contiguous manner. This scenario is expected where a single band is allocated and the middle carriers are loaded with other users or networks.

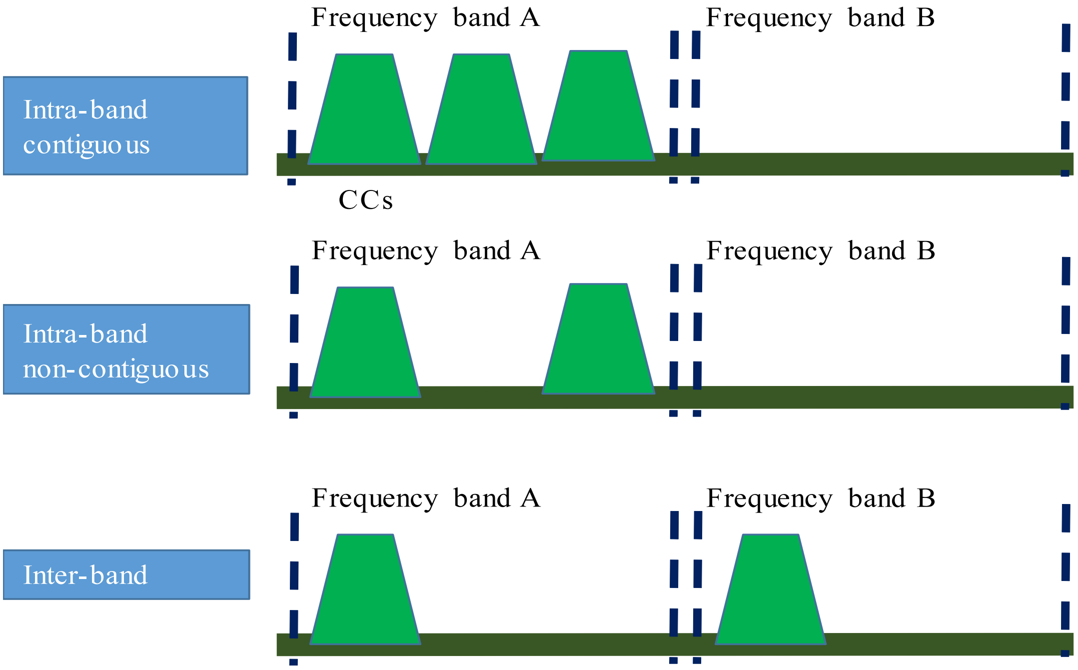


Figure 3.1: Types of CA (adapted from [8])

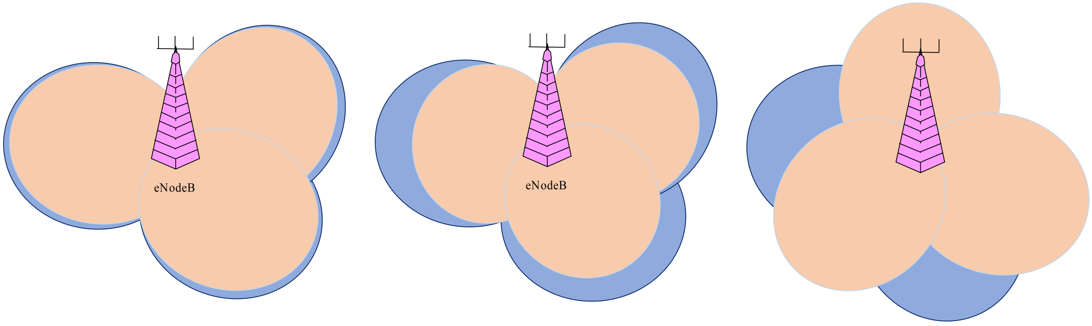
Inter-band non-contiguous CA: is used when multiple CCs belonging to different bands are allocated. Thus, with this type of aggregation by exploiting different radio propagation characteristics of different bands mobility robustness can potentially be improved.

As a result of the existing spectrum allocation policy, and because of the spectrum resource in the low frequency band (<4 GHz) is scarce, it is difficult to allocate contiguous 100 MHz bandwidth for a mobile network. Therefore, the non-contiguous CA technique provides a practical approach to enable an operator to utilize its current spectrum resources fully, including unused scattered frequency bands and the frequency bands already allocated for legacy mobiles [19].

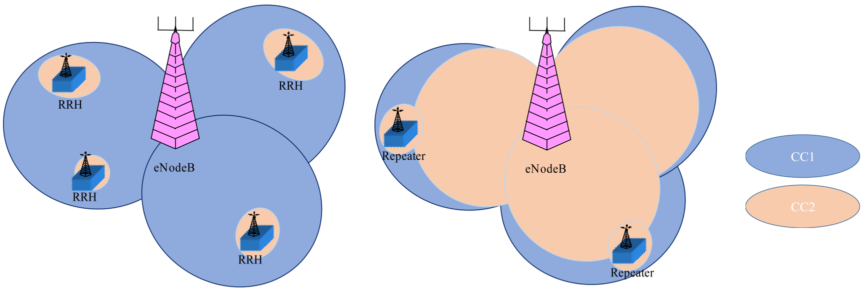
3.2 Deployment Scenarios

CA deployment scenarios depend largely on the operator's needs. For efficient deployment, operators consider various factors, such as spectrum allocation, hot spots, environment, antenna direction and so on. Some of the possible deployment scenarios are illustrated in Figure 3.2. The possibilities enabled by the usage of several aggregated frequency bands allows a variety of deployment scenarios for the operator [27, 19].

Scenario 1, as shown in Figure 3.2a, is where the antennas of the cells are collocated, and the cells are overlaid with little frequency separation and within the same band. Therefore, the overlaid cells provide almost the same coverage.



(a) Scenario 1 (b) Scenario 2 (c) Scenario 3



(d) Scenario 4 (e) Scenario 5

Figure 3.2: CA deployment scenarios

Scenario 2, as shown in Figure 3.2b, is where the antennas of the cells are collocated, but the cells are overlaid with large frequency separation, which leads to different cell coverage. Due to different path loss, cell coverage with a higher frequency is less than that with a lower frequency. Spectrum across different bands can be allocated in this scenario.

Scenario 3, as shown in Figure 3.2c, is where the antennas of cells are collocated, but the antenna directions are different in order to fill the coverage hole at the cell boundary. By this scenario the coverage is improved and/or the cell edge throughput is increased.

In Scenario 4, the antennas of cells are not collocated because Remote Radio Head (RRH) cells are used in addition to normal eNodeB cells, as shown in Figure 3.2d. As an RRH is a low-power node compared to the normal eNodeB, the cell coverage of RRH cells is typically less than that of eNodeB cells. Therefore, RRH cells are usually placed in hot spots to enhance throughput, thereby serving as a cost-efficient deployment option to the operator.

Scenario 5, as shown in Figure 3.2e, is where a part of the cells is amplified by frequency-selective repeaters. A repeater may be deployed by operators to extend cell coverage in rural and urban areas.

3.3 Operating Bands and Channel Bandwidth

The channel arrangements presented in this section are based on the operating bands and channel bandwidths defined in release of 3GPP specifications in Release 14, which can be found in [28].

3.3.1 Operating Bands

There are variety of possible band combinations for LTE-Advanced CA operation. The intra-band contiguous CA operating bands are shown in Appendix A. For the case of inter-band CA and intra-band non-contiguous CA there are plenty amount of operating bands combination, which can be found on specification [28].

3.3.2 Channel Bandwidth

The CC can have a bandwidth of 1.4, 3, 5, 10, 15 or 20 MHz and a maximum number of five CCs can be aggregated allowing for an overall transmission bandwidth of up to 100 MHz. The channel bandwidths and there transmission bandwidth are listed in Table 3.1.

Table 3.1: Transmission bandwidth [28]

Channel bandwidth ($BW_{channel}$) [MHz]	1.4	3	5	10	15	20
Transmission bandwidth (N_{RB})	6	15	25	50	75	100

For intra-band contiguous CA aggregated channel bandwidth, aggregated transmission bandwidth configuration and guard bands are defined as follows, which can be seen Figure 3.3.

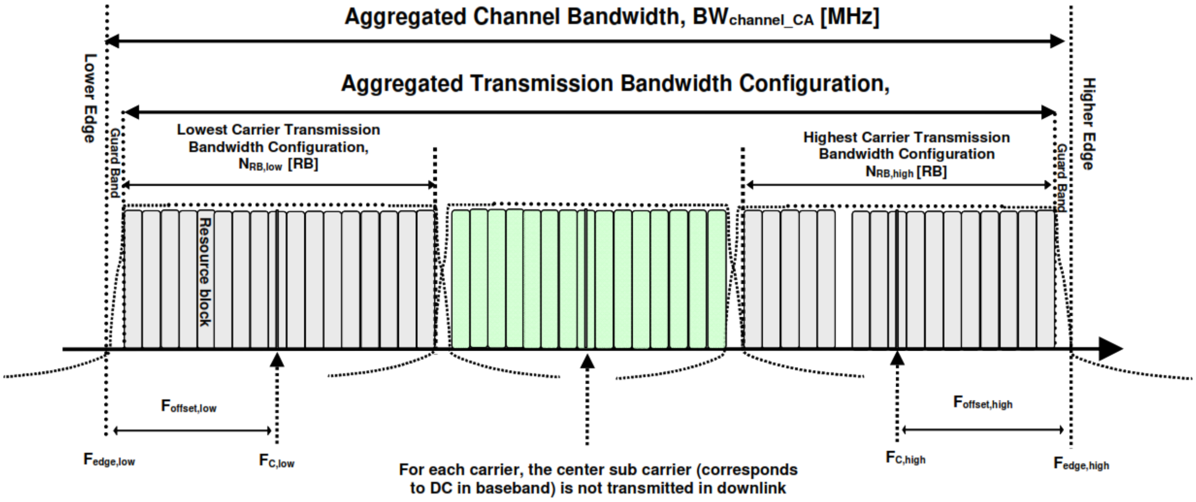


Figure 3.3: Aggregated channel bandwidth and edges [28]

The aggregated channel bandwidth, $BW_{ChannelCA}$, is defined as

$$BW_{channelCA} = F_{edge,high} - Fedge, low[MHz] \tag{3.1}$$

The lower bandwidth edge $F_{edge,low}$ and the upper bandwidth edge $F_{edge,high}$ of the aggregated channel bandwidth are used as frequency reference points for transmitter and receiver requirements and are defined by

$$F_{edge,low} = F_{c,low} - F_{offset,low} \tag{3.2}$$

$$F_{edge,high} = F_{c,high} - F_{offset,high} \tag{3.3}$$

The lower and upper frequency offsets depend on the transmission bandwidth configurations of the lowest and highest assigned edge component carrier and are defined as

$$F_{offset,low} = (0.18N_{RB,low} + \Delta f_1)/2 + BW_{GB}[MHz] \tag{3.4}$$

$$F_{offset,high} = (0.18N_{RB,high} + \Delta f_1)/2 + BW_{GB}[MHz] \tag{3.5}$$

where $\Delta f1 = \Delta f$ for the downlink with Δf the subcarrier spacing and $\Delta f1 = 0$ for the uplink. $N_{RB,low}$ and $N_{RB,high}$ are the transmission bandwidth configurations according to Table 3.1 for the lowest and highest assigned component carrier respectively. BW_{GB} denotes the nominal guard band and is defined in Table 3.2, and the factor 0.18 is the PRB bandwidth in MHz.

Table 3.2: CA bandwidth classes and corresponding nominal guard bands [28]

CA Class	Aggregated Transmission BW	No. CCs	Nominal Guard Band BW_{GB}
A	NRBagg $\leq$ 100	1	a1 $BW_{Channel(1)}$ - 0.5Δf1 (NOTE)
B	25 < NRBagg $\leq$ 100	2	0.05max($BW_{Channel(1)}$, $BW_{Channel(2)}$) - 0.5Δf1
C	100 < NRBagg $\leq$ 200	2	0.05max($BW_{Channel(1)}$, $BW_{Channel(2)}$) - 0.5Δf1
D	200 < NRBagg $\leq$ 300	3	0.05max($BW_{Channel(1)}$, $BW_{Channel(2)}$, $BW_{Channel(3)}$) -0.5 Δf1
E	300 < NRBagg $\leq$ 400	4	0.05max($BW_{Channel(1)}$, $BW_{Channel(2)}$, $BW_{Channel(3)}$, $BW_{Channel(4)}$) - 0.5Δf1
F	400 < NRBagg $\leq$ 500	5	Applicable for later releases
I	700 < NRBagg $\leq$ 800	8	Applicable for later releases
NOTE: a1 = 0.16/1.4 for 1.4 MHz whereas a1 = 0.05 for others.			

The values of $BW_{ChannelCA}$ for UE and eNodeB are the same if the lowest and the highest CCs are identical. Aggregated transmission bandwidth configuration is the number of the aggregated Resource Blocks (RBs) within the fully allocated aggregated channel bandwidth and is defined per CA bandwidth class in Table 3.2.

For inter-band CA, a CA configuration is a combination of operating bands, each supporting a carrier aggregation bandwidth class. For intra-band contiguous CA, a CA configuration is a single operating band supporting a CA bandwidth class.

Table 3.3 shows some selected intra-band contiguous CA configurations and bandwidth combination. Full requirements for intra-band contiguous CA and requirements for inter-band CA and intra-band non-contiguous CA can be fund in specification [28].

Table 3.3: CA configurations and bandwidth combination

CA configuration	CCs in order of increasing carrier frequency [MHz]					Maximum bandwidth [MHz]
	CA1	CA2	CA3	CA4	CA5	
CA_1C	15	15				40
	5, 10, 15	20				
	20	5, 10, 15, 20				
CA_3C	5, 10, 15	20				40
	20	5, 10, 15, 20				
CA_7C	10	20				40
	15	10, 15, 20				
	20	10, 15, 20				
CA_43C	5	20				40
	10	15, 20				
	15	10, 15, 10				
	20	5, 10, 15, 20				
CA_48F	5, 10, 15, 20	20	20	20	20	100
	20	20	20	20	5, 10, 15, 20	

3.4 Protocol Impact of Carrier Aggregation

The use of CA is visible in the physical layer and the MAC layer. The user plane layers above the MAC are unchanged and whether CA is being used or not is not visible to the core network. The impact on the core is that it enables data rates beyond Release 8 and 9 capabilities. The MAC layer divides the data between different CCs [18].

The example in Figure 3.4 shows the use of two DL CCs, which is the most common case and supported by RF requirements work in Release 10. The physical layer structures and signaling is not limited to the use of only two CCs, up to four secondary cells can be configured in addition to the primary cell. The UL and DL MAC layer structures are identical but the scheduling functionality of the DL MAC layer deals with scheduling of multiple users.

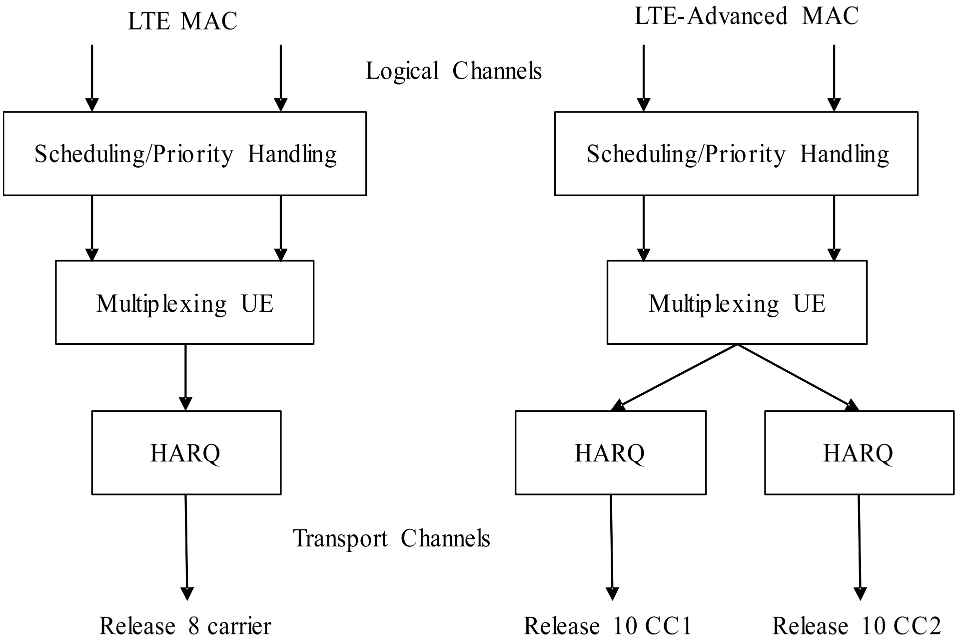


Figure 3.4: LTE and LTE-Advanced MAC layer structures (adapted from [18])

3.5 Physical Layer Impact of Carrier Aggregation

The effects of CA on the LTE physical layer concern on feedback structures for multiple carriers. There are changes as a result of part of the single carrier UL operation, with the introduction of discontinuous PUCCH/PUSCH and PUSCH/PUSCH allocations. There are some minor changes in procedures but in general the primary cell is the reference for UE [18].

In the DL, the key adjustment is in the related signaling as the UE now needs to obtain information about allocations on all the CCs that it is able to receive, otherwise the individual CCs operate in a similar fashion to Releases 8 and 9. In the UL direction it is preferable to stay with the single UL carrier as the UE will need to use less transmitter power if multiple UL carriers are used.

3.6 Mobility

One target of the LTE radio network is keeping network management simple and provide seamless mobility. Mobility offers benefits to the end users, by maintaining a reliable connection in the areas between two cells where the best serving cell is changing [19].

For a handover, the general principle is that the radio configuration to be used at the target cell is decided by the target cell and then signaled to the UE via a handover command in the source cell. This principle also applies for carrier aggregation, and the handover command can include the configuration of the SCell(s) to be used at the target cell.

The selection of the PCell to be used at the target cell in Release10 is no different from the selection of a serving cell to be used at the target cell in Releases 8/9. The selection of the SCell(s) for use in the target cell, however, did not exist in Releases 8/9. To assist in the selection of the SCell(s) at the target cell, additional signaling has been introduced to provide information from the UE to the target cell via the source cell.

3.7 Performance

The CA feature increases the bandwidth for a CA capable UE by aggregating several LTE carriers, thereby increasing the UEs bit rate. CA produces performance gains by ways of load balancing, resource sharing, frequency domain joint scheduling over more than one frequency and by giving more bandwidth which results to higher peak data rate.

The spectral efficiency requirements were 15 bit/s/Hz for DL and 6.75 bit/s/Hz for UL. 3GPP defined higher targets for LTE-Advanced. The system should support 30 bit/s/Hz peak spectral efficiency for DL (assuming 8x8 MIMO) and 15 bit/s/Hz for UL transmission (assuming 4x4 MIMO). The requirement for low mobility data rate is 1 Gbit/s and for high mobility 100 Mbit/s.

New UE categories were specified in LTE-A to support the new features. They are presented in following section followed by the possible peak data rates for LTE-A.

3.7.1 UE Capabilities

UE Category information is used to allow the eNodeB to communicate effectively with all the UEs connected to it. The UE category defines a combined UL performance capability and DL performance capability. The UE devices are to be specified with the supported UE category, so that consumer has an idea of capability of the device before using that particular device [29].

Table 3.4: UE category [29]

	UE category	Max data rate (Mbps)		DL CCs	DL MIMO layers	Highest modulation	
		DL	UL			DL	UL
Rel 8	1	10	5	1	1	64 QAM	16 QAM
	2	50	25		2		
	3	100	50				
	4	150	50				
	5	300	75				64 QAM
Rel 10	6	300	50	1 or 2	2 or 4		16 QAM
	7	300	100				
	8	450	150	5	8		64 QAM
Rel 11	9	450	50	2 or3	2 or 4		16 QAM
	10	450	100				
	11	600	50	2, 3 or 4		256 QAM	
	12	600	100				

There is single UE category upto Rel 11 which defines both the DL throughput performance as well as UL throughput performance, as shown in Table 3.4. But in Rel 12, this single category definition got decoupled into two individual categories, where UE category DL defines the DL throughput performance and UE category UL defines the UL throughput performance.

3.7.2 Data Rates

The peak data rate increases with wider bandwidth and more antennas. LTE Release 8 offers peak data rate of 150 Mbps in DL by using 20 MHz of bandwidth and 2X2 MIMO, however the average data rates in the commercial networks range between 20 and 40 Mbps in DL and 10–20 Mbps in UL.

In LTE-Advanced with two carriers, the peak data rate could be as high as 300 Mbit/s. Furthermore, if the maximum of 4 x 4 UL MIMO and full 100 MHz spectrum were utilized, the data rate would increase to 1.5 Gbit/s. And later to even 3 Gbps by using 8X8 MIMO. The LTE-Advanced peak data rates with different multi-antenna configurations and with 20+20 MHz are illustrated in Figure 3.5 [20].

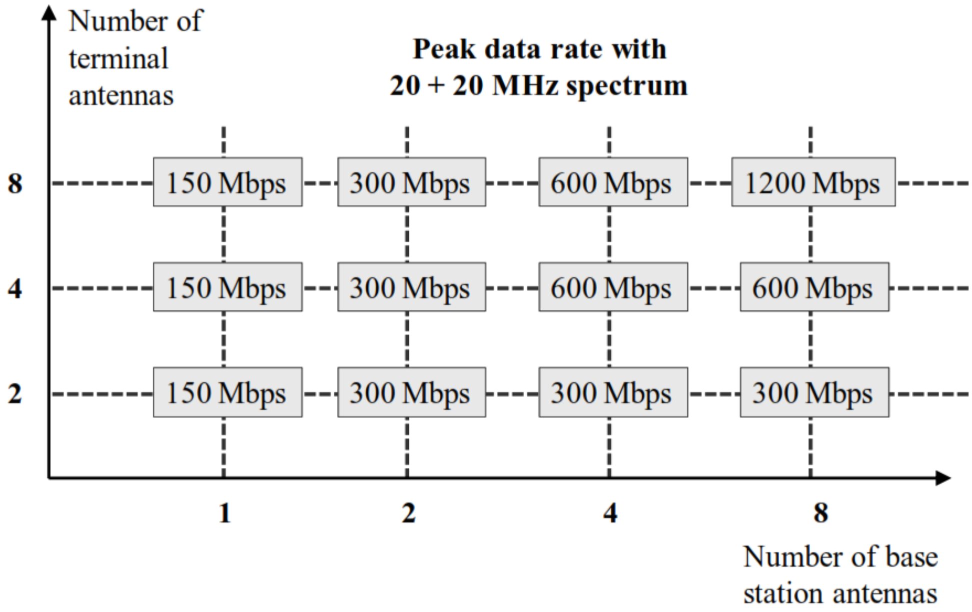


Figure 3.5: DL peak data rate with different antenna configuration, 20+20 MHz [20]

Aggregation of carriers increases spectrum resources, which provides higher speeds across the cell coverage. It also includes trunking gains from dynamically scheduling traffic across the entire spectrum. This in turn increases cell capacity and network efficiency and improves the experience for all users. A user previously facing congestion on one carrier can be seamlessly scheduled on a carrier with more capacity and maintain a consistent experience [25].

Chapter 4

System Model

In this chapter simulation procedures and system parameters selection are discussed.

4.1 Area Selection

The selected area is found at Bole sub city in Addis Ababa, which covers 10.38 Km^2 (3.259 Km x 3.186 Km). There are 22 macro sites with tri-sector, which gives 66 sectors/cells. Selected sites are shown in Figure 4.1.

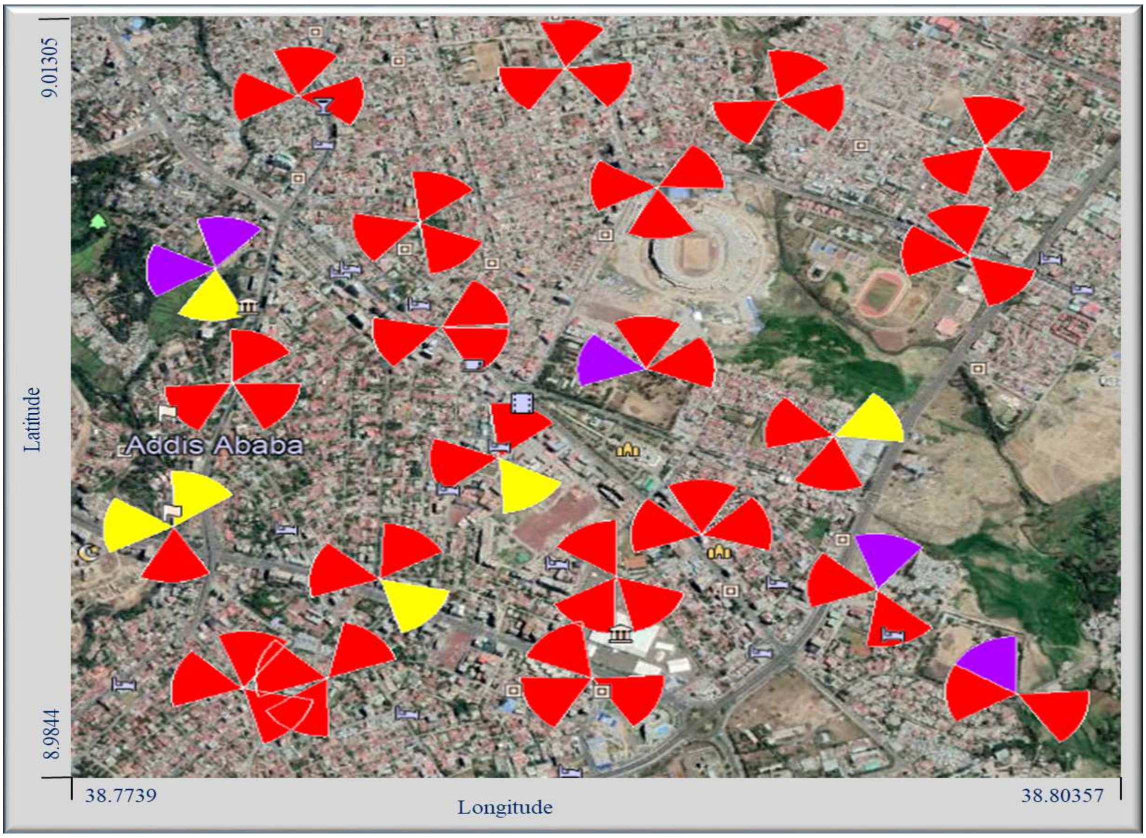


Figure 4.1: Satellite view of selected area

The selected cells within the area are selected by taking high traffic follow area by analyzing January 2019 LTE traffic data, and dividing Addis Ababa traffic data per cell into three:

- "Red" High traffic - above 250 GB/month;
- "Yellow" Medium traffic - between 100 and 250 GB/month; and
- "Blue" Low traffic = less than 100 GB/month.

From Figure 4.1, 55 cells(83.33%) from 66 cells have high data traffic flow, in case of all cells only 25% have high data traffic.

Some of the selected sites and cells information is shown in Table 4.1. It consists of the cell's height in meter, longitude and latitude in degree, data usage GB/month, azimuth in degree and down tilt information.

Table 4.1: Sites and cells information

Sites	Sector ID	Cell	Azimuth	Down Tilt	Hight	Latitude	Longitude	DL Traffic
Site 1	1	Cell1	30	9	27	8.99177	38.7832	987.293
	2	Cell2	130	7	27	8.99177	38.7832	162.129
	3	Cell3	280	8	27	8.99177	38.7832	544.6
Site 2	1	Cell4	10	7	27	9.00671	38.7989	414.874
	2	Cell5	125	4	27	9.00671	38.7989	701.714
	3	Cell6	225	3	27	9.00671	38.7989	634.363
Site 3	1	Cell7	5	8	25	9.00916	38.7875	318.015
	2	Cell8	110	5	25	9.00916	38.7875	708.63
	3	Cell9	240	5	25	9.00916	38.7875	1019.91
Site 4	1	Cell10	5	4	31	9.00803	38.7802	841.088
	2	Cell11	95	5	31	9.00803	38.7802	910.016
	3	Cell12	270	6	31	9.00803	38.7802	789.609

4.2 Simulation Parameters and Assumptions

The macro cell parameter and system simulation assumptions follow commonly used 3GPP parameters as well as considering some of ethio telecom current configuration, which are listed in Table 4.2. The antenna height, azimuth and down-tilt configuration are based on Table 4.1.

Table 4.2: Simulation parameters and assumptions

Parameter	Values or Assumptios
Deployment Scenario	Macro network; Downlink
Carrier frequency	Band 3 (1800 MHz), Band 7 (2600 MHz) and Band 43 (3700 MHz)
Bandwidth	10MHz or 20 MHz
No. of component carrier	1CC or 2CC
Resource block size	180 KHz
Transmit Power	43 dBm
Antenna Patterns	Kathrein 742212
eNodeBs antenna gain	18 dBi
UE height	1.5 m
UE antenna gain	0 dBi
UE noise figure	9 dB
long-normal fade shadow	6 dB
Thermal noise density	-174 dBm/Hz

4.3 Tool

The simulation study focuses on macro sites DL performance. The radio coverage estimations are based on realistic three-dimensional building vectors and topographical data. For the simulation, the propagation is evaluated using WinProp propagation modeling tool [30], which is also used in [12]. The system level simulation is conducted using Matlab.

WinProp is designed for modeling radio propagation in different environment (rural, urban and indoor). ProMan propagation manager is the software package that is used from Winprop for this thesis.

ProMan is a propagation modeling and network planning tool which generates signal predictions for a desired area. The WinProp propagation models are fully three-dimensional, i.e. consider 3D object data and compute all rays in 3D. WinProp offers a wide variety of empirical and ray optical propagation models for urban scenarios. The propagation models include COST 231 Walfisch-Ikegami Model, Urban Dominant Path Model (UDPM), and 3D Ray Tracing Model. In order to accelerate the time-consuming path determination the intelligent ray tracing model can be utilized, which is based on a single pre-processing of the building data. For pure predictions of the radio coverage the urban dominant path model can be applied which combines high accuracy with short computation time [30].

4.4 Propagation Model

In this thesis the propagation model used is the UDPM. UDPM is proposed to combine the accuracy of the ray optical models and the speed of the empirical models. In addition, the prediction is less dependent on the vector database compared to the Ray Optical Model. UDPM works by determining the dominant path between the transmitter and receiver. This is done with the following equation [31]:

$$P_L = 20 * log(\frac{4\pi}{\lambda}) + 20 * \rho log(d) + \sum_{i=0}^{n} \alpha(\Phi, i) - \frac{1}{c}\sum_{k=0}^{c} w_k \tag{4.1}$$

Where P_L is the path loss in dB of a path with a length of d (meter). λ (meter) is the wavelength. The factor ρ depends on the visibility state between the current pixel and the transmitter. $\alpha(\Phi, i)$ is a function which determines the loss in dB due to an interaction, that is changing the direction of propagation. The parameter w_k is called wave guiding factor.

The propagation result for one cell (total 66 cells) is shown in Figure 4.2, where the x and y are meter.

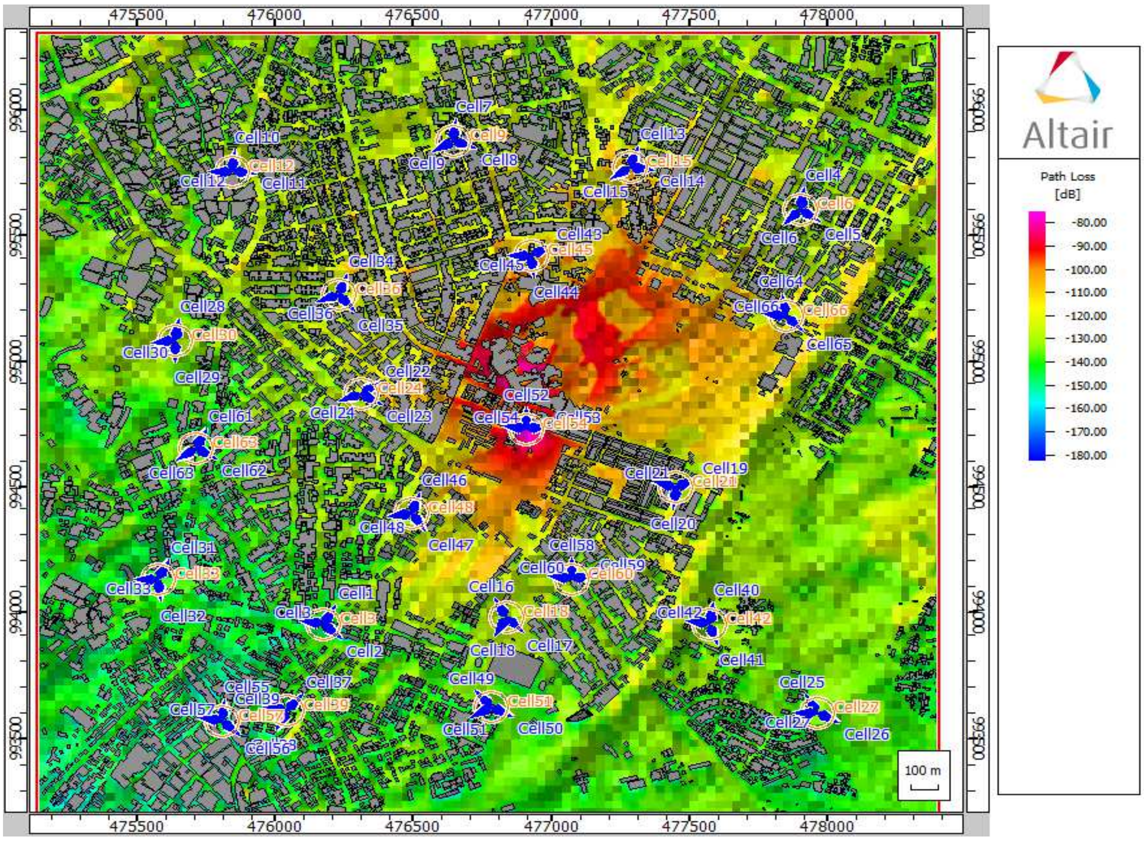


Figure 4.2: Path loss (WinProp simulation result)

4.5 UEs and eNodeB Position

The UEs number are determined as follows. The capacity of Addis Ababa city LTE network is 399725 UEs, 332 sites with three sectors [5]. This gives a cell capacity of 401 users. Then assuming that 10% of the day, 2 hours and 24 minute, the users are active which gives 40 active users per cell. Thus, the 66 cells users will be 2640.

From this total number 80% are dropped in clusters around macro cells, site radius of 425 meters, UEs number varies 90 to 120 per site in each iteration. The rest of the UEs are dropped over whole area in order to be accessed over sites estimation distance. Static system-level simulations are then performed for 500 iteration to investigate network performance. The UEs distribution for first iteration is shown in Figure 4.3, with eNodeBs position based on Table 4.1 information.

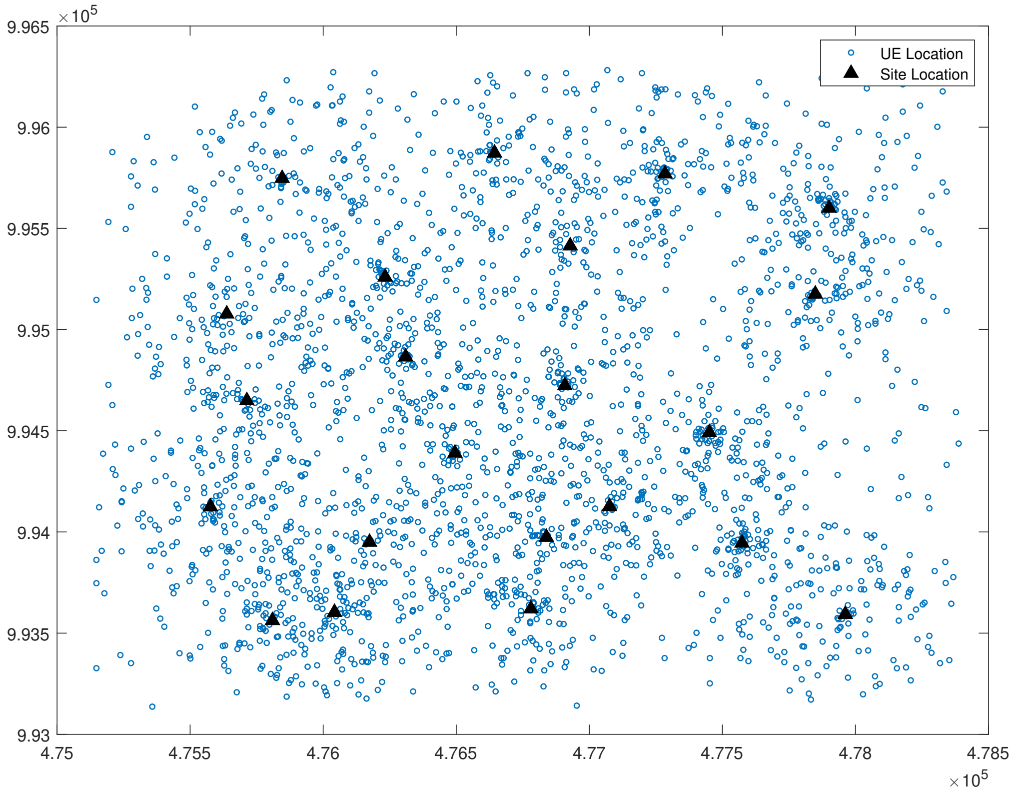


Figure 4.3: Users and sites location

4.6 Throughput Calculation

For the simulation area, the path loss is evaluated using the dominant path model implemented in the WinProp propagation modeling tool. Then the Matlab simulator calculates SINR value, and the throughput value can be found from mapping the SINR value.

In the downlink of a multiuser OFDMA system, such as LTE, SINR for a UE_k on the RB_n in the cell i is given by [32]:

$$SINR_{k,n}^{i} = \frac{P_n^i * G_{k,n}^i}{\sum_{j \# i} P_n^j * G_{k,n}^j + P_{TN}} \tag{4.2}$$

Where P_n^i is the downlink transmission power allocated by the base station i for the RB_n, $G_{k,n}^i$ is channel gain for UE_k served by eNodeB i on RB_n, and P_{TN} is the thermal noise power on the considered RB.

Throughput refers to how much data can be transferred from one location to another in a given amount of time. UE throughput results are found through mapping the $SINR$

results using a modified Shannon formula [12, 33].

$$TP = \begin{cases} N_{RB}BW_{PRB}min\left(S_{max}, BW_{eff}log_2\left[1+\frac{SINR}{SINR_{eff}}\right]\right), SINR \geq SINR_{min} \\ 0, SINR < SINR_{min} \end{cases} \tag{4.3}$$

Where TP is UE throughput, N_{PRB} is the number of PRBs, BW_{PRB} is the bandwidth per PRB, S_{max} is the maximum spectral efficiency, $SINR_{min}$ is the minimum required SINR, BW_{eff} adjusts bandwidth to fit with LTE the system bandwidth efficiency and $SINR_{eff}$ adjusts for the SINR implementation efficiency.

The SINR to throughput mapping parameters for 1x2 MIMO configurations are based on link-level simulations done in paper [33], and also used in paper [12], as presented in Table 4.3.

Table 4.3: SINR-Throughput mapping

Parameter	Assumption
$SINR_{min}$ (dB)	-10
BW_{eff}	0.62
$SINR_{eff}$	1.8
S_{max} (b/s/Hz)	4.4

In LTE, the basic resource unit of eNodeB is a PRB. This resource can be allocated to users in a number of scheduling techniques. Many scheduling algorithms for cCA have been proposed. One of the simplest scheduling techniques is the Round Robin (RR) which allocates resources uniformly to users and used in this thesis. Based on RR technique and assuming uniform traffic demand per user, the maximum cell capacity is equal to the number of PRBs. The number of PRB is directly related to the bandwidth being used and this is the basic assumption for cell capacity [34].

Chapter 5

Simulation Results and Discussions

The gain of using CA on the system performance in term of throughput is evaluated and investigated under five different deployment scenarios to realize the benefit of using CA in LTE-Advanced system.

5.1 Simulation Scenarios

The simulation is done based on assumptions made in the previous chapters and five scenarios are proposed to investigate the effects of implement CA and frequency band on the system performance in term of throughput, as illustrated in Table 5.1. The first scenario show the current real case of Addis Ababa city.

The simulation scenarios are divided into two main parts. The first part focuses on the same frequency band, but with different bandwidths. And the second part focuses on the same bandwidth but with different frequency bands. The following figures, Figure 5.2 to 5.7, illustrates the simulation results.

5.2 SINR Results

The Cumulative Distribution Function (CDF) of SINR result for three frequency bands is presented in Figure 5.1. It shows that the 1800 MHz has a lower SINR than 2600 MHz and 3700 MHz. In the figure the SINR value is close each other for all frequency carriers, this because of UEs are close enough to the eNodeB.

Table 5.1: Simulation scenarios

Scenarios	Description
Scenario 1	Frequency band = 1800MHz, Total BW = 20 MHz Non-CA with 1CC, CC BW = 20 MHz
Scenario 2	Frequency band = 1800MHz, Total BW = 30 MHz CA with 2CC, CC1 BW = 20 MHz and CC2 BW = 10 MHz
Scenario 3	Frequency band = 1800MHz, Total BW = 40 MHz CA with 2CC, CCs BW = 20 MHz
Scenario 4	Frequency band = 2600MHz, Total BW = 40 MHz CA with 2CC, CCs BW = 20 MHz
Scenario 5	Frequency band = 3700MHz, Total BW = 40 MHz CA with 2CC, CCs BW = 20 MHz

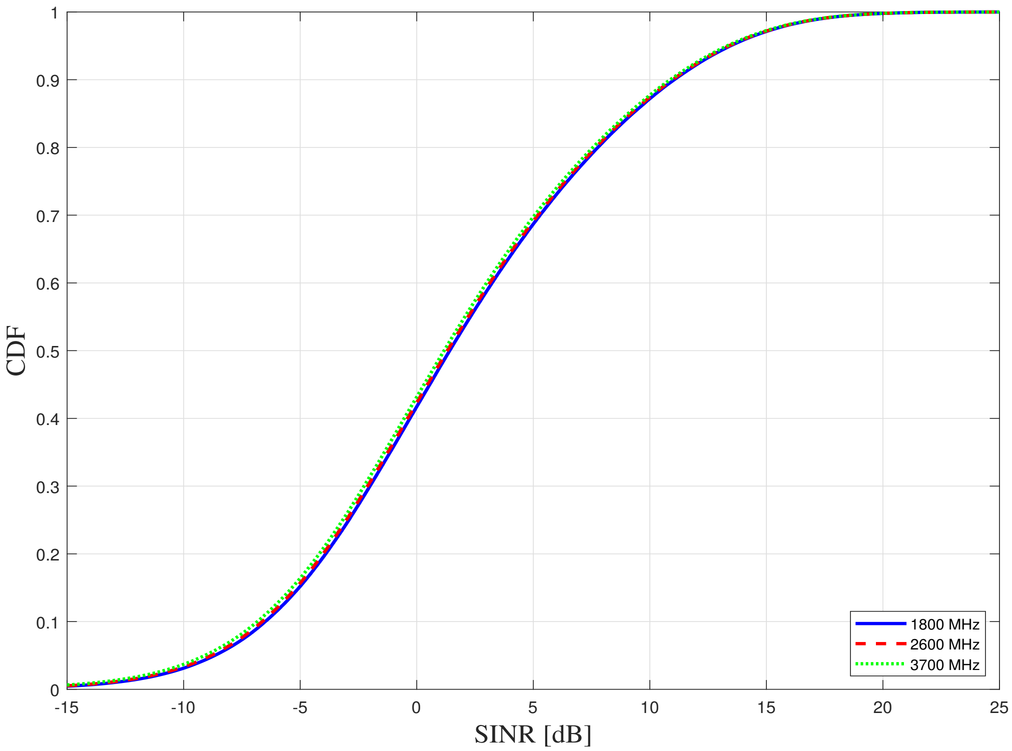


Figure 5.1: SINR results

5.3 CA with Different Bandwidth

In this scenario the base line frequency band is band 3 (1800MHz) with 20 MHz bandwidth (Scenario 1). Then simulation is conducted for CA with 10 MHz and 20 MHz (Scenario 2 and Scenario 3).

In Figure 5.2, the CDF illustrates the differences between the throughput per user with three different scenarios. From the result, it can be seen that the probability of getting a throughput of 1 Mbps or less is 95%, 90% and 84% for, no CA, 10MHz CA and 20MHz CA respectively.

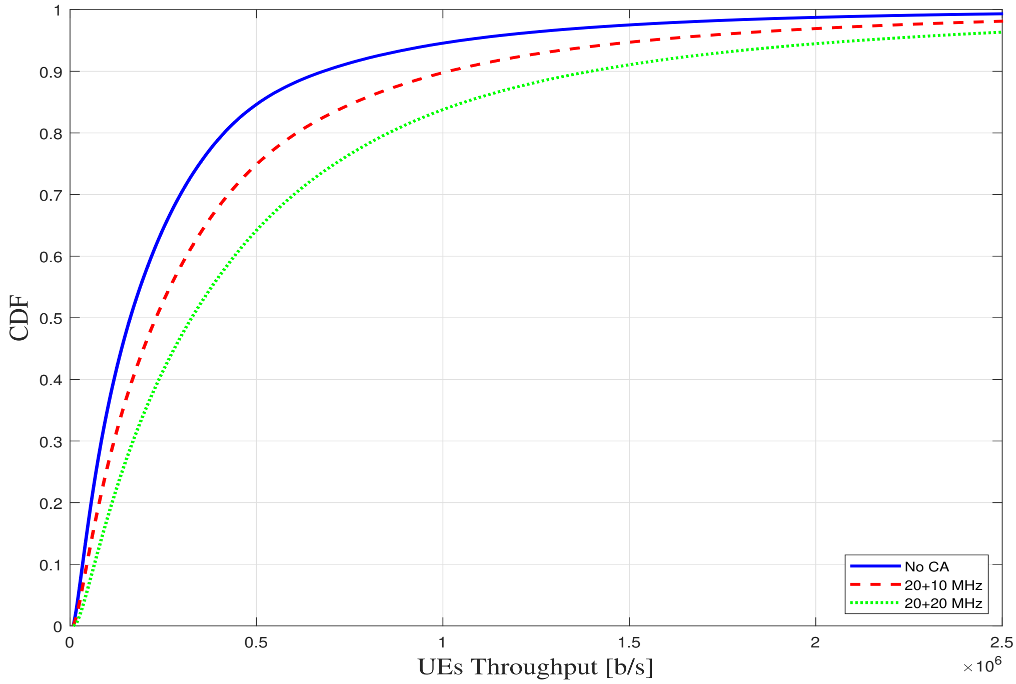


Figure 5.2: Throughput CDF for different bandwidth

The throughput gap from these CA scenarios can be seen in Figure 5.3, it is calculated by subtracting the throughput at 10 percentile, 50 percentile and 90 percentile with respect to the baseline senario. The 10 MHz CA (Scenario 2) provides 0.01134, 0.06899 and 0.33509 Mbps UE throughput gains at 10 percentile, 50 percentile and 90 percentile respectively, on the base line 0.03372, 0.16159, and 0.67961 Mbps UE throughput. On the other hand, the 20 MHz CA (Scenario 3) provides 0.03163, 0.16472 and 0.716 Mbps UE throughput gains at 10 percentile, 50 percentile and 90 percentile respectively.

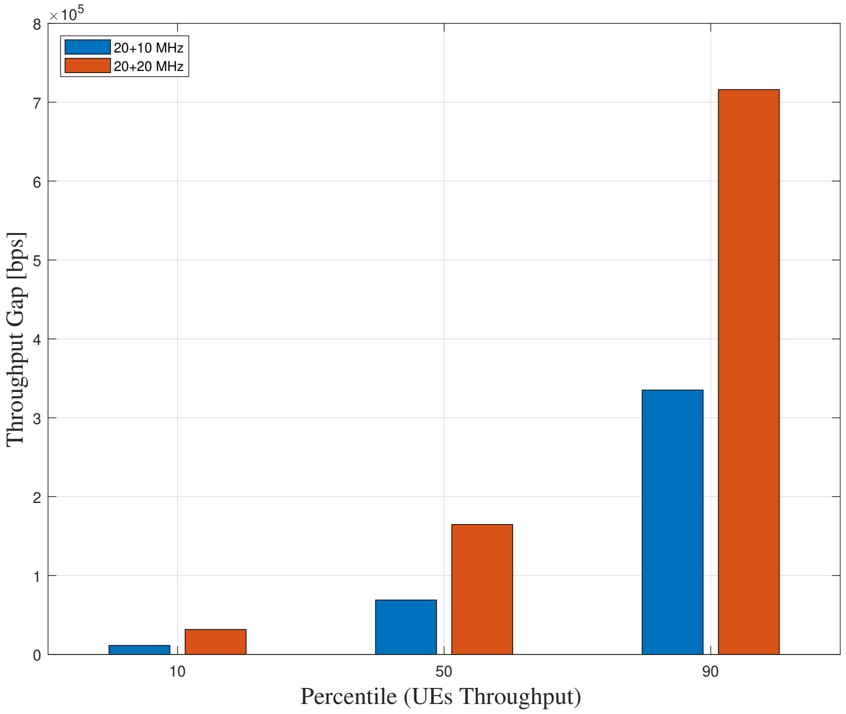


Figure 5.3: Throughput gap for different bandwidth

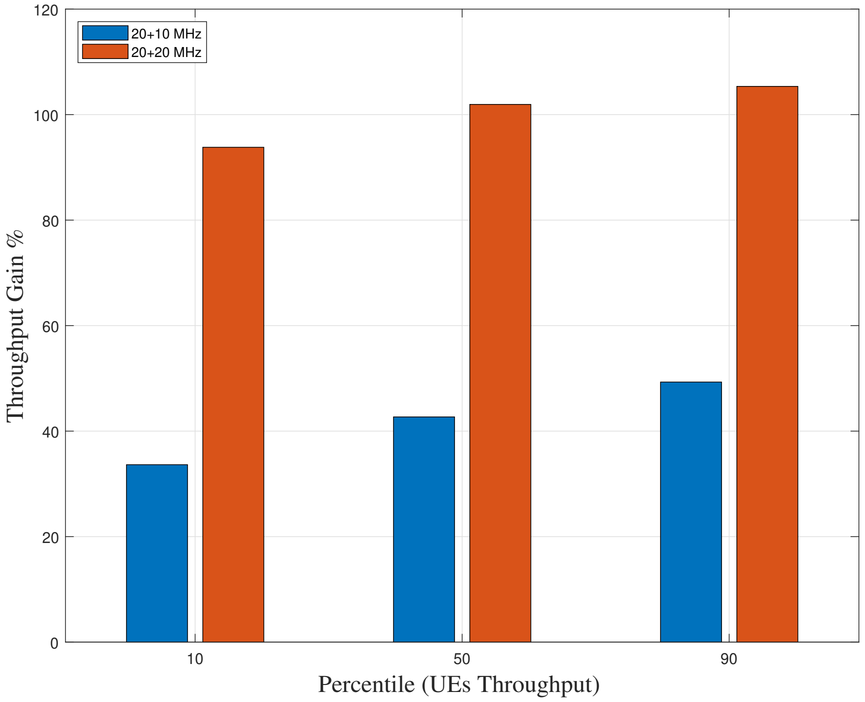


Figure 5.4: Throughput gain for different bandwidth

As Figure 5.4 shows, the addition 10 MHz CC on 20 MHz provides 33.64%, 42.69% and 49.31% UE throughput gains at 10 percentile, 50 percentile and 90 percentile respectively. For case of 2CC 20 MHZ, throughput gains of 93.82%, 101.94% and 105.36% can be get at 10 percentile, 50 percentile and 90 percentile respectively.

From the above results we can conclude that addition of 10MHz CC and 20 MHz CC can increase UE throughput on all areas and especially high throughput gain at cell center. The gains attained from 2CC are also related to the trunking gains from dynamically scheduling of traffic using RR algorithm.

5.4 CA with Different Frequency Bands

In this scenario the base line frequency band is band 3 (1800MHz) with 20 MHz bandwidth. Then simulation for additional CC is conducted for frequency bands 1800 MHZ, 2600MHz and 3700MHz. As the CDF in Figure 5.5 shows for case of no CA, the probability of the users to get a throughput of less than 1 Mbps is 95%, this implies only over 5% UEs get a throughput over 1 Mbps.

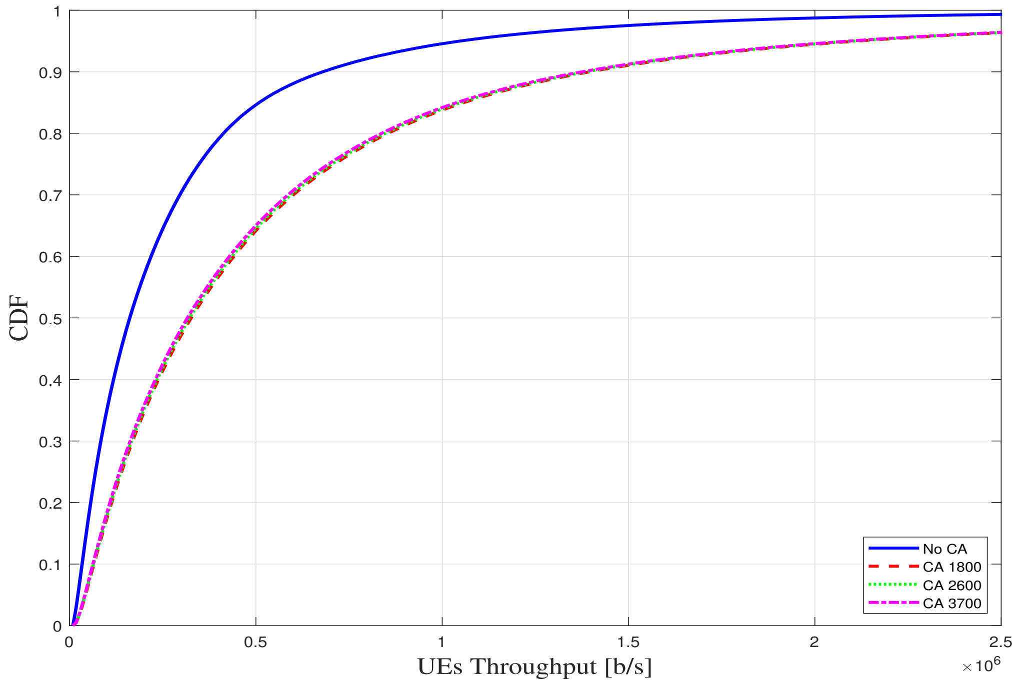


Figure 5.5: Throughput CDF for different frequency bands

While for the case of 2CC CA, for all three bands, the probability of the users to get a throughput of less than 1 Mbps is less around 84%, which show 11% improvement. Even though on the figure it is tight to identify, CA on 1800MHz shows better improvement, this is due to lower SINR observed at CA 1800 MHz as shown in Figure 5.1.

The throughput gap from these CA scenarios can be seen in Figure 5.6. The 1800 MHz provides 0.03163, 0.16472 and 0.71601 Mbps UE throughput gains at 10 percentile, 50 percentile and 90 percentile respectively, on the base line 0.03372, 0.16159 and 0.67961 Mbps UE throughput. On the other hand, the 2600 MHz CA provides 0.03061, 0.16037 and 0.7075 Mbps UE throughput gains at 10%-ile, 50%-ile and 90%-ile respectively. While, the 3700 MHz CA provides 0.0291, 0.1548 and 0.6965 Mbps UE throughput gains at 10 percentile, 50 percentile and 90 percentile respectively. In all scenarios it can be observed that there is high gain at cell center. The gains attained from 2CC are also related to the trunking gains.

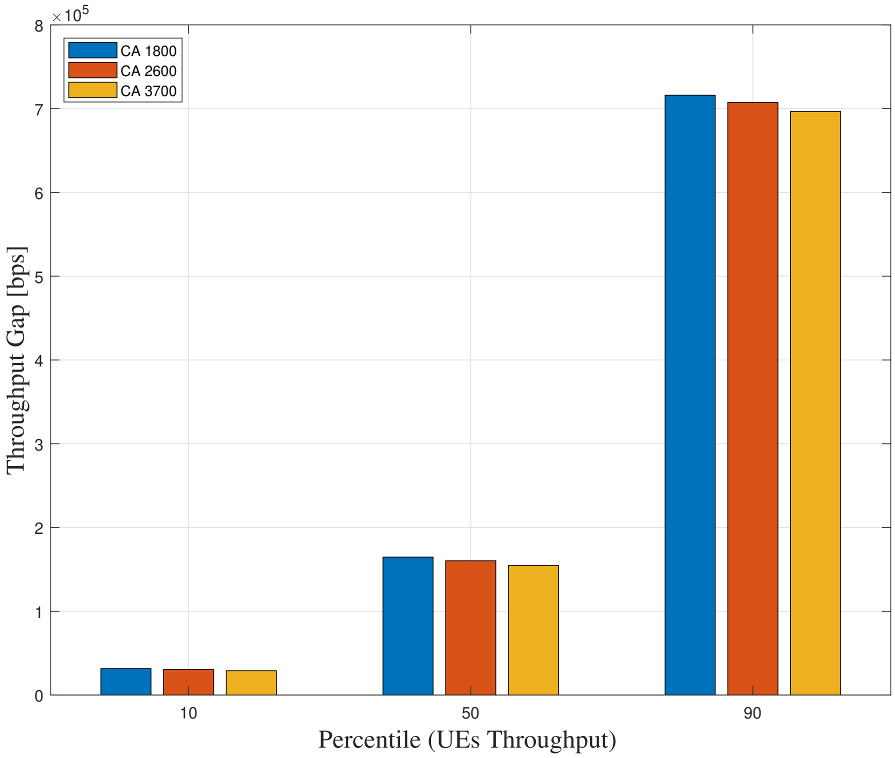


Figure 5.6: Throughput gap for different frequency bands

At 1800 MHz, throughput gains of 93.82%, 101.94% and 105.36% can be attained at 10 percentile, 50 percentile, and 90 percentile respectively. The 2600 MHz, provides throughput gains of 90.78%, 99.25% and 104.10% at 10%-ile, 50%-ile and 90%-ile respectively. While, the 3700 MHz provides throughput gains of 86.31%, 95.81% and 102.49% at 10 percentile, 50 percentile and 90 percentile respectively. The three cases simulation result is shown in Figure 5.7.

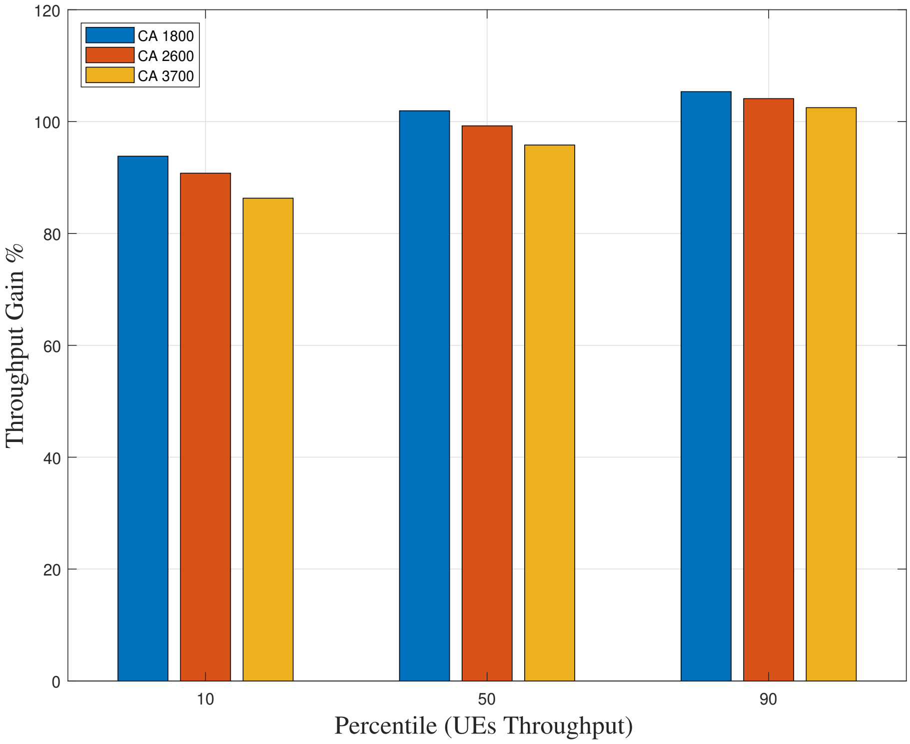


Figure 5.7: Throughput gain for different frequency bands

From the above results we can conclude that all three frequency bands with 2CC can provide a throughput gain of over 100%, at cell center. Even though the throughput gain decreases as the carrier frequency increase, the scenarios in thesis shows a considerable gain can be found for bands less than 4 GHz. However in all areas (from cell center to cell edge) the 1800 MHz frequency band show a better throughput gain, which shows having access to a lower frequency band is necessary to maintain good service.

Chapter 6

Conclusion and Future Work

6.1 Conclusion

This thesis investigates improvements that can be gained by CA advanced features in LTE networks, giving special emphasis to capacity aspects, for case of Addis Ababa city. It demonstrated through extensive simulation study, that shows deployment of CA in dense urban hotpots can provide notable throughput gains. The simulation study particularly highlights possible performance improvements through the use of CA at different bands and bandwidths.

The first analysis is to vary the aggregated bandwidth, 10 or 20 MHz, using the component carrier 1800 MHz band. These configurations can be explained by the use of the same combination of frequency bands with more RBs available per sector, delivering the same coverage basis. The results show that the UEs throughput value improved with increase in bandwidth. The 10 MHz CA provides 49% gain, while the 20 MHz provides 105% gain, which shows the advantage of wider bandwidth aggregations.

The second analysis is conducted by simulating different CA configurations, keeping the same two aggregated bandwidth, and using different combinations of frequency bands, testing both intra-bands aggregation. Results show all three frequency bands can provide a considerable throughput gains, especially of over 100% at cell center. When using low frequency bands, such as the 1800 MHz band, the network is able to cover large area thus providing a better throughput from cell center to cell edge.

6.2 Future Work

This thesis paper shows intra-band contiguous CA analysis for the case of Addis Ababa city, for two component carries at 1800 MHz, 2600 MHz and 3700 MHz. However, further analysis on throughput enhancement is important to insight the available resources and its utilization, such as

- For three and upto five component carries.
- For UL CA
- Analysis for other LTE-Advanced features, like enhanced MIMOs and relay nodes

In addition if LTE-Advanced is deployed in ethio telecom, comparing this realistic simulation with the practical one, can be one main work to insight the gap difference between them.

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Appendix A

E-UTRA operating bands

E-UTRA operating bands	Uplink operating band BS receive UE transmit	Downlink operating band BS transmit UE receive	Duplex mode
	FUL_low – FUL_high	FDL_low – FDL_high	
1	1920 MHz – 1980 MHz	2110 MHz – 2170 MHz	FDD
2	1850 MHz – 1910 MHz	1930 MHz – 1990 MHz	FDD
3	1710 MHz – 1785 MHz	1805 MHz – 1880 MHz	FDD
4	1710 MHz – 1755 MHz	2110 MHz – 2155 MHz	FDD
5	824 MHz – 849 MHz	869 MHz – 894MHz	FDD
6[1]	830 MHz – 840 MHz	875 MHz – 885 MHz	FDD
7	2500 MHz – 2570 MHz	2620 MHz – 2690 MHz	FDD
8	880 MHz – 915 MHz	925 MHz – 960 MHz	FDD
9	1749.9 MHz – 1784.9	1844.9 MHz – 1879.9 MHz	FDD
10	1710 MHz – 1770 MHz	2110 MHz – 2170 MHz	FDD
11	1427.9 MHz – 1447.9 MHz	1475.9 MHz – 1495.9 MHz	FDD
12	699 MHz – 716 MHz	729 MHz – 746 MHz	FDD
13	777 MHz – 787 MHz	746 MHz – 756 MHz	FDD
14	788 MHz – 798 MHz	758 MHz – 768 MHz	FDD
15	Reserved	Reserved	FDD
16	Reserved	Reserved	FDD
17	704 MHz – 716 MHz	734 MHz – 746 MHz	FDD
18	815 MHz – 830 MHz	860 MHz – 875 MHz	FDD
19	830 MHz – 845 MHz	875 MHz – 890 MHz	FDD
20	832 MHz – 862 MHz	791 MHz – 821 MHz	FDD
21	1447.9 MHz – 1462.9 MHz	1495.9 MHz – 1510.9 MHz	FDD
22	3410 MHz – 3490 MHz	3510 MHz – 3590 MHz	FDD
23[1]	2000 MHz – 2020 MHz	2180 MHz – 2200 MHz	FDD
24	1626.5 MHz – 1660.5 MHz	1525 MHz – 1559 MHz	FDD

25	1850 MHz – 1915 MHz	1930 MHz – 1995 MHz	FDD
26	814 MHz – 849 MHz	859 MHz – 894 MHz	FDD
27	807 MHz – 824 MHz	852 MHz – 869 MHz	FDD
28	703 MHz – 748 MHz	758 MHz – 803 MHz	FDD
29	N/A	717 MHz – 728 MHz	FDD
30	2305 MHz – 2315 MHz	2350 MHz – 2360 MHz	FDD
31	452.5 MHz – 457.5 MHz	462.5 MHz – 467.5 MHz	FDD
32	N/A	1452 MHz – 1496 MHz	FDD
33	1900 MHz – 1920 MHz	1900 MHz – 1920 MHz	TDD
34	2010 MHz – 2025 MHz	2010 MHz – 2025 MHz	TDD
35	1850 MHz – 1910 MHz	1850 MHz – 1910 MHz	TDD
36	1930 MHz – 1990 MHz	1930 MHz – 1990 MHz	TDD
37	1910 MHz – 1930 MHz	1910 MHz – 1930 MHz	TDD
38	2570 MHz – 2620 MHz	2570 MHz – 2620 MHz	TDD
39	1880 MHz – 1920 MHz	1880 MHz – 1920 MHz	TDD
40	2300 MHz – 2400 MHz	2300 MHz – 2400 MHz	TDD
41	2496 MHz – 2690 MHz	2496 MHz – 2690 MHz	TDD
42	3400 MHz – 3600 MHz	3400 MHz – 3600 MHz	TDD
43	3600 MHz – 3800 MHz	3600 MHz – 3800 MHz	TDD
44	703 MHz – 803 MHz	703 MHz – 803 MHz	TDD
45	1447 MHz – 1467 MHz	1447 MHz – 1467 MHz	TDD
46	5150 MHz – 5925 MHz	5150 MHz – 5925 MHz	TDD^2
47	5855 MHz – 5925 MHz	5855 MHz – 5925 MHz	TDD^3
48	3550 MHz – 3700 MHz	3550 MHz – 3700 MHz	TDD
...			
64	Reserved		
65	1920 MHz – 2010 MHz	2110 MHz – 2200 MHz	FDD
66	1710 MHz – 1780 MHz	2110 MHz – 2200 MHz	FDD
67	N/A	738 MHz – 758 MHz	FDD
68	698 MHz – 728 MHz	753 MHz – 783 MHz	FDD
69	N/A	2570 MHz – 2620 MHz	FDD
70	1695 MHz – 1710 MHz	1995 MHz – 2020 MHz	FDD
NOTE 1: Band 6, 23 is not applicable NOTE 2: This band is an unlicensed band restricted to licensed-assisted operation NOTE 3: This band is unlicensed band used for Vehicle to Everything (V2X) communication			